Regional Specialisation for Enhanced Agricultural Productivity and Transformation

Proceedings

Eastern Africa Agricultural Productivity Programme
End-of-Phase One Project Conference & Exhibition

September 14 - 18, 2015
Correct citation


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Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA)
Plot 5, Mpigi Road,
P. O. Box 765, Entebbe (Uganda)
Tel: +256 414 320 212/320 556/321 885
Fax: +256 414 321 126/322 593
Email: asareca@asareca.org
Website: www.asareca.org

Creative Director: Ben Moses Ilakut
Design/Layout: Peter Mugeni, Slick Republic Limited, Uganda


Cover Photos:
Top: ASARECA Interim Executive Secretary, Prof. Francis Wachira; Kenya’s Principal Secretary State Department of Livestock in the Ministry of Agriculture, Livestock and Fisheries, Prof. Fred Segor; and the World Bank Representative, Dr. Ladisy Chengula (seated 5th, 6th, 7th from right) join delegates in a group photo during the official opening of the conference.

Right: Some of the participants during the EAAPP conference and exhibition.

Left: Prof. Francis Wachira, Prof. Fred Segor and Dr. Ladisy Chengula appreciate a traditional performance during the opening ceremony.

Title Page: Prof. Francis Wachira, Dr. Tobias Onyango, Prof. Fred Segor, EAAPP Regional Coordinator, Mr. Vincent Akulumuka and Dr. Ladisy Chengula appreciate a performance at the opening ceremony.
Regional Specialisation for Enhanced Agricultural Productivity and Transformation

Proceedings

Eastern Africa Agricultural Productivity Programme
End-of-Phase One Project Conference & Exhibition

Edited by:

Foustine Wandera, Vincent Akulumuka, Jedidah Maina, Joan Otiang,
Jackson F. Mubiru, David Mbugua, Rahab Muinga
Organizing Committee

Mr. Vincent Akulumuka  
EAAPP Regional Coordinator – ASARECA (Chairperson)

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EAAPP National Coordinator - Ethiopia

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EAAPP National Coordinator - Kenya (Secretary)

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KALRO Kenya

Ms. Joan Otiang  
State Department of Livestock - Kenya

Ms. Grace Kimaru  
State Department of Livestock - Kenya

Dr. Douglas Indetie  
Livestock Breeding Specialist – EAAPP Kenya

Mr. Samuel Matoke  
State Department of Livestock - Kenya

Dr. Charity Nguoy  
State Department of Livestock (DVS) – Kenya

Mr. David Mbugua  
KALRO - Kenya

Ms. Adija Baraza  
State Department of Agriculture – Kenya

Dr. Joseph Kamau  
EAAPP PCU - Kenya
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<th>Description</th>
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<tbody>
<tr>
<td>ACMD</td>
<td>African cassava mosaic disease</td>
</tr>
<tr>
<td>AEF</td>
<td>Agro-Ecological Fitness</td>
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<tr>
<td>AFLB1</td>
<td>Aflatoxin B1</td>
</tr>
<tr>
<td>AI</td>
<td>Artificial Insemination</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>APPSA</td>
<td>Agricultural Productivity Program for Southern Africa</td>
</tr>
<tr>
<td>ARI</td>
<td>Agricultural Research Institute</td>
</tr>
<tr>
<td>ART</td>
<td>Assisted Reproductive Techniques</td>
</tr>
<tr>
<td>ASALs</td>
<td>Arid and Semi-Arid Lands</td>
</tr>
<tr>
<td>ASARECA</td>
<td>Association for Strengthening Agricultural Research in East and Central Africa</td>
</tr>
<tr>
<td>BecA</td>
<td>Bovine Tuberculosis</td>
</tr>
<tr>
<td>BTB</td>
<td>Cassava mosaic disease</td>
</tr>
<tr>
<td>CBB</td>
<td>Cassava bacterial blight</td>
</tr>
<tr>
<td>CBSD</td>
<td>Cassava brown streak disease</td>
</tr>
<tr>
<td>C-ELISA</td>
<td>Competitive enzyme linked immune-sorbent assay</td>
</tr>
<tr>
<td>CFT</td>
<td>Compliment Fixation Test</td>
</tr>
<tr>
<td>CGM</td>
<td>Cassava green mite</td>
</tr>
<tr>
<td>CIMMYT</td>
<td>International Maize and Wheat Improvement Centre</td>
</tr>
<tr>
<td>CIP</td>
<td>International Potato Centre (Spanish)</td>
</tr>
<tr>
<td>CM</td>
<td>Cassava mealybug</td>
</tr>
<tr>
<td>CMD</td>
<td>Cassava mosaic disease</td>
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<tr>
<td>CSA</td>
<td>Central Statistical Authority</td>
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<tr>
<td>DAOs</td>
<td>District Agriculture Officers</td>
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<tr>
<td>DRC</td>
<td>Democratic Republic of Congo</td>
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<tr>
<td>DRD</td>
<td>Department of Research and Development</td>
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<tr>
<td>DVC</td>
<td>Dairy Value Chain</td>
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<td>EAAPP</td>
<td>East African Agricultural Productivity Project</td>
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<tr>
<td>EACMV-UG</td>
<td>East African cassava mosaic virus-Uganda</td>
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<tr>
<td>EARRNET</td>
<td>Eastern Africa Root Crops Research Network</td>
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<td>EASZ</td>
<td>East African Shorthorn Zebu</td>
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<td>ECA-</td>
<td>Eastern and Central African</td>
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<td>EIAAR</td>
<td>Ethiopian Institute of Agricultural Research</td>
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<tr>
<td>ES&amp;AI</td>
<td>Estrous synchronization and Artificial Insemination</td>
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<td>ESARCC</td>
<td>Southern Africa Regional Research Centre</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organization</td>
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<tr>
<td>FGDs</td>
<td>Focus Group Discussions</td>
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<td>FLG</td>
<td>Farmers Innovation Group</td>
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<tr>
<td>FMD</td>
<td>Foot and Mouth Disease</td>
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<td>FREGs</td>
<td>Farmers Research and Extension Groups</td>
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<td>FTCs</td>
<td>Farmers Training Centers</td>
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<td>GAPs</td>
<td>Good Agricultural Practices</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
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<tr>
<td>GLM</td>
<td>General Linear Model</td>
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<tr>
<td>GMO</td>
<td>Genetically Modified organisms</td>
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<tr>
<td>ICARDA</td>
<td>International Centre for Agriculture Research in the Dry Areas</td>
</tr>
<tr>
<td>ICIPE</td>
<td>International Centre for Insect Physiology and Ecology</td>
</tr>
<tr>
<td>IDM</td>
<td>Integrated Disease Management</td>
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<tr>
<td>IFPRI</td>
<td>International Food Policy Research Institute</td>
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<tr>
<td>IITA</td>
<td>International Institute of Tropical Agriculture</td>
</tr>
<tr>
<td>ILRI</td>
<td>International Livestock Research Institute</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<td>--------------</td>
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<tr>
<td>IVEP</td>
<td>In-vitro embryo production</td>
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<tr>
<td>KAGRC</td>
<td>Kenya Animal Genetic Resources Centre</td>
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<tr>
<td>KALRO</td>
<td>Kenya Agricultural and Livestock Research Organization</td>
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<tr>
<td>KARI</td>
<td>Kenya Agricultural Research Institution</td>
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<tr>
<td>KENAFF</td>
<td>Kenya National Farmers Federation</td>
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<tr>
<td>MAFC</td>
<td>Ministry of Agriculture, Food Security and Cooperatives</td>
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<tr>
<td>LEAZ</td>
<td>Large East African Zebu</td>
</tr>
<tr>
<td>MAFAP</td>
<td>Monitoring African Food and Agricultural Policies</td>
</tr>
<tr>
<td>MOET</td>
<td>Multiple Ovulation and Embryo Transfer</td>
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<tr>
<td>MoLFD</td>
<td>Ministry of Livestock and Fisheries Development</td>
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<tr>
<td>MRT</td>
<td>Milk Ring Test</td>
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<tr>
<td>MT</td>
<td>Metric Tonnes</td>
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<tr>
<td>NAADS</td>
<td>National Agricultural Advisory Services</td>
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<tr>
<td>NaCRRRI</td>
<td>National Crops Resources Research Institute</td>
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<tr>
<td>NARO</td>
<td>National Agricultural Research Organisation (Uganda)</td>
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<tr>
<td>NARS</td>
<td>National Agricultural Research Systems</td>
</tr>
<tr>
<td>NESEG</td>
<td>North Eastern Savannah Grasslands</td>
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<tr>
<td>NEXTGEN</td>
<td>Next generation methods to preserve farm animal biodiversity</td>
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<tr>
<td>NSD</td>
<td>Napier stunt disease</td>
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<tr>
<td>PCR</td>
<td>Polymerase Chain Reaction</td>
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<tr>
<td>PPD</td>
<td>Purified Protein Derivatives</td>
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<tr>
<td>PVA</td>
<td>Pro-Vitamin A</td>
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<td>QTL</td>
<td>Quantitative trait locus</td>
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<tr>
<td>RBPT</td>
<td>Rose Bengal Plate Test</td>
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<tr>
<td>RCBD</td>
<td>Randomized Complete Block Design</td>
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<tr>
<td>RCoE</td>
<td>Regional Centre of Excellence</td>
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<td>RLDC</td>
<td>Rural Livelihoods and Development program</td>
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<td>RSeS</td>
<td>Regional Seed Enterprises</td>
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<tr>
<td>RT-PCR</td>
<td>Real time-polymerase chain reaction</td>
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<tr>
<td>SARD</td>
<td>Strategic Agricultural Research and Development</td>
</tr>
<tr>
<td>SARD-SC</td>
<td>Support to Agricultural Research for Development of Strategic Crops</td>
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<tr>
<td>SEAZ</td>
<td>Small East African Zebu</td>
</tr>
<tr>
<td>SICTT</td>
<td>Single Intradermal Comparative Cervical Tuberculin Test</td>
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<td>SIDO</td>
<td>Small Scale Industry Development Organization</td>
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<td>SMS</td>
<td>Subject Matter Specialists</td>
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<td>SNF</td>
<td>Solids-Not-Fat</td>
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<td>SNNJP</td>
<td>Southern Nation Nationality People</td>
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<td>SPSS</td>
<td>Statistical Package for Social Sciences</td>
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<tr>
<td>SSA</td>
<td>Sub Saharan Africa</td>
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<tr>
<td>TMR</td>
<td>Total Mixed Ration</td>
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<tr>
<td>ToT</td>
<td>Training of Trainers</td>
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<tr>
<td>TVLA</td>
<td>Tanzania Veterinary Laboratory Agency</td>
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<tr>
<td>UNCCST</td>
<td>Uganda National Council for Science and Technology</td>
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<tr>
<td>VIRCA</td>
<td>Virus Resistant Cassava for Africa</td>
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<tr>
<td>WAAPP</td>
<td>West Africa Agricultural Productivity Program</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organization</td>
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<tr>
<td>WHR</td>
<td>Western Highland Ranges</td>
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</table>
Children of Damacrest Primary School in Kukuyu, Kenya entertain guests with a performance loaded with messages on food security.

An exhibitor explains an innovation for milk processing and storage to Profs. Segor and Wachira.

Participants listen attentively to proceedings.

Dr. Foustine Wandera, the EAAPP focal person at KALRO, Kenya and Dr. Adugna Wakiira, the deputy Director General, EIAR, enjoy a performance by a traditional Kenyan group at the opening of the conference.
Kenya, Tanzania, Ethiopia, Uganda and the World Bank jointly designed a ten-year Eastern Africa Agriculture Productivity Project (EAAPP). As a regional initiative, this project fits within the development framework of the World Bank, COMESA and ASARECA because it (i) supports activities that are coordinated across four countries, (ii) generates benefits that spill over country boundaries, and (iii) provides a platform for policy harmonization. EAAPP phase I has been in operation since mid 2009, after the World Bank and the participating countries entered into a mutually negotiated financing agreement.

EAAPPs Development Objectives (PDO) are to; i) enhance regional specialization in agricultural research, ii) enhance collaboration in agriculture training and technology dissemination, and iii) facilitate increase of transfer of agricultural technologies, information and knowledge across national boundaries. The PDO were planned to be accomplished within a ten-year period, divided into two phases of five years each. Phase I closed on December 31, 2015 and EAAPP is now ready for phase II after fulfilling all the necessary triggers for the new phase. The end of phase I evaluation found that the project had moved in the right direction in fulfilment of its development objectives.

At the country level, EAAPP activities have been managed through different institutional arrangements. In principle, the management of national projects is mainstreamed into the national research and innovation systems. Taking into consideration different institutional contexts and capacities, EAAPP could not come up with a blueprint for country organizational arrangements. It was however noted that, the EAAPP national coordination units (PCU) when well resourced by dedicated staff, improved efficiency and timeliness of project implementation. The PCU staff were able to engage in relevant scaling-out and partnership activities.

At regional level, ASARECA provided assistance for networking, capacity building and technical backstopping, monitoring and evaluation, regional coordination and supervision, and policy analysis.

During EAAPP phase 1, ASARECA effectively facilitated all the regional meetings, identified topics for regional research projects, developed guidelines for the description of the technologies, trained stakeholders on Environmental and Social Safeguards (ESS) issues and value chains, guided the working group on policy harmonization and provided the Monitoring and
Evaluation framework and the Project Monitoring, Evaluation, Reporting and Learning (PMERL) software.

At continental level, EAAPP is among the three Agriculture Productivity Programmes (APPs) in Africa, South of Sahara promoting productivity of selected commodities with the aim of reducing poverty, addressing food and nutrition insecurity and increasing household income. Others are the West Africa Agriculture Productivity Programme (WAAPP) and the Agriculture Productivity Programme for the Southern Africa (APPSA).

These programmes support the objectives of the World Bank’s Africa Action Plan (AAP), which identified regional integration as an important driver to achieving higher economic growth and reducing poverty. APPs are enshrined in a shared vision of the AU/NEPAD and CAADP agenda of attaining the Millennium Development Goals (MDGs) through supporting governments to develop viable investment plans that will facilitate agriculture to grow at an annual rate of 6%.

At the sub-regional level, EAAPP has also continued to provide a vehicle for implementing the agricultural transformation agenda of ASARECA, which was created to enhance regional collective action in agricultural research for development, extension, training, and education. ASARECA has been mandated by COMESA and Forum for Agricultural Research in Africa (FARA) to take lead in coordinating implementation of CAADP Pillar IV and the application of the FAAP principles in Eastern Africa. EAAPP phase 1 focused on four main commodities– Cassava (Uganda), Dairy (Kenya), Rice (Tanzania), and Wheat (Ethiopia).

Since its inception, EAAPP has recorded significant strides in terms of building capacity of the involved institutions and staff, generating technologies and disseminating the same to beneficiaries through various pathways, strengthening regional collaboration and policy harmonization for increasing access to knowledge, information and technologies.

Following closure of phase 1 of the programme, it is imperative to document and share the achieved results, success stories and lessons learned over the five-year implementation period of phase 1.

This is expected to i) inform the design of phase 2 of EAAPP or similar initiatives; ii) enhance experience sharing from EAAPP as a regional initiative; iii) contribute to new strategies on technology out-scaling beyond the current EAAPP operational timeframe.

EAAPP focuses on four main commodities– Cassava (Uganda), Dairy (Kenya), Rice (Tanzania), and Wheat (Ethiopia).
Phase II targets to reach 2-3 million households, strengthen partnership with international and regional research and development institutions, enhance linkages with the private sector and promote farmer organizations for more technology uptake.

to have the right skills for addressing regional priorities, and iii) generating appropriate pathways for diffusing agriculture technologies, innovations and management practices for the beneficiaries across the four countries. These involved increasing collaboration among researchers, extension agents and other stakeholders along the value chains, initiating and facilitating the harmonization of policy and regulatory frameworks necessary for facilitating the smooth sharing of technologies, knowledge and information and catalyzing more collaboration.

The Independent Evaluation Report and the Project Results Framework have both found that EAAPP met all the triggers for phase II jointly agreed by the implementing countries and the World Bank during the design stage. The project had established and equipped the four commodity-based regional centres of excellence; in Kenya (dairy), in Uganda (cassava), in Ethiopia (wheat) and in Tanzania (rice) and had improved regional research capacity by training 44 PhD and 105 MSc scientists. The project had also generated 138 new technologies, innovations and management practices out of which 23 had been disseminated across national borders. The project had reached over 1 million household beneficiaries with project interventions. It had also demonstrated significant spill over with one project beneficiary reaching 12 non-beneficiaries with information and knowledge about the improved technologies; and among those, 6 of them were using the technologies.

Overall, trends showed that between 25-50% of beneficiaries had recorded improved agricultural productivity and incomes. When it materializes, Phase II of EAAPP will harness the gains made in phase I. Emphasis will be on: i) enhancing implementation of policy harmonization frameworks at the country level to boost benefit sharing and collaboration; ii) scaling-out of the proven technologies generated in phase I and those to be generated in phase II; iii) establishment of agribusiness groups as part of commercialization of agriculture along the value chains, and iv) the Regional Centres of Excellence will continue to address key bottlenecks arising from the commodity value chains. Phase II targets to reach 2-3 million households, strengthen partnership with international and regional research and development institutions, enhance linkages with the private sector and promote farmer organizations for more technology uptake.

To document the achievements obtained in the first five years, the lessons learned, the success stories and testimonies from beneficiaries, an end of phase 1 conference was therefore held in September 14-18, 2015. The conference also aimed to i) inform the design of phase 2 of EAAPP or similar initiatives; ii) share widely the experience from EAAPP as a regional initiative; iii) to strategize on technology out-scaling beyond the EAAPP operational timeframe. It is my sincere hope that this document, which consolidates all the above aims, will be a useful learning tool on regional research for development initiatives. I thank all those who worked hard to document every detail that emanated from the conference.

Prof. Francis Wachira
Interim Executive Secretary - ASARECA
Preface

This proceedings document the Eastern Africa Agriculture Productivity Program (EAAPP) End of Phase I Conference and Exhibition held at Kilimo Grand Resort, Nairobi Kenya in September 14-17, 2015. The Principal Secretary Prof. Fred HK Segor from the State Department of Livestock in the Ministry of Agriculture, livestock and fisheries in Kenya officially graced its opening, and the Regional Commissioner, Dr. Rajab Rutengwe of Morogoro Region in Tanzania officially closed it.

The conference and exhibition was designed to document i) achievements of EAAPP during its first phase, ii) the lessons learned, iii) the success stories and iv) the challenges the programme faced. The conference had two parts; exhibitions and presentations. The exhibitions showed the products developed by EAAPP implementing institutions in the four (4) countries of Kenya, Uganda, Tanzania and Ethiopia and the presentations involved papers, posters, testimonies from farmers and two side events, one with farmers who shared and exchanged experiences and specialized session of breeders on Breeding Management Systems (BMS) facilitated by IITA and BecA - Kenya.

This conference, the first among the APPs, drew participants from the four (4) EAAPP implementing countries, West Africa Agriculture Productivity Programme (WAAPP) represented by Nigeria country programme, Agriculture Productivity Programme for the Southern Africa(APPSA) represented by Malawi and Zambia country programmes, the World Bank, CGIAR centers (IITA, CIMMYT), farmers and private sector. A total of 250 participants attended the conference and among those 27% were female. Kenya hosted the conference and was held at the Kilimo Grand Resort, a facility owned by Kenya National Farmers Federation (KENAFF) located at Kikuyu area in the outskate of Nairobi city.

In September 2014, the first conference preparation meeting was held in Awasa city in Ethiopia where the three (3) sub committees were formed, drafted the conference theme and sub themes and identified the host country and conference dates. Broader roles and responsibilities of the formed committees were identified, such as the organizing committee was to provide the conference oversight and mobilize resources, the technical committee
charged for organizing conference papers and the logistics committee was assigned to deal with logistical issues and organizing the exhibitions. Consequently, the four (4) Regional Centres of Excellence (RCoEs) displayed technologies, ready for market products and innovations were displayed. A total of 300 farmers and stakeholders participated in the exhibition.

The conference theme and sub-themes were discussed and agreed through participatory process. The conference is “Regional Specialization for Enhanced Agricultural Productivity and Transformation” and six (6) sub-themes are; i) genetic resource management and improvement; ii) integrated pests and disease management; iii) soil and water management; iv) feeds and feedings in dairy production; v) access and utilization of technologies, innovations and management practices and vi) value addition and socio-economics. Based on the themes and sub-themes, technical subcommittee called for write-ups and received a total of 102 abstracts. Seventy nine (79) were approved for full paper development; 47 for oral presentation and 32 as posters. All 79 papers were subjected to peer review process before the conference. At the end of presentations, questions were asked and responses provided by the presenters. During the general discussion, opinions were sought from the participants about progress made on regional specialization, the level of collaboration and the efforts towards sharing of technologies, innovations and management practices. These proceedings provide a synthesis of what transpired with this regards.

Day one of the conference was dedicated for exhibitions and conference opening. This was done specifically to give enough time for the chief guests and the stakeholders to see the exhibits and appreciate the efforts EAAPP did over the past five years. In day 2 up to the end, the conference was dedicated to paper and poster presentations and side meetings.

A keynote speech opened the conference presentation. The speech was on “regional trade on food staples: main instruments for getting research into use for wealth creation” was delivered by Prof. Nuhu Hatibu, a Chief Executive Officer (CEO) of Kilimo Trust. Prof. Hatibu is a high profile agriculture practitioner, a PhD holder in agricultural engineering and a CEO of Kilimo Trust for the past eight (8) years. Prior to his present position, Prof. Hatibu was a Regional Coordinator of the ASARECA’s Soil and Water Improvement Network (SWIMNET). Before joining SWIMNET, Prof. Hatibu was a senior lecturer and a Professor of Agricultural Engineering at Sokoine University of Agriculture in Tanzania for 20 years.

The lead papers presented were on wheat, cassava and dairy. They all talked about research and development in eastern Africa region; past, present and future. The paper on wheat was presented by Dr. Ayele Badebo who holds a PhD in Plant Pathology from Goettingen University in German. Since 1984, Dr. Ayele has been working as a lead
scientist on seed systems and wheat pathology research in Ethiopia and he continued to do so up to mid 2013. In September 2013, Dr. Ayele joined CIMMYT as a wheat seed coordinator in the Global Wheat Program based in Addis Ababa, Ethiopia.

A lead paper on cassava was presented by Dr. Edward Kanju, a senior scientist (cassava breeder) with IITA based in Dar es Salaam, Tanzania. Dr. Kanju obtained his PhD on plant breeding at the University of Free State, South Africa in 2000. Dr. Kanju has been working with the research and development department of the Ministry of Agriculture Food Security and Cooperatives in Tanzania in the roots and tuber programme. He joined IITA in 2002 and currently is a program manager of the Gates Foundation regional project on “New Cassava Varieties and Clean Seed to Combat CBSD and CMD” (SCP) implemented in Malawi, Mozambique, Kenya, Tanzania and Uganda”.

Dr. Jean Ndikumana presented a lead paper on dairy. Dr. Ndikumana holds a PhD on pasture management from the University of Gent in Denmark. Dr. Ndikumana worked in Burundi National Research Organization (ISABU) and became the Director General of the institute. Then he joined Ukiriguru Agricultural Research Institute in Tanzania as a cotton breeder and later as roots and tuber crops breeder before he went to Belgium for his PhD studies. Upon arrival, Dr. Ndikumana joined the International Livestock Research Institute (ILRI) of which he worked for 17 years. Then, for the last 8 years up to March 2015, Dr. Ndikumana worked for ASARECA as a programme manager for livestock and fisheries programme. Dr. Ndikumana is a known feeds and forage scientist and has been leading research initiatives in the same area at continental and regional level.

The success of this conference and exhibition is a result of team work. However, I would like to register my heartfelt gratitude to all who worked tirelessly and their efforts have resulted into this document. I wish to specifically recognize impeccable contribution of Prof. Francis Wachira, the Interim Executive Secretary of ASARECA for his constant encouragement, guidance and interest that uplifted my spirit throughout the conference preparation period. In a special way, I register my sincere thanks to Dr. Foustine Wandera, the chairperson of technical sub-committee and his team for their immeasurable dedication rendered to this conference.

I wish also to recognize the dedicated efforts of Ms. Catherine Kinyanjui and her team for excellent job done on ensuring all conference logistics and exhibitions were done to the high level professionalism. I also recognize and profoundly thank the EAAPP TTL, Mr. Assaye Legesse, and the EAAPP co-TTLs their constant encouragement, soul touching support and support they provided before and during the conference. Lastly, but not the least, I wish to thank, in a special way, my colleagues, the National Project Coordinators; Ms. Jane Muriuki of Kenya, Dr. Hussein Mansoor of Tanzania, Dr. Yitaye Alemayehu of Ethiopia and Dr. George Lukwago of Uganda, who, jointly worked with me throughout the preparation period, encouraged me and ensured that resources are available for the conference. To all of you mentioned and those I did not, I kindly say THANK YOU VERY MUCH.

Vincent Akulumuka
EAAPP Regional Coordinator - ASARECA
Opening Session

Honourable Guest, Principal Secretary, State Department of Livestock, Kenya,
Delegates from WAAPP, APPSA, EAAPP Countries,
Representative from the World Bank
Executive Secretary, ASARECA,
CEO KENAFF
Honourable farmers, Ladies and gentlemen

Welcome to EAAPP End of Phase One Regional Conference and Exhibition.
On behalf of EAAPP implementers, let me take this opportunity to thank you sincerely for positively responding to our invitation and being with us today. I sincerely thank the PS, State Department, Livestock, Prof. Segor, for gracing this occasion as our honourable guest.

I wish to also to acknowledge all invited guests from Ethiopia, Tanzania, Uganda, entire region and beyond. Delegates from WAAPP and APSA are also here with us and it is my hope that you will enjoy the warmth of Kenya.

We are gathered here today to celebrate the achievements made in the last 5 years when the journey started. The immense support provided by the World Bank was timely for successful implementation of EAAPP and we are indeed grateful. The beginning was tough as this was the first regional agricultural project the World Bank was piloting in the Eastern Africa region. It took plenty of time for the Regional teams to coalesce and galvanize into action. Due to requisite stakeholder consultation, the process in priority setting on the research agenda also took considerable time. Coordination at the regional
Some notable achievements include infrastructure development at the 4 Centres of Excellence, over 138 technologies and information generated along the 4 commodity value chains, about 1 million farmers reached (directly and indirectly) with technologies and technical information to enhance productivity.

level was a major challenge until ASARECA established an EAAPP Desk under the able leadership of Vincent.

Let me take this opportunity to thank the Executive Secretary Prof. Francis Wachira and your entire team for exemplary work in coordinating the Regional aspect of this project. Special recognition goes to Enock Warinda who spearheaded the M&E docket and we are proud to report today that EAAPP has one of the best systems of data capture any project could have. Regional Policy harmonization process in daily, Seeds and the development of IPR went on slowly but sure. We hereby request for fast tracking of the process into legislation.

Allow me to recognize the support our policy makers have played over the years. The Principal/Permanent Secretaries and Heads of implementing ministries and Institutions have all along been available for guidance and consultations. They also facilitated smooth flow of funds to the Project Coordinating Units and other implementing arms of the project.

EAAPP implementers have received tremendous support and backstopping by both the World Bank and Project Steering Committees (both Regional and National). With such tremendous support, we had no alternative but to deliver. Some notable achievements include infrastructure development at the 4 Centres of Excellence, over 138 technologies and information generated along the 4 commodity value chains, about 1 million farmers reached (directly and indirectly) with technologies and technical information to enhance productivity.

An effort to decentralize Liquid nitrogen and semen distribution is underway through establishment of 4 liquid nitrogen plants (Uganda and Kenya). Two high yielding Rice varieties (Komboka, Saro 5) developed in Tanzania were registered in Kenya in 2014. In addition Kenya has received wheat varieties from Ethiopia and vise versa to mention but a few. In human resource development, 44 PhDs and 105 MSCs students have been facilitated to train in local universities. I leave for you to carefully consider and make informed opinions at the end of this week if taxpayers’ money was well spent.

In conclusion, let me voice our great hope and expectation that we shall advance into second phase of this project. We also call upon our policy makers to persuade the World Bank to open their purses so that the investments made in the centres of excellence in the First Phase of EAAPP can realize the intended impacts.

We as implementers have a passion to see our farmers, youth groups that we have been working with not only increase productivity but also move into the level of agribusiness and transformation.

Thank you Honourable Guests, ladies and gentlemen.
A message from ASARECA

Honourable Chief Guest, the Principal Secretary State Department of Livestock, Kenya; delegates from WAAPP, APPSA and EAAPP; representatives from the World Bank, the CEO KENAFF, the Honourable farmers, distinguished ladies and gentlemen.

On behalf of ASARECA Secretariat, the entire ASARECA fraternity and my own behalf, I welcome you all to the EAAPP End of Phase I Conference and Exhibition held here at the Kenya National Farmers Federation Headquarters.

Allow me to register a special warm welcome to our colleagues from Zambia, Malawi and Mozambique, who are implementing a similar program like EAAPP, known as the Agricultural Productivity Programme in Southern Africa (APPSA) and colleagues from Nigeria who are implementing another similar programme known as the West Africa Agriculture Productivity Programme (WAAPP). I sincerely welcome you all to the Eastern and Central Africa sub-region. I wish to also specifically acknowledge the presence of our dear farmers, who are the testimony of our efforts to impact the daily lives of ordinary people in the sub-region.

The farmers are here to testify to us the benefits they have gained and are continuing to accrue as a result of their engagement with EAAPP.
Honourable Chief Guest

Allow me to say a few words about ASARECA.

ASARECA is a sub regional R4D organization, which was officially launched in 1992 by 10 member countries; Burundi, the Democratic Republic of Congo, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania and Uganda. Membership has since grown to 11 following the birth of South Sudan.

ASARECA brings together agricultural scientists and stakeholders from the national agricultural research institutions, agricultural extension service providers and other strategic development partners to generate, share, promote and out scale knowledge, technologies and innovations with an overarching purpose of solving the common challenges facing agriculture in the member countries. ASARECA enables the member countries to work collectively to assist smallholder farmers to practice productive and profitable agriculture.

ASARECA is currently working towards becoming a knowledge hub of agricultural research and development in ECA region. In that respect, we see Regional Centres of Excellence as commodity-specific knowledge hubs and ASARECA will work closely with these Centres in supporting generation, documentation and publication of information and knowledge at RCoEs level.

Honourable Chief Guest

This conference and exhibition marks the end of phase I and is intended to document achievements of EAAPP in its first phase of implementation. The documentation will also capture the success stories, lessons learnt, challenges faced and possible solutions. The output of the conference will be published widely in scientific journals and in the web using various social media tools.

In this Conference, there will be total of 94 presentations; 47 oral papers, 32 posters, 1 keynote speech, 3 lead papers, 4 testimonies from farmers, 4 cross cutting presentations and 2 presentations from our sister programmes – APPSA and WAAPP. In addition to the presentations, the conference will also showcase selected technologies, innovations and products developed by the programme during the first phase.

The presentations and the interactions that will arise from the conference will result into a pool of experience and knowledge that will help to remodel the next stage of EAAPP – be it phase II or mainstreaming of completed activities into Asareca’s other on-going initiatives/programmes

Honourable Chief Guest

ASARECA and the implementing countries will ensure that the outputs of this conference are well documented in the form of proceedings which will be published online and in prints for wide circulation and accessibility so that they can contribute to the existing pool of knowledge on regional AR4D initiatives in Africa.

Furthermore, should there be a phase II of EAAPP, ASARECA is ready and willing to carry out its role in coordinating the regional component. We are ready to discuss with the implementing countries and the World Bank on how we can implement our role to ensure increased effectiveness and efficiency of the programme.

I wish all the delegates of the EAAPP End of Phase I Conference and Exhibition very fruitful and productive deliberations.

May God Bless you.
I thank you all.
Dr. Apochi observed that WAAPP is constituted under the Economic Community Of West African States (ECOWAS) and implemented at national levels by National Research Councils. WAAPP, which comprises four components is the best option for West Africa considering declining National budgets for agriculture.

The focus of WAAPP was improved agricultural productivity and integrated agricultural research into technology generation. Improved agricultural productivity in one country has spillover effects in the whole region.

Lessons learnt in project implementation and achievements since project inception in 2012 were shared during the conference. Dr. Apochi looked forward to learning from EAAPP during the exhibition and conference and thanked organizers for the invitation.
The second component of the project is strengthening regional centers of leadership. This component will support activities to strengthen the core capacity of the RCoLs.

The choice of activities to be financed will be driven primarily by the specific needs of each RCoL, as identified at national level. The third component of the project is coordination and facilitation.

This component will finance three main categories of activities: 1) national level research coordination and management, 2) regional facilitation by Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA), and 3) Research and Development (R&D) policy analysis and dialogue. Malawi focus is on Maize and maize farming systems; Mozambique – rice and rice farming systems and Zambia – Legumes and legume farming systems, all coordinated by CCARDESA.
INTRODUCTION

Highlight of key outcomes

Welcome to EAAPP End of Phase One Regional Conference and Exhibition. On behalf of EAAPP implementers, let me take this opportunity to thank you sincerely for positively responding to our invitation and being with us today. I sincerely thank the PS, State Department, Livestock, Prof. Segor, for gracing this occasion as our honourable guest.

Introduction

The four (4) countries of Kenya, Tanzania, Ethiopia and Uganda in collaboration with the World Bank and ASARECA initiated the Eastern Africa Agricultural Productivity Programme (EAAPP) as a Regional Agricultural Research for Development initiative. The overall goal was to contribute to enhanced sustainable productivity, value added and competitiveness of sub-regional agricultural system. EAAPP specific objectives are to:

- Enhance regional specialization in agricultural research
- Increase regional collaboration in agricultural training and dissemination
- Facilitate increased sharing of agricultural knowledge and technologies across national boundaries
EAAPP is a ten-year programme with two phases. Phase I, approved in 2009, focused on capacity building with the establishment of the Regional Centres of Excellence (RCoEs) through construction/improvement of infrastructure and human resource development; technology generation and dissemination; and improving seeds and breeds availability. EAAPP focuses on four commodities: cassava where Uganda is leading, dairy led by Kenya, rice by Tanzania and wheat by Ethiopia.

**Key Programme Impacts**

**Indicator 1: Rate of change in regional specialization and collaboration in agricultural research**

Average level of regional specialization and collaboration across the four countries was 63%, an increase of 53 percentage points above the baseline and exceeding targets (EAAPP M&E data). Table 1 shows the thirty-three regional research sub-projects initiated during phase I and also indicating the high levels of country participation. A total of 23 projects (70%) were implemented in all four (4) countries followed by 9 projects (27%) implemented in three (3) countries and the one project (3%) being undertaken in two countries.

The capacity for undertaking research in the EAAPP countries has increased, both, in quantity and quality. In 2010, there were only 232 researchers attached to the regional centres of excellence and ready to carry out regional projects. By the end of 2014, that number has increased almost three-fold to 661. This increase is due to redeployment of researchers to be attached to RCoEs as well as undergoing long-term training. During phase I, the project trained one hundred and five (105) scientists at Master degree level, of whom 34% were female and forty four (44) candidates were on PhD program, of which 19% were female.

A commendable progress is recorded in acquisition of infrastructure in all countries and the completion of the labs and commissioning of the lab equipment was finalized during a no cost extension. This has brought significant improvements in capacity to generate technologies through research, support dissemination and enhance exchanges in the region of which many of these are expected to show results in Phase 2.

<table>
<thead>
<tr>
<th>Commodity</th>
<th># of projects</th>
<th># of countries and corresponding projects implemented</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Cassava</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Dairy</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>10</td>
<td></td>
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<tr>
<td>Total</td>
<td>33</td>
<td>1</td>
</tr>
</tbody>
</table>

*Source: EAAPP Evaluation Report 2014*
Indicator 2: Rate of increase in information and knowledge transfer across national boundaries.

One hundred and thirty eight (138) new technologies have been developed by the regional centres of excellence. Many are new varieties of cassava, rice, wheat and forage crops. Out of them, twenty-three (23) new technologies have been disseminated across national boundaries. Examples of such sharing include the four (4) rice varieties from Tanzania which were shared to the other EAAPP implementing countries and out of them, two (2) were released in Kenya and Uganda, while Ethiopia is testing them under the National Variety Trials (NVT); four clones of Napier grass from Kenya were recommended for dissemination in Uganda; the RCoE in Uganda shared botanical seed of cassava with enhanced carotene sent to Ethiopia, Tanzania and Kenya; assisted reproductive technologies from Kenya sent to the other countries.

Indicator 3: Rate of change in adoption of new technologies

In phase I, EAAPP attained an increase in adoption of new varieties, breeds, and other selected management practices by farmers from 35 percent to 53 percent (2010-2014) in project areas. Large increases are seen in Ethiopia (all commodities) and Kenya, with smaller increases in Tanzania. Evaluation findings confirm that the proportion of beneficiaries using improved varieties of cassava, wheat and rice has increased in all countries between 2009 and 2014. In 2014, 65 percent of targeted households were using improved cassava, 87 percent improved rice varieties and 97 percent improved wheat and adoption of improved breeds of dairy cows has also increased.

The implementers used several technology pathways to disseminate technologies, innovations and management practices. Figure 1 show the pathways used and the existing interrelations within and between the pathways.

Indicator 4: Rate of increase in land area with seeds of improved cultivars

The land planted with improved cultivars increased from 2,755 ha in 2010 to 12,807 ha in 2014. This is attributed to the substantial increase in production of planting material and farmer awareness in EAAPP project areas. Large increases are reported in Ethiopia, Kenya (cassava, rice, wheat) and Uganda (cassava). Beneficiary groups and key informants interviewed during the evaluation confirmed sizeable increases in areas planted for each of the commodities in the four countries.

Indicator 5: Increase in productivity at farm level over control technology for all disseminated new technologies

Almost all technologies performed positively over control technologies, with productivity increases ranging from zero to 8% between 2010 and 2013. Large improvements in productivity of new technologies over controls were recorded in wheat (Kenya and Uganda) and cassava (Kenya). Rice and...
dairy technologies showed lower increases over controls over the project period: possibly due to spillover effects. Findings from the evaluation survey on output per unit of land indicate higher increases in land productivity for all commodities except cassava in Uganda.

**Indicator 6: Level of stakeholder satisfaction with the technologies and innovations**

Farmer satisfaction with technologies has increased from 23 percent to 69 percent of households in targeted project areas. The greatest increases were in cassava and wheat. This may be partly the result of disease resistance traits of the new technologies. The evaluation survey found that a quarter to half of beneficiaries had experienced improvements in their production or incomes as a result of adopting the technologies.

Overall, programme targets have been met and, in some cases, exceeded. Thus the overall assessment is quite positive. Regional research projects are on target, though with some variation between commodities. Training targets are also on track.

All EAAPP partner countries had relatively high increases in their agricultural research and development spending between 2000 and 2011. All saw increased numbers of agricultural researchers during the same period, but the magnitude was much greater in Ethiopia. Phase 2 of the project needs to build in mechanisms for mentoring returning students and integrating them into RCoE activities.

**Beneficiary impact**

Evaluation household survey findings indicate that EAAPP beneficiaries are already seeing a positive impact from their involvement in the programme in terms of: production, yields, incomes, food security and economic status. In a number of cases these improvements were found to be significantly greater than non-project households.

Average yields for beneficiaries in 2014 were 15 tonnes per hectare for cassava, 7 for wheat and 9 for rice. These exceed regional productivity figures for rice and wheat. Despite these improvements, there is large variability in farmer yields across all the four commodities.

Net incomes from key EAAPP commodities of surveyed beneficiary and non-beneficiary households have increased over the project period.
period. This has been most significant in dairy in Kenya, rice in Tanzania and cassava in Uganda. Non-beneficiaries have also increased their net incomes, partly through scaling out effects to neighbouring farmers and communities. Net incomes of beneficiaries from key commodities were significantly higher than those of non-beneficiaries in dairy and rice. Low incomes were received by wheat farmers in Tanzania who complained of low prices. Returns for dairy farmers in Uganda were very low at $300pa, below the $1 per day income threshold.

Beneficiaries with household food surplus rose significantly in Ethiopia, Kenya and Tanzania, and slightly in Uganda. Beneficiaries in Ethiopia and Kenya were significantly more likely to be food surplus households than non-beneficiaries in EAAPP project areas in 2014. Nutrition security, indicated by the number of food groups consumed, was significantly higher for project farmers compared to non-beneficiaries for wheat in Ethiopia and dairy in Uganda, implying a positive impact on diversity of foods consumed in the household. However, beneficiary rice households in Kenya were less likely to have a diversified diet than non-project farmers. This may be because these are households who have so far not seen an increase in incomes through the project.

Poverty self-assessment showed significant improvements by 2014, with large numbers of households being lifted out of the poorest group. This could be the result of transmission of benefits to non-project members, as well as to non-EAAPP interventions in the area. Beneficiary households in Uganda and Ethiopia appear to have improved their economic status relative to non-project members in their community over the life of the project. Beneficiaries are also scaling-out technologies to non-beneficiaries at quite a high rate.

Gender: The Impact Evaluation looked at several aspects of gender, including inclusion and roles of women and female-headed households in EAAPP projects. Project staff have been trained in Gender mainstreaming and are targeting women farmers. An exception was dairy farmers in Kenya where one group was found to be all male. Before the start of EAAPP activities in 2009, yields of female-headed households were lower than those of their male counterparts for wheat, dairy and rice. By 2014, female-headed households were yielding more than male-headed households for wheat in Ethiopia, rice in Tanzania and cassava in Uganda. This implies that the technologies are having a positive gendered impact. Only in Kenya were female-headed dairy households lagging behind. The EAAPP Kenya programme is prioritising gender issues in an attempt to address this.

**Beneficiaries reached**

EAAPP reached 5,559,229 beneficiaries, whereby among those, 799,891 were reached directly and 4,759,338 were reached indirectly.
Remarks by Director General, KALRO

The Principal Secretary, State Department of Livestock Prof. Fred Segor, The Regional Commissioner (Morogoro Tanzania) Dr. Rajab Rutegwe, World Bank Representative Dr. Ladisy Chengula, ASARECA Interim Executive Secretary Prof. Francis Wachira, Representative of West Africa Agricultural Productivity Program (WAAPP), Dr. James Apochi, Representative of Agricultural Productivity Project for Southern Africa (APPSA), Dr. Wilkson Makumba, fellow directors of research from the three other EAAPP member countries (Uganda, Ethiopia and Tanzania), National EAAPP coordinators of the four countries, scientists, exhibitors and farmers, ladies and gentlemen;

It gives me great joy to be part of this conference and exhibition that marks a significant milestone in the project that was conceived way back in 2008, to enhance regional specialization for technology development and dissemination within the Eastern African Region. The Kenya Agricultural and Livestock Research Organization (KALRO) was part of the regional team, which conceptualized the Eastern African
agricultural Productivity Project (EAAPP), within the ambit of ASARECA. It is therefore gratifying that towards the end of phase one of the project we have gathered here - scientists, farmers, extension service providers and private sector to take stock of achievements made in technology generation and dissemination as well as share lessons learned.

Guest of honour, ladies and gentlemen, the Kenya Vision 2030 envisages an agricultural sector that is “innovative, commercially oriented and globally competitive”. In line with this vision, the Kenya Agricultural and Livestock Research Organization (KALRO) was created through the KALR Act in January 2013. This umbrella body brings together the former Kenya Agricultural Research Institute (KARI), Tea Research Foundation (TRF), Coffee Research Foundation (CRF) and Kenya Sugar Research Foundation (KESREF). Under the Organization there are now 16 Institutes focusing on specific commodities/factors for more effective delivery of the organization mandate. These Institutes are; food crops, horticulture, industrial crops, coffee, tea, sugar, dairy, beef, Sheep and goats, non-ruminants, apiculture, veterinary science, arid and rangelands, biotechnology, genetic resources. The KALRO is charged with responsibility of promoting, streamlining, coordinating and regulating research in crops, livestock, genetic resources and biotechnology in Kenya.

Together with local, regional and international partners, KALRO seeks to expedite equitable access to research information, resources and technology and promote the application of research findings in the field of agriculture within Kenya and regionally. Our research efforts are geared towards generation and dissemination of agricultural and livestock knowledge, innovative technologies and services that responds to clients demands for sustainable livelihoods.

The KALRO is indeed grateful to the Government of Kenya and our development partners who have provided financial support in technology generation. Among several partners, please allow me to single out the World Bank whose support through the Eastern African Agricultural Productivity Programme (EAAPP) has in the last 5 years enabled capacity building of KALRO facilities and human resource within the four commodities of Dairy, Wheat, Rice and Cassava, which the project is focusing on within the EAAPP implementing Countries. I am happy to report that with this support, state-of-the art laboratory equipment have been acquired for the Dairy Centre of Excellence at KALRO Naivasha. This facility is now ready and available for scientists from the region to utilize in their research endeavor. The laboratory is...
Regional Dairy Centre of excellence has indeed taken shape and I strongly urge scientists from the Tanzania, Ethiopia, Uganda and other ASARECA member countries to feel free to come and utilize these research capacity. This was the spirit of establishing the Centres of Excellence in the four countries.

Guest of honour, Ladies and Gentlemen

Investments in agricultural research and development are regularly shown to have an annual rate of return in the range of 40-60%. Spillovers across national borders can raise this rate of return even higher. It has been shown that investments yielding regional benefits in African agriculture, delivered as much as 3 to 4 times the gain over and above direct benefits in the country of origin. However this response to investments varies among commodities, for example the benefits from cow milk in innovating countries would be KES 350 million in addition to KES 250 million spillover gain to non-innovating countries in the region. For rice the gains from specific research efforts would be KES 65 million for innovating country and KES 110 million additional spillover gains from non-innovating countries in the region.

During the conceptualization of EAAPP, the Ex Ante economic analysis showed that Internal Rate of Return to investment in dairy was 32.2% in Kenya alone and 37.5% with spillover effects in Tanzania and Ethiopia (definitely more when Uganda is added). It was assumed that in order for the benefits to be realized, there would be incremental adoption of new technologies coming from research and increase in productivity. It was therefore assumed that by the end of 5 years of Phase 1, 20% more
The project has generated 138 technologies, innovations and management practices out of which 23 have been disseminated regionally.

stakeholders/farmers would be adopting new technologies. It was therefore expected that extension service would be affecting 4% additional farmers every year for the 5 years, and causing increase in productivity.

The four countries implementing EAAPP have collectively invested heavily in this project to the tune of US$120 million to run for five years, in the area of Infrastructure and human resource development, technology generation and dissemination and improved availability of crop and livestock germplasm.

KALRO scientists in collaboration with their counterparts in local universities and the region, have carried out research in dairy, wheat, rice and cassava commodities along the programme thematic areas. Collectively the project has generated 138 technologies, innovations and management practices out of which 23 have been disseminated regionally. In dairy research, among key technologies generated and shared in the region include Assisted Reproductive Technologies Protocols, Napier Clones tolerant to Smut and stunt diseases, Tube silage for feed conservation, Improved Indigenous Germplasm exchange, Crop Residue Block, Forage Suitability maps and utilization of Rice by products. Kenya on the other hand has received germplasm from the three Centres of excellence, and even registered two rice varieties from Tanzania (Saro 5 and Komboka).

This spirit of regional collective action and sharing in technology development and dissemination should be continued, if we have to solve common agricultural constraints that make us not competitive on the global stage.

The performance of EAAPP in the last 5 years has been to my view very impressive, as you have heard from the results of external evaluation of the project, presented by ASARECA EAAPP manager earlier. This is despite the complexity of the project and challenges in establishing effective regional teams, and delivering the project development objective, within this short period.

As stated earlier the research facilities are now in place in the four countries, trainees sponsored by the project are just coming out of training institutions well armed with the tools to utilize these facilities to further benefit agriculture and livestock in the region. Regional teams are well established to work together. All the components of collective action envisioned in this project are in place. We are therefore very hopeful that phase two, which was designed for this project from the start shall be forthcoming to concertize the efforts made in phase one.

It is now my pleasure to call upon the World Bank Representative Dr. Ladisy Chengula to make his remarks.

Thank you very much and God bless you.
Remarks by World Bank Representative

Dr. Ladisy noted that the biggest measure of success is the number of technologies adopted and put into practice. He commended the teams for regional commodity specialization and technology adoption which was above 70%. He lauded the demonstrated strong coordination in the programme. With appreciation, Dr. Ladisy noted that the programme has gone beyond research to dissemination and effectively working with farmers in research and adoption of technologies.

Appreciating that the programme had activities in adding value to products produced in the four commodities, Dr. Ladisy noted that satisfactory performance has been achieved to trigger 2nd Phase and discussions for phase II are being held at the World Bank. However, in the ECA region, there was lack of institutional framework for co-ordination unlike ECOWAS where there is political vision and technical implementation. He also noted that harmonizing of regulatory policies was not concluded in the 1st Phase and this should be pursued.

Knowledge base is being eroded through retirement without replacement, creating huge skill gaps. There is therefore need to establish how to bridge the skill gaps through policy decisions.

Need to build a mechanism for sustained financing research and development at National Level and regionally and gaps filled with donor funding. Value chain approach should pay attention to all nodes of the value chain and in particular pay attention to value addition, marketing and consumption.
Kenya’s Principal Secretary
State Department of Livestock
in the Ministry of Agriculture,
Livestock and Fisheries, Prof.
Fred Segor.
Speech by the Guest of Honour, Prof. Fred Segor

The Executive Secretary, ASARECA
The Regional Commissioner, Morogoro, Tanzania
Representatives of the World Bank
The Chief Executive Officer, KENAFF
Delegates from the Western Africa Agricultural Productivity Program (WAAPP)
Delegates from Agricultural Productivity Project of Southern Africa (APPSA)
EAAPP Country Delegates
County Officials, Kenya
Distinguished Farmers
Distinguished Guests, Ladies and Gentlemen.

I am pleased to be here today to preside over this important regional conference which marks the end of phase 1 of the Eastern Africa Agricultural Productivity Project (EAAPP). I take this opportunity to warmly welcome all our guests to Kenya. The importance of this conference cannot be over emphasized. This event will enable us assess achievements and/or challenges during implementation of phase one of the project and hence strategize appropriately for the next course of action. This is also an opportunity for the various Regional Centers of Excellence (RCoE) to display and share their successes in technologies generated and disseminated and outcomes realised.

I am encouraging you to pick best lessons from this conference to assist you in enhancing productivity in the priority commodities of Dairy, Wheat, Rice and Cassava.

Ladies and Gentlemen

Agriculture remains the economic mainstay of the Eastern Africa region. It is estimated to contribute 45% of the GDP of the East and Central African Countries and 85% of the livelihoods of the region’s population. The economies of the region are overwhelmingly agricultural based and are dominated by smallholder farmers who are resource poor, with limited investment in agricultural development to promote agribusiness initiatives.

These households account for 80% of the total agricultural production making the region inherently food insecure. Therefore, if the region has to adequately satisfy its food needs, the current agricultural production systems must shift towards intensive commercial-oriented farming for meaningful transformation to be realized in the sector. It is on this basis that the Eastern Africa countries through AU-NEPAD initiatives with support from the World Bank, are placing strong emphasis on revitalization of agriculture to address food security and economic development in the region. This will lead to reduced poverty and food insecurity at household level and increase employment opportunities (especially for the youth).

Ladies and Gentlemen,
The agricultural sector in the region is faced by numerous challenges including: Climate change, high cost of inputs, low modernization of agriculture leading to low productivity. Other factors that have impeded the realization of full agricultural potential in the region are; inadequate value addition of farm produce, unfavourable policies to name but a few. The Sector’s growth is also hindered by socio-economic issues including high population pressure and reducing land size, poor infrastructure, inappropriate land tenure systems and high poverty levels that limit investment in the sector.

To transform this sector a paradigm shift is necessary from the current production systems towards intensive/extensive, commercially oriented farming. We must therefore focus our energies and synergies at addressing these challenges through forging partnerships with all stakeholders. I am glad that EAAPP has identified different institutions relevant for this purpose and has gone ahead to adequately involve them in the implementation of the project. I am therefore happy that this conference has drawn participants including research, extension, farmer organizations and other actors along the value chains of the four enterprises. There is also need to strengthen linkages among the various actors and ensure that technologies flow to our farmers so that they can reap benefits.

Ladies and gentlemen

Appropriate policies should be enacted to address these bottlenecks and facilitate trade among countries. I am aware you have been working on harmonization of dairy feeds, breeding, dairy processing and seed policies to facilitate easy movement and exchange of genetic materials and products across the region. These policies need to be fast tracked without undue delay.

In Kenya, for example, Vision 2030 envisages to transform the Country into a middle level economy with quality life for its citizens, and it identifies agriculture as the engine of economic growth. In this regard, the Agriculture Sector Development Strategy (ASDS) and the National Dairy Master Plan (2010 to 2030) were developed as guiding policies in enhancing agricultural productivity in Kenya. Implementation of these strategies and others not mentioned here, will greatly contribute to improving rural livelihoods and meet the MDG goal of eradicating extreme poverty and hunger.

Ladies and Gentlemen

EAAPP was designed to complement the activities of ASARECA, a regional research organisation by scaling up investment that have capacity to generate both regional and national benefits.
As you are aware, EAAPP has greatly invested in these research and dissemination approaches on the basis of comparative advantages in selected commodities. Kenya has developed the Dairy Centre of Excellency hosted by KALRO at Naivasha and has supported development of promising technologies and appropriate infrastructure along the dairy value chain which are available for use by the region’s stakeholders.

Our EAAPP partner Countries, Ethiopia, Uganda and Tanzania on the other hand are promoting wheat, cassava and rice through Regional Centers of Excellence and we have all enjoyed the benefits of this collaboration.

We therefore expect that the innovations and technologies generated from these RCoE’s will be shared harmoniously across the region to enhance agricultural productivity and agribusiness development.

Ladies and Gentlemen

EAAPP presents a paradigm shift on regional research and development approaches and has taught us important lessons on the advantages of embracing the strengths of our brothers in the region. The project has also provided important platforms for collaboration in technology development and dissemination and has taught us to look beyond ourselves and take advantage of the many opportunities that the Continent provides.

Through EAAPP, we have learnt that the Eastern Africa Region has a significant pool of scientists, development experts and research facilities which can be harnessed to provide solutions to the challenges in agriculture. Further, each partner country has demonstrated its comparative and competitive advantages that promote development of the commodities prioritized under EAAPP. It is therefore reassuring to note that EAAPP has achieved significant results by focusing on regional approaches in order to transform the agriculture sector in order to achieve food and nutritional security.

The technologies developed by the Regional Centres of Excellence during phase one need to be up-scaled in Phase 2 in order to realize transformation as the project prepares to transition into phase two.

Ladies and Gentlemen

You will all agree that EAAPP deserves a second phase to sustain the gains made in Phase 1. I wish to request the World Bank to consider the Joint Communiqué the four Permanent/ Principal Secretaries submitted as an Expression of Interest for EAAPP to advance into Phase 2. I hope there will be a seamless transition so that investments made realise the intended impacts.

Ladies and Gentlemen

With these few remarks ladies and gentlemen, I now wish to declare this conference officially opened and wish you fruitful deliberations.

Thank you and God Bless You.
INTRODUCTION

(L-R) Dr. Juma Kisa Ngeiywa of Kenya’s Agriculture ministry, Prof. Segor, Prof. Wachira and Dr. Chengula scan through EAAPP success story book at ASARECA exhibition booth.

The Regional Commissioner, Morogoro, Tanzania, Dr. Rajab Rutengwe speaks at the officially closing of the conference.
Mr. Assaye Legesse, the World Bank Task Team leader for EAAPP addresses delegates.

A farmer makes a submission during the conference.
Regional Trade in Food Staples—Main Instrument for Getting Research into Use for Wealth Creation

Abstract

Without doubt, Sub-Saharan Africa (SSA) is destined as the frontier of the next agricultural revolution in the world as it is estimated that nearly 60% of untapped agricultural potential of the world is in SSA and that at one billion, Africa’s population will be the largest and youngest of any continent in the world, by 2040. However, the available and expanding markets require high levels of competitiveness in quality and timely delivery of large quantities. At the same time, food marketing systems in SSA have not been developed adequately, even at the national level let alone with respect to regional and global markets. This has led to the current situation where smallholder food producers in SSA are faced with inadequate markets for their produce, while SSA spend US$ 50 billion per year on imported food.

To deal with the current challenges, strategies are urgently required to: i) deliberately expand internal markets for staple foods; ii) target agricultural investment to all components of integrated value chains; and iii) effective utilization of the regional common markets, such as the East African Community (EAC).

1 Key Note Paper presented at the EAAPP’s End of Phase One Conference and Exhibition: KENAFF Farmers Conference Centre, Kikuyu, Kenya. 14th – 18 the September, 2015
A markets first development of the food staples sector requires a change of gear from supporting the production end of value chains, to more support of post-harvest value-adding and trading processes. Therefore, strategic public sector funding (including public sector procurement) is required to build: trade-supporting infrastructure, knowledge, skills and capital for the creation of value-adding enterprises as part and parcel of the development of the food staples sector.

Agricultural research, education and extension should therefore be significantly diversified and re-oriented so as to generate technologies, build capacities/skills, and support entrepreneurs with post-harvest handling, value-adding processing, business development/management, and logistics for regional trade – for market oriented food sector that enhances rural employment and international competitiveness. Specifically, it is urgent that, we:

a. Eliminate “civil service” approach to agricultural research, so as to:
   ■ Focus more at development and commercialization of differentiated and high value products from the commodities we produce; and
   ■ Expand innovation by entrepreneurs, by focusing more at building an innovation culture and capacities to absorb and put science into use for wealth creation.

b. Expand linkages of science and technology beyond biology and farming and support innovation across the entire value chain (especially MEGA agro-industries).

c. Radically Transform Agricultural Extension System - to eliminate the failed “supply push” and foster “commercial pull” for knowledge and technologies to improve adoption and utilization.

d. Increase engagement of researchers’ minds to solve the “data famine” through “Big Data”, so as to use new technology to assist our food systems to “leap frog” other parts of the world, as we did with mobile telephone technology.

**Introduction**

“It is the economy, stupid!” was campaign slogan which helped former President Clinton of the USA to win election in 1992. Basically, the slogan was “an answer” to the question what is the major election issue of the moment? This leads us to ask a similar question - what is the most critical problem facing the food sector in Sub-Saharan Africa (SSA) today – and the answer will be – it is trade, stupid!!

This is because inadequate trade in food commodities and/or their processed products, within countries and among countries in the region, is a major stumbling block to the improvement of the productivity, profitability and sustainability of the food sector in the East African Community (EAC), in particular and SSA in general. Most of the work on agricultural development is dominated by biological thrusts (mainly breeding, other agronomic research and extension), with most experts having been trained and continue to hold the belief that, their responsibility is to develop technical solutions to production constraints. They rarely link their work to the fact that, trade is vital to income and wealth generation for smallholder agro-entrepreneurs.

This bias is clearly demonstrated by the thrusts that were funded by the Eastern Africa Agricultural Productivity Program (EAAPP) (Figure 1). The investment on capacity building, research and improved availability in inputs was all directed at biological solutions. For instance, the end-of-project evaluation of EAAPP found that, out of the 19 projects implemented in Tanzania, only one had a market component. It is also reported that, the 23 technologies finalized by EAAPP and made ready for scaling-out, were all about pre-harvest operations and none looked at
post-harvest handling, value addition processing and or trade linkages to competitive markets (Wellard et al.; 2015). The same is seen in the allocation of capacity building activities, with a dominance of breeding capacity and very little attention to building capacity in post-harvest processes including trading.

Consequently, in SSA we are faced by a paradox (illustrated in Box 1), that:

a. On one hand:
   - The majority of people are farmers producing mainly crops and livestock for food, and
   - Our agricultural development programs are all directed at assisting the smallholders to produce more staple foods; yet

b. On the other hand, the region spends billions to import food annually, receives millions of tons in food aid,

Box 1: The dilemma – feast then famine

In 2011 the international community was busily engaged with the famine in Eastern and the Horn of Africa, yet only a year earlier, in 2010, we witnessed food commodities worth millions of US dollars rotting on farms in the same region because of lack of markets. We also saw thousands of litres of milk going to waste because increased production had overstretched the available processing capacity. An estimated 200,000 MT of maize harvest became infected by aflatoxin poisoning and had to be destroyed resulting in substantial income losses for farming households. In neighboring Southern Africa, maize farmers reaped their biggest harvest in 28 years, but for many their reward was bankruptcy because they failed to get access to profitable markets.

In 2013/14 Season maize growers in Tanzania lost billions of shillings because of failure to offload a mere 26% surplus harvest - due to lack of and/or poor access to profitable markets, while Kenya was importing the same from outside the EAC.
and still leaves hundreds of millions of its people chronically hungry.
c. All these, while most smallholder producers of food lament that their main problem is lack of markets.

More seriously, this is happening in the 21st Century, nearly 60 years after the Green Revolution. It is difficult not to conclude that agricultural development limited to biological thrusts is not enough to bring about green revolution in the SSA – especially in the era where the world produce enough food to feed everybody.

There is no dispute that proven technologies and practices are not being taken-up fast and extensive enough to narrow the productivity gaps in the small-scale farming. However, what is not understood is the fact that, the smallholders, just like any other rational business, rarely adopt and spend hard earned cash on inputs that do not bring them profitable returns in cash or cash-equivalent benefits. In general, it is rare to get adoption of productivity-enhancing technologies (such as certified seed of improved varieties, fertilizers, or irrigation) where there are poor linkages to cash markets. Where adoption has happened, it has led to fallacy of composition, which means that less income is earned as more is produced, which always leads to immediate reversal of adoption.

At the same time, linkage between trade and adoption of productivity-enhancing technologies is common in SSA with respect to the export commodities sub-sectors. The use of certified seed, fertilizers, pesticides and modern irrigation by smallholders has already been optimized for crops (such as coffee, tea or horticulture) produced for global markets. However, despite this clear evidence of importance of trade, agricultural development investment in nearly all countries in SSA is still driven by the illusion of food self-sufficiency. Policies advocating food self-sufficiency at household, district or national level, are counter-productive as they stifle commercialization and limits utilization of comparative advantages inherent in different agro-ecologies. More seriously, these policies have led to SSA moving from a net exporter of food commodities (prior to year 2000), to a net importer (by 30%) in 2015.

Consequently, the annual import bill for food into SSA is over US$ 50 billion. For example, East Africans spend US$ 500 million/year on imported rice, while the EAC region has 5 million hectares suitable for wetland rice production. If this area was grown with TXD306 variety (popularly known as SARO 5) at only 5MT/ha of milled rice; the EAC would produce 250 million MT/year of rice, which at a price of US$ 650/MT, would translate to US$ 150 billion/year (KT, 2014).

This keynote paper explores, concludes and makes recommendations on what kind of gear change is necessary to achieve highly commercialized and profitable production of food in East Africa in particular, and SSA in general. The hypothesis is that: “the entry point to increased adoption of productivity-enhancing technologies for food staples, is not more of the same (breeding, agronomy, extension or subsidized inputs), but enhanced income generation through regional trade that links smallholder farmers to profitable markets”. This requires systemic change in priorities of the investment we make for agricultural development.

But, the Future is Positive
Next agricultural revolution. As illustrated in Figure 2, Africa is a very large continent, geographically larger that the USA, Europe, China, India, Japan and Mexico put together. At the same time, it is estimated that:

a. By 2050, Africa’s GDP could be larger than that of USA and Europe combined; At one billion, Africa’s population will be the largest and youngest of any continent in the world, by 2040;
b. Africa is currently leading the world with more people linked with mobile technology and use of mobile money; and

c. Nearly 60% of untapped agricultural potential of the world is in SSA.

Therefore, as estimated by (MGI, 2011) SSA can and should play a big role in meeting the projected enormous global demand for food and other agricultural commodities, under which:

a. It is projected that the world will see a 40 year period of continuous high and increasing demand and prices of food and other agricultural commodities - as an example, project global rice demand will reach 650 million MT/year, by 2050;

b. The rapid urbanization will lead to 5 billion people living in urban areas (concentrated in Africa and Asia), with 3 billion joining the middle class, by 2030; and

c. There is currently, zero spare land for expansion of farming in South Asia, Middle East and North Africa.

SSA is well positioned because it has the right asset base of natural capital and human (in numbers not skills) capital as illustrated in the Livelihood Assets Framework (Figure 3), which gives it a significant upper hand in “strategic transformation of assets”.

The assets framework divides the resources available to an individual, community or country to five different categories [Box 2]. The size and shape of the asset pentagon - that is, the amount and relative importance of each type of capital - varies between individual, communities and between countries. Often, each community or country starts on the development path endowed in one form of natural capital. Therefore, all other factors remaining equal, it is the effectiveness by which people or community transform the one asset they have in abundance to other forms of assets, which distinguishes between the “wealthy”, and the “poor” regions, nations and/or communities.
Wealth creation therefore has historically meant the transformation of land and other natural resources to physical
and financial capital, which are then used to increase effectiveness in further transformation of natural and human
resources. Further development then leads to improved social capital (especially policies and institutions) which
is in turn used to improve even further the performance in the transformation of other assets.

The unimaginable growth of the economy of the United Arab Emirates (UAE), a federation of seven emirates,
is an excellent example of this process. For many years the UAE economy has been largely oil-dependent,
but, contrary to the consumerist image of the “oil sheikhs”, most of the income from oil has actually been
spent on diversification efforts to cultivate and grow non-oil sectors which have now surpassed the oil
sector in contribution to GDP (UAE Interact, 2008). This is strategic transformation of assets per excellence.

In this process, the UAE transformed their natural capital (oil and gas) to physical assets for sea and air
transportation. They have built state-of-the-art air and sea port facilities, business service, road network,
banking system, and telecommunications facilities to exploit their “central location” between Europe, Asia
and Africa. They have also used some of the income to even expand their natural capital by building new
islands in the sea, as well as man-made sea ports such as the Dubai’s Jebel Ali Free Zone considered as the
largest man-made port in the world.

As a result of this, the UAE, a desert with zero agricultural potential, is now ranked as one of the leading
exporters of processed agricultural products. This is because; an estimated 70% of the UAE’s agricultural
imports are re-exported after significant value addition. The UAE is now about to close the loop by investing
their huge wealth into clean-energy technology, centred on one of their other abundant natural capital,
solar energy.

Now imagine the extent of development SSA could achieve through similar transformation of its natural assets.
Take the Democratic Republic of Congo which is easily in the top 10 richest countries in the world with respect
to natural resources. The DRC has all within its borders the second largest river in the world by volume of water,
as well as the world’s second largest rainforest. The country is very rich in minerals and is reputed to be home
to 80% of tantalum, the all important raw material for the manufacture of capacitors used in computers, mobile
phones and other digital equipment. Tantalum is therefore an important ingredient of the ICT revolution, as it is the
material of choice for a new generation of electrical and electronic applications.

At the same time we are seeing strong economic and free trade blocks been developed in SSA, in which:
a. The EAC is the most vibrant economic community;
b. Through Mombasa Auction, the EAC is the largest tea exporting “country” in the world;
c. Together, EAC and Ethiopia form the largest exporter of flowers in the world;
d. With its current population of 155 million, the EAC would be the 9th largest “country” in the world;
e. By FAO data, the “United States” of EAC would be the world leading producer of Bananas (1st); Sweet potatoes (2nd); Tea (3rd); Beans (4th) and Groundnuts (6th); and
f. The only shortcoming is that Ethiopia is not part of the EAC.

Furthermore, EAC is endowed with the best combination of assets; for example:
a. Youth (i.e. those aged between 15 and 35 years) account for over 40% of the population of the EAC, as of now;
b. Abundant fertile land and water resources, as the EAC is a home to largest lakes in the world by volume of water, and Lake Tanganyika, which is seven times larger than Lake Victoria by volume of water, provides 670 km of “God-given” transportation corridor;
c. The energy resources being discovered each passing day; and
d. If efficiently coupled together – the youthful labour and the natural resource Assets, would lead to unprecedented wealth creation in the EAC.

At the same time, the EAC has made significant progress in creating a conducive environment for regional trade in food staples. For example, through work supported by Kilimo Trust, the EAC has already adopted two far reaching strategies for regional trade in staples.
a. The EAC Food Security Action Plan (EAC, 2011); under which the EAC Summit of Heads of State, committed to:
  ■ Making the EAC common market the key to food security in the region;
  ■ Enhancing joint approach to food security in the EAC as a block;
  ■ Using structured trade to efficiently move foods across the EAC from areas of sustainably produced surplus to areas of deficit;
  ■ Sustainable utilization of all food sources (crops, livestock, marine and fisheries, and forestry systems);
  ■ Improved purchasing power of low income earners in rural and urban areas; and
  ■ Enhancement of efficiency in food handling, processing and utilization to eliminate losses and wastes.
b. The East Africa Agro-industries and Agro-enterprise Development Program (E3ADP) a program of the EAC in response to the Abuja 2010 declaration on the African Agribusiness and Agro-Industries Development Initiative (3ADI). The vision of E3ADP is “an agriculture sector in the EAC Partner States, which supply high-valued and differentiated food, fibre, feed and other agricultural products for local, regional and international markets”. The purpose is to “expand agro-industries and agricultural enterprises in the EAC for value addition processing, preservation and marketing of agricultural commodities and products”.

Why Should Trade Be Priority One?

SSA is a continent that is far behind others in trading with itself, where only 10% of its total trade done within SSA. This is very low compared with the 60% of total trade carried out within the European Union. Even the relatively well developed EAC is registering only 13% intra-regional compared to its total trade volume. The very little regional trade in food staples is limiting opportunities for: i) enhanced incomes for producers, and/or ii) providing
good nutrition at prices that low-income earners in rural and urban areas can afford. Despite large investment on farm-productivity-enhancing technologies and practices, productivity continues to be low and/or fluctuating. This is driven by a “low–yields trap”, itself driven by frequent negative gross margins attained by smallholder farmers. Consequently, structures (such as irrigation and warehouses) installed through public sector funding, are under-utilized, smallholders fail to attract off-takers (e.g. millers/processors) due to lack of sufficient and consistent supply of quality raw commodities – which completes the vicious circle because the off-takers decrease their investment, leading to reduced access to markets even further (KT, 2014). Consequently, national governments and international donors are investing billions of US$ each year with little impact on i) poverty reduction on millions of smallholder farmers; or ii) enhanced food security for low income consumers.

What is required is to link the many millions of impoverished smallholders to national, regional, and global markets so as to effectively utilize the expanding opportunities. National and regional food trade especially targeting the quality conscious urban markets would provide the experience for the competitiveness needed to succeed in global markets. It is clear that the main challenge to be addressed is that, although trade in food staples is growing in the region, it is limited to local markets with producers reporting to be selling most of what they produce (Figure 4a), but there is very little formal and recorded cross-border trading within the EAC Region – with the maximum in 2010 being only about 4% (for rice) as illustrated in Figure 4b. (KT, 2011).

Figure 4a: Extent (%) to which Farming HHs sell what they Produce – EAC Average for Key Staples
Therefore, it seems that although there are already policies, strategies and action plans for regional food trade, very little trade is actually taking place within the EAC. Why? There are several mutually reinforcing factors:

a. Millions of smallholders “as” producers of food staples do not trust the market enough to expand production significantly beyond the minimum they need for their own consumption – this is a significant disincentive to uptake of new technologies and it also stifles commercialization and specialisation and/or exploitation of comparative advantages.

b. Smallholders “as” consumers also do not trust the market to supply the staples foods they desire, and thus resort to investing time and effort producing their own food often in agro-ecologies not suitable for such production, leading to frequent failures that perpetuate hunger and poverty while also limiting investment in enterprises for commodities that are more suitable.

c. Because of inadequate safety nets to deal with pockets of food shortages, provisional and national governments are worried about political consequences and thus fall back to the “comfort zone” of subsistence supply enforced through export bans.

d. As a result of all the above, limited investment is made in agro-processing and the development of effective trade and distribution networks – reducing the depth and effectiveness of markets especially of food staples.

This indicates that, market-driven approaches will only be sustainable if the markets for staple foods expand in size and deepen in terms of reach through efficient trading systems. This can only happen if there are more net buyers of any particular food staple food, which in turn can only happen if producers specialize according to agro-ecological and economic comparative and competitive advantages.

Effective utilization of agro-ecological and economic comparative and competitive advantages – is the most critical reason for, as well as basis for expanded trade in food staples. This is because to achieve efficiency and profitability, production of different food commodities needs to be correctly matched with resource (land, water and biodiversity) endowments and carrying capacities, since these vary widely across
agro-ecosystems and/or countries. In fact, what is required is food trade between different agro-ecologies rather than between countries.

However, currently, the food industry the world over is faced with two major trade-distorting trends.

a. First, there is a nearly universal policy of the rich and the poor alike, to be as independent of food imports as possible. Up to very recent past when some tentative liberalization started, most of OECD countries operated farm subsidies that made farm production to look like a privileged “civil service”. For example, it has been estimated that, “subsidies paid to farmers in the European Union, could have bought outright 40% of the EU farms (land, buildings, machinery, livestock – the lot)” (Thurston, 2008).

b. Second, there is a misconception that farming (and by hand-hoe for that matter) has a limitless capacity to lift a high proportion of the poor out of poverty. There is also this misplaced belief that to provide food to the poor at the prices they can afford, then all of them have to be helped to grow the food they need. The green revolution was a success in Asia but south Asia remains the part of the world with the highest concentration of poor and hungry people. Why? Because manual labour farming, no matter how efficient, cannot provide decent employment for everybody. This limit must be recognized and our investment in agriculture must be made in the context of a well balanced development agenda that encompass the entire value chain and trade - directing more efforts and funds into mechanization and value-addition activities in the rural areas and nearby urban centers to create producers-driven hubs for the supply of value-added differentiated products in the final form desired by consumers (whether in the local, national, regional or export markets). We should also invest more in the development of “last-mile” infrastructure to leverage more benefits from existing major infrastructure. This kind of investment will solve three problems together; namely: (i) create employment, (ii) improve market access, and (iii) create genuine local food market by increasing local purchasing power.

Trade in food staples is very critical because, it is a fallacy to hold to the thinking that even SSA need to produce more food to feed those who are hungry today – since, the people who go hungry today are hungry not because there is no food but because the trade system limits their access to the available food (see Box 1). The fact of the matter is that we have reached the limit and we cannot continue with artificial incentives to farmers as it is evident, and the global financial crisis has shown, that even the rich countries cannot afford it any longer. Given global food sufficiency, the solution is a well balanced, dependable and fair trade system (at local, national and global levels); coupled with post-harvest systems that eliminates losses and food waste. It is our opinion that such system will allocate production of different commodities according to comparative advantages in production potentials within the limits of available technologies. This will improve efficiency of resource utilization as well as price ratios for producers. It will also create more decent jobs in the agribusiness and agro-industry sub-sectors that are needed to link the centres of production on one hand, with the centres of consumption on the other.

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2 See for example FAO and Kilimo Trust 2009. Investing in Last Mile Market Oriented Agricultural Infrastructure in Africa. Report of the FAO-Kilimo Trust Round-table, 8th–10th June 2009, Kämpala, Uganda. FAO, Rome. In transportation, “last-mile” infrastructure is what we normally call feeder roads. In most of Sub-Saharan Africa this kind of infrastructure is largely missing and a very high % of the agricultural transportation of produce and inputs is done on the heads of women and children. In power supply, “last-mile” investment concerns the electrical powered equipment and the necessary connections to allow rural areas to exploit the national grid. In water systems, “last-mile” infrastructure is the down-stream and tail-end structures that enable farmers to exploit major water storage dams. For example, in Mozambique there are more than 10 large dams with a total storage capacity of over 50 billion cubic meters but only 9% percent of the stored water is utilized for irrigation.
The suggestions made above require some serious political will and determination and we are in no illusion that they will come easy. What should push us in this direction is the fact that SSA will not be able to achieve the full benefits of its pole position as the next frontier of agricultural revolution without sorting out its national, regional and continent-wide trade in food staples and other agricultural products.

**BUT, Trade Will Not Succeed Without Agro-industries**

Most food commodities such as milk, beef and cassava have short shelf life if not processed as shown in Figure 3. In the EAC Region, more than 40% of the food losses occur at post harvest and processing levels (FAO, 2011). Only 28% of the agricultural produce in the EAC is processed (Kilimo Trust, EAC, UNIDO and FAO, 2011). However, as illustrated in Figure 5, the shelf life of many perishable commodities can be increased to several years through processing – enabling them to be traded widely in space and time.

Processing commodities can also assist to overcome non-tariff and tariff barriers to trade. For instance, current standards for export meat products require the region where the animal is farmed to be disease free. However, processed products do not carry infections, for example; cow milk does not contain infectious quantities of the prion protein that causes BSE (*mad cow disease*) even if obtained from infected cows. Matured and deboned beef from which major lymph nodes have been removed presents minimal risk of transmitting foot and mouth disease, BSE and many other infections. In this case, animal products can be safely traded if processing methods are effectively regulated (DFID, 2007).

Therefore, Agro-processing is vital because of the tremendous backward and forward linkages and multiplier effects with respect to:

a. Increased access to markets that are distant in space and time;
b. Extension of the reach of food, also in space and time;
c. Creation of non-farm employment and income generation opportunities;
d. Retention of high proportion of the value;
e. Elimination of seasonality effects
f. Reduction of post-harvest losses; and
g. Improvement of food quality and safety.

This means that going forward; efforts to increase production should therefore go hand in hand with investments to increase agro-processing capabilities. The problem is that, in SSA, most of the processed food found in supermarkets or consumed by large public institutions such as the military, are imported. To be fair there is a very good reason for this: buyers requiring timely delivery of large volumes such as processors and large institutions are resorting to importation because of a mismatch between the nature of demand - large quantity aggregated in one location; and the nature of supply, a lot of commodities but in highly dispersed small quantities. Basically, although together they account for large quantities (millions of MTs), most of the tradable surplus from the smallholders is available in highly dispersed small quantities of variable types and quality. This makes the process of aggregation and other Post Harvest Handling (PHH) to volumes and quality attractive to most serious processors, traders and institutional buyers, very expensive and thus not commercially viable.

It is because of the importance of agro-food-processing in the development of regional trade in food staples that KT is among the very few agricultural development organizations focused at promoting regional trade using KT
Consortia Approach (KT-CA) to value chain development. KT-CA moves away from the standard agricultural value chains development (VCD) which often:

- Focus too much on supporting the smallholder farmers (SHFs) to increase yields/production, while often presenting traders as enemies of the SHFs; and/or
- Neglect investment to increase the participation in the value chains by private firms undertaking trade, agro-processing, and/or the supply of inputs and services – on a wrong assumption that their involvement will be automatic once SHFs produce more.
Figure 6: All Inclusive VCD with Agro-Food-Processors in the Lead

Therefore, to deal with the past failures, the KT-CA focuses and uses market-first approach to catalyze formation of consortia of private sector players along value chains (Figure 6). Project funds are used to undertake “public good” interventions needed to expand equity investment required to expand/improve marketing structures and processing of food staples into differentiated products demanded by the market. To leverage this kind of private sector funding, the KT-CA uses matching grants (MGs) to support the building of strong market linkages that improves chances of the private sector obtaining good returns on investment. The MGs are necessary to break the “first mover” paralysis that often stops business partnerships between smallholders and private agro-food-processing firms, from developing.

The KT-CA uses quality knowledge and information on markets and demand characteristics, to:

a. Support development of market-driven win-win business consortia anchored on an agribusiness firm, which is then coupled with a competitive, transparent and commercially driven MGs, leading to interventions to up-grade the value chain, implemented, managed and owned by the consortia of SHFs and other necessary private sector partners.

b. Integrate current practices and introduce new innovations to mainstream “state-of-art” use of ICT-based platforms for improving sharing of market information, collective marketing of produce and/or collective procurement of inputs and services for SHFs – supported by robust monitoring, evaluation and learning.

c. Develop collective professional management shared across cooperatives and/or trade associations of the SHFs, to improve efficiency, reduce costs of management, and thus make collective marketing and procurement commercially sustainable and attractive to inputs and outputs markets.

The KT-CA has been developed through practical learning over ten years since KT was established in 2005. In the first six years, KT followed the standard approach of giving stand alone grants to other NGOs and research institutions to implement over 50 projects with limited linkages among those projects. This approach did not yield satisfactory results, but it gave KT a treasure trove of knowledge on what works and what does not. Hence,
since 2012, KT has been developing the KT-CA focused at eleven food staples of the EAC. The aim is to support transformation of food and nutrition security in the EAC away from high risk subsistence farming into lower risk trade-based systems; with the vision to see:

a. Specialization in production of staples to: i) effectively utilize resilience-driven comparative advantages; and ii) enable smallholder producers of the key food commodities to “farm as business” and become competitive.

b. A structured regional trade in foods driven by the private sector business linkages for each commodity.

c. A high proportion of the food commodities (especially perishables) produced in the EAC, being transformed to differentiated value-added products preferred by the final consumer.

Turning Knowledge into Wealth and Development: The EAAPP Concept Was Spot On

Impact of research is realized when knowledge is used for wealth creation and improvement of welfare, through innovations. This makes the concept of EAAPP very attractive as it was designed to facilitate international spill-over. This is because as illustrated in Figure 7, the relative distribution of Nobel Prizes in Physics, Chemistry and Medicine between 1901 and 2005, demonstrate the fact that basic science has always been produced by few countries, but many countries have used this science to innovate technologically and institutionally.

![Figure 7(a): Distribution of Nobel Prizes in Physics, Chemistry and Medicine](chart)

![Figure 7(b): Distribution of Resident Patents (After WIPO, 2009)](chart)

Using the distribution of Nobel prizes as a proxy, we see that prior to the mid 50s, and most of the basic science was done by German, the UK and France. During the 55 years after 1956, we see the scientific contribution shifting from these three countries as well as from the other European countries towards the USA as well as other countries in the world.
At the same time, the trend with respect to resident patents, show that inventions (and by extension innovations) were higher for regions with “lower” scientific contribution. These distributions indicate that the rest of the world has depended on only four countries to produce basic science in the last 110 years, but innovation and invention has been globally distributed. This is an indication of high level of spill-over of the impacts of science and technology – a key element in the design of EAAPP. We expect that these trends will become more pronounced in the future, because the number of countries that can contribute to science and technologies has increased, these countries are spread across more regions of the world, and there is an increased drive towards regional economic communities.

The trends have been the same and just as important in agricultural R&D where assessments show that spill-over have often been responsible for over 50% of the total measured contribution of R&D to enhancing agricultural productivity. However, apart from CGIAR system, there are limited global linkages that formally facilitate the spill-over of science and technology.

One area that requires urgent attention is the establishment of a global mechanism for producing and expanding the pool of basic science and up-stream (especially platform1) technologies as “international public good”. This will also be enhanced if the private sector can contribute to this pool. This will require economic communities such as the EAC and AU, to review relevant intellectual property systems to ensure that patenting or varietal protection, do not work against poverty alleviation, farmer-led innovation or publicly funded research efforts – something that EAAPP was designed and attempted to do.

The best evidence of the role of spill-over in innovation and impacts of R&D on development is the recent unprecedented progress in innovation in agriculture in China, India and Brazil. The ASTI database shows that in these countries, rapid growth in agricultural production and improvement of food security was underpinned by rapid expansion in key factors (such as quantity and quality of human resource in agriculture science and technology) that facilitated innovation in general and in agriculture in particular. Therefore, we see a good correlation of improvement in agricultural productivity and production, on one hand, and increase in the quantity and quality of human resource, on the other hand (China now has the largest capacity in numbers, and India has the most qualified human resource base, in AR&D).

Therefore, for SSA countries, the following are recommended actions, in order of priority:

- Build capacity to absorb knowledge to support innovation;
- Develop a robust innovation culture including more emphasis in increasing the ability of the general public to articulate demand for R&D products;
- Increase support for technology-driven and hence innovation-supporting development programs, enterprises, and public procurement; and
- Enhance the linkages supporting flow of knowledge.

**Build capacity to absorb knowledge to support innovation**

The SSA countries need to do more to increase capacity to absorb available and future global stock of knowledge. The starting point is the realization that innovation is an organic process which cannot be ordered to take place. However, innovation thrives in communities, societies and countries that ensure that a critical mass of knowledgeable human resource is available across all sectors of the economy. In the case of food staples agriculture, what is required is to ensure an adequate supply of actors in all components of the value chain and supporting sectors, with appropriate basic skills needed to absorb knowledge from all sources.
For SSA, the priorities would be to: (i) recognize that the extent of global flow of information and knowledge, made possible by rapid explosion in ICTs, offers tremendous opportunities; and (ii) focus attention on optimizing capabilities to maximize the absorption and utilization of such knowledge [Box 3]. The main areas requiring priority action are three; namely:

a. Serious investment in lifelong (quality) education and learning in all aspects, but with a much increased attention to scientific and technical skills. What we are learning from countries such as China which has seen rapid economic development in the last 40 or so years, is that science and technological skills, are capital assets. For these assets to be more useful they required a system of training and learning, which gives people capabilities to work across boundaries of narrow disciplines, to solve problems.

b. Although research is not the only driver of innovation, it plays a crucial role. Therefore, while building the general capacities to support innovation, there is an urgent need to rapidly improve the currently dilapidated public research institutions and university through increased funding for quality work, even if it means reducing the size of the system in the short term. To support regional trade in food staples, his process should include strengthening of R&D in fields other than biological.

c. Build linkages between NARES, the private sector (from inputs suppliers to retailers of differentiated agricultural products), development supporting organizations, and other public institutions (see the KT-CA Figure 6). This should be designed to accelerate the use of existing knowledge while expanding indigenous capacity for the generation of knowledge.

Develop a robust innovation culture
The capacity called for in the previous section will not meet its potential if there is no innovation culture in the society, including increased ability of the general public to articulate demand for R&D products. It is very difficult to describe the required culture, but its main element is a balance between rewards and penalties to innovators. A high ratio of penalties to rewards, forces many would be innovators to play safe or migrate (leading to a loss in the investment made in training to PhD levels).

Box 3: Capacity is key
The competitive position and the quality of a country’s economy are determined to a large extent by the size and density of the country’s “knowledge cloud” – namely the body of knowledge that has the potential to affect the economy. If many people possess a lot of good knowledge, then the “cloud” is dense. This would lead to higher rates of innovations in the areas of technologies, processes, new industries, better strategies for the market place etc. At the same time, the density of the “knowledge cloud” is determined by the ability of the entire population to absorb relevant knowledge.

Modified after Janssen, 2002

Therefore, SSA need to put in place the following:

a. Social, economic and legal systems and institutions that support competition, collaboration, and trust among its people – exactly what EAAPP was designed to do.

b. High commitment to set and pursue vigorously long-term development goals.

c. Systems for integration of knowledge and innovation into the way the target producers and other agro-entrepreneurs do business. The most important actions are:
Overcome the existence of a large informal sector with poor linkage to sources of knowledge, and
- Bring agro-business enterprises into the centre of the innovation system through public policies that motivate and support the private sector along the entire agricultural value chains to invest more in the utilization of new knowledge and generation of innovations.

**Use “lead-frog” approach to technology–driven development programs**

The rapid expansion in the access and utilization of the mobile telephone by many poor people in rural areas (some very remote in other measures) who previously did not even know a telephone, provides us with many lessons of how technology-driven programs can support innovation. Therefore, the agricultural and trade development programs should be designed to exploit the best knowledge and technologies the world has to offer. Governments have an important role to play on this with respect to how they value technologies in the programs they invest in. The most important actions are:

a. Ensure that both public and private development programs are designed with substantial technological components that prioritize local procurement and thus invest in building durable local capacities.

b. Improve the financing of technological acquisition by local enterprises through different financial mechanisms.

c. Build stronger public-private linkages and partnerships, through public procurement (such as the way military procurement has been a major driver of innovation by USA’s, European and Indian private sector companies).

A key lesson, from the successes of China, India and Brazil in the exploitation of the global stock of knowledge and technologies, is that, the size of local economy and its linkages to international value chains, matters. The majority of the countries that are lagging behind, especially in SSA are often those with very small economies. In these cases, agricultural development programs of individual countries tied to national boundaries have failed to provide the economies of scale necessary for accelerated innovation.

Therefore, for countries with small economies, most important actions needed to mobilize global linkages will include:

a. Increased participation in global value chains, but with emphasis given to the building of regional agricultural value chains and trade. This should be based on close and strong regional economic communities, regional markets, and expanded investment in trade-supporting infrastructure for food staples in particular, and agriculture in general.

b. Adherence to the international IPR protocols so as to create an environment for exploiting the positive aspect of IPR; namely encouraging and providing incentives to the private sector (local and multinationals) and international organizations to disclose new knowledge for scaling-up. In order to facilitate this, national laws, policies and institutional frameworks need review to assist individuals/organizations to recognize, handle, protect and market intellectual properties.
Summary of Recommendations

Eliminate “civil service” approach to agricultural research, so as to:

a. Focus more at development and commercialization of differentiated and high value products from the commodities we produce. This calls for urgent removal of the command and control food policies now dominant in nearly all countries – which in SSA has led to a serious “poverty trap” called subsistence agriculture. This is a result of the failure to realize that to produce food; farming cannot and should not be the employer of the majority of the poor people.

b. Expand innovation by entrepreneurs, by focusing more at building an innovation culture and capacities to absorb and put science into use for wealth creation. This requires:
   - Greater investment in innovation-supporting activities such as technology-driven programs, and public procurement strategies that support local innovations; and
   - Adoption and adherence to international IPR protocols to achieve the openness needed to allow the flow of knowledge and technologies.

Expand linkages of science and technology beyond biology and farming and support innovation across the entire value chain (especially MEGA agro-industries), so that strong agribusiness linkages revolving around agro-industries (small and large) can support adoption of necessary and sufficient technologies for more production and supply of differentiated value-added products.

Radically Transform Agricultural Extension System - to eliminate the failed “supply push” and foster “commercial pull” for knowledge and technologies to improve adoption and utilization.

In the EAC, become more serious about the common market and make regional food trade an instrument of resilient food security, starting by forming an EAC Commission for Food and Nutrition Security - fully responsible for the transformation of food and nutrition security in the EAC away from high risk subsistence farming into lower risk trade-based systems.
References


FAO, 2011. Global food losses and food waste. Extent, causes and prevention. Study conducted for the International Congress. Available at:


Dr. Ambrose Agona – Director General NARO Uganda and ASARECA BoD Chairperson

Dr. Yitaye Alemayehu, EAAPP National Programme Coordinator, Ethiopia

Dr. Hussein Mansoor, EAAPP National Programme Coordinator, Tanzania

Dr. Jackson Mubiru, NAGRIC, Uganda

Dr. Jean Ndikumana – Dairy Consultant

Dr. George Lukwago - EAAPP National Programme Coordinator, Uganda

Catherine Kinyajui, EAAPP-Kenya

Dr. Ayele Badebo, CYMMYT, Ethiopia

Dr. Joseph Oryokot, EAAPP Co-TTL, World Bank, Uganda
Ekobu Moses, Makerere University, Uganda

Elizabeth Wanjiekeche, Kenya

Dr. Tebke Damte, EIRA, Ethiopia

Andrew Chotta, livestock scientist, Tanzania

Daniel Mutisya, cassava scientist, Kenya

Rashid Lusewa, Rice Breeder, Tanzania

Laston Milambo, Zambia

Dr. Sheilla Butungi – EAAPP Dairy Focal Person, Uganda

Dr. Deogratias Lwezaura, EAAPP M+E Specialist, Tanzania
Emma Marigi, cassava scientist, Kenya

Nicholas Mbinjiwe, dairy farmer, Kenya

Beatrice Mwaura, Gender Specialist, Kenya

Fredrick Kabi, scientist NARO, Uganda

Joanne Adero, scientist, NARO

Justa Katunzi, scientist, Tanzania

Moses Gichuru, Businessman, Kenya

Teresa Okiyo, Rice scientist, Kenya

Douglas Indetie, Animal Breeding Specialist, EAAPP Kenya
Wheat research and development
Wheat Research and Development in the Eastern and Central Africa: Past, Present and Future Outlook

A.Badebo, B.Abeyo, and V.Akulumuka

Introduction

Wheat production and consumption

Wheat is one of the most important staple crops grown worldwide. It is a temperate and semi-tropical crop, but can also be grown in tropical environments to some extent by breeding and through influence of cultural practices. Annually, a total of 685 million tonnes of wheat is produced on 220 million hectares (FAOSTAT, 2014). Wheat ranks number one in terms of acreage and production and contributes more calories and proteins to the world’s human diet than any other cereal. Bread or common wheat (Triticum aestivum L.) and durum wheat (T. turgidum var. durum) are widely grown. Durum wheat contributes about 10% of the total wheat production worldwide. The average wheat production is 3.1MT/ha. The highest average yield were obtained in Western Europe, with more than 8 t ha-1, in contrast to less than 1 t ha-1 in several countries of Africa and Asia. Production gain for the last half a century has been about 1 percent per year due to the technological advances of more productive cultivars and adoption of improved cultural practices. Future projection is to reach nearly 2.5 percent by the year 2025 to match the population growth (FAOSTAT, 2014).

Africa produces 25.1 million MT on 9.9 million ha with an average yield of 2.54 tonnes/ha which is 3.5% of the world wheat production with the bulk of it coming from North Africa. Ten Countries (Burundi, DRC, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania and Uganda) in Eastern and Central African (ECA) produce on average 4.3 million MT of wheat on 2.2 million ha of land (Table 1). The bulk of wheat comes from Ethiopia, Kenya and Sudan with Ethiopia being the largest producer in sub Saharan Africa. Ethiopia produces about 76% of the total wheat production in ECA.

Wheat is a traditional crop grown by about five million households in the highlands of Ethiopia mainly under rain-fed conditions. The major wheat growing areas are: the South Eastern, Central, Northern and North western Ethiopia (Fig 1). Vavilov reported six species of wheat in the mid-1920s (Gebre-Mariam, 1991); currently bread wheat (Triticum aestivum L) and durum wheat (T. turgidum L. var. durum) are grown in ca. 80: 20 ratio.
Table 1: Wheat Production in ten countries of Eastern and Central Africa

<table>
<thead>
<tr>
<th>Wheat</th>
<th>Burundi</th>
<th>DRC</th>
<th>Eritrea</th>
<th>Ethiopia</th>
<th>Kenya</th>
<th>Madagascar</th>
<th>Rwanda</th>
<th>Sudan</th>
<th>Tanzania</th>
<th>Uganda</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area ('000 ha)</td>
<td>10.1</td>
<td>7.3</td>
<td>25.9</td>
<td>1601.7</td>
<td>140.6</td>
<td>4.2</td>
<td>41.3</td>
<td>226.1</td>
<td>105.8</td>
<td>13.0</td>
<td>2175.9</td>
</tr>
<tr>
<td>Production ('000 MT)</td>
<td>7.6</td>
<td>8.9</td>
<td>30.1</td>
<td>3264.3</td>
<td>385.5</td>
<td>9.7</td>
<td>77.3</td>
<td>385.1</td>
<td>94.1</td>
<td>20.6</td>
<td>4283.2</td>
</tr>
<tr>
<td>Productivity (MT/ha)</td>
<td>0.8</td>
<td>1.2</td>
<td>1.2</td>
<td>2.0</td>
<td>2.7</td>
<td>2.3</td>
<td>1.9</td>
<td>1.7</td>
<td>0.9</td>
<td>1.6</td>
<td>1.97</td>
</tr>
</tbody>
</table>

(FAO STAT, mean of 2009-2013)

The largest volume of wheat production comes from Oromia (59%), Amhara (25.9%), SNNPR (8.8%) and Tigray (6%). Wheat contributes approximately 200 kcal/day in urban areas, as compared to about 310 kcal in rural areas (Demeke and Marcantonio, 2013). In addition to industrial products, the wheat grain is used in the preparation of a range of traditional food recipes such as: pancake (injera), bread (dabo), local beer (tella), and several other local food items: dabokolo, ganfo, kinche, etc. Besides, wheat straw is commonly used as a roof thatching material, and as a feed for animals.

Wheat consumption has increased in the ECA countries in the last two decades (Figure 1). The wheat consumption ranged from 3 kg in Burundi to 51.7 kg/p/y in Ethiopia. Sudan is the second wheat consumer (50kg/p/y). The mean consumption of wheat in ECA countries is 35.9 kg/person/year. Wheat self-sufficiency ranged from 1.7% for DRC to 64.6% for Ethiopia. The mean self-sufficiency for the ten ECA countries is 38.4% which shows that the region relies heavily on wheat imports. Rwanda is also increasing local production to 56.8% self-sufficiency level. Wheat consumption is expected to increase due to urbanization and population growth. The population in ECA countries is expected to double in 2040 (from FAOSAT).

Figure 1: Wheat self-sufficiency (%) and consumption of wheat in ECA countries (from FAOSTAT, 2014)
The ten ECA countries import 6.4 million tonnes of wheat grain and flour worth US$ 2.1 billion annually. The majority (81%) imports were in grain form while the rest (19%) was in form of wheat flour (Table 2). Sudan is the highest importer (1.7 million tonnes) followed by Ethiopia (1.6 million tonnes) mainly in the form of grain (FAOSTAT, 2014). Wheat consumption is increasing due to population growth and urbanization in ECA countries. Unless we increase local wheat production, wheat importation is expected to grow annually. There is uncertainty in future wheat prices and supply. The hard currency is limited in most of the ECA counties. To increase wheat production, they need to increase productivity and/or expand the acreage under wheat. They also need to narrow the gaps between the potential yields and the actual farm yields as observed in Ethiopia (8t/ha) and Kenya (6-7t/ha).

**Table 2: Wheat import in ECA**

<table>
<thead>
<tr>
<th>Country</th>
<th>Import ('000 MT)</th>
<th>Import Value (Million US$)</th>
<th>%</th>
<th>Grain</th>
<th>Flour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burundi</td>
<td>21.0</td>
<td>9.5</td>
<td>77</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>DRC</td>
<td>502.3</td>
<td>184.8</td>
<td>75</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Eritrea</td>
<td>136.8</td>
<td>39.0</td>
<td>52</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Ethiopia</td>
<td>1599.1</td>
<td>529.1</td>
<td>98</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Kenya</td>
<td>979.8</td>
<td>275.2</td>
<td>95</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Madagascar</td>
<td>105.8</td>
<td>46.4</td>
<td>32</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Rwanda</td>
<td>58.5</td>
<td>23.0</td>
<td>89</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Sudan</td>
<td>1661.4</td>
<td>518.6</td>
<td>97</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Tanzania</td>
<td>932.4</td>
<td>314.8</td>
<td>97</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Uganda</td>
<td>404.5</td>
<td>154.6</td>
<td>99</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ECA total</td>
<td>6402</td>
<td>2095.0</td>
<td>81</td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>

(FAOSTAT, 2008-2012)

**Wheat growing environments and production systems**

Tanner and van Ginkel (1988) reported four wheat growing environments in Eastern and Central Africa. According to Rajaram (1995), a mega-environment is defined as a broad, not necessarily contiguous area, occurring in more than one country and frequently transcontinental, defined by similar biotic and abiotic stresses, cropping-system requirements, consumer preferences and for convenience, by a volume of production. The bulk of the wheat crop produced in the ECA (Burundi, DRC, Eritrea, Ethiopia, Kenya, Rwanda, Tanzania and Uganda) comes from cool and wet highlands- rain-fed production systems at altitudes above 1500 m asl. The wheat growing environment in Sudan is characterized by low altitude, very hot and dry –irrigated “Tropical wheat” environment. Whereas wheat production in Madagascar is characterized by mid altitude, irrigated, Cool, Dry (winter season) and mid altitude, warm, humid (rainy season) environments.

The production systems varied among countries in ECA. Small scale rain-fed production systems are dominant in Burundi, Eritrea, Ethiopia, Rwanda and Uganda. Small scale farmers use ox for land preparation and threshing while the other countries use hoe for similar activities. The dominant production system in Kenya and Tanzania are rain-fed mechanized while in Sudan it is the irrigated mechanized one. In addition,
commercial and emerging farms in Ethiopia use tractors for land preparation and combine harvester for harvesting. The number of farmers who use rented tractors and combine harvesters are increasing among small scale wheat farmers in Arsi and Bale zones in Ethiopia. In Ethiopia, wheat is a traditional crop cultivated by five million households and 95% of the wheat production comes from small scale farmers. In Kenya, 20% of the mechanized farms contribute 80% of the wheat production (Macharia et al., 2012).

Table 3: Wheat Production systems in ECA

<table>
<thead>
<tr>
<th>Country</th>
<th>Production System</th>
<th>Dominant</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burundi</td>
<td>Rain-fed + Hoe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eritrea</td>
<td>Rain-fed + Ox</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Rain-fed + Ox</td>
<td>Rain-fed + Mechanized</td>
<td></td>
</tr>
<tr>
<td>Kenya</td>
<td>Rain-fed + Mechanized</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rwanda</td>
<td>Rain-fed + Hoe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sudan</td>
<td>Irrigated + Mechanized</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanzania</td>
<td>Rain-fed + Mechanized</td>
<td>Rain-fed + Hoe</td>
<td></td>
</tr>
<tr>
<td>Uganda</td>
<td>Rain-fed + Hoe</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Wheat production constraints

Wheat production is constrained by various biotic, physical, technical and socio-economic factors in the region. Tanner and van Ginkel (1988) categorized the constraints based on the wheat growing environments (Table 4).

Biotic: The biotic constraints are more important in the cool humid highlands – quite common in ECA- and Mid altitude, warm, humid (rainy season) specifically in Madagascar: Diseases, insect pests and weeds have been reported to be among the major constraints in ECA. The three rusts, Septoria tritici blotch, Septoria nodorum blotch, spot blotch, tan spot, Fusarium head blight (FHB) are yield limiting, especially in the wet cool highlands. Cereal leaf beetle (Chnootribasimilis) and Russian wheat aphid have also been often reported.

Table 4: Wheat production constraints in ECA

<table>
<thead>
<tr>
<th>Climate zone</th>
<th>Constraints</th>
<th>Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool humid highlands</td>
<td>Weeds, acid soils, fungal diseases, water logging</td>
<td>Ethiopia, Kenya, Uganda, Rwanda, Burundi, Eastern DR Congo, Tanzania</td>
</tr>
<tr>
<td>Mid altitude, irrigated, cool, dry (winter season)</td>
<td>Fungal diseases, high production costs</td>
<td>Madagascar</td>
</tr>
<tr>
<td>Mid altitude, warm, humid (rainy season)</td>
<td>Acid soils, fungal diseases</td>
<td>Madagascar</td>
</tr>
<tr>
<td>Low altitude, very hot, dry (irrigated)</td>
<td>Heat stress</td>
<td>Sudan</td>
</tr>
<tr>
<td>Low rainfall environments</td>
<td>Moisture stress</td>
<td>Scattered in Uganda, Ethiopia, etc.</td>
</tr>
</tbody>
</table>
Physical: In the high rainfall cool and dry environments, over cultivated degraded soils accompanied by poor soil and moisture conservation greatly limit wheat productivity in the highlands. The aluminium concentration in the high rainfall areas of the regions limits the availability of phosphorous to the wheat plant. Excess rainfall in waterlogged veritsol also affects nutrient absorption. Erratic rainfall and terminal moisture stress also limit wheat productivity in some areas. Heat stress in the low altitude with very hot and dry (irrigated) environment specifically in Sudan negatively affects wheat productivity.

Technical and socio-economic: The technical constraints limit wheat productivity that include lack of knowledge, low yielding farmers’ varieties accompanied with poor agronomic practices limit wheat productivity. The socio-economic problems are deeply rooted among small scale farmers in the region. Most small scale farmers use traditional practices for land preparation, weed control, harvesting and threshing. Resource poor farmers cannot afford the recommended agricultural inputs (seed, fertilizer, pesticide) and in most cases farm inputs are hardly available in the local market on time. Poor utilization of agricultural inputs not only decreases the amount of produce but it also affects the quality of wheat. Inefficient credit and marketing systems accompanied by poor infrastructure are the main bottle necks for wheat production and productivity in the region.

Wheat Research Milestone

Wheat research in the region started early in the colonial period. Kenya was the leading country in wheat breeding research in the ECA. Wheat breeding was initiated by an English plant breeder in 1910 with the aim of developing varieties resistant to stem rust (Dairyinple, 1976). He had initially employed varieties from Italy (Rieti), Australia, Canada (Red Fife) and Egypt. In 1920, the government employed a full-time wheat breeder, stationed near Nairobi; then the main station was set up at Njoro in 1928. Wheat research in Ethiopia started in 1930 (Gebre Mariam, 1991) and several wheat varieties of Kenyan origin were used in the breeding programs and/or released as commercial varieties in Ethiopia in the 1960s and 70s. Varieties such as Enkoy, K6295-4A and other crosses of Kenyan origin are still grown by farmers in Ethiopia. Wheat research was initiated in Burundi in 1937 by introduction of varieties from Kenya and other Countries (Dairyinple, 1976). Most of the Kenyan materials are known for their diseases’ resistance including rust and septoria (Danial and Stubbs, 1992). Some of the varieties developed by Burton at Njoro, such as Kenya Blanco and Kenya Rojo, were used in the early CIMMYT breeding work. Over time, Mexican varieties of CIMMYT origin have been in turn used in the breeding program in the region including Kenya (Dairyinple, 1976). CIMMYT has been the major sources of improved wheat varieties grown in the region since in the early 1970s. CIMMYT’s involvements in germplasm supply and capacity building of young researchers have increased with time in the region. For example, about 70% of the wheat varieties grown in Ethiopia were originated from CIMMYT. The semi-dwarf improved bread wheat varieties give up to 8 t/ha on research plots and ca 5-7 t/ha on model farmers’ fields in the high potential areas in Ethiopia (Bedada Girma, unpublished) and 6-7 tonnes/ha in Kenya (Macharia, 2012).

Enhancing wheat productivity

Research results indicated that semi-dwarf CIMMYT originated wheat varieties could give 6-7 t/ha on research plots and well managed wheat farms in Ethiopia and Kenya. However, the actual farmers yields are by far lower than this potential. The ECA region should develop a strategic R4D plan to minimize dependency on wheat imports. The options would be increasing yields per unit area or expanding wheat to none traditional wheat growing areas.
Rain-fed wheat: Small portion of the 20 million ha (FAO estimates) classified as agro-climatically suited for wheat production currently are sown to wheat in Africa. Negassa et al. (2012) analyzed the biophysical suitability and economic profitability of wheat in 12 African countries that include Burundi, DRC, Ethiopia, Kenya, Madagascar, Rwanda, Tanzania and Uganda. They applied wheat growth simulation model and GIS based soils and climate data under different farm management practices (low, medium and high intensification). Their report indicates that there is high potential in terms of cultivated area and productivity in the region. According to their report, the eight ECA countries could produce 22.3 million tonnes of wheat under medium intensification (using 50% of the recommended fertilizer levels), if they utilize only 10% of the potential area at the indicated profit margin (Table 5). The researcher has shown only the minimum scenario, but according to these authors, figures might be increased depending on the percentage of pixel they applied to describe the potential areas under different fertilizer level and profit margins.

Table 5: Simulated profitable (> $2000/ha) wheat area and production for rain-fed wheat under medium level of intensification

<table>
<thead>
<tr>
<th>Country</th>
<th>Area (million)</th>
<th>Production (Million tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10%</td>
<td>25%</td>
</tr>
<tr>
<td>Burundi</td>
<td>0.14</td>
<td>0.34</td>
</tr>
<tr>
<td>Rwanda</td>
<td>0.14</td>
<td>0.36</td>
</tr>
<tr>
<td>Uganda</td>
<td>0.2</td>
<td>0.51</td>
</tr>
<tr>
<td>DRC</td>
<td>0.25</td>
<td>0.62</td>
</tr>
<tr>
<td>Kenya</td>
<td>0.67</td>
<td>1.67</td>
</tr>
<tr>
<td>Tanzania</td>
<td>1.21</td>
<td>3.02</td>
</tr>
<tr>
<td>Madagascar</td>
<td>1.27</td>
<td>3.17</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>2.6</td>
<td>6.5</td>
</tr>
<tr>
<td>Total</td>
<td>6.48</td>
<td>16.19</td>
</tr>
</tbody>
</table>

(Adapted from Negassa et al. (2012))

Irrigated wheat: The potential of irrigated wheat has not been fully explored in the region except for Sudan and Madagascar to some extent. In Sudan land is not a limiting factor. Yield could be increased through developing high yielding, heat tolerant and short period maturing varieties. Ethiopia has huge water potential (surface and ground water) which can be used for irrigated agriculture. The country has irrigation potential for 3.8 million ha (Awulachew, 2010) distributed across high rainfall zone (24%), moisture deficit zone (32%) and pastoralist zone (44%). According to the findings, Ethiopia has ground water potential that vary from 2.6 to 13.5 billion m³ that can irrigate 1.1 million ha per year.

In Ethiopia, there is a huge potential for irrigated wheat in the lowland areas of Somali and Afar region. The wheat growing environment is similar to Sudan and hence early maturing, heat tolerant wheat varieties are required. Salinity could be a problem unless proper irrigation scheme is developed. Wheat could be planted in the cool season (October-January) in rotation with cotton or sesame. Research and development in irrigated wheat is still at infantry stage in Ethiopia. Few wheat varieties
released were adapted to the irrigated areas of Middle Awash. The varieties produced (4.0 to 4.5 tons/ha) on research plots and up 3t/ha on-farm in the middle Awash (Badebo, unpublished).

Figure 2: Irrigated wheat potential in the middle Awash, Ethiopia (Photo: in courtesy of Banje, D., Werer research center, EIAR, Ethiopia)

Challenges and opportunities

Challenges

The East African highlands favour both the host and the rust pathogen. Wheat farmers in the region are challenged by periodic epidemics of yellow and stem rusts. Yellow rust also called stripe rust is caused by the fungus *Puccinia striiformis f.sp. tritici*. Unlike the leaf and stem rusts, the disease is quite common in cool highlands. It may also be important in mid altitudes depending on weather conditions. For example due to humid, foggy, and cool weather conditions that prevailed in Ethiopia in 2010, the yellow rust epidemic devastated mega wheat varieties grown in mid altitude as well. Losses were severe (60%) due to shriveled grain and damaged tillers and in extreme situations it incurs up to 100% losses, especially when the spikes are infected at higher altitudes in Ethiopia (Badebo et al., 2008). Stem rust also known as black rust is caused by *Puccinia graminis f. sp. tritici*. The fungus is pathogenic on barley as well. It requires free moisture and warmer temperatures (18-30°C) to infect the plant. It is quite important at low to mid altitudes where humid and warm temperatures prevail during the growing season. Stem rust could be important at higher altitudes on late sown and/or late maturing wheat varieties grown on clay/vertisols. The pathogen has ability to cause total loss on susceptible varieties if it occurs early in wheat growth stage.

East African highlands have been considered as hot spots for the evolution of new stem and yellow rust races (Singh et al; 2008). Yellow and stem rust races, which have been identified in the region, were virulent on most of the internationally known differential lines. Rust spores are carried by wind among the East African
countries and even sometimes extend to the Middle East (Dubin & Rajaram, 1996). Yellow rust race virulent on Yr9 was reported in East Africa in 1986 and gradually moved to Yemen and beyond. Similarly, yellow rust race virulence on CIMMYT originated bread wheat cv. Attila '5' was detected in Uganda some time before it was reported in Ethiopia in 1998 (Badebo, 2008). The East African region is known for evolution of new stem rust races as well. New stem rust race (TTKSK) virulence for Sr31 was reported by Pretorius et al. (2000) in Uganda.

Recently, different variants of this race have been reported in Kenya and beyond (Jine al., 2008; 2009). The UG 99 race and its variants overtake Sr31 and most of the known resistance genes deployed in breeding program. The stem rust resistance gene Sr31 has been widely employed in CIMMYT wheat germplasm, which had been originally introduced from rye through 1B/1R translocations (Rajaram et al., 1983). The different planting dates and eco-zones as well as the presence of volunteer crops in wheat fields provide continuous sources of inocula within or between countries in East Africa (Bonthuis, 1985). Moreover, the mutation rate of the pathogen could be increased at higher altitudes of these regions because of more intensive UV light. Previous studies indicated that the mutability of yellow rust isolates increased when exposed to UV light (Johnson et al., 1978).

Opportunities

Despite the rust challenges, East and Central Africa has a huge potential for wheat production. The region has huge genetic resources to be utilized in breeding programs especially for tetraploid wheat in Ethiopia. The countries have also strong public research support and longstanding international collaboration with CG-centres (CIMMYT, ICARDA). Resources including information, knowledge and genetic and human resources could be pooled to the benefit of the region through ASARECA, a regional hub for research coordination. Projects funded by World Bank (EAAP), African Development Bank (SARD-SC), BMG (DRRW), USAID, GIZ, etc. have been quite useful for capacity building and enhancing wheat production and productivity in the region.

Future Outlook

Wheat is a strategic food security crop in the region. Wheat consumption in the region is expected to increase with population growth and urbanization. The ECA is only 38.4% self-sufficient in wheat. The population of the ECA countries is expected to double by the year 2040. Foreign currency of the ECA countries is dwindling and there is uncertainty in the future price and supply of wheat in world market. Under such circumstances, there is no option but to increase wheat production at country and regional level. To minimize dependency on wheat imports, countries require analyzing their potentials and pool resources to support R4D agenda.

Investment in wheat R4D

Countries need to explore their potential and invest proportionally on infrastructure and human resource capacity building that supports the wheat R4D agenda. Resources could be pooled together at regional level to address common R4D issues.

Research prioritisation, collaboration and coordination

Most of the ECA countries have similar wheat growing environments. Wheat production is dominated by small scale farmers. They share common technical, biotic and physical
constraints. Capital and human resources are limited. Under such circumstances, prioritization of R4D themes that could be addressed at a regional level may be important. In these aspects, the RWCoE under the first phase of EAAPP has already started some regional projects among the four ECA countries (Ethiopia, Kenya, Tanzania and Uganda). These collaboration and coordination work by ASARECA should be strengthened and extended to other countries in the region.

Trans-boundary constraints
The biotic constraints such as the wheat rust diseases are trans-boundary. New races often evolve in the highlands of ECA countries. However, the sources and causes of periodic outbreak of new races in the region have not been well studied and documented. Their movements within the region and beyond should be monitored and halted ahead of the damage. Monitoring of the evolution and migration of rust races in the region and knowledge of the resistance genes deployed in commercial cultivars are quite useful. In these aspects, information and germplasm exchange at regional and global bases would be pertinent.

Sustainable intensification
Wheat is primarily grown under rain-fed conditions in the region where changing climate patterns might affect the sustainability of wheat production and productivity. Therefore any intensification of activities should maintain the natural eco-system. Research has to support in generating and promoting climate resilient technologies. R4D activities in the area of soil and moisture conservation, minimum tillage, and cropping systems help to increase wheat production and productivity on sustainable bases. A robust seed system and active involvement of private sectors is crucial.

Wheat value chain development
The whole process of the wheat value chain which affect the input and output system should be revisited. Researchers need to develop wheat varieties with acceptable quality parameters and research has to generate technologies that minimize post-harvest losses and improve the quality of produce. Availability of the required amount and quality of agricultural inputs (wheat seed, fertilizers, herbicides and pesticides) at the right time is critical for improving the competitiveness and profitability in wheat production. Countries need to support local seed enterprises, cooperatives and farmers’ cooperative unions and millers so that they become more efficient and competitive in local and international markets. The whole market infrastructure including credit facilities should be revisited.

Explore wheat production in the non-traditional areas
Countries need to explore additional wheat growing areas. Research has explored new potential wheat growing areas; challenges and opportunities should be investigated. Competitiveness
of wheat should be investigated in new areas where other crops are dominant. Possibility for irrigated wheat should be investigated. Early R4D attempts on irrigated wheat should be strengthened in Ethiopia. Variety selection (heat tolerant and short maturing), sustainable agronomic practices such as planting date, irrigation methods that minimize salinity should be investigated and popularized.

Regional integration and policy harmonization
The regional countries need to harmonize policies that enable the use of their resources for the common agenda. Regulations and policies in the area of technology generation and adaptation should be harmonized. Any trade barriers that hinder the movement of technologies including farm inputs (small machineries, seeds, etc.) should be eased across boundaries.

Gender main streaming in wheat R4D
Wheat is produced mainly by small scale households where family labor is dominant. Technologies which ease the burden of women farmers; small and intermediate farm tools and machineries for land preparation, planting, harvesting, threshing and processing is very critical in our research and development agenda. Family members in the household should be involved in technology selection and adoption.

References


Development and implications of regional variety trial in Eastern Africa

Zerihun, T.1,*, Dawit, A.1, Habtemariam, Z.1, Njau, P.2 and Mongi, R.3

1Ethiopian Institute of Agricultural Research (EIAR), P. O. Box 2003, Addis Ababa, Ethiopia; 2Kenya Agricultural and Livestock Research Organization-Njoro, Private Bag (20107) Njoro, Kenya; 3Uyole Agricultural Research Institute, Ministry of Agriculture, P. O. Box 400, Mbeya, Tanzania.

*Correspondence: zerbest2008@gmail.com

Abstract

Developing high yielding and stable genotypes for wide and specific adaptation are important in wheat and evaluation across locations would form a basis for breeding. Thirty-three advanced bread wheat lines along with two check varieties (Danda’a and Hidasse) were evaluated at ten locations during 2013 main cropping season to evaluate and identify bread wheat genotypes for their yield performance and to assess the nature and magnitude of genotype by environment interaction across Ethiopia and Kenya. Experiment was laid out in alpha lattice design in three replications. AMMI was computed for grain yield. The analysis of variance for AMMI model of grain yield showed that environment, genotypes and genotype by environment interaction (GEI) effects were highly significant (p≤0.01) and accounted for 62.4%, 4.8% and 15.8% for the total sum of squares (SS) variations, respectively. High environmental and significant GEI indicated that environment had major influence for inconsistent performance. The mean grain yield of all genotypes was 4.12 t ha⁻¹ ranging from 1.58 t/ha (G30) to 9.05 t ha⁻¹ (G31). Genotypes G31 (4.96 t ha⁻¹), G18 (4.59 t ha⁻¹) and G35 (4.55 t ha⁻¹) were best performing lines across environments. The AMMI biplot using the first two principal components showed that testing site Njoro and Arsi-Robe highly discriminated the tested genotypes; Njoro is negatively interacting with high yielding genotypes and was different environment from any of the testing locations of Ethiopia for these sets of genotypes. It may be difficult to develop high yielding and stable varieties for the two countries but one should look for specific adaptation. Genotypes G31 (4.96 t ha⁻¹) and G18 (4.59 t ha⁻¹) produced high grain yield with low stability across locations which were favouring high yielding environments. However, G21 and G8 had above mean grain yield and good stability across locations. Therefore, the study indicated that wheat breeding for specific adaptability could be very important to exploit the genetic advantage of specific genotypic performances across the region. However, extensive testing considering many locations across East African countries is vital for delineating and exploiting wheat environments for marked developments.

Key words: East Africa, Wheat, GEI, AMMI

Introduction

Wheat is grown on roughly 200 million hectares with an average total production of 700 million metric tons worldwide (FAOSTAT 2014). Global average productivity is around 3 t ha⁻¹ with high variability among countries and regions. It is the most important food grain source for humans supplying 40% of the world’s food and 25% of calories consumed in developing countries. In Ethiopia, Kenya, Tanzania and Uganda,
wheat is one of the most important cereal crops cultivated in a wide range of agro-ecologies and it is the main staple food for about 36% of the Ethiopian population. Despite enormous economic and dietary values of the crop in the region, the average yield has remained extremely low. This has been attributed to multifaceted biotic and abiotic factors including insufficient and erratic rainfall, poor agronomic practices, poor soil fertility, diseases and insect pests.

The development of cultivars or varieties, which can be adapted to a wide range of diversified environments, is the ultimate goal of plant breeders in a crop improvement program. The adaptability of a variety over diverse environments is usually tested by the degree of its interaction with different environments under which it is planted. A variety or genotype is considered to be more adaptive or stable if it has a high mean yield but a low degree of fluctuation in yielding ability when grown over diverse environments. Hence, the genotype-by-environment interaction is probably the main cause of why traditional plant breeding failed to develop wide adaptable varieties (Ceccarelli et al., 2003). Developing high yielding and stable genotypes for wide and specific adaptation are important in wheat variety development strategy and evaluation across locations would form a basis for breeding. Therefore, the present investigation was aimed to evaluate and identify bread wheat genotypes for their yield performance and to assess the nature and magnitude of genotype by environment interaction across Ethiopia and Kenya.

**Materials and methods**

Thirty three bread wheat advanced lines (Table 2) along with two check varieties (Danda’a and Hidasse) were evaluated in different locations of Ethiopia (9 location) and Kenya (1 location) during 2013/14 main cropping season (Table 1). The locations are different in altitude, mean annual rainfall and soil types. These locations represent the major wheat growing agro-ecologies ranging from mid to high altitude. The genotypes were planted in alpha lattice (5x7) with three replications in all experimental sites. Each plot had six rows of 2.5 m length with a spacing of 0.2 m between rows. Planting dates of each location was on the onset of the main rainy season. Fertilizer and other agronomic practices also carried out as per the recommendation of each location. Grain yield data was recorded on plot basis and converted to t ha⁻¹ for analysis.

**Table 1: Description of the test locations**

<table>
<thead>
<tr>
<th>Location</th>
<th>Location Code</th>
<th>Altitude (m.a.s.l)</th>
<th>Annual R.F (mm)*</th>
<th>Representing Agro-ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADET</td>
<td>AD</td>
<td>2240</td>
<td>869</td>
<td>Optimum area</td>
</tr>
<tr>
<td>AREKA</td>
<td>AR</td>
<td>-</td>
<td>-</td>
<td>Optimum area</td>
</tr>
<tr>
<td>BEKOJI</td>
<td>BK</td>
<td>2780</td>
<td>1020</td>
<td>Optimum and high RF area</td>
</tr>
<tr>
<td>HOLETTA</td>
<td>HO</td>
<td>2800</td>
<td>-</td>
<td>Optimum area</td>
</tr>
<tr>
<td>JAMA</td>
<td>JM</td>
<td>-</td>
<td>-</td>
<td>Low potential area</td>
</tr>
<tr>
<td>KULUMSA</td>
<td>KU</td>
<td>2200</td>
<td>820</td>
<td>Optimum area</td>
</tr>
<tr>
<td>MEHONI</td>
<td>MH</td>
<td>-</td>
<td>-</td>
<td>Low potential area</td>
</tr>
<tr>
<td>NJORO</td>
<td>NJ</td>
<td>2120</td>
<td>-</td>
<td>Optimum area</td>
</tr>
<tr>
<td>SINANA</td>
<td>SN</td>
<td>2400</td>
<td>950</td>
<td>Optimum area</td>
</tr>
<tr>
<td>WUKRO</td>
<td>WK</td>
<td>2020</td>
<td>646.6</td>
<td>Optimum area</td>
</tr>
</tbody>
</table>
**Statistical Analysis:** Separate analysis of variance for grain yield for each location was performed prior for combined analysis. The mean square of genotype by environment interaction (GEI) for grain yield was used to test the effect of genotypes. The genotypes (G) and environments (E) were subjected to AMMI method of analysis (Gauch and Zobel, 1997). The AMMI model combines the analysis of variance for main effects of G and E with principal components analysis of GEI. The bi-plot constructed from main effect of means vs the first Interaction Principal Component Analysis Axis (IPCA) from AMMI analysis was used to study the pattern of response of G, E, and GEI. It was also used to identify genotypes with broad or specific adaptation to target environments for grain yield. AMMI-II biplot was constructed in the dimension of first two IPCA, using a singular-value decomposition procedure (Yan et al., 2000). The genotypes were represented on the biplots as the points derived from their scores and the environments as the vectors from the biplot origin to their points.

The equation for AMMI model (Zobel et al., 1998) is:

$$Y_{ij} = \mu + G_i + E_j + \sum_{n=1}^{N} \lambda_n \alpha_i \gamma_{jn} + e_{ij}$$

Where; $Y_{ij}$ is the yield of the $i^{th}$ genotype in the $j^{th}$ environment; $\mu$ is the grand mean; $G_i$ and $E_j$ are the genotype and environment deviations from the grand mean, respectively; $\lambda_n$ is the eigen value of the PCA axis $n$; $\alpha_i$ and $\gamma_{jn}$ are the genotype and environment principal component scores for axis $n$, respectively; $N$ is the number of principal components retained in the model and $e_{ij}$ is the error term.

AMMI model does not make provision for a specific stability measure to be determined, such a measure is essential in order to quantify and rank genotypes according to their yield stability. Since the IPCA-1 score contributes more to GEI sum of squares, it has to be weighted by the proportional difference between IPCA-1 and IPCA-2 scores to compensate for the relative contribution of IPCA-1 and IPCA-2 in to the total GEI sum of squares called AMMI stability values (ASV). The following measure was proposed by Purchase (1997):

$$ASV = \sqrt{\frac{\text{IPCA sum of squares (IPCA1 score)}}{\text{IPCA2 sum of squares}}} + (\text{IPCA2 score})^2$$

**Table 2: Bread wheat genotypes evaluated across ten locations in 2013/14 cropping season**

<table>
<thead>
<tr>
<th>Code</th>
<th>Designation</th>
<th>Pedigree</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>Danda’a</td>
<td>KIRITATI//2<em>PBW65/2</em>SERI.1B</td>
</tr>
<tr>
<td>G2</td>
<td>ETBW 6832</td>
<td>CNO79/PPF70354/MUS/3/PASTOR/4/BAV92/2/5/HAR311</td>
</tr>
<tr>
<td>G3</td>
<td>ETBW 6837</td>
<td>CNO79//PF70354/MUS/3/PASTOR/4/BAV92/2/5/FH6-1-7</td>
</tr>
<tr>
<td>G5</td>
<td>ETBW 6840</td>
<td>PRL/2<em>PASTOR</em>2//FH6-1-7</td>
</tr>
<tr>
<td>G6</td>
<td>ETBW 6841</td>
<td>PBW343/2/KUKUNA*2//FRTL/PIFED</td>
</tr>
<tr>
<td>G7</td>
<td>ETBW 6845</td>
<td>ATTILA*2/PBW65/2//MURGA</td>
</tr>
</tbody>
</table>
WHEAT RESEARCH & DEV'T

Result and discussions

Pooled analysis of variance for grain yield showed highly significant (P < 0.05) differences between genotypes (G), environment (E) and genotype by environment interaction (GEI) (Table 3). Highly significant differences between the G and E for grain yield indicating the presence of genetic variability among the genotypes as well as the environments under study. This is indicated by the mean yield of genotypes across environment range from 1.58 t ha⁻¹(G30) to 9.05 t ha⁻¹(G31) and environmental index range from 2.30 t ha⁻¹ (JAMA) to 6.93 t ha⁻¹ (BEKOJI) (Table 4). Significant GEI suggested the linear function of the additive environment effects and was reflected by the change in the ranking order of genotypes under varying environments. Similar results have been reported by different authors (Cotes et al. (2006), Ali (2006), Amin et al. (2005)). However, overall performance of genotypes depends upon the magnitude of GEI.

ETBW = Ethiopian Bread Wheat

<table>
<thead>
<tr>
<th>ETBW</th>
<th>Genotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>G8</td>
<td>ETBW 6847 ROLF07<em>2/5/REH/HARE/2</em>BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES</td>
</tr>
<tr>
<td>G9</td>
<td>ETBW 6848 ROLF07*2/5/FCT/3/GOV/AZ//MUS/4/DOVE/BUC</td>
</tr>
<tr>
<td>G10</td>
<td>ETBW 6850 FRNCLN/ROLF07</td>
</tr>
<tr>
<td>G11</td>
<td>ETBW 6852 ROLF07/MUU</td>
</tr>
<tr>
<td>G12</td>
<td>ETBW 6853 BECARD/5/PGO//CROC_1/AE.SQUARROSA (224)/3/2*BORL95/4/CIRCUS</td>
</tr>
<tr>
<td>G13</td>
<td>ETBW 6861 WAXWING*2/HEILO</td>
</tr>
<tr>
<td>G14</td>
<td>ETBW 6862 KIRITATI/4/2*BAV92/IREN/AKAUZ/3/HUITES</td>
</tr>
<tr>
<td>G15</td>
<td>ETBW 6866 KLRD/PEWITI//MILAN/DUCULA</td>
</tr>
<tr>
<td>G16</td>
<td>ETBW 6869 MURGA/WAXWING/KIRITATI</td>
</tr>
<tr>
<td>G17</td>
<td>ETBW 6870 ATTILA*2/PBW65/MURGA</td>
</tr>
<tr>
<td>G18</td>
<td>ETBW 6871 ROLF07<em>2/4/CROC_1/AE.SQUARROSA (205)/BORL95/3/2</em>MILAN</td>
</tr>
<tr>
<td>G19</td>
<td>ETBW 6875 WAXWING/KIRITATI*2/YANAC</td>
</tr>
<tr>
<td>G20</td>
<td>ETBW 6876 CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/HAR311</td>
</tr>
<tr>
<td>G21</td>
<td>ETBW 6882 PRL/2/PASTOR*2/2/FH6-1-7</td>
</tr>
<tr>
<td>G22</td>
<td>ETBW 6883 FINSI/METSO//FH6-1-73/FINSI/METSO</td>
</tr>
<tr>
<td>G24</td>
<td>ETBW 6890 ATTILA<em>2/PBW65</em>2//MURGA</td>
</tr>
<tr>
<td>G25</td>
<td>ETBW 6911 REH/HARE/2*BCN/3/CROC_1/AE.SQUARROSA (213)//PGO/4/HUITES/5/PVN</td>
</tr>
<tr>
<td>G27</td>
<td>ETBW 6928 KIRITATI/4/2*BAV92/IREN/AKAUZ/3/HUITES</td>
</tr>
<tr>
<td>G28</td>
<td>ETBW 6932 SKAUZ/BAV92//2<em>WBL1</em>2/KKTS</td>
</tr>
<tr>
<td>G29</td>
<td>ETBW 6937 AGUILAL/FLAG-3</td>
</tr>
<tr>
<td>G30</td>
<td>ETBW 6939 UTIQUE 96/FLAG-1</td>
</tr>
<tr>
<td>G31</td>
<td>ETBW 6943 SKAUZ/BAV92/3/CROC-1/AE.SQUARROSA (224) //OPATA</td>
</tr>
<tr>
<td>G32</td>
<td>ETBW 6947 WON-D 83/3/NS732/HER//KAUZ*S=(FIDIYA-26)</td>
</tr>
<tr>
<td>G33</td>
<td>ETBW 6948 REBWAH-12/ZEMAMRA-8</td>
</tr>
<tr>
<td>G34</td>
<td>ETBW 6953 CROW’S/BOW’S*-3-1994/95/TEVEE’S/TADINIA</td>
</tr>
<tr>
<td>G35</td>
<td>Hidasse YANAC/3/PRL/SARA//TSI/VEE#5/4</td>
</tr>
</tbody>
</table>

ETBW = Ethiopian Bread Wheat

Result and discussions

Pooled analysis of variance for grain yield showed highly significant (P ≤ 0.05) differences between genotypes (G), environment (E) and genotype by environment interaction (GEI) (Table 3). Highly significant differences between the G and E for grain yield indicating the presence of genetic variability among the genotypes as well as the environments under study. This is indicated by the mean yield of genotypes across environment range from 1.58 t ha⁻¹(G30) to 9.05 t ha⁻¹(G31) and environmental index range from 2.30 t ha⁻¹ (JAMA) to 6.93 t ha⁻¹ (BEKOJI) (Table 4). Significant GEI suggested the linear function of the additive environment effects and was reflected by the change in the ranking order of genotypes under varying environments. Similar results have been reported by different authors (Cotes et al. (2006), Ali (2006), Amin et al. (2005)). However, overall performance of genotypes depends upon the magnitude of GEI.
Table 3: AMMI analysis of variance for grain yield (t/ha) of 35 genotypes tested in 2013

<table>
<thead>
<tr>
<th>Source</th>
<th>Df</th>
<th>SS</th>
<th>MS</th>
<th>Sum of square Explained (%)</th>
<th>Total variation</th>
<th>GxE Explained</th>
<th>GxE Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environments</td>
<td>9</td>
<td>1459.185</td>
<td>162.132***</td>
<td>62.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reps within Env.</td>
<td>20</td>
<td>31.943</td>
<td>1.597</td>
<td>1.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genotype</td>
<td>34</td>
<td>112.089</td>
<td>3.297***</td>
<td>4.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Genotype x Env.</td>
<td>306</td>
<td>370.546</td>
<td>1.211***</td>
<td>15.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPCA 1</td>
<td>42</td>
<td>122.74</td>
<td>2.922***</td>
<td>33.12</td>
<td>33.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPCA 2</td>
<td>40</td>
<td>71.975</td>
<td>1.799***</td>
<td>19.42</td>
<td>52.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPCA 3</td>
<td>38</td>
<td>64.437</td>
<td>1.696***</td>
<td>17.39</td>
<td>69.94</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IPCA 4</td>
<td>36</td>
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Grand Mean = 4.12 t/ha R-squared = 0.84 C.V = 17.7% LSD (5%) = 0.37

Significant Codes: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

***= significant at P ≤ 0.001 and ns= non-significant; IPCA= Interaction principal component axis

The highest grain yield over environments recorded from BEKOJI location 9.05, 8.67 and 8.45 t/ha from G31, G21 and G5, respectively (Table 4). The standard check variety G35 (Hidasse) remained the third highest yielding 4.55 t/ha over all locations followed by G31 (4.96 t/ha) and G18 (4.59 t/ha). This revealed at least two promising genotypes were better than the standard check based on grain yield potential across locations. Whereas, the other check G1 (Danda’a) ranked 20th with a grain yield of 4.04 t/ha. BEKOJI (6.93 t/ha), AREKA (4.95 t/ha) and KULUMSA (4.49 t/ha) was among the first three high yielding location whereas JAMA (2.3 t/ha), WUKRO (2.83 t/ha) and SINANA (3.61 t/ha) is the lowest yielding environment. Location tested in Kenya (NJORO) recorded average yield of 4.03 t/ha which is near to the grand total mean 4.12 t/ha (Table 4).

From the total treatment sum of square of the model, 62.4% was attributed to environmental effects and the rest to genotypic effects (4.8%) and GEI (15.8%). The highly significant mean squares of environment indicated that the environments were diverse, with large differences among environmental means causing most of the variation in grain yield. This shows that the overpowering influence that environments have on the yield performance of wheat genotypes. GEI component of variation was partitioned into nine possible interaction principal component axes (IPCA). The F-test indicates that only the first four IPCA were highly significant (P≤0.01) and the remaining are non-significant (Table 3). The first four significant IPCA explained 80.8% of the total GEI sum of square while the remaining IPCA explained only 19.2%. Therefore, the first four significant IPCA can be taken as adequate dimensions for this data set. However, the prediction assessment indicated that AMMI model with only two IPCA was the best predictive model (Yan et al., 2000).
### Table 4: Mean grain yield (t ha⁻¹) of 30 genotypes tested across ten locations in 2013

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AD=ADET, AR=AREKA, BK=BEKOJI, HO=HOLETTA, JM=JAMA, KU=KULUMSA, MH=MEHONI, NJ=NJORO, SN=SINANA, WK=WUKRO
AMMI-1 biplot for grain yield of 35 wheat genotypes and ten locations plotted from the main effect against IPCA-1 scores of the genotypes and environment (Figure 1). Accordingly, the IPCA-1 scores range from 1.472 down to -1.656 and grain yield means from 2.83 up to 6.93 t/ha, which explained 87.6% of the total sum of square. Locations are dispersed widely in all quadrants than the genotypes in the biplot (Figure 1). The lowest IPCA-1 scored by G11 (-0.044), G22 (-0.032) and G30 (0.025). However, these genotypes scored lower grain yield across tested locations. On the other hand, G13 (1.108), G29 (0.940) and G34 (-0.771) scored the highest IPCA-1 and they are non-stable except for G34 the other genotypes showed better grain yield performance across the locations (Table 4).

Figure 1: AMMI-1 biplot for grain yield of 35 wheat genotypes evaluated in 2013
All location and genotypes having the same sign of IPCA-1 score interacts with each other positively and different IPCA-1 score sign interacts negatively (Yan et al., 2000). Therefore, BEKOJI, AREKA, KULUMSA, ADET, SINANA and HOLETA interact positively with the highest yielding genotypes G31, G18, G35 and negatively with G11, G16 and G34. NJORO is negatively interacting with the high yielding genotypes across locations and this makes it complicated to develop high yielding and stable varieties for the two countries (Figure 1).
In addition, AMMI-2 biplot generated by using the first two interaction principal component axes (IPCA 1 and 2) used to visual interpretation of the GEI patterns and identify genotypes or locations that exhibit low, medium or high levels of interaction effects (Yan, 2002). Accordingly, AREKA, NJORO, HOLETA and BEKOJI were the most discriminating environments among the genotypes evaluated as indicated by the longer vectors projected from the origin, indicating that these locations give good information among genotypes. On the contrary; SINANA, ADET, JAMA and MEHONI identified as a least interactive environment with the tested genotypes and it indicates lower interaction of these locations with the genotypes evaluated. NJORO has a different environment from any of the tested locations from Ethiopian (Figure 2).

Genotypes near the origin are non-sensitive to environmental interactive forces and those distant from the origin are sensitive and have large interactions (Samonte et al., 2005). Accordingly, genotypes G30, G26, G22 and G15 are non-sensitive to environmental interactive forces; and hence, these genotypes are considered as stable genotypes. Whereas; G11, G7, G29 and G13 were highly influenced by the interactive force of environment and sensitive to environmental changes, so these varieties were considered as unstable genotypes due to the long projections from the origin (Figure 2).

**Figure 2:** AMMI-2 interaction biplots for grain yield of 35 wheat genotypes tested in 2013

**AMMI stability value (ASV):** In ASV method, genotypes with least ASV score is the most stable than genotypes with
higher ASV (Purchase et al., 2000). Accordingly, genotypes with small ASV values i.e. G30, G22 and G26 were found stable in the current study except G26, all the genotypes had low grain yield performance across locations (Table 4). The most unstable genotypes according to the ASV approach are G13, G29 and G7 having high ASV values. However, these genotypes had above average grain yield potentials. Therefore, genotypes having high ASV correlated with high yield performance and those with low ASV correlated with low yield potential.

Conclusion and recommendation
GEI between tested location across Ethiopian and Kenyan were very high. It will be difficult to develop high yielding and widely adaptable varieties for both countries if the interaction is consistent. More locations should be sampled and two more years testing are necessary to have general conclusion or to recommend specific adaptation. In addition, developing the same genetic background varieties for the region could have its own negative impact. Furthermore, verification of the selected genotypes for disease resistance, particularly for stem and yellow rust, will be very critical since wheat rust is a historical problem in Eastern Africa. Strong collaboration is very crucial in the region for wheat variety development and to support resource-poor farmers in marginal and fragile environments to attain wheat self-sufficiency.

Acknowledgment
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References


Development of wheat germplasm for stem rust resistance in Eastern Africa

Worku, D.1,*, Zerihun, T.1, Daniel, K.1, Habtemariam, Z.1, Dawit, A.1 and Wanyera, R.2

1Ethiopian Institute of Agricultural Research (EIAR), Wheat Regional Center of Excellence, KARC, P.O. Box 489, Addis Ababa, Ethiopia; 2Kenya Agricultural and Livestock Research Organization (KALRO); Njoro, Private Bag (20107), Njoro, Kenya.
*Correspondence: workudi@yahoo.com

Abstract

Wheat rust outbreak is the primary production constraint in Eastern Africa. Ethiopia, Kenya and Uganda are hot spots for the epidemic development of rusts due to higher rate of evolution of new pathogen races. The virulent stem rust (Puccinia graminis) race, Ug99, has caused severe losses since 1999. High susceptibility to Ug99 and its variants of the most widely grown varieties is responsible for such losses. A rigorous evaluation of lines is required for durable stem rust resistance.

Therefore, collective efforts between these countries through regional platform of variety development are crucial to achieve regional food security and boost longer-term wheat growth. Three hundred six elite breeding lines, selected and advanced at Wheat Regional Center of Excellence (WRCoE), were planted in stem rust hot spot areas of Ethiopia (Arsi-Robe) and Kenya (Njoro) during 2012 under natural infections. Severity of stem rust was recorded and coefficient of infection was also calculated to compare the performance of lines. Stem rust scores of 18, 25.8 and 56.2% of lines at Arsi-Robe and 35, 49 and 16.7% of the lines at Njoro were resistant to moderately resistant, intermediate and moderately susceptible to susceptible category, respectively.

The average coefficient of infection (ACI) of all lines at Arsi-Robe (24) was greater than Njoro (13) indicating higher disease pressure at Arsi-Robe than at Njoro. Among the lines, 67% and 49% showed good level of resistance with a severity of <20% at Njoro and Arsi Robe, respectively. However, only 32% of the lines showed good level of resistance (<20% severity) at both locations. These lines could have combined resistance to the multiple stem rust races prevailing at both locations. Generally, most of the lines, which showed better resistant at Njoro were susceptible at Arsi-Robe. It could be due to differences in race composition of the two locations, favourable environmental conditions or some other factors. The identified 73 lines could be used as potential sources of stem rust resistance in the regional breeding program.

Key words: Stem rust, races, severity, coefficient of infection

Introduction

Wheat stem rust caused by Puccinia graminis f. sp. tritici is the major biotic constraints of wheat production in the world and in the Eastern part of Africa in particular. Countries such as Kenya and Ethiopia are always experiencing recurrent epidemics of stem rust due to the evolution of new stem rust races. This has been evidenced in the evolution of new stem rust races with additional virulence to the deployed stem rust resistance genes in wheat cultivars.
For instance, variants with virulence for Sr24 (Jin et al., 2008) and Sr36 (Jin et al., 2009) genes were detected in Kenya. Similarly, virulence to StTmp (David Hodson, Unpublished data) gene was detected from stem rust samples collected during the 2013 season epidemics that wiped out Digalu in Bale zone of Ethiopia, which is one of the breadbasket of Ethiopia. However, the race responsible for the loss of effectiveness of StTmp gene in Digalu was reported in Turkey (Zafer et al., 2012) prior to its discovery in Ethiopia.

Currently race Ug99 (TTKSK) is continuously evolving and undergoing stepwise mutations to bear additional virulence. There are at least seven variants of this race reported across many parts of Africa and its migration and spread to other parts of Africa, Asia and other parts of the world is inevitable (Singh et al., 2011). In view of the recurrent epidemics of stem rust in this part of the world, an international aggressive breeding strategy was followed and resistant cultivars were released in countries most vulnerable to this race. For instance, in Kenya two bread wheat cultivars, Eagle-10 and Robin, were released in 2009 (Njau et al., 2011) and in Ethiopia, Kakaba and Danda’a were released in 2010 as resistant cultivars to Ug99.

Even though the release of resistant cultivars to Ug99 has paramount importance for those countries that were at immediate risk of the pathogen, the continuous evolution of new races and/or variants of the same race requires sustainable efforts to deal with epidemics of the kind of Ug99 or the one that wiped out mega bread wheat cultivar Digalu in Ethiopia by the race TKTTF. Because of this, it was essential to evaluate bread wheat elite lines selected at/developed from the WRCoE in stem rust hotspot areas of Ethiopia such as Arsi Robe and Kenya Njoro for their resistance across the two locations against multiple pathotypes of the same rust during the 2012 main season. The objective of this study was to identify sources of resistance to the major pathotypes of stem rust prevalent in both Ethiopia and Kenya.

**Materials and methods**

A total of 306 elite bread wheat lines that were either selected from international nurseries or developed from the WRCoE including susceptible and resistant checks were included in the evaluations. Among the cultivars resistant to Ug99 included in the study were Danda’a, Kakaba and Digalu. The susceptible cultivar, Hawi was included. Millenium which carries Sr24 gene was also included in the test to evaluate its performance across the two locations. These elite bread wheat lines were planted in two rows of 1-meter length at Arsi Robe, Ethiopia, and Njoro, Kenya in 2012 main season. At Arsi Robe station, there was no artificial inoculation of stem rust since the disease occurs at epidemics proportions most of the time under natural conditions.

In Kenya Njoro however, disease development was encouraged by making artificial inoculations at different growth stages of the crop development. The spreader rows were planted with super susceptible bread wheat Cacuuke, completely susceptible to Ug99 (Kimani et al., 2015) in Kenya and PBW343 was used as spreader rows in the case of Arsi Robe. When the susceptible check started to show stem rust development, scoring began and the severity of stem rust was scored using the modified Cobb scale (Peterson et al., 1948). Average Coefficient of Infection (ACI) was calculated by taking into account the severity of stem rust of the lines and cultivars and their field response (Stubbs et al., 1986). The scores were converted to average coefficient of infection by multiplying severity by an assigned value for the field response (Table 1).
Table 1: Field response values

<table>
<thead>
<tr>
<th>Field response</th>
<th>Symbol</th>
<th>Constant Value</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
</tr>
<tr>
<td>Resistant</td>
<td>R</td>
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</tr>
<tr>
<td>Resistant to moderately resistant</td>
<td>RMR</td>
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</tr>
<tr>
<td>Moderately resistant</td>
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<tr>
<td>Intermediate</td>
<td>M (MRMS)</td>
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<tr>
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<td>MSS</td>
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<tr>
<td>Susceptible</td>
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</table>

Results

Reactions of elite lines to stem rust of wheat: Out of the 306 lines tested at Arsi Robe, ten were immune to the pathogen populations prevailing there during the 2012 main season. However, at Njoro none of the lines were immune to stem rust infection. Eleven lines were resistant at Arsi Robe and only four lines were resistant at Njoro. Five and 12 lines displayed resistant to moderately resistant reactions at Arsi Robe and Njoro, respectively. 29 lines at Arsi Robe and 91 lines at Njoro exhibited moderately resistant reactions whereas 79 and 150 lines displayed intermediate reactions at Arsi Robe and Njoro respectively. 31 lines at Arsi Robe showed moderately susceptible reactions whereas 24 lines showed the same reaction at Njoro. With respect to moderately susceptible to susceptible reactions (MSS), more number of lines i.e. 45, displayed this reaction at Arsi Robe. However, only 16 lines displayed MSS reactions at Njoro. Ninety-six lines were completely susceptible at Arsi Robe and only nine lines were susceptible at Njoro. In general considering the diseases reactions at Arsi Robe and Njoro, more number of lines were in the moderately susceptible and susceptible categories at Arsi Robe than at Njoro (Figure 1 and Table 3). However, in reaction categories ranging from resistant to intermediate, the number of lines at Njoro exceeded by far the number of lines at Arsi Robe (Figure 1 and Table 3).

Table 2: Number of elite bread wheat lines in resistance and susceptibility category at Arsi Robe and Njoro in 2012 main season

<table>
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<th>No</th>
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<th>Number of lines</th>
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<tr>
<td>2</td>
<td>R</td>
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<td>MR</td>
<td>29</td>
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<td>6</td>
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<td>7</td>
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<td>45</td>
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<tr>
<td>8</td>
<td>S</td>
<td>96</td>
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</tbody>
</table>

R= Resistant, RMR= Resistant to moderately resistant, MR= Moderately Resistant, M= Moderately resistant to moderately susceptible, MS= Moderately Susceptible MSS= Moderately susceptible to susceptible and S= Susceptible
Figure 1: Number of bread wheat elite lines in different classes of stem rust reactions at Arsi Robe and Njoro in 2012

Severity of stem rust of wheat on elite lines of bread wheat: Half of the elite lines (151) tested at Arsi Robe showed a severity less than or equals to 20% whereas at Njoro almost two-third of the lines (204) showed the same severity levels (Figure 2); 21 and 20% of the lines showed a severity of 25-30% at Arsi Robe and Njoro; 91 (30%) of the lines at Arsi Robe and 42 (14%) of the lines at Njoro displayed a severity of greater than 30%.

Figure 2: Elite lines of bread wheat evaluated at Arsi Robe and Njoro and their severity level during 2012 main season
Table 3: Terminal stem rust severity, coefficient of infection and average coefficient of infection of selected elite lines and check cultivars at Arsi Robe and NJoro in 2012 main season

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<th>CI-value</th>
<th>ACI value</th>
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<td>Ars Robe</td>
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<td>2</td>
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<td>244</td>
<td>Digalu</td>
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<td>10MSS</td>
<td>12</td>
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<td>245</td>
<td>Kakaba</td>
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<td>5MR</td>
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<td>6.2</td>
<td>306</td>
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CI = coefficient of infection, ACI = average coefficient of infection
Discussion
The variability in both severity and infection response of elite lines and check cultivars at both testing locations during 2012 season clearly shows that the stem rust pathogen populations have differences in their virulence profiles. More number of lines were found to be susceptible at Arsi Robe than at Njoro. Cheruiyot et al., (2015) reported Narok as the most stem rust prone compared to Njoro and in the current study more number of lines were found resistance which could be attributed to the low stem rust pressure compared with Arsi Robe. During the 2012 season, stem rust race analysis reports depicted the dominance of race TTKSK across many wheat growing areas of Ethiopia (Woldeab et al., 2013) and hence this race attributed to the development of stem rust epidemics that resulted in the susceptibility of tetraploid wheat accessions evaluated during the season (Worku, 2014). Ismail et al. (2012) reported race TTKST as the dominant stem rust race in major wheat growing cultivars of Kenya because of the widespread production of bread wheat cultivar KS Mwamba. Therefore, 73 of the lines that displayed resistant to moderately resistant reactions to the prevalent races of both Arsi Robe and Njoro could be potential sources of resistance to race Ug99 and its derivative with virulence for Sr24 gene. The Arsi zone of Ethiopia is a known hotspot for the development of stem rust epidemics and many stem rust race analysis works indicated the presence of broad races with wider virulence spectrum (Admassu and Fekadu, 2005; Admassu et al., 2009).

The shuttle-breeding program between Mexico and Kenya has resulted in the identification and development of high-yielding and stem rust resistant bread wheat lines with high level of APR to the prevailing stem rust races in Kenya and other countries of Africa (Singh et al., 2012). Taking the success of CIMMYT’s shuttle breeding strategy, a shuttle breeding program is initiated between Ethiopia and Kenya that has resulted in the identification and development of stem rust resistant and high yielding bread wheat lines that fits in the agro-ecologies of East African countries such as Tanzania and Uganda. Selection and advancement of breeding lines with low level of severity (usually less than 20%) with moderately susceptible or moderately resistant infection types (responses) to the prevailing stem rust races in the test environments is a dependable breeding option to identify durably resistant bread wheat lines which has been utilized for wheat improvement in Ethiopia (Bechere et al., 1995).

Conclusion and recommendations
The 73 lines that displayed low level of stem rust severities and resistant to moderately resistant reactions to the stem rust pathogen populations of both test locations can directly be utilized as resistant parental lines in the regional wheat breeding program or they can be advanced to regional yield trials for the development of high yielding and stem rust resistant cultivars to combat with the ever evolving races of stem rust.

It is highly recommended to incorporate more number of stem rust hotspot locations from both Ethiopia and Kenya to catch the broader virulence spectrum to develop multiple stem rust race resistant breeding lines that can be utilized in the regional variety development and deployment strategy.

Acknowledgment
We would like to thank the Wheat Regional Center of Excellence (WRCoE) of Ethiopian Institute of Agricultural Research (EIAR) in giving us the opportunity to participate in the joint germplasm evaluation and selection. Kenyan Agricultural and Livestock Research Organization (KALRO) is gratefully acknowledged for hosting us.
References


Importance of Russian wheat aphid *Diuraphis noxia* (mordvilko) (hemiptera: aphididae) in irrigated and rain-fed wheat in eastern Africa.

Tebkew, D.1,*, Munene, M.2, Njuguna, M.2 and Ndungu, J.2

1*Ethiopian Institute of Agricultural Research, Debre Zeit Center, P.O. Box 32, Debre Zeit, Ethiopia; 2*KALRO, Food Crops Research Centre- Njoro, P.O. Private Bag-20107, Njoro, Kenya.

*Correspondence: tebkew@yahoo.com

Abstract

Although the Russian wheat aphid (RWA), *Diuraphis noxia* infests wheat throughout the Eastern Africa region, its pest status has not yet been determined. Therefore, experiments were conducted to quantify yield losses caused by RWA in wheat grown under rain-fed and irrigated conditions in Kenya and Ethiopia, respectively. The experiment consisted of four varieties (in Ethiopia) and six varieties (in Kenya) as subplot and insecticide (sprayed and unsprayed) as main plot in three replications. The test varieties had different levels of RWA infestation. At Njoro in Kenya, the mean number of RWA per tiller was less than one in insecticide sprayed wheat plots, while it was between 4 and 19 in unsprayed plots. The yield losses ranged from 12 to 29%. Similarly, at Mau Narok the mean number of RWA per tiller was less than one in insecticide sprayed wheat plots and 3 to 14 in unsprayed (control) plots.

The yield loss ranged from 16 to 34%. In the irrigated wheat, at Debre Zeit, Ethiopia, the level of RWA infestation and associated yield loss was variable between seasons and genotypes. In the 2012, at peak infestation the mean number of RWA per tiller ranged from 47 to 67 in unsprayed (control) plots, while it was less than three on in insecticide sprayed ones. This RWA infestation level caused a yield loss of 69 to 93%. In the 2013 season, the mean number of RWA per tiller in insecticide sprayed wheat was less than one, while it was 10 to 11 on unsprayed wheat. The yield losses varied between 15 and 41%. RWA infestation also reduced 1000 seed weight, protein, starch and gluten contents. This shows that the RWA is economically important pest of wheat in the region. Therefore, integrated pest management strategy for RWA should be developed, which includes development of aphid resistant wheat varieties, identifying safe and effective insecticides and determination of economic injury level.

Keywords: Russian wheat aphid, *Diuraphis noxia*, Eastern Africa, wheat, yield loss

Introduction

The exact date of introduction of the Russian wheat aphid (RWA), *Diuraphis noxia* (Mordvilko) (Hemiptera: Aphididae) to the Eastern Africa region is not known. However, it was first reported as pest of barley in 1972 in northern Ethiopia (Adugna and Tesema, 1987) and in 1995 in Kenya (Macharia and Maling’a, 2010). Currently, it has invaded wheat growing areas of Uganda.
The RWA is a serious pest of wheat when the crop is subjected to moisture stress particularly at the vegetative stage. For instance, according to Hailu et al. (1989) in most wheat growing areas of Ethiopia aphids are the principal insect pest on wheat and the problem is aggravated by late planting. Similarly, in Kenya high yield losses (90%) occur due to RWA infestation in wheat if no chemical control measures are applied (Macharia et al., 1999). This aphid is also known to develop biotypes that shorten the durability of resistant wheat varieties (Burd et al., 2006). It sucks sap from leaves and shoots which results in rolling and chlorosis on leaves and distortion of heads (Akhter and Khaliq, 2003).

Although RWA is a serious pest of wheat in the Eastern Africa region, there are no empirical data on the incidence and associated yield losses in rain-fed or irrigated wheat in the region. Determining the amount of yield loss caused by a particular pest has many uses at regional, national, farm and individual field level. The information could be used to develop integrated pest management (IPM) strategies for the management of RWA in wheat. Therefore, this study was conducted with the objective of quantifying the amount of yield losses caused by the RWA in irrigated or rain-fed wheat.

**Material and Method**

**Incidence and effect of RWA on irrigated wheat**

RWA susceptible each two durum (Denbi and Werer) and bread (Kubsa and Millennium) wheat varieties were sown on Vertisols at Debre Zeit (Alt. 1900 m.a.s.l, 8°44” N and 38°58” E), Ethiopia at an average seed rate of 140kg/ha. The plot size was 3m x 3m and planting was done on January 25 and 23 in 2012 and 2013, respectively. The experiment was laid in a split plot design with varieties as sub-plot and insecticide (sprayed and unsprayed) as main plot, and was replicated three times. DAP fertilizer was applied at the time of sowing at the recommended rate of 100kg/ha. Irrigation was given at weekly intervals as spray until the crop was established, and as flood thereafter until the crop matures.

The population intensity (number per tiller) of RWA was estimated at ten days interval by counting the number of aphids on randomly selected 20 tillers per plot in a cross diagonal line. Tillers were examined daily beginning from seedling emergence to detect the initial occurrence of the aphid. Then, two weeks after the initial appearance of the aphid, Dimethoate was sprayed three and two times in 2012 and 2013 seasons respectively, with a hand-operated knapsack sprayer at a rate of 1 Lha⁻¹ in a spray volume of 200 Lha⁻¹. Insecticide was applied at fortnightly intervals when insecticide was applied two or three times in a season.

The amount of yield loss caused by the RWA was estimated by comparing grain yield of each variety from insecticide sprayed and unsprayed plots. The percentage of avoidable loss in yield (w %) was calculated using the method of Walker (1987) as

\[ w\% = \frac{(m_i - y_i)}{m_i} \times 100 \]

where \( m_i = \) yield of variety \( i \) obtained in sprayed plots and \( y_i = \) yield of variety \( i \) obtained in unsprayed plot. Moreover, data on 1000 seed weight was recorded and percent loss was calculated using the above formula.

**Incidence and effect of RWA on rain-fed wheat**

RWA susceptible bread wheat varieties NJBW2, Kwale, Heroe, Duma, Robin, and K. Eagle were grown at Njoro (00 20’ S, 35° 56’E, at 2160 m.a.s.l.) and Mau Narok (0° 39’S, 35° 57’E, at 2835m a.s.l.) in 2013/2014. Each variety was sown on 3.0 m x 6.0 m plot. Agronomic practices recommended for each site were applied uniformly.
in each plot. The experiment was arranged in a split plot design with three replications. Varieties and insecticides (sprayed and unsprayed) were the main-plot and sub-plot factors, respectively. Seeds for insecticide treated plots were admixed with Cruiser 350FS (thiamethoxam) (150 ml/90kg seed) at planting and later sprayed with Thunder 145OD (Imidacloprid 100g/l + beta-cyfluthrin 45g/l) at the rate of 0.3l/ha after a month and then applied in two weeks interval until the crop heads. From each plot five plants were selected at random at two weeks interval and the number of RWA were counted and recorded. At crop harvest, grain yields and 1000 kernel weights of both insecticides sprayed and unsprayed plots were compared to assess yield losses. Yield losses were calculated as described in irrigated wheat experiment. Grain quality for insecticide sprayed and unsprayed plots was assessed using Near-infrared Reflectance Spectroscopy [Infratec® 1241] (Dowell et al., 2006). Then, starch, protein and gluten content losses were calculated in similar way as the yield loss was estimated.

Statistical analysis
To stabilize the variance data on RWA number were transformed to log (x+1), where x is the original aphid number. The transformed RWA number was used only for the analysis and actual mean values were reported. All data were analyzed by proc GLM of SAS version 9.0.

Results
Incidence and effect of RWA on irrigated wheat

Intensity of RWA:
In both seasons, there was no significant difference in RWA intensity in the pre-spray count among varieties, insecticide and variety x insecticide interaction. Moreover, in the post spray count the effect of varieties and variety by insecticide interaction on RWA was not statistically significant (P >0.05), whereas the effect of insecticide spraying was highly significant (P< 0.01) in reducing RWA number. The aphid began infesting wheat at three to five leaf stage Zadoks GS 22 (Zadoks et al., 1974) in mid February and in unsprayed wheat it reached peak intensity (number per tiller) in the last and the second week of March in 2012 and 2013 season, respectively. At the time of peak infestation the average number of RWA per tiller were 46.9 on variety Denbi, 59.6 on Kubsa, 63.6 on Millennium and 56.2 on Werer. The corresponding population intensities on insecticide sprayed wheat were 0.8, 2.3, 2.4 and 1.8. In the 2013 season, the population intensity of RWA was generally very low on all varieties. At the peak population intensity in unsprayed plots, the average RWA population per tiller was 10.1, 10.5, 9.6, and 10.2 on Denbi, Kubsa, Millennium and Werer, respectively. However, on sprayed wheat, the average population intensity was less than one per tiller.

Effect of RWA on grain yield:
In both seasons, the RWA significantly (p < 0.05) reduced thousand seed weight and grain yield (Figure 1). When the varieties were sprayed with insecticide they had large sized grain and gave more grain yield than when they were not sprayed. Consequently, in the 2012 season, depending on the variety, the avoidable loss in 1000 seed weight and grain yield ranged from 32 to 47%, and 69 to 93%, respectively. Similarly, in 2013, the avoidable loss was 14 to 20% in 1000 seed weight and 15 to 41% in grain yield.
Incidence and effect of RWA on rain-fed wheat

Intensity of RWA:

As in the case of irrigated wheat, insecticide spraying significantly reduced RWA intensity in wheat grown under rain-fed condition. Under unsprayed condition at Njoro, the average number of RWA per tiller was 18.9 on NJBW2, 11.3 on Heroe, 10.0 on Duma, 8.9 on Robin, 8.5 on K Eagle and 4.0 on Kwale. RWA intensity based rank of varieties at Mau Narok was identical to the rank at Njoro and the corresponding RWA intensity values were 13.7, 12.7, 11.0, 10.7, 6.5 and 2.6. On other hand, at both locations insecticide spraying reduced the mean intensity of RWA to less than one per tiller on all varieties.

Effect of RWA on grain yield:

Russian wheat aphid infestation significantly (p < 0.05) reduced grain yield and thousand seed weight at both locations (Figure 2). At Njoro, the highest grain yield loss (29%) was recorded on variety Duma followed in decreasing order, by K Eagle, Kwale, Robin, Heroe and NJBW2. Similarly, loss in thousand seed weight was the highest (21.0%) on variety Duma, while the lowest loss (1.1%) was recorded on variety Robin. At Mau Narok, the grain yield loss ascribable to RWA was also the highest (33.9%) on Duma followed in decreasing order by NJBW2, K Eagle, Robin, Heroe and Kwale (Figure 2). The losses in thousand seed weight, on the other hand, were highly variable and ranged from no loss to 6.2% in Eagle.
Figure 2: The effect of Russian wheat aphid infestation on grain yield and thousand seed weight of rain-fed wheat at Njoro and at Mau Narok, Kenya, in 2013/2014

Russian wheat aphid also affected protein, starch and gluten content of wheat (Table 1). At Njoro, grains from insecticide unsprayed wheat had less protein, starch and gluten content than grains from counterparts, indicating that there were substantial losses of protein, starch and gluten due to RWA feeding. The protein and gluten content of NJBW2 was unaffected by RWA infestation. However, at Mau Narok all tested varieties had less protein, starch and gluten content under insecticide unsprayed condition than when they were sprayed with insecticide (Table 1). Thus, the protein content losses due to RWA feeding ranged from 2% in Heroe and K Eagle to 11% in NJBW2; the losses in starch also varied between close to one percent in NJBW2 and Duma and 3% in Robin. Similarly, the gluten content was reduced by 1% in Robin to 10% in Duma.
Table 1: Losses in wheat grain quality due to Russian wheat aphid attack at Njoro and Mau Narok, Kenya in 2013/2014

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<tr>
<td></td>
<td></td>
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<td>Protein (%)</td>
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<td>Content</td>
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<tr>
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<td>3.1</td>
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</table>

Discussion

This study has shown that all the test varieties were susceptible to RWA attack which is in agreement with Macharia et al. (1999) and Tebkew (2012) who stated that the wheat varieties developed so far in Kenya and Ethiopia respectively, are susceptible to RWA. The RWA intensity and the extent of grain yield as well as thousand seed weight losses highly varied between seasons under irrigated condition. This is attributed to the difference between seasons in temperature and rainfall, which in turn affects the RWA intensity and duration of infestation (Tebkew, 2015). In 2012, it rained 85.6mm of rainfall in 9 days but after the RWA reached peak population intensity. On the other hand, in 2013 the rain began one week earlier than the 2012 season and it rained 120.3mm in 13 days. In both seasons the RWA population intensity began to decline after the first rain event. Also the mean minimum temperature fluctuated between seasons particularly in February during which the aphid was at the start of infestation. Thus, in February of 2012 the mean minimum temperature was 7.67± 0.48°C, while in 2013 it was 9.05±0.46°C.

Both under rain-fed and irrigated conditions, spraying wheat with insecticide increased grain yield and thousand seed weight. This indicates that the use of insecticides on wheat against RWA in either production system might be economical. The amount of yield losses attributable to RWA attack range from 12 to 93% depending on the type of wheat production system, location, season, and variety grown. According to Mirik et al. (2009), RWA infestation in wheat can lead to yield losses of 50 to 83%. With the exception of variety Kwale, the extent of grain yield losses at Mau Narok was greater than at Njoro. However, according
to Ngenya et al. (2014) the Njoro RWA biotypes are more virulent than the Mau Narok RWA biotype. This discrepancy might be due to varietal difference in the expression of resistance under laboratory and field conditions.

Although the effect of RWA infestation on grain quality was similar on most varieties and both location, the effect on protein and gluten contents on NJBW2 was variable between locations despite the highest number of RWA per tiller. The probable reason for this discrepancy is that the distribution of RWA within the field might have not been uniform. According to Fauvergue and Hopper (1994) the RWA had clumped (aggregated) type of spatial distribution in all wheat fields. Therefore, there might have been more uninfested plants in insecticide unsprayed NJBW2 plots, which bore normal grains. Nonetheless, our results are in agreement with Girma et al. (1993) who reported that RWA infestations reduced yield, protein content and milling qualities in wheat. Moreover, Franzen et al. (2007) reported that D. noxia feeding has the potential to alter carbohydrate- partitioning patterns and alters source-sink relationships in wheat seedling. However, it is difficult to extrapolate this finding to protein content of grain as the RWA did not infest wheat after heading stage. Other aphid species such as the English grain aphid, Sitobion avenae and bird-cherry aphid, Rhopalosiphum padi that feed on wheat head cause significant reduction in protein content of the grain (Ba-Angood and Stewart, 1980). A controlled experiment must be conducted in the future to determine the actual effect of RWA attack on grain quality.

Conclusion

This study has shown that RWA is a serious pest of irrigated and rain-fed wheat in Eastern Africa, causing substantial yield losses and reducing grain qualities in different seasons and locations. In study released wheat varieties in both countries were tested for resistance and they were susceptible to RWA as they were developed in the absence of RWA or under insecticide protected condition in the presence of the pest. Therefore, the future wheat breeding program should be geared towards developing RWA resistant wheat varieties. Moreover, integrated pest management strategy for RWA should also be developed, which includes development of aphid resistant wheat varieties, identifying safe and effective insecticides and determination of economic injury level and the generated technology should be made available to wheat growers.

Acknowledgment

The study was financially supported by the East African Agricultural Productivity Program (EAAPP). The authors acknowledge Chuchu Kebede, I. Koros and G. Ngotho for their help during the execution of the experiment and data collection.
References


Cultural approach for the management of Russian wheat aphid (*Diuraphis noxia kurdjumov*) infestation on selected bread wheat varieties


Kenya Agricultural and Livestock organization -Njoro P.O. Box private bag 20107 Njoro, Kenya.

*Correspondence: michael.njuguna@kalro.org

Abstract

Wheat is the second important cereal after maize in Kenya. It is an important source of food, feed and income. However its production (442,000 MT) does not meet domestic demand (1,750,000 MT) annually. Cereal aphids are among the major constraints in wheat production due to high cost chemicals used to control them. The most serious cereal aphid in Kenya is the Russian wheat aphid (RWA). It can cause yield losses of ≥ 90% if uncontrolled. Currently chemicals are the only RWA management strategy. Chemicals are costly and unfriendly to the environment. A field study was conducted in 2011, 2012 and 2013 crop seasons in Njoro, Kenya to develop low cost cultural, sustainable and environmentally safe practices for the management of the RWA. Nine commercial wheat varieties, K. Tai, K. Kingbird, K Wren, K. Korongo, K. Hawk, K. Sunbird, Robin, K. Eagle, and NBWII were sown in Randomised complete block design (RCBD) in split plot arrangement. Main plots were assigned to wheat varieties sown at three seeding rates 75, 100 and 125 kg/ha. While sub-plots were assigned to three rates of nitrogen, 75, 100 and 130 kg N/ha soil applied at tillering stage (GS 22). No insecticides were applied against RWA damage. The results obtained showed that variety K. Korongo gave the lowest aphid count of 2.8 aphids/5 plants, followed by Robin (2.9 aphids) and K. Hawk (3.1). Robin gave the highest grain yield 5307.0 kg/ha, followed by K. Korongo (2509.6 kg/ha) and K. Hawk (2430.4 kg/ha). Nitrogen at 100 kg N/ha and seeding at 100 kg/ha appeared to be the best rates. The results show that combining optimum rates of nitrogen sowing rates in the management of RWA can lower cost of production and keep the environment healthy.

Key words: Russian Wheat Aphid, Nitrogen and, seed rates wheat varieties.

Introduction

Wheat is an important staple food crop ranking second after maize in Kenya. It is an important source of both food and feed (FAOSTAT, 2009). Kenya’s annual domestic requirements stand at 1,750,000 MT against production of 442,000 MT (USAID, 2014). Cereal aphids are among the most serious biotic constraint to wheat production. Several species of cereal aphids attack wheat causing about 90% losses. The Russian wheat aphid (RWA) (*Diuraphis noxia kurdjumov*) is the most destructive followed by Greenbug (*S. graminum* L.). RWA can cause up to 25-95% yield loss depending on the severity and stage of infestation (Macharia *et al*., 2002). All commercial wheat varieties grown by farmers are susceptible to RWA (Macharia *et al*., 2002). Currently the main control is the application of aphicides (Macharia *et al*. 2012) and hence the need for the development of an integrated approach for the management of the cereal aphids that will reduce the cost of production and keep the environment safe.

Materials and Methods

Field studies were conducted to evaluate appropriate varieties, seeding and nitrogen rates in the management of...
RWA in order to reduce the cost of chemicals in wheat production. Field trials were conducted for three seasons, (2011, 2012 and 2013) at KALRO - Njoro (35° 31’ E and 0° 21’ S, 2,164m a.s.l, AEZ LH3). The rainfall is about 1012mm per annum, mean maximum temperature of 27.9°C and mean minimum 7.9°C. It is characterized with mollic – andosols type of soils (Jaetzold et al. 2010). The trials were laid out in a split plot arrangement replicated three times, with wheat varieties forming the main plots and seed rates were the sub plot treatments. The wheat varieties used were K. Tai, K. Kingbird, K Wren, K. Korongo, K. Hawk, K. Sunbird, Robin, K. Eagle, and NBWII. Wheat was sown in rows using experimental plot seeder in the main plots. The sowing time coincided with RWA peak infestation period. Seed rates (SR) used were 75, 100 and 125 kg/ha. Diammonium phosphate (18: 46: 0) was applied at 100 kg/ha to provide starter nutrients. Nitrogen (N) was applied at tillering stage through the soil at 75, 100 and 130 kg N/ha. Crop management was done according to recommendations (KARI, 2005), with no application of insecticides. Five plants/plot were randomly selected, RWA identified and counted. RWA symptoms identified were rolled flag leaf, leaf/sheath purple coloration and fish hook ears (Macharia et al. 2012). RWA counts were transformed using formula √x+1 (Gomez and Gomez, 1984). Plots were harvested with a sickle and threshed by experimental plot thresher. Data on tillers, spikes, biomass, thousand grain weight (TKW), harvest index (HI) and grain yield were taken and recorded. Harvest index was calculated as the ratio of grain yield to above ground dry matter at maturity (Metho & Hammes, 1999; Rashid, et al., 2007).

Grain moisture was adjusted to 12%, the grain weight was recorded; 1000 grains were counted and weighed. The data was analyzed using (SAS, 1994). Data collected was subjected to the analysis of variance (ANOVA) at 5% level of significance. The treatment means were separated using Least Significant Difference (LSD). Yield benefits were calculated in order to establish whether use of different rates of nitrogen application and seeding rates were useful practices to the farmer and also to compare yield increase due to higher rates of nitrogen application and seeding rates as follows:

- Grain yield benefit = Grain yield (N top-dressed plots) - Yield (No N top-dressed plots)
- Grain yield benefit = Grain yield (higher SR plots) - Yield (Lowest SR plots)

**Results**

Significant (P<0.05) differences in aphid counts were observed among varieties (Table 1). NBW11 recorded the highest number of RWA in 2011 and 2012 while Robin recorded the highest in 2013. Tillers/m² and spikes/m², were significant (P<0.05) among the varieties. Njoro BWII gave the highest number of tillers/m² and spikes/m², while K. Wren and K. Kingbird had the lowest tillers/m² and spikes/m² respectively. Biomass accumulation was significant (P<0.05) among varieties. Application of N had significant (P<0.05) influence on aphid infestation densities and crop performance were as shown in Table 2: Seeding rates had significant (P<0.05) effects on both aphid counts and grain yield (Table 3). There were no interactions i.e. Variety X Nitrogen; Variety Seed Rates and Variety X Nitrogen X Seed Rates

**Table 1: Effect of aphid counts on yield and yield determinants of wheat varieties**

<table>
<thead>
<tr>
<th>Variety</th>
<th>K Tai</th>
<th>K Sunbird</th>
<th>K Wren</th>
<th>K Korongo</th>
<th>K Hawk</th>
<th>K Kingbird</th>
<th>Robin</th>
<th>K Eagle</th>
<th>NBWII</th>
<th>MEAN</th>
<th>LSD</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aphids</td>
<td>3.3bc</td>
<td>3.6bc</td>
<td>3.6bac</td>
<td>2.8c</td>
<td>3.1bc</td>
<td>3.8ba</td>
<td>2.9bc</td>
<td>3.2bc</td>
<td>4.3a</td>
<td>3.4</td>
<td>0.88</td>
<td>2.11</td>
</tr>
<tr>
<td>Tillers/m²</td>
<td>111.1b</td>
<td>116.9a</td>
<td>90.9c</td>
<td>120.5a</td>
<td>104.3bac</td>
<td>94.5bc</td>
<td>117.7a</td>
<td>114.4a</td>
<td>121.9a</td>
<td>110.2</td>
<td>18.3</td>
<td>1.97</td>
</tr>
<tr>
<td>Spikes/m²</td>
<td>82.2bdc</td>
<td>88.1bac</td>
<td>74.3dc</td>
<td>95.0ba</td>
<td>81.4bdc</td>
<td>71.0d</td>
<td>96.0ba</td>
<td>88.0bac</td>
<td>99.1a</td>
<td>86.1</td>
<td>15.8</td>
<td>1.97</td>
</tr>
<tr>
<td>Bio t/ha</td>
<td>5.1bdac</td>
<td>5.2bac</td>
<td>4.6de</td>
<td>5.5ba</td>
<td>5.3bac</td>
<td>4.2e</td>
<td>5.6a</td>
<td>4.8dc</td>
<td>4.9bdc</td>
<td>5.0</td>
<td>0.7</td>
<td>1.97</td>
</tr>
</tbody>
</table>
Nitrogen application

Application of nitrogen at 100 kg/ha gave the highest infestation of RWA in the three seasons (3.7, 4.1 and 5.7 aphids), whereas N at 75 kg and 130 kg N/ha were not significantly (P>0.05) different in concurrence with Fluegel and Johnson (2001) report where different levels of nitrogen application had no significant (P>0.05) effect on aphid infestation.

Table 2: Effect of nitrogen on cereal aphid counts, yield and yield components

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N rates</td>
<td>75</td>
<td>100</td>
<td>130</td>
<td>Mean</td>
<td>Isd (0.05)</td>
<td>CV (%)</td>
</tr>
<tr>
<td></td>
<td>Aphids/m2</td>
<td>3.3ba</td>
<td>3.7a</td>
<td>3.1b</td>
<td>3.4</td>
<td>0.6</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>Tillers/m2</td>
<td>106.5b</td>
<td>116.7a</td>
<td>107.6b</td>
<td>110.3</td>
<td>9.1</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>Spikes/m2</td>
<td>82.6</td>
<td>90.6</td>
<td>85.1</td>
<td>86.1</td>
<td>NS</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>Biomass t/ha</td>
<td>4.9</td>
<td>5.2</td>
<td>5.0</td>
<td>5.0</td>
<td>NS</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>TKW</td>
<td>35.4b</td>
<td>36.5a</td>
<td>35.9b</td>
<td>35.9</td>
<td>0.6</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>HI</td>
<td>31.2</td>
<td>30.4</td>
<td>30.3</td>
<td>30.6</td>
<td>NS</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>Yield t/ha</td>
<td>2.0b</td>
<td>2.4a</td>
<td>2.2b</td>
<td>2.2</td>
<td>0.04</td>
<td>1.97</td>
</tr>
<tr>
<td></td>
<td>Yield benefit kg/ha</td>
<td>-</td>
<td>400</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letter in the same column are not significantly different at (α=0.05).
Means followed by the same letter in the same column are not significantly different at (Ɑ=0.05).

Nitrogen at 100 kg/ha increased tillers/m² (116.7, 128.4 and 151.1) in 2011, 2012 and 2013 and spikes/m² in 2012 only, which concurs with Hussain et al. (2008) findings. Nitrogen at 100 kg N/ha gave the highest TKW (36.5, 40.2 and 31.2 g) and grain yields (2.4, 2.5 and 2.5 t/ha) in the three seasons. Nitrogen at 100 kg N/ha gave the highest TKW (36.5, 40.2 and 31.2 g) and grain yields (2.4, 2.5 and 2.5 t/ha) in the three seasons. Although plots that received 100 kg N/ha had high infestation, they gave the highest grain yield (2.4, 2.5 and 2.5 t/ha) and yield components in the 3 seasons. It would therefore appear that nitrogen enhanced plants’ tolerance to aphid resulting in high grain yield in the study concurring with Silvina et al. (2005). This observation compares well with findings by Sara et al. (2010) where they reported improved oilseed rape performance on application of higher levels of nitrogen despite higher number of cabbage aphid. In this case it would appear that N at 100kg/ha was the optimum rate. Our observation agrees with Riedell, (2008) suggesting that N fertilization may be a useful strategy for limiting yield reduction caused by RWA in N deficient wheat crop. The results indicate that it is not technically useful to apply more than 100kg N/ha due increased cost of additional nitrogen.

**Seeding rates**

Seeding at 75 kg/ha gave the highest aphid counts (3.7, 4.0 and 5.7 aphids) while SR of 100 kg/ha gave the lowest counts (2.9, 3.2 and 15.0 aphids). The result from our study agrees with Infonet biovision, (2013) that low plant densities are more susceptible to aphid attacks. Seeding rate had significant (P<0.05) effect on spikes/m², biomass, HI and grain yield but no significant (P>0.05) effect on tillers/m² in 2011. SR at 125 kg/ha gave the highest number of spikes/m² in 2011 and 2012 crop seasons biomass production followed by SR at 100 kg/ha. The high number of spikes recorded in the higher SR may have resulted from the high plant density contrary to Childress et al. (2012), postulation that yield components are impacted by genetics than SR. Moderate SR (100 kg/ha) were observed to be beneficial in the management of RWA in wheat production.

**Table 3: Effect of seeding rates on cereal aphid counts, yield and yield components**

<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75</td>
<td>100</td>
<td>125</td>
<td>Mean</td>
<td>lsd (0.05)</td>
<td>CV (%)</td>
</tr>
<tr>
<td>Aphids/m²</td>
<td>3.7a</td>
<td>2.9b</td>
<td>3.4ba</td>
<td>3.3</td>
<td>0.05</td>
<td>2.03</td>
</tr>
<tr>
<td>Tillers/m²</td>
<td>105.6</td>
<td>110.7</td>
<td>114.6</td>
<td>110.3</td>
<td>NS</td>
<td>1.97</td>
</tr>
<tr>
<td>Spikes/m²</td>
<td>79.0b</td>
<td>86.9ba</td>
<td>91.7a</td>
<td>85.9</td>
<td>91.1</td>
<td>1.97</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th></th>
<th>2011</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75</td>
<td>100</td>
<td>125</td>
<td>Mean</td>
<td>lsd (0.05)</td>
<td>CV (%)</td>
</tr>
<tr>
<td>Aphids/m²</td>
<td>3.7a</td>
<td>2.9b</td>
<td>3.4ba</td>
<td>3.3</td>
<td>0.05</td>
<td>2.03</td>
</tr>
<tr>
<td>Tillers/m²</td>
<td>105.6</td>
<td>110.7</td>
<td>114.6</td>
<td>110.3</td>
<td>NS</td>
<td>1.97</td>
</tr>
<tr>
<td>Spikes/m²</td>
<td>79.0b</td>
<td>86.9ba</td>
<td>91.7a</td>
<td>85.9</td>
<td>91.1</td>
<td>1.97</td>
</tr>
</tbody>
</table>
Table 4: Yield benefits due to Nitrogen application and seeding rates

<table>
<thead>
<tr>
<th>Season/year</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>N kg/ha</td>
<td>75</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td>Yield t/ha</td>
<td>2.0</td>
<td>2.4</td>
<td>2.2</td>
</tr>
<tr>
<td>yield benefit (kg/ha)</td>
<td>-</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>Seedling rates kg/ha</td>
<td>75</td>
<td>100</td>
<td>125</td>
</tr>
<tr>
<td>Yield t/ha</td>
<td>2.1</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td>yield benefit (kg/ha)</td>
<td>-</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

Means followed by the same letter in the same column are not significantly different at (Ɑ=0.05)

Discussion

Variety K. Korongo gave the lowest RWA counts in all the 3 seasons contrary to Terri et al. (2003). Variety NBWII gave the highest RWA counts (4.3) and (4.7) in 2011 and 2012 followed by Kingbird (3.8) in 2011 and K Wren (4.4) in 2012. Robin had the highest aphid count (6.6) in 2013. Results from this study confirm findings by Macharia et al. (2012) that all commercial wheat varieties grown by farmers in Kenya are susceptible to RWA. However findings from our study are in agreement with De Zutter et al. (2012) report where aphids showed preference to certain wheat varieties. In our study it was apparent that RWA had preference for NBWII compared to K Korongo which gave the lowest aphid counts in the 3 seasons. The high number of tillers and spikes recorded in NBWII did not result in significant increased grain yield probably due to its attraction to high number of aphid infestation resulting in reduced biomass (Burd and Burton, 1992) and hence low yields which is consistent with (Macharia et al., 2002 and Botha and Mustazilla, 2004) observation that severe aphid infestation causes high grain yield losses. Robin had...
the highest biomass accumulation (5.6, 6.2 and 5.6 t/ha), while K Kingbird gave the lowest biomass (4.2, 4.6 and 4.9 t/ha), indicating that the test varieties in our study have different genetic potentials for biomass accumulation in concurrence with (Hassain, et al., 2008 findings Kenya Korongo gave the highest TKW (38.5, 42.4 and 30.9g in 2011 and 2012 whereas K Wren gave the highest TKW (33.1g) in 2013) while K Kingbird had the lowest TKW (30.2, 33.2 and 28.1g) in concurrence with Silvina et al. (2005) report. Robin gave the highest grain yield (2.5, 3.1 and 3.1) t/ha) followed by K Korongo (2.5 and 3.0 and 2.6 t/ha). The high susceptibility to RWA observed in NBWII may have caused herbivory damage, which reduces biomass by 55-77% Miriki et al. (2009) and leaf area, disrupts the function of leaves and ultimately alters yield and productivity Nabity et al. (2009).

Conclusion

Variety K. Korongo was the least attacked by the cereal aphids and NBWII was the most affected. Robin gave the highest grain yield while NBWII gave the lowest grain yield. Nitrogen at 100 N kg/ha had the highest aphid infestation but also the highest grain yield. However it would appear that N was useful in making the plants tolerant to aphid infestation and hence high grain yield. Aphid counts varied with seeding rates, the highest counts being recorded in the lowest seeding rate. Higher SR and N levels were not beneficial to the grower since they did not increase grain yield and yet could be additional cost of production. It could be concluded from the study that low plant densities (due to low SR) are susceptible to heavy attacks by the RWA. Nitrogen fertilization may be a useful strategy for limiting both yield reduction and increased cost of production (pesticides use) caused by RWA in wheat crop.

Recommendations

Moderate seeding rate (100 kg/ha) can be appropriate for the management of the Russian wheat aphid. Application of nitrogen to wheat at 100 kg N/ha could be used in the cultural management of the Russian wheat aphid in wheat production. A combination of SR 100kg and 100kg N/ha was the best for cultural management of RWA.

Acknowledgement

Authors acknowledge with appreciation the Eastern Africa Agricultural Productivity Program (EAAPP) and KALRO Director General through the Centre Director, KALRO- Njoro for facilitating this study.

References


**Discussion Session**

**Question:** Wanted to know the cost implications and hence the advice to farmers on the use of fertilizer or pesticide since the study found both of them to be effective in controlling Russian wheat varieties.

**Answer:** When recommending pesticides normally rates are given in a range when a crop has been supplied with N, it will be healthy and hence have less load of the pests which can be managed by use of lower recommendation rate. Therefore both may be used as an aspect of IPM where you use a mix of different practices economically and safe for the environment.

**Question:** It is noted that there is a conflicting message on the title referring to cultural approaches while nitrogen (a chemical) is also used.

**Answer:** Nitrogen is used to boost the plant vigour, not as control measure. It is widely known that healthy plants tolerate disease/pest attack and hence reducing the incidences save the environment from over use of chemicals to control the Russian wheat aphid (pests).
Economics of weed management using herbicides in wheat in Ethiopia

Hussein S.*, Wogayehu W. and Bedada B.

Ethiopian Institute of Agricultural Research, P.O. Box 2003, Addis Ababa, Ethiopia.
*Correspondence: husseinsareta@yahoo.com

Abstract
Post-emergence herbicides trial for the control of annual grass and broadleaf weeds in wheat field was conducted at Kulumsa Agricultural Research Center main station, Bekoji and Lole farmer’s fields during 2011/12 and 2012/13 main cropping seasons. The aim was to evaluate different herbicides against annual grass and broadleaf weeds in wheat that would be selected and incorporated in to an integrated weed management program (IWM). Treatments used for the study were Mesosulfron methyl+Idosulfuron methyl sodium (liquid)1lit/ha a.i, Pyroxsulam (liquid) 0.5 lit/ha a.i, twice hand weeding (30-35 and 55-60 DAE) and untreated weedy check. Out of the annual grass weeds Snowdenia polystachya, Avena fatua, Bromus pectinatus, Phalaris paradoxa and Setaria pumila, and most broad leaf weeds like Polygonum nepalense, Guizotia scabra, Galinsoga parviflora and Gallium spurium were controlled with the efficacy ranging from 75 to 100% by the test herbicides. Mesosulfron methyl +Idosulfuron methyl sodium, Pyroxulam and twice hand weeding treated plots out yielded the weedy check by 63%, 58% and 53%, respectively. Maximum wheat grain yield (5184 kg/ha), biomass (12808 kg/ha), thousand kernel weight (48.55) and hectoliter weight (74.2) was obtained due to the application of Mesosulfron methyl +Idosulfuron methyl sodium. In addition, it has a yield advantage over Pyroxulam, two hand weeding and weedy check by 12%, 21% and 63% respectively. Similarly, application of Mesosulfron methyl + Idosulfuron methyl sodium ($1596.31/ha) had the highest net field benefit compared to Pyroxulam ($1379.21/ha), two hand weeding ($1126.7/ha) and weedy check ($574.1/ha) by 13.6, 29 and 64% respectively. Moreover, the herbicide is also economically profitable for farmers, providing a marginal rate of return (MRR) of 1737% and sensitivity analysis (+MRR) also remained the most profitable even when the price of herbicide is increased by 20%. Thus, Mesosulfron methyl +Idosulfuron methyl sodium is preferred herbicide than Pyroxulam and other currently available control methods for the effective control of annual grasses and broad leaf weeds in wheat and can be used as one of the component in an Integrated Weed Management Program (IWM) in wheat fields at a rate of 1 lit/ha.

Key words: Evaluation, Marginal rate of return, Mesosulfron methyl+Idosulfuron methyl sodium, Pyroxulam, Sensitivity analysis, wheat fields

Introduction
Ethiopia is the largest producer of wheat in the sub-Saharan Africa. The current total area suited to wheat production in the country is estimated to be over 1.6 million ha, with an average grain yield of 1.8 tons per hectare (CSA, 2010). Durum and bread wheat are the two major wheat types produced in the country whose proportion in 1991 was about 60 and 40%, respectively (Eshetu and Zerihun, 2003). Durum and emmer wheat are indigenous to Ethiopia and have been cultivated since prehistoric period in the highlands.

Weed interference is one of the most important but less noticed factors, contributing towards lowering the yields
of wheat (Hassan and Marwat, 2001). Weeds reduce the crop yield, deteriorate the quality of farm produce and also trim down the market value of wheat. In crop-weed competition, a considerable yield loss is encountered. This requires management intervention for sustained wheat yield. An estimated yield loss of up to 25% could be lost due to weeds (Akobundu, 1987).

In Ethiopia, a yield loss of above 36.3% was recorded in wheat due to uncontrolled weed growth (Rezene, 2005). Similarly, in a competition study of Avena abyssinica, Lolium temulentum L., Snowdenia polystachya and Phalaris paradoxa L. with bread wheat, a yield loss of 48-86% were recorded by the maximum weed density of 320 weed seedlings/m² (Taye et al., 1996). In Durum wheat, Convolvulus arvensis and Cyperus spp poses significant yield loss. Besides, considerable yield loss has been recorded in irrigated wheat due to Sorghum arundinaceae, Cyperus esculentus, Cyperus rotundus, Portulaca oleracea, Corchorus olitorius and Sorghum arundinaceae around 60% inWerer research (Kassahun et al., 1998).

Bromus pectinatus and Snowdenia polystachya are such weed species that recently became prominent in the affected cropping systems due to a weed population shift attributed primarily to continuous cereal cropping and frequent use of selective herbicides against previously common grass weeds such as Avena fatua (Tanner and Giref, 1991; Amanuel et al., 1992; Rezene and Yohannes, 2003). Therefore, the study was designed with the objective to evaluate the different herbicides for the control of annual grasses and broadleaf weeds in wheat and to incorporate the best herbicide in an integrated weed management program to increase the productivity of wheat.

**Materials and Methods**

The activity was conducted at Kulumsa Agricultural Research center main station, Bekoji and Lole (Ego) farmers field during the main cropping season of 2011/12 and 2012/13. Kulumsa is situated in the main wheat belt of Ethiopia at an altitude of 2200 m.a.s.l located in the north periphery of Asella town which is about 168 km South East of Addis Ababa. It is found at 8°01′10″N and 39°09′11″E and receives an average rainfall of 832 mm. The mean minimum and maximum temperature is 10°C and 23°C respectively. Bekoji is found at 7°32′37″N and 39°15′21″ E with an altitude of 2780 m.a.s.l and receives an average rainfall of 1066 mm and the mean minimum and maximum temperature is 9.6°C and 24°C respectively. Dominant soils in these areas are Luvisol and Nitosol respectively. Bekoji and Lole (Ego) are 61km and 39km away from Asella town respectively.

Pyroxsulam (liquid) 0.5 lit/ha a.i, Mesosulfuron methyl +Iodosulfuron methyl sodium (liquid) 1 lit/ha a.i, two hand weeding and weedy check left as control were the treatments of the activity. Herbicides were applied post-emergence at 30-35 days after emergence (DAE) and hand weeding was done 30-35 and 55-60 DAE. The required quantity of the herbicide was calculated and measured out into manual knapsack sprayer with a water volume of 200 lit/ha for each herbicide treatment plots. All the necessary agronomic practices were applied equally for all treatments.

Dendea bread wheat variety was used for the trials at different locations at a seeding rate of 150 kg/ha by row planting method of sowing and 100kg/ha Di Ammonium Phosphate (DAP) and 50 kg/ha Urea fertilizers were applied at the time of sowing for all the treatments in a plot size of 5m by 4m (20m²) which is laid out in randomized complete block design (RCBD) using three replications.

The necessary agronomic data such as plant height, number of tillers, spike length, weed count before, two and four weeks after herbicide application on 1 m² quadrates, general weed control visual score (1-5 scale; 1= Complete eradication; 2= effective destruction; 3= proper reduction in growth and population; 4= reduced growth and
population and 5 = healthy), dry weed biomass, crop biomass, grain yield, TKW, HLW were properly collected.

All the data were subjected to statistical analysis software using Proc GLM procedure in SAS (SAS Institute Inc., 1994). Comparisons among treatments with significant differences were computed based on LSD test. Linear correlation was used to determine the association between grain yield and yield components using Minitab software.

For the economic analysis, yield and economic data were collected to compare the economic advantage of each herbicide in different treatments. Economic data include input cost that was varied and costs for chemical and labour during the execution of the experiments. Accordingly, cost of Pyroxulam was $125/lit and cost of Mesosulfuron methyl + Idosulfuron methyl sodium was $50/lit in 2012/13. Costs of herbicides were obtained from pesticide companies and local distributing agencies. Labor cost for two hand weeding was $156.25/ha. Harvesting and threshing was done manually by daily laborers which need 20 and 30 man days per hectare respectively with one daily laborer cost of $1.875 per day and accordingly the cost for daily laborer for harvesting and threshing of wheat for Pyroxulam, Mesosulfuron methyl + Idosulfuron methyl sodium, two hand weeding and weedy check treatments was $93.75, $93.75, $93.75 and $65.5 respectively. The average grain price of wheat was $37.5/100kg in 2012/13 season. Labor cost for three times ploughing was uniform for each treatment and cost $140.5 per hectare. Average daily laborer cost and rent for knapsack sprayer for herbicide application was $5.94/ha. Cost for land preparation and inputs (seed and fertilizers) were uniform for all treatments. To minimize unnecessary exaggerations of grain yield, productivity of the locations mean grain yield obtained was adjusted by 10%. Exchange rate of 1 US$ was 16 Eth. Birr in 2012/13.

Based on the data obtained from both locations, economic analysis was computed using partial budget analyses, Marginal Rate of Return (MRR) and sensitivity analysis even when herbicide cost is increased by 20% (CIMMIT, 1988). The following formulas were used to compute partial budget and marginal rate of return (MRR) analysis respectively.

Net field benefits (NBs) = Gross field benefits (GB) - Total Variable costs (TVC) and MRR=DNI/DIC

Where, MRR is the marginal rate of return; DNI, difference in net income compared with control; DIC, difference in input cost compared with control.

**Results and discussion**

**Efficacy of herbicides**

Efficacy result over the locations indicated that all the treatments except untreated weedy check were effective for the control of the target annual grass weeds like Snowdenia polystachya, Avena fatua, Bromus pectinatus, Phalaris paradoxa, Setaria pumila and broad leaf weeds like Gizotia scabra, Galinsoga parviflora, Gallium spurium and Polygonum nepalense controlled at efficacy rate of 75-100%. Effectiveness of the treatments in controlling S. polystachya by Mesosulfuron methyl + Idosulfuron methyl sodium, Pyroxulam and two hand weeding was 100%, 75% and 100% respectively as shown in Table 1: For that of A. fatua; Mesosulfuron methyl + Idosulfuron methyl sodium, Pyroxulam and two hand weeding controlled the weeds at efficacy rate of 87%, 88% and 100% respectively. P. paradoxa was controlled by Mesosulfuron methyl + Idosulfuron methyl sodium, Pyroxulam and two hand weeding at 100% efficacy level. Whereas, Bromus pectinatus was controlled at 85%, 100% and 100% efficacy level respectively shown on Table 1: Rezene, et. al. (2007) reported that Propoxycarbozone-sodium (Attribute 70WG)
was effective against *Bromus pectinatus* and gave satisfactory suppression of *Snowdenia polystachya* constantly across all locations of the experimental sites. On the other hand, *Shambel et al.,* 2000 reported that the herbicidal chemical *sulfosulforol* and *ethiozin* exhibited significant potential to control problematic grass weeds including Brome grass in the wheat growing areas of Ethiopia. Similarly, both herbicides and two hand weeding controlled *Gallium spurium, Gizotia scabra, Galinsoga parviflora* and *Polygonum nepalense* at 89-100% efficacy level as indicated in Table 1: The negative values in the efficacy of the applied herbicides were resulted from the increasingly late emergence of the weeds after herbicide applications.

*Mesosulfron methyl +Idosulfuron methyl sodium* is best recommended in areas where *Snowdenia polystachya, Avena fatua, Phalaris paradoxa, Setaria pumila* and broad leaf weeds like *Galinsoga parviflora, Gallium spurium, Gizotia scabra* and *Polygonum nepalense* are dominant weed problems. For areas where *Bromus pectinatus, Phalaris paradoxa, Setaria pumila, Lolium temulentum* and broad leaf weeds like *Polygonum nepalense, Galinsoga parviflora, Gizotia scabra* are dominant, this study recommends use of *Pyroxsulam*.

**Yield and yield components**

Grain yield of wheat showed significant (P<0.05) difference due to *Mesosulfron methyl +Idosulfuron methyl sodium, Pyroxsulam* and two hand weeding. The highest grain yield (5184kg/ha) was recorded in *Mesosulfron methyl +Idosulfuron methyl sodium* followed by *Pyroxsulam* (4567kg/ha) and two hand weeding (4079kg/ha). However, the lowest grain yield (1895 kg/ha) was recorded in weedy check treatment as indicated on Table 2:

The combined analysis over locations indicated no significant difference of treatments on plant height, spike length, TKW and HLW but the analysis result showed that there is significant differences among treatments with respect to weed biomass, crop biomass and grain yield at (P<0.05) compared to the weedy check treatment as shown in Table 2: Yield wise, both *Mesosulfron methyl +Idosulfuron methyl sodium, Pyroxsulam* and two hand weeding outperformed weedy check in yield by 63%, 58% and 53% respectively as shown on Table 2: Similarly, *Mesosulfron methyl +Idosulfuron methyl sodium* has a yield advantage over *Pyroxsulam*, two hand weeding and the weedy check by 12%, 21% and 63% respectively as shown in Table 2:

Dry weed biomass showed significant difference (P<0.05) due to *Mesosulfron methyl +Idosulfuron methyl sodium, Pyroxsulam* and two hand weeding. The lowest (317 kg/ha) dry weed biomass was recorded in *Mesosulfron methyl +Idosulfuron methyl sodium* treated plot followed by two hand weeding (684kg/ha) and *Pyroxsulam* herbicide (709kg/ha) while the highest (1492 kg/ha) was recorded in untreated weedy check as indicated in Table 2:

**Economic analysis**

The results of the partial budget analysis in Table 3 indicated that application of *Mesosulfron methyl + Idosulfuron methyl sodium* ($1596.31/ha) had the highest net field benefit compared to *Pyroxsulam* ($1379.21/ha), two hand weeding ($1126.7/ha) and weedy check ($574.1/ha) by 13.6, 29 and 64% respectively. Similarly, the marginal rate of return (MRR) analysis in Table 4 revealed that *Mesosulfron methyl + Idosulfuron methyl sodium* was more profitable for farmers, providing a MRR of 1737%. In the sensitivity analysis (*^MRR*), *Mesosulfron methyl + Idosulfuron methyl sodium* remained the most profitable weed treatment even when the cost of herbicide is increased by 20%.
Table 1: Efficacy of Mesosulfon methyl +Iodosulfon methyl sodium as compared to Pyroxulam on major grass and broad leaf weeds two weeks after application at two locations in Arsi Zone, Ethiopia

<table>
<thead>
<tr>
<th>Locations</th>
<th>Name of weed species</th>
<th>Mesosulfon methyl +Iodosulfon methyl sodium (liquid) 1 lit/ha a.i</th>
<th>Pyroxulam(liquid) 0.45lit/ha a.i</th>
<th>Twice hand weeding</th>
<th>Untreated weedy check</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Weed count before application on 20 m2</td>
<td>Weed count after application on 20 m2</td>
<td>Efficacy (%)</td>
<td>Weed count before 1st hand weeding on 20 m2</td>
</tr>
<tr>
<td>Bekoji</td>
<td>Snowdenia polystachya</td>
<td>80</td>
<td>0</td>
<td>100</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Avena fatua</td>
<td>68</td>
<td>9</td>
<td>87</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Bromus pectinatus</td>
<td>3400</td>
<td>510</td>
<td>85</td>
<td>2180</td>
</tr>
<tr>
<td></td>
<td>Phalaris paradoxa</td>
<td>25</td>
<td>0</td>
<td>100</td>
<td>260</td>
</tr>
<tr>
<td></td>
<td>Gallium aparine</td>
<td>58</td>
<td>0</td>
<td>100</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>Polygonum nepalense</td>
<td>117</td>
<td>0</td>
<td>100</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Gizotia scabra</td>
<td>17</td>
<td>0</td>
<td>100</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Galinsoga parviflora</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>Lole</td>
<td>Snowdenia polystachya</td>
<td>1260</td>
<td>0</td>
<td>100</td>
<td>860</td>
</tr>
<tr>
<td></td>
<td>Avena fatua</td>
<td>48</td>
<td>6</td>
<td>87.5</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Bromus pectinatus</td>
<td>1720</td>
<td>256</td>
<td>85</td>
<td>1820</td>
</tr>
<tr>
<td></td>
<td>Phalaris paradoxa</td>
<td>17</td>
<td>0</td>
<td>100</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Gallium aparine</td>
<td>94</td>
<td>5</td>
<td>99</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>Polygonum nepalense</td>
<td>55</td>
<td>0</td>
<td>100</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Gizotia scabra</td>
<td>5</td>
<td>1</td>
<td>90</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Galinsoga parviflora</td>
<td>16</td>
<td>1</td>
<td>99.9</td>
<td>28</td>
</tr>
</tbody>
</table>
Table 2: Mean grain yield (kg/ha) of wheat after Pyroxsulam and Mesosulfron methyl +Idosulfuron methyl sodium herbicides at three locations in Arsi Zone, Ethiopia

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant height (cm)</th>
<th>Spike length (cm)</th>
<th>No. of tillers per plant</th>
<th>TKW (gm)</th>
<th>HLW</th>
<th>Crop BM (kg/ha)</th>
<th>GY (kg/ha)</th>
<th>Weed biomass (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyroxsulam</td>
<td>96</td>
<td>7.4</td>
<td>3.4</td>
<td>47.85</td>
<td>73.7</td>
<td>10750</td>
<td>4567b</td>
<td>709</td>
</tr>
<tr>
<td>Mesosulfron methyl +Idosulfuron methyl sodium</td>
<td>98</td>
<td>8.0</td>
<td>3.9</td>
<td>48.55</td>
<td>74.2</td>
<td>12808</td>
<td>5184a</td>
<td>317</td>
</tr>
<tr>
<td>Two hand weeding (30-35 and 55-60 DAE)</td>
<td>98.5</td>
<td>7.7</td>
<td>3.25</td>
<td>47.6</td>
<td>73.55</td>
<td>8792</td>
<td>4079c</td>
<td>684</td>
</tr>
<tr>
<td>Weedy Check</td>
<td>101</td>
<td>7.0</td>
<td>2.85</td>
<td>46.8</td>
<td>72.9</td>
<td>7467</td>
<td>1895d</td>
<td>1492</td>
</tr>
<tr>
<td>Mean</td>
<td>98.4</td>
<td>7.5</td>
<td>3.35</td>
<td>47.7</td>
<td>73.6</td>
<td>9954</td>
<td>4265</td>
<td></td>
</tr>
<tr>
<td>LSD</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>2058</td>
<td>617</td>
<td></td>
</tr>
<tr>
<td>CV (%)</td>
<td>5.57%</td>
<td>14.78</td>
<td>16.38</td>
<td>1.09</td>
<td>0.03</td>
<td>37.2</td>
<td>3.7</td>
<td></td>
</tr>
</tbody>
</table>

GY = Grain yield, SL = Spike length, NS/S = Number of tillers per plant, PH= Plant height, TKW= Thousand kernel weight, HLW= Hector liter weight, CBM= Crop Biomass yield, EC=Efficacy, ns= statistically non-significant.
Table 3: Partial budget analysis for weed control with herbicides and two times hand weeding

<table>
<thead>
<tr>
<th>List of different costs</th>
<th>Treatments</th>
<th>Pyroxsulam 0.5 lit/ha</th>
<th>Mesosulfron methyl + Idosulfuron methyl sodium 1 lit/ha</th>
<th>Two hand weeding (30-35 and 55-60 DAE)</th>
<th>Weedy Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted mean yield (kg/ha)</td>
<td>4110.3</td>
<td>4665.6</td>
<td>3671.1</td>
<td>1705.5</td>
<td></td>
</tr>
<tr>
<td>Gross field benefit</td>
<td>1541.4</td>
<td>1746</td>
<td>1376.7</td>
<td>639.6</td>
<td></td>
</tr>
<tr>
<td>Cost of herbicide ($)</td>
<td>62.5</td>
<td>50</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Herbicide application cost and rent for knapsack sprayer ($)</td>
<td>5.94</td>
<td>5.94</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Labor cost ($)</td>
<td>-</td>
<td>-</td>
<td>156.25</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Harvesting cost ($)</td>
<td>37.5</td>
<td>37.5</td>
<td>37.5</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Threshing cost ($)</td>
<td>56.25</td>
<td>56.25</td>
<td>56.25</td>
<td>37.5</td>
<td></td>
</tr>
<tr>
<td>Total variable cost ($)</td>
<td>162.19</td>
<td>149.69</td>
<td>250</td>
<td>65.5</td>
<td></td>
</tr>
<tr>
<td>Net field benefit ($)</td>
<td>1379.21</td>
<td>1596.31</td>
<td>1126.7</td>
<td>574.1</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Marginal rate of return analysis for weed control with herbicides and two times hand weeding

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Rate (lt/ha)</th>
<th>Net field benefit ($)</th>
<th>Total variable costs ($)</th>
<th>MRR</th>
<th>MRRa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weedy check</td>
<td>-</td>
<td>574.1</td>
<td>65.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyroxsulam</td>
<td>0.5</td>
<td>1379.21</td>
<td>162.19</td>
<td>833</td>
<td>726</td>
</tr>
<tr>
<td>Mesosulfron methyl + Idosulfuron methyl sodium</td>
<td>1.0</td>
<td>1596.31</td>
<td>149.69</td>
<td>1737</td>
<td>1464</td>
</tr>
<tr>
<td>Two hand weeding</td>
<td>-</td>
<td>1126.7</td>
<td>250</td>
<td>D</td>
<td>D</td>
</tr>
</tbody>
</table>

*MRR (marginal rate of return) calculated for cost of herbicides increased by 20%. D: treatments with MRR < 50% considered as dominated.

Conclusion and Recommendation

Mesosulfron methyl +Idosulfuron methyl sodium is best recommended in areas where Snowdenia polystachya, Avena fatua, Phalaris paradoxa, Setaria pumila and broad leaf weeds like Galinsoga parviflora, Gallium spurium, Gizotia scabra, Polygonum nepalense are dominant weed problems.

For areas where Bromus pectinatus, Phalaris paradoxa, Setaria pumila, Lolium temulentum and broad leaf weeds like Polygonum nepalense, Galinsoga parviflora, Gizotia scabra are dominant weed problems, Pyroxsulam is recommended.

Mesosulfron methyl +Idosulfuron methyl sodium is economically profitable and preferred herbicide than Pyroxsulam and other currently available control methods for the effective control of annual grasses and broad leaf weeds in wheat and can be used as one of the component in an Integrated Weed Management Program (IWM) in wheat fields at a rate of 1 lit/ha.
References


Discussion Session

Question: How did you determine the rate of application of the two herbicides?

Answer: The rate of application of herbicides was first given to us by the manufacturers (importers) to our research center for verification purpose to test the efficacy of herbicides so that we check the rate of application. We were to establish phytotoxicity to the crop on three locations and finally report the result to pesticide research program of Ethiopian Institute of Agriculture Research then to Ministry of Agriculture which will give import permission based on the report.
Question: Clarify the Marginal Rate of Return (MRR) which was reported as up to 1737%?
Answer: The MRR result (1737%) indicates the profitability the technology (by applying mesosulfuron methyl and idusulfuron methyl, Sodium herbicide) and implies that farmers (users) obtain $17.37 for the invested one dollar over the other herbicide called pyroxsulam.

Question: Did you assess the residual effects of the herbicides evaluated?
Answer: Residual effect of the applied herbicides was assessed on the crops grown after the herbicides applied on wheat crop and I did not observe effect on the next crop. But it was not scientifically assessed.

Question: What is the acceptable level of coefficient of variation (CV%) at field level?
Answer: Most of the time at field condition, the CV% is between 10 -20%. As CV% is greater than 20% it indicates error has increased. To reduce error the CV% has to be less than 20%.

Question: What was the reason for conducting the study both on station and on farm? Was there a commercial herbicide to be included in the treatments? Why was farmers’ assessment not done which could give more insight on technology adoptability?
Answer: The aim of conducting the study was to get real data and information from both the research station and on farm fields. Both herbicides used in the experiment are verified and released to be used for control of both annual grass and broad leaf weeds. I used two hand weeding as a standard and with no other commercial herbicide. Informally, the farmers’ assessment on economic advantage of mesosulfuron methyl + idosulfuron methyl sodium herbicide was good.

Question: Is the cost of water, at 200l/ha, captured in the variable costs? Why is there no effect of treatment on yield parameters e.g. panicle size, and yet there is significant differences in yields?
Answer: No cost of water was included because farmers do not buy water for herbicide application but labour cost for transportation was factored. I did not get significant difference between treatments on grain yield because the applied herbicides are different.

Question: Analysis you have done is not budget analysis but economic analysis; Identify the dominant treatments; why didn’t you conduct environmental interaction and include the gender aspects?
Answer: To evaluate the economic benefit of the chemical herbicides partial budget analysis has been conducted by considering only the variable costs among the treatments as indicated in detail in the paper. Two hand weeding is the dominant treatment identified as indicated in Table 4 in the paper. Herbicides have environmental pollution in various aspects but I did not conduct environmental interaction during the study but will consider this in the next herbicide related research. The technology is released to all male and female farmers, therefore gender aspects are considered.
The impact of improved wheat technology adoption on productivity and income in Arsi Zone, Ethiopia

Tesfaye, S.1*, Bedada, B.1 and Mesay, Y.2

1Wheat Regional Center of Excellence, Kulumsa Agricultural Research Center, Ethiopia; 2PhD candidate, Department of Agricultural Economics, Pretoria University, South Africa.

*Correspondence: tesyeshi@gmail.com

Abstract
Following the devastating effects of yellow rust in 2010 in Ethiopia, the Eastern Africa Agricultural Productivity Project (EAAPP) started engaging farmers in demonstrations, promotion, and popularizing the newly released wheat varieties. This was done along with recommended production packages in 42 wheat-growing districts of Ethiopia by linking the formal and informal seed systems. This paper presents the adoption of improved wheat varieties and their impact on productivity and income of wheat farm households in EAAPP districts of Arsi Zone, Ethiopia. The rate of adoption of improved wheat varieties was 56%. Probit model provided empirical evidence of a positive impact of household head’s gender and livestock ownership in enhancing of adoption of wheat technology and a negative effect of the head of the household’s educational level in enhancing the adoption of improved wheat varieties. Moreover, EAAPP’s improved wheat technology dissemination intervention achieved significant improvements in terms of increased farm incomes and wheat productivity. Improved wheat technology adoption on average increased wheat productivity of adopters by about 1 to 1.1 tons ha⁻¹ than the non-adopters. The study provided empirical evidence that the average income of adopters was higher by 35 to 50% compared to the non-adopters.

Key words: Impact, Adoption, Improved wheat technology, Probit and Propensity Score Matching

Introduction
In Ethiopia, wheat is the fourth most important cereal in cultivated area after Teff, maize and sorghum and the third in production after maize and Teff that plays a significant role in ensuring food sufficiency. About 4.7 million farm households are directly dependent on wheat production (Central Statistical Authority (CSA); 2013/4). An average person in Ethiopia consumes about 29.6kg of wheat per year which ranks as 3rdnext to Maize (37.7 kg) and Sorghum (32.2 kg) (Berhanu, et al., 2011). Wheat has been recognized as a strategic food security crop in the country’s attempt to bridge the persistent food gap. Cognizant of its importance, the government of Ethiopia has been investing heavily in the development and dissemination of improved wheat technologies. Over the past years, a number of wheat technologies have been developed and promoted for different agro-ecological zones of the country by agricultural research institutes, universities, in collaboration with international research centers like CIMMYT and ICARDA.

Wheat production and productivity is largely limited on account of several types of biotic and abiotic factors. Among the biotic constraints, wheat rusts have been recognized as grave diseases impeding wheat production.
Yellow and stem rusts have appeared to be the most serious diseases in recent years. In 2010 cropping season, yellow rust epidemics devastated wheat production areas of the country causing estimated yield loss of about 80%. As a result of the devastating effects of yellow rust in 2010, EAAPP was engaged in demonstration, promotion, and popularization of newly released wheat varieties. This was done along with recommended production packages in 42 wheat-growing districts of Ethiopia by linking the formal and informal seed systems.

The ultimate goal of generation and dissemination of high yielding varieties is to reduce hunger, malnutrition, poverty and increase the incomes of poor people living in marginal areas. However, the impact of these technologies on farmers’ livelihoods has not been determined so far. Information on the impact of adoption of improved wheat technologies is imperative to target interventions efficiently and equitably, and to justify investment in such technologies.

Consequently, this study assesses the impact of adopting improved barley technologies by constructing a counterfactual comparison group. In this setting, a comparison of the outcome variable (total household income) is made between farmers using a given technology (henceforth-treated farmers) and their counterparts with similar observable covariates (henceforth untreated farmers). The objective of the study was to estimate the impact of adoption of improved wheat varieties on wheat productivity and farm household income level for wheat producers in the selected districts.

**Material and Methods**

The study was conducted in the three districts of Arsi zone namely Arsi-robe, Digelu-tijo and Hetosa Districts, Ethiopia. A household questionnaire was used to collect primary data from wheat farmers, from 22nd May to 8th June, 2013. A registration list of farmers from each kebele1 was used as a sampling frame. Probability proportional to sample size technique was then performed to ultimately select a sample of 177 farmers. Properly trained and carefully selected enumerators pre-tested the questionnaire and later collected data on input use, outputs, socioeconomic and farm characteristics. The total sample size consisted of 122 male-headed and 55 female-headed households. Interviews were conducted by means of structured and semi-structured interview schedules.

Analytical tools: If technology was randomly assigned to households, as it would be in an experiment for example, the author could evaluate the causal effect of technology adoption on farm households’ income or food security as the difference in average income or food security status between adopters and non-adopters of the new technology (rust resistant varieties). However, with observational data, the researcher needed to use some statistical solutions to the crucial problem of causal inference (Mendola, 2007). This problem can be solved through different estimation procedures. These are parametric and non-parametric methods. The parametric procedures are Ordinary least square (OLS) estimates, IV estimates and the Heckman’s selection correction model. However, all these come at the cost of some restriction assumptions, for example selection on unobservable for OLS, the exclusion restriction for IV and strong distributional assumptions for Heckman selection correction. Besides, all the parametric estimation procedures impose functional forms, i.e linear function. Therefore in this study the researchers employ the non-parametric methods of propensity score matching estimation procedure to remove some of the restriction assumptions imposed on parametric methods.

The propensity score matching: The propensity score is defined as the conditional (predicted) probability

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1 The lowest administration unit in Ethiopia.
of receiving treatment given the relevant controls X (Rosenbaum and Rubin, 1983). It can be expressed as:

Where \( D = [0,1] \) is the indicator of exposure to treatment and X is the multi-dimensional vector of pre-intervention characteristic. \( D=1 \) for treated observations and \( D=0 \) for control observations.

The propensity scores are estimated using the probit or logit models with dependent variable coded as 1 for rust resistant wheat varieties adopters and 0 for non-adopters of rust resistant wheat varieties. The propensity score is a single-index variable that summarizes pre-treatment characteristics of each subject, which makes matching possible.

After the propensity score is estimated, the average treatment effect on the treated (ATT) can then be estimated as follows:

\[
\text{ATT} = E
\]

and are the potential outcomes in the two counterfactual situations of (respectively) treatment and no treatment.

Once the propensity scores are estimated, each adopter is matched to a non-adopter with similar propensity score values, in order to estimate the average treatment effect for the treated (ATT). Several matching methods developed to match adopters with non-adopters of similar propensity scores. Asymptotically, all matching methods should yield the same results. The three commonly used matching algorithms (nearest neighbor matching, kernel-based matching and radius matching) were employed.

**Results and Discussion**

The average age of the household head was 43 years and had been involved in farming for about 25 years (Table 1) and the average family size was 6.5 persons. The number of livestock owned (including cattle, sheep, goat, donkey, horse, mule and poultry) was 27 for adopters and 20 for non-adopters i.e there was difference in livestock numbers between adopters and non-adopters. Livestock ownership is a proxy measure for asset ownership. Therefore according to the study results, the more assets a farmer owns the more likelihood to adopt improved wheat varieties. Similarly, the average farm size was statistically different between adopters and non-adopters (10% significance level) implying the importance of farm size in adoption of improved wheat varieties.

Farmers who did not grow improved wheat varieties (non-adopters, mean=5) were significantly better educated than the adopters (mean=3.91) by having one additional year of schooling on average. The extension officers may have played a significant role in sensitizing farmers about the benefits of improved wheat varieties. Similar findings were reported previously in China (Lin, 1990), Afghanistan (El-Beltagy et al., 2002) Kenyan (Mussei et al., 2001), Ethiopia (Zegeye et al., 2001) and others (Nguezer et al., 2011). Informal education was also the driving force for dissemination of information about new varieties (Heisey et al., 1990). Informal education may be as important as and sometimes more important than formal education in determining the rates of adoption. Furthermore, Mussei et al. (2001) found that information from other farmers was the most influential factor for production or adoption decisions followed by extension visits.

**Table 1: Characteristics of adopters and non-adopters (summary statistics for Continuous variables)**
Sample households were composed of both male and female-headed households (Table 2). The total sample household heads were 68% male and the remaining were female (32%). The proportion of male-headed households from the total sample was 42% for adopters and 26% for non-adopters. The female-headed households were 14% for adopters and 18% for non-adopters. The percent of male-headed households of adopters of wheat were significantly higher than that of female-headed households. This could be attributed to various reasons related to the economic or social status of female-headed households such as shortage of labor, limited access to information and required inputs. This finding is consistent with (Tesfaye, Mesay, & Bedada, 2015) in Ethiopia who concluded that there were gender gaps in land ownership, family size, asset ownership and farm income in agricultural production. Among the farmers who adopted improved wheat varieties, 29% were Muslims and 26% were Christians.

The descriptive results (Table 2) also reveal that out of the total adopters 23% participated in off-farm activities while 22% of the non-adopters participated in off-farm activities. However, no significant differences ($\chi^2=1.3$) were found between adopters and non-adopters in terms of participation of off-farm activities. Both adopters (44%) and non-adopters (36%) reported that they had access to credit services for crop and livestock production whenever the need arose.

**Probit Model and Propensity Scores results:** Before the estimation of the impact of technology, probit model...
was employed to predict the probability (propensity score) to adopt the improved wheat varieties using different household characters (Table 3). Education of the household head, sex of household head, livestock ownership and occurrence of wheat diseases in wheat fields were important variables that had an effect on the likelihood of farmers to adopt.

Table 3: Results of the probit regression

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coef.</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.01445</td>
<td>-0.83</td>
</tr>
<tr>
<td>Education</td>
<td>-0.07126**</td>
<td>-2.13</td>
</tr>
<tr>
<td>Farming experience</td>
<td>0.008663</td>
<td>0.49</td>
</tr>
<tr>
<td>Household head Sex</td>
<td>0.436001*</td>
<td>1.87</td>
</tr>
<tr>
<td>Family size</td>
<td>-0.05969</td>
<td>-1.38</td>
</tr>
<tr>
<td>Farm size</td>
<td>0.104456</td>
<td>1.3</td>
</tr>
<tr>
<td>Off-farm income</td>
<td>-0.1971</td>
<td>-0.97</td>
</tr>
<tr>
<td>Land fragmentation</td>
<td>-0.03885</td>
<td>-0.38</td>
</tr>
<tr>
<td>Livestock ownership</td>
<td>0.016488***</td>
<td>2.34</td>
</tr>
<tr>
<td>Access to credit</td>
<td>-0.1842</td>
<td>-0.74</td>
</tr>
<tr>
<td>Wheat disease dummy</td>
<td>0.790298*</td>
<td>1.88</td>
</tr>
<tr>
<td>Constant</td>
<td>0.608472</td>
<td>1.03</td>
</tr>
<tr>
<td>Sample size</td>
<td>176</td>
<td></td>
</tr>
<tr>
<td>Pseudo R²</td>
<td>0.11</td>
<td></td>
</tr>
</tbody>
</table>

*, **, and *** significant at 10%, 5% and 1%, respectively.

A balance test was conducted to compare the similarities of the sub-sample of control cases with the treated cases. Prior to the matching analysis, adopters significantly differed from non-adopters in most characteristics. The process of matching thus creates a high degree of covariate balance between the treatment and control samples that were used in the estimation procedure. According to the results (Table 4), the imbalance between the treatment and control samples in propensity score reduced much below 10% after matching and in no case significantly different from zero at the 1% level.
This indicated that all differences in means between treatments and controls had been removed through matching in the initial period (before participation in adoption). The values of Pseudo $R^2$ and LR chi-square before and after matching can be used as indices for the fulfillment of the balancing requirement (Table 4). The low value of pseudo-$R^2$ and the insignificant LR Chi-square after matching supported the hypothesis that both groups have the same distribution in covariates after matching.

### Table 4: Overall covariate balance test

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Before Matching</th>
<th>After Matching</th>
<th>Nearest Neighbor</th>
<th>Kernel Matching</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Income</td>
<td>Income</td>
</tr>
<tr>
<td>Pseudo $R^2$</td>
<td>0.109</td>
<td>0.029</td>
<td>0.037</td>
<td>0.018</td>
</tr>
<tr>
<td>LR $X^2$</td>
<td>29.93</td>
<td>6.29</td>
<td>9.12</td>
<td>3.92</td>
</tr>
<tr>
<td>P- value $X^2$</td>
<td>0.002</td>
<td>0.853</td>
<td>0.611</td>
<td>0.972</td>
</tr>
<tr>
<td>Mean bias</td>
<td>18.2</td>
<td>7</td>
<td>9.8</td>
<td>4.9</td>
</tr>
<tr>
<td>Percent bias reduction</td>
<td>61</td>
<td>46</td>
<td>73</td>
<td>63</td>
</tr>
</tbody>
</table>

**Estimation of Treatment Effect-Matching Algorithms:** The impact of adoption of improved wheat varieties on productivity are given in Table 5. The effect of adoption of improved wheat varieties on productivity was estimated through the two different matching methods, i.e. the nearest neighbor and the kernel-based matching methods. Adoption of improved wheat varieties significantly affected the wheat productivity of farmers. According to the nearest neighbor, causal effect of technology adoption on wheat productivity is highly significant and equal to 11.3, which is the average wheat productivity difference between adopters and non-adopters i.e adopters were significantly (at 1% P level) better than non-adopters by 1.13 tons in wheat productivity using nearest neighbor matching method.

Using Kernel-based matching method, the effect of wheat technology on wheat productivity was positive and highly significant. The Average Treatment effect on the Treated ATT estimates suggest that improved wheat varieties adoption significantly increased the wheat productivity by about 1ton ha$^{-1}$. This is the average change in productivity ha$^{-1}$of farm households that contributed by a change in technological status.
The impact of adoption of improved wheat varieties on farm household income: The two matching estimates (Table 4) showed that improved wheat varieties adoption had a positive and significant effect. The nearest matching algorithm indicated that the effect of adoption of improved wheat varieties was significant (at 5%) and equal to 0.401.

Since income was expressed in logarithmic terms, the average income ratio between adopters and non-adopters was 1.50 implying that the income of adopters is almost 50% higher on average than income of non-adopters. Similarly, the estimates of the Kernel-based matching showed that the income of adopters was almost 35% higher on average than income of non-adopters. Previous studies also showed a positive impact of the adoption of agricultural technologies (Mendola, 2007; Wu et al 2010; Nguezer et al., 2011).
The sampled wheat farmers were stratified by quintiles based on area under improved wheat varieties to observe effect of wheat technology on household income using level of wheat technology adoption among adopters (Table 5). The results showed heterogeneous effects of wheat technology adoption among adopters. Nearest neighbor matching method revealed that farmers who allocated 20-80% of their wheat area to improved wheat varieties earned two times as much as non-adopters.

Similar results were found using kernel-based matching method. However, the effect of technology adoption on household income for farmers who allocated their total wheat area to improved wheat varieties was found to be non-significant but was positive. The impact was significantly higher in household heads who allocated 60-80% of their wheat farm to improved wheat varieties.

**Table 8: Level of adoption per area under improved wheat varieties**

<table>
<thead>
<tr>
<th>Level of Adoption (area under improved wheat varieties)</th>
<th>Nearest Neighbor ATT</th>
<th>Kernel-based ATT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less 20%</td>
<td>0.278</td>
<td>0.379</td>
</tr>
<tr>
<td>20 - 40%</td>
<td>0.799***</td>
<td>0.724***</td>
</tr>
<tr>
<td>40 - 60%</td>
<td>0.762***</td>
<td>0.733***</td>
</tr>
<tr>
<td>60 - 80%</td>
<td>0.827***</td>
<td>0.724***</td>
</tr>
<tr>
<td>80 - 100%</td>
<td>0.704</td>
<td>0.563</td>
</tr>
</tbody>
</table>

***Significant at 1%**

**Conclusions**

The adoption of improved varieties had a positive effect on wheat productivity and farm household income, thereby increasing their likelihood of decreasing poverty levels. The results provide empirical evidence that agricultural technology adoption can contribute to improving productivity and raising income of farm households, poverty alleviations and food security.

**Recommendation**

Wide dissemination of improved wheat varieties enhances adoption and uptake of improved varieties by the farmers. Thus, it could be a policy instrument to improve wheat productivity and raise farm household income. Along with improved wheat technologies, effective extension services, efficient input provision and scaling-up of the best practices of adopters should be in place as a complementary measures.
References


Discussion Session

Question: Ownership of livestock as a factor to adoption of wheat technologies; what made it a factor? Elaborate
Answer: Livestock can be used by being converted into money for farmers to buy the new improved variety.
Development and introduction of pre-harvest implements to smallholder farmers in EAAPP countries

Friew, Kelemu*, Mubarak, Mohammed and Abiy, Solomon.
Agricultural Mechanization Research Process, Ethiopian Institute of Agricultural Research, F.O Box 436, Adama, Ethiopia
*Correspondence: friewkelemu@yahoo.com

Abstract
Ploughing has been a back breaking exercise especially in wheat growing regions where the soil is heavy, high weed infestation is exhibited and the land is ploughed up to five times before planting. Broadcasting of seed as practiced by many small holder farmers does not assure proper seed germination and emergence and makes subsequent crop management operations cumbersome. To overcome the land preparation problem, an animal drawn mouldboard plough developed by the Agricultural Mechanization Research Center in Melkassa and tested at different sites was introduced to the project sites. The plough was batch produced and given out to 106 farmers in Robe and Digilu Tijo districts. To overcome the planting problem, a six row animal drawn planter was developed at the Agricultural Mechanization Research Center at Melkassa, with the EAAPP project. The implement was developed by taking the seed geometry and seeding rate data as basis for the design of the implement. Based on these basic parameters, the driving speed ratio between the ground wheel and the seed metering mechanism was set at 1: 3 ratio with a simple chain sprocket arrangement. The seed metering device is circular having an eccentric arrangement with the housing which made fabrication simple. The covering device is made from two bent flat iron attached to the furrow opener making a ‘V’shape arrangement avoiding the conventional drag chain and press wheel covering devices. These components were easy to fabricate and did not require any extraordinary skill and facility for the fabrication. The planter was tested on station and on farmer’s field in two seasons. The planter was compared with other hand row planting and broadcasting planting practices in a replicated trial in RCBD at Kulumsa and Melkassa. Planting time, emergence and finally yield were the major parameters considered. The planting time per plot by the planter was five times faster than hand planting and subsequent field management works were less cumbersome. It takes about five hours to plant a hectare compared to 24 hours using manual row planting, hence saves time for the operator for other activities. However no significant difference in yield was observed between hand row planted (precise planting) and the planter at the field trial in both sites. Besides, manufacturing was not difficult as manifested in the training conducted in the workshop. This was underlined as the exit strategy for the research as these trained manufacturers will be the next group who will avail the technology to the end user in their vicinity.

Key words: mechanization, plough, seed geometry, planter, broadcasting, emergence, seeding rate
Introduction

Timeliness is very important in crop production for good yield and quality product. Land preparation, planting, weeding and the other operations should be handled in time to get reasonable yield and quality product acceptable along the value chain. To attain these, a proper package of mechanization technology comprising of tillage through crop establishment and including post harvest handling is necessary.

In most wheat production areas in Ethiopia, the land is ploughed up to 5-6 times before planting using the traditional plough. This can be attributed to the narrow width, shallow depth and non soil turning or inefficient trash burial nature of the implement. Ploughing takes a long time, which inhibits the farmer from using the whole growing period, thus resulting in reduced yield especially in areas where late onset and early cessation of rainfall occurs. In most places, seed is also broadcasted which results in higher seed rate and makes weed management laborious. Use of untreated seed even if planted in time or planted in row, seed germination could be low, resulting in low crop stand and productivity.

These shortcomings have resulted in poor quality of work, timeliness problem and low yield at the end of the season. To overcome these problems, an efficient animal drawn moldboard plough developed earlier and a six-row wheat planter developed through the East African Agricultural Productivity Project (EAAPP) have been introduced to the project sites and favorable responses have been received from the end users. The main objective of the study was to introduce improved pre-harvest technologies for increased wheat production.

Methodology

The work comprised of survey, prioritization of intervention areas, design and development, testing, demonstration, training of farmers and manufacturers.

Survey

A survey was conducted in Robe and Degelu Tijo districts in June 2011. Six villages and 20 farmers from each district were selected with the recommendation of the district agricultural offices. From Degelu Tijo District; Delu Bora, Ashebka Welkite and Lolle Abosera villages were picked, while Habe Daengize, Gina Gedemessa and Habe villages were selected from Robe district. Nearly 120 farmers were interviewed from the two districts. Four people conducted the survey in June 2011. The questionnaire focused crop enterprise, land holding, draft power condition, crop production technique and constraints ranging from land preparation, crop establishment, harvesting and post harvest handling, including the priority areas the project needs to address.

Prioritization of interventions

Collected data was summarized and frequency was analyzed using SPSS. Then based on the outcome of the analysis priorities were set for appropriate interventions.

Plough

The animal drawn plough developed by the research center has been in operation for some time. Farmers at the project sites were given hands on training on the assembly, operation of the plough and on the proper guidance of the oxen.
Training of farmers: Sixty and forty two farmers were selected from Digelu Tijo and Robe districts respectively in association with the Districts Bureau of Agriculture. The selected farmers were given practical field training on the use of the plough for three days at their respective sites. Each trainee was given a plough as well. Farmers were advised to use the ploughs for their land preparation operations. A field day was organized on a farmer’s field, which used the plough to grow wheat. There were more than 100 participants, the farmer explained about the performance of the equipment and the participants were able to appreciate the merits of the technology.

Training of manufacturers: Seven people from Assela, Arisi Robe, Sire, Eteya and Huruta were trained on the manufacturing of the plough at Melkassa workshop for five days.

Planter

As there were no animal drawn wheat planters, the work started with the actual design. The main focus in this work was the seed metering device, where the seed physical characteristic and recommended seed rate were the starting points. The seed geometry (length, depth read as major diameter and minor diameter), 100 seed weight were determined in the laboratory. Seed rate of 150 kg ha⁻¹ and 20 cm distance between rows were taken as basis for the design based on the agronomic recommendation. These gave the seed metering flute depth, width and the ratio between the ground wheel and the seed metering sprockets size. The hopper was constructed from 1mm sheet metal, with six openings at the base to make it a six row planter. It has six furrow openers with an integrated covering device on each. The handle was made from a half inch water pipe with a provision for controlling the animals’ movement.

Field Testing: The planter was calibrated in the workshop and on unploughed land. Adjustment was made on the degree of the opening which regulates the seed from the hopper to the metering device. The equipment was tested on station and on farmer’s field. The test was done on a plot size of 10mx40m, using the implements test procedure used at the Agricultural Implements Research and Improvement center. Data on speed, crop emergence, seed rate and time of operation were collected. In addition replicated trials at Melkassa and Kulumsa were conducted. The experiment was conducted in a plot size of 12mx40m with broadcasting, hand row planting, and row planting using planter as treatments. Data on time taken for planting, emergence and finally yield were collected. Duration was taken using a stop watch. Emergence was counted by taking five samples in each plot along the diagonal using a 0.5cm x 0.5 cm sampling grid. Yield was measured by taking samples using the above mentioned grid and threshing by hand and oven drying at 105°C. Data was analyzed using SPSS.

Results

Survey

The results of the survey presented in the Table 1 showed that ploughing was the first priority area followed by threshing and planting.
Table 1: Survey results indicating priority areas of intervention

<table>
<thead>
<tr>
<th>Variables</th>
<th>Quantity</th>
<th>Percent case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land allotted for wheat</td>
<td>&lt;1 hectare</td>
<td>77%</td>
</tr>
<tr>
<td>Power Source</td>
<td>A pair of oxen</td>
<td>90%</td>
</tr>
<tr>
<td>St. time/ Fin time</td>
<td>Feb-March/June-July</td>
<td>80%/83%</td>
</tr>
<tr>
<td>Number of ploughings</td>
<td>3-5</td>
<td>83%</td>
</tr>
<tr>
<td>Major weed type</td>
<td>Grass weed</td>
<td>94%</td>
</tr>
<tr>
<td>No. of weeding</td>
<td>3 times</td>
<td>71%</td>
</tr>
<tr>
<td>Priority</td>
<td>Plowing, threshing, planting</td>
<td>43.4%, 18.4%, 18.4%</td>
</tr>
</tbody>
</table>

Plough

Components of the plough include, beam, handle, moldboard and share (Plate 1). The handle and the beam are made of wood. The main ground engaging parts; the moldboard is made of 3mm sheet metal, while the share is made from heat-treated 6mm flat iron. The other specifications are indicated in Table 2:

Table 2: Specification and working features of the plough

<table>
<thead>
<tr>
<th>Overall dimension (mm)</th>
<th>Weight (kg)</th>
<th>Working depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Width</td>
<td>Height</td>
</tr>
<tr>
<td>660</td>
<td>310</td>
<td>243</td>
</tr>
</tbody>
</table>

Source: Improved small scale Agricultural Equipment; Catalogue, 2009
Training

Farmers were given hands-on training at the project sites and field days were conducted to create awareness among the main stakeholders (Plate 2). As a result 106 ploughs were given out to the project sites and have now started to use the ploughs on their farms.

Plate 2: Field day on the moldboard plough

Training of Manufacturers

Seven manufacturers from Assela, Arisi Robe, Sire, Eteya and Huruta were trained on the manufacturing of the plough at Melkassa workshop for five days from 4th to 8th March 2013. They were able to manufacture ploughs, carts and have successfully met the training objective.

Testing of Planter

The results of tests made on planter are given in tables 3 and 4 below.

| Table 3: Comparison between hand planting and use of planter in terms of time and field capacity on farmers' fields and research centers at different sites |
|---|---|---|---|---|
| No | Name | Area(m²) | Time (min) | Application rate (kg/ha) | Field capacity (hr/ha) |
| 1 | Kulumsa (planter) | 400 | 11min | 187.5 | 4.57 |
| | Manual planting | 400 | 58min | 156 | 24 |
| 2 | Farmer 1 (planter) | 400 | 13min | 195 | 5.4 |
| 3 | Farmer 2 (planter) | 320 | 8min | 150 | 3.33 |
| 4 | Melkassa Research Center (planter) | 1000 | 23min | 180 | 3.83 |

| Table 4: Yield results of the Kulumsa replicated trial for the 2014 crop season |
|---|---|
| Treatment | Kulumsa (kg/plot) |
| Broadcasting | 90.4b |
| Hand planting | 99.6a |
| Planter | 96.5ab |

CV (%) - 4.01; Figures within same column with different letters are significantly different
**Plate 3: Crop planted using the row planter at the seedling stage.**

**Training of farmers and field evaluation**

Training of farmers was initially hampered by lack of training of animals and poor degree of soil pulverization. In addition some manufacturing problems were observed, which had some bearing on the performance of the machine.

Problems encountered in the 2013 season were corrected in 2014 season. Farmers in the project sites of Digilu Tijo and Robe were selected and training given on the operation of the planters. The farmers also trained their oxen (Plates 4 and 5). The planter was used by farmers in Kulumsa, Digilu Tijo and Robe (Plate 4) and was rigorously tested in a replicated trial on station at Melkassa and Kulumsa in the 2013 cropping season.

**Training of manufacturers on planter manufacturing**

Training was given on planter manufacturing and other implements for 16 manufacturers who came from Oromya, Amhara, Tigray and SNNP Regions. Each group manufactured one planter and a cassava processor. These groups are expected to fabricate the respective implements and make them available at least in their respective regions.

**Conclusion and Recommendations**

The plough showed remarkable performance as witnessed by the farmers’ field trial and the field day conducted in October 2012. It cuts operation time remarkably but there was no significant yield difference from its use. The animals need to be trained to go on straight lines, which is easy to pick up as observed in the fields. Though no yield advantage was recorded, the plough saves on time and turns the soil completely hence useful at onset of rainfall and high weed infestation.

The planter saved time in planting substantially and enabled operations like weeding easier compared to the traditional practice. From the tests conducted, it was been established that the planter requires well leveled field with few heavy clods and the animal should be well trained.
Training was given to the local MoA staff, manufacturers and farmers. Periodic awareness creation and experience sharing and the use of the distributed implements need to be monitored. The status of job order for the local plough from the trained manufacturers should be assessed. Methods should be devised with local financing institutes on the means of getting credit for both the manufacturers and farmers to avail the technology to the wider community.

Acknowledgements

The authors acknowledge Mr. Tilahun Teka and all agricultural mechanization research technicians and field assistance for their contribution in manufacturing the implements.

References

Prediction models for determination of lime requirements for acid soils of Ethiopia

Dawit, H.1, Geremew, T.2, Fekadu, M.3, Bahiru, A.3, Kassu, T.1, Jerry N.4, Wubengda, A.1, Ooro, P.5

1 Ethiopian Institute of Agricultural Research, Kulumsa Agricultural Research Centre. Wheat Regional Centre of Excellence, P.O. Box 489, Asella, Ethiopia; 2 Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Centre; 3 Ethiopian Institute of Agricultural Research, Ambo Agricultural Research Centre; 4 Southern Highlands Agricultural Research Institute, Uyole, Tanzania; 5 Kenya Agricultural and Livestock Research Organization (KALRO)

*Correspondence: dawithabte99@yahoo.com

Abstract

Soil acidity is one of the major agricultural problems in the highlands of Eastern Africa threatening the agricultural development. Generally about 41% of the total land in Ethiopia and 13% of the arable land in Kenya is covered by acid soils. The highlands of Tanzania and Uganda are also included in this soil category. A trial was, therefore, started in 2013 in Ethiopia to develop soil test based lime recommendations for acid soils of different areas. A total of 16 composited sample assays were collected from 4 districts in the highland areas of Ethiopia, located within an average radius of 199 km from Addis Ababa. The samples were categorized in to 3 groups based on pH data; and bulked soils from each group were used for laboratory incubation experiment to determine the buffering capacities (BC). Grain yield response data taken from field trials conducted in 2014 cropping season was used to validate the prediction capacity of the models. Consequently, the BC values to raise the pH of soils in the ranges of 5.1-5.6, 4.6-5.0, and 4.2-4.5 to target values of 6.0 was found to be 664, 1870, and 2260 kg/ha of CaO, respectively. Prediction equations were also developed for each soil group. The yield response data proved that equation 1 is a very good estimator of Lime Requirement (LR) for soils categorized in groups 1 and 2; and equation 3 for group 3. But the BC method is proven to be a very good estimator for soils in all groups.

Introduction

The central, western, south eastern, north western highlands are part of the high potential areas for bread wheat production in Ethiopia. Some of the soils in these areas are highly acidic with pH ranging from 3.8 to 5.5. Generally about 41% of the total land in Ethiopia (Mesfin Abebe, 2007) and 13% of the total land of Kenya (Kanyanjua, et al., 2002) is covered by acid soils. To develop appropriate management options, research has been going on for decades in the central and western parts of Ethiopia; and some significant findings made. However, adoption of recommended practices is very low. This calls for work to clearly understand the production constraints under such environment.

Acid soils management research is mainly related to the determination of amount of liming material required to reclaim unit area of land. The lime requirement (LR) of soils is determined most directly by field trials. However, these methods are expensive and time consuming. When such activities are intended to be done on a large scale, the time and money required to develop recommendations would be very high. To account for such difficulties that would be involved in the development of recommendations at a large scale, tools that can model the relationship between measurable parameters of soils and LR are in use in some parts of the world (David L Rowel, 1994). Data for the development of prediction equations
can be obtained from laboratory incubation experiments. The results of incubation experiments can also be used for the determination of buffering capacity of soils (BC). The determined BC values can be applied by users to calculate the lime requirements of acid soils based on initial soil pH values obtained from field measurements and predetermined target pH values assigned based on individual crop's sensitivity. Generally, determination of the LRs of acid soils of different locations using such techniques can be very useful for planning and management purposes at zonal and regional level. Thus, this study was conducted with the objectives of developing prediction models for soil test based lime recommendations for acid soils of the central, western, and south eastern highlands of Ethiopia. The results of the experiments could also be applied in other parts of Ethiopia and eastern Africa countries based on one year validation trials under field conditions.

**Methodology**

**Areal Description**

Experiments were conducted in 2013 and 2014 by three agricultural research centres of Ethiopian Institute of Agricultural Research (EIAR) with the aim of developing prediction tools for the determination of lime requirements for acid soils of different locations based on measurements of soil characteristics. The study areas were Chelia District, Gebre Guracha, highlands of Butajira, Lemu-Bilbilo, and Meraro. However, field trials were done in Chelia and Lemu-Bilbilo districts, sites with very strongly to strongly acidic areas, respectively. The sites are located within 10-30 km distance of 09°08’ N and 37°18’ E in Chelia district, 9°48’ 19” N and 38°23’ E in Gebre Guracha, 07°32’ 37”N and 39°15’ 21” E in Lemu Bilbilo and Meraro areas, and 8°7’ N and 38°22’ E in Butajira districts. The elevations of the district areas lie between 2250-2900, 2500-2600, 2500-2900, and 1600-3600 m.a.s.l. for Chelia, Kuyu, Lemu-Bilbilo, and Butajira districts, respectively. The average annual rainfalls vary from 1180mm for Kuyu to 1522mm at Chelia districts (Samsam Water foundation, 2015). The soils of the areas vary from Eutric Nitosols to Chromic Luvisols in Lemu-Bilbilo, Eutric to Dystric Nitosols in Chelia, Eutric Cambisols in Kuyu, and Chromic Luvisols in Butajira districts (Ethio GIS, 2008). Wheat is one of the main crops in the areas.

**Experimental Procedures and Designs**

Composite soil samples were collected from Gedo, Gebre Guracha, highlands of Butajira, Lemu-Bilbilo, and Meraro areas for physical and chemical analysis. That included soil particle size distribution, pH, organic matter, bulk density, and exchangeable acidity. This report, however, discusses pH data only. The laboratory experiment was conducted at Holeta Agricultural Research Centre, soil and nutrition laboratory. The field trials were done by Ambo Agricultural Research Centre in Chelia district, and Kulumsa Agricultural Research Centre in Lemu-Bilbilo. For laboratory incubation experiment, 16 representative soil samples using standard sampling procedures were collected from major acid affected districts in Ethiopia; and were air dried, sieved with 1cm aperture sieve size, and stored in appropriate condition. For incubation experiments and laboratory analysis 2 kg of the air dried samples were passed in 2mm sieve. The initial pH of all soil samples were measured in soil water ratio of 1: 2.5. Initial incubation experiment was conducted to determine the amount of time required to reach equilibrium levels for each sample. Then the samples were divided in to three groups and composited accordingly: soils with pH ranges of 3.8 – 4.5, 4.5 – 5.0, and 5.0- 5.5. The second incubation experiment was conducted on the composited soil samples. An array of 12 samples of each 100g air-dried soil with ≤ 2mm were added in to 300 ml plastic bottles from each group. A series of 12 different dilute solution of CO (0.1 - 0.6 g) treatments were pipetted to the same amount of
given soils (100g each) in plastic bottles and was shaken for some times. Soil pH was measured at 24 hours interval for 3 days and then at one week interval. The measurements were done for six weeks.

**Development of Prediction Models**

The array of data of incubation experiments run for six weeks, were graphed in Excel spread sheet to examine and determine the equilibrium levels of the soils response in pH to applications of 12 rates of lime (0.05-0.6 g CaO/ 100 g soils). The equilibrium levels for group 1 soils (pH 3.8-4.5) were obtained from 5th week, for group 2 soils (pH 4.6-5.0) from 3rd week, and for group 3 soils (pH 5.1-5.5) from 1st week data. The equilibrium data were used for the development of predictor equations for each group. Each data were evaluated to fit different regression models using SPSS 20 curve estimation method. Then the variables were transformed in to cubic form and run using linear regression model to develop predictor equations.

**Determination of Soil BC and LR:**

The changes in pH measured against each treatment levels were plotted to determine the buffering capacity (BC) of each soil from the buffer curve. The reciprocal of the slope of the buffer curve is the buffering capacity of the soil (David L Rowel, 1994). The value of BC is the amount of lime required in kg per ha for each unit pH rise. Therefore, the BC values in g/100g soil were converted to kg/ha based on 1400 kg/m³ bulk density and 0.15m slice of soils. The value of lime required to bring the soil pH to optimum (target) pH for bread wheat production was determined from the curves corresponding to lime responses of each soil group.

**Field Experiment and Model Validation:**

Field experiments were carried out in 2014 to determine the relationships between the responses of test crop with different rates of lime applications and soil characteristics; and to evaluate the capacity of the model equations to predict the lime requirement of acid soils. Four lime rates (350, 700, 1050, and 1400 kg/ha) and 2 P rates (RNP, 2RNP) on soils with pH: 5.2 and (0.7, 1.4, 2.1, and 2.8 t/ha) with two P levels on very strongly acidic (pH 4.5 and 4.8) soils were used. The treatment factors were factorially combined and replicated 3 times. A control treatment received no lime and recommended NP rates. All other recommended agronomic and soil practices were implemented. The results of the field experiment were used to validate the capacity of the model equations to predict the LR of different soils.

**Data Analysis**

Data obtained from laboratory incubation experiments was subjected to correlation and regression analysis using SPSS 20 statistical software (IBM Corporation, 2011); and the relationship between laboratory measured parameters was determined from multiple regression equations. The relationship of pH rise in relation to lime rates is also represented by graphs. Buffer curves drawn for each soil group and developed from data of lime treatments and pH rise was used to determine the buffering capacity of each soil group. Field data were analyzed using SAS 9.0 statistical software package (SAS Institute, 2002), and the results were compared with predicted data.

**Results and discussion**

**Determination of LR Prediction Models and Buffering Capacity:** Prediction models were developed by running the equilibrium pH data for each group in a linear regression model and setting the pH values as dependent variable and LR as independent variable. The regressed data from which the cubic models were
developed are presented in table 1, 2, and 3.

Table 1: Regression coefficients for predictors’ model developed from soil samples of pH: 3.5-4.5

<table>
<thead>
<tr>
<th>Model B</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>4.220</td>
<td>.073</td>
<td>57.67</td>
<td>.000</td>
</tr>
<tr>
<td>LR1</td>
<td>22.836</td>
<td>2.842</td>
<td>8.035</td>
<td>.015</td>
</tr>
<tr>
<td>LR2=LR^2LR</td>
<td>-109.968</td>
<td>28.248</td>
<td>-3.893</td>
<td>.060</td>
</tr>
<tr>
<td>LR3=LR^3LR</td>
<td>209.630</td>
<td>74.193</td>
<td>2.825</td>
<td>.106</td>
</tr>
</tbody>
</table>

Table 2: Regression coefficients for predictor model developed from soil samples of pH: 4.5-5.0

<table>
<thead>
<tr>
<th>Model B</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>4.695</td>
<td>.159</td>
<td>29.510</td>
<td>.000</td>
</tr>
<tr>
<td>LR1</td>
<td>26.351</td>
<td>5.026</td>
<td>5.243</td>
<td>.014</td>
</tr>
<tr>
<td>LR2</td>
<td>-132.524</td>
<td>41.083</td>
<td>-3.226</td>
<td>.048</td>
</tr>
<tr>
<td>LR3</td>
<td>224.444</td>
<td>89.879</td>
<td>2.497</td>
<td>.088</td>
</tr>
</tbody>
</table>

Table 3: Regression coefficients for predictor model developed from soil samples of pH: 5.1-5.6

<table>
<thead>
<tr>
<th>Model B</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Constant)</td>
<td>5.239</td>
<td>.157</td>
<td>33.445</td>
<td>.019</td>
</tr>
<tr>
<td>LR1=LR</td>
<td>33.486</td>
<td>7.969</td>
<td>4.202</td>
<td>.149</td>
</tr>
<tr>
<td>LR2=LR^2LR</td>
<td>-263.429</td>
<td>101.198</td>
<td>-2.603</td>
<td>.233</td>
</tr>
<tr>
<td>LR3=LR^3LR</td>
<td>720.000</td>
<td>332.609</td>
<td>2.165</td>
<td>.275</td>
</tr>
</tbody>
</table>

For practical use the constant values are replaced by initial pH values of the soils of interest. Equations 1, 2, and 3 are the LR predictor models developed by linear regression.

Where: pH_i and pH_f are used to designate the target and initial soils pH values. The target pH value for wheat is 6.0. Raising the pH values by 0.5 above the target values, which is usually recommended, drastically raises the costs of lime, reducing the economic feasibility.

Determination of Buffering Capacity of Soils: Use of buffer curves to determine the BC of the soil groups is an alternative option to determine the LR of soil samples. It is the amount of lime required to raise the pH of acid soils by 1 unit. The LR is, therefore, determined based on the BC value, target pH, and initial soil
pH using eq.4.

Consequently, the BC values to raise the pH of soils within the ranges of 5.17-5.6 to target values of 6.0 was found to be 664 kg/ha CaO. Using this BC value the LR to raise the pH from 5.2 to 6.0 would be 530 kg/ha. Examples of lime rate determinations for a range of initial soil pH values are shown in table 4. Table 4 can be used as a guide for practical applications. Note that slight discrepancies can exist between estimated values using the BC method and the model equations.

Validation of Model Equations Using Field Trial Data: for model validation, plot level data of soil pH changes was not made available. Therefore, only crop response data (grain yield), as presented in figure 1, was used for evaluating the models.

The initial pH of the soils in the trial sites selected to represent group 1, 2, and 3 soils is 4.5, 4.8, and 5.2, respectively. Evaluation of the models prediction capacity of lime requirements of different soils with respect to the lime rate treatment levels in the trials that corresponded to the optimum yield responses is made based on the initial soils pH values of 4.5, 4.8, and 5.2 for the respective soil groups and a target pH value of 6.0 for all. It is assumed that additional lime application aimed to elevate the pH of the soils above the predetermined target pH of 6.0 could result to insignificant yield increments that can be demonstrated by non responsive or declining yield response curves.

**Table 4: Estimation of lime requirements for different soils using BC method**

<table>
<thead>
<tr>
<th>pH ranges used</th>
<th>Curve Slopes</th>
<th>BC in g/100g soils</th>
<th>BC in kg/ha</th>
<th>Remark or Recommendation on the use of BC values</th>
<th>Examples of Lime rates to bring given soil pH to target pH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5.0-5.6</strong></td>
<td>31.61</td>
<td>0.0316</td>
<td>664</td>
<td>For soils with pH 5.0 - 5.6</td>
<td>5.2</td>
</tr>
<tr>
<td><strong>5.2-6.0</strong></td>
<td>11.21</td>
<td>0.0892</td>
<td>1873</td>
<td>For soils above pH 4.6</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>4.27-5.6</strong></td>
<td>16.24</td>
<td>0.0616</td>
<td>1293</td>
<td>Cheap for one time use; with some yield penalty.</td>
<td>4.27</td>
</tr>
<tr>
<td><strong>4.27-5.8</strong></td>
<td>13.48</td>
<td>0.0742</td>
<td>1557</td>
<td>Acceptable with insignificant yield penalty</td>
<td>4.27</td>
</tr>
<tr>
<td><strong>4.27-6.0</strong></td>
<td>11.23</td>
<td>0.0891</td>
<td>1871</td>
<td>Acceptable</td>
<td>4.27</td>
</tr>
<tr>
<td><strong>4.27-6.2</strong></td>
<td>11.05</td>
<td>0.0891</td>
<td>2314</td>
<td>Acceptable</td>
<td>4.27</td>
</tr>
<tr>
<td><strong>4.27-6.4</strong></td>
<td>11.05</td>
<td>0.0891</td>
<td>2314</td>
<td>Acceptable</td>
<td>4.27</td>
</tr>
<tr>
<td><strong>4.27-6.5</strong></td>
<td>11.05</td>
<td>0.0891</td>
<td>2314</td>
<td>Acceptable</td>
<td>4.27</td>
</tr>
</tbody>
</table>

**Figure 1: Grain yield response curves for different group of soils.**

The graphs in figure 1 shows that the response of group 1 soil continued up to the highest level (2800 kg/ha lime
rates). But for group 2 soils the response continued up to the 3\textsuperscript{rd} level (2100 kg/ha lime rates). For group 3 soils, the response to lime level 2 and 3 are nearly the same, and showed slight increase to the fourth level. Apparently, the 2\textsuperscript{nd} treatment for group 3 soils is the optimum as the difference in response between the 2\textsuperscript{nd} and 3\textsuperscript{rd} lime level is very small (< 10 kg/ha). Using model equation 3, the predicted value to bring initial soil pH of 5.2 to 6.0 is 630 kg/ha. Using the BC the predicted lime rate is 530 kg/ha. Though both models slightly underestimated the LR compared to the 2\textsuperscript{nd} treatment level (700 kg/ha), the estimates using the predictors are good. For group 2 soil treatment level (2100 kg/ha) is the optimum. Equation 2 underestimated it to about 1500 kg/ha, but equation 1 to about 1700 kg/ha. Using the method of BC the estimate is 2060 kg/ha. Therefore, equation 1 and the method of BC can be taken as useful tools for prediction of LR for group 2 soils (4.6–5.1). For group 1 soils the model prediction is 2500 kg/ha, but the BC method gives 2800 kg/ha, indicating that the BC method estimates is closer than equation 1. Despite the slight differences in estimates between the two methods, both methods can be taken as good predictors for group 1 soils.

**Conclusion**

The model equations can provide a very good estimate of the LR for the range of soil pH classes. Equation 2 underestimated the LR of group 2 soils by about 30\%. Yet, the estimate for group 2 and group 1 soils using equation 1 was good. Therefore, equation 1 can be used for soils with initial soil pH values up to 5.0. Equation 3 provided good estimate for group 3 soils (above pH: 5.0). The estimate using BC are good for all soil groups and can be used for all. Nonetheless, it should be understood that there are limitations in the evaluation of the models. Plot level pH measurements were not used in the analysis and interpretation of results. The results also indicate that the intervals between treatment levels 2 and 3 for group 2 and 3 and 4 for group 3 soils are wide enough to reduce the accuracy of interpretations of results.

**Recommendations**

Equation 1 can be used for prediction of LR for soils with initial pH values ranging from 3.8 to 5.0. The underestimates from equation 2 for group 2 soils are high enough to reduce the acceptability of the model for use. The method of BC can be used for all soil groups.
The liming material used for the experiment was CaO. But CaO is not usually available for users. Therefore, recommendations are usually made based on the calcium carbonate equivalent values (CCE) of the liming material used for the experiment. The CCE of CaCO3 is considered as a standard (100%), and the CCE of CaO is 178%. Because of its higher CCE value, the predicted LR using the models should be multiplied by 1.78, when CaCO3 is used as the agricultural lime.

The results of this experiment can be applied for determination of lime requirements for acid soils of different parts of Ethiopia and partner countries, provided that the predicted values of BC and model equations are validated under filed conditions.

**Limitations of the research and way forward**

To improve the accuracy of model's prediction, correlation of different data of soil physical and chemical characteristics is necessary. The cation exchange capacity (CEC) of soils is one important factor that determines the reaction rates and lime requirements of acid soils. Particle size distributions of soils and organic matter contents are also other useful data for such correlation studies (David L Rowel, 1994). Therefore, the use of additional data can improve the accuracy of prediction of the models under different conditions of soil physical and chemical properties. For maximum returns on these soils, Mesfin Abebe (2007) stated that the approaches and methodologies could be worked out through continuous collection, description, and prediction of data to arrive at packages of technology for levels of production that nearly approach the genetic limits of the crops. To reduce the effect of macro scale heterogeneity of soil acidity at a national and regional level and improve the prediction capacity of the models under different soil conditions, sample size should be increased.

**References**


IV Success Stories in Wheat research and development

A testimony by Mrs. Tsechay Assefa, from Digelu-Tijo District, Ethiopia

The farmer is from Digelu-Tijo District, Ethiopia. She was quite grateful that EAAPP had enabled her to travel to Kenya to be able to share the success story of wheat. She used to do charcoal trading, hand crafts and could hardly feed her family with the income she earned. She lived in a mud house thatched with grass. She was struggling in paying school fees and was hardly providing adequately care for her children. Her main challenge was lack of quality seed, and knowledge of proper planting. She used traditional wheat planting and management methods and hence the harvest was always low.

Therefore when EAAPP came, she took keen interest on wheat farming. She received certified wheat seeds from the project which she planted and the harvest increased six times (from 1 tonne per hectare to 6 tonnes). As a result she has been able to feed her family members of six after her husband passed on. She is able to educate her children two of whom have graduated, one with a Diploma while the other with a Bachelor’s degree. The others are in private schools.

EAAPP Intervention

The farmer testified having been assisted through;

- Provision of 100 kg of certified seeds
- Training, demonstrations on appropriate land preparation, application of fertilizers, proper planting methods
- Technical backstopping and regular visits by extension staff to review progress and address challenges
- Farmers exchange tours to model farms in the country
Achievements
The farmer has been able to accomplish the following as a result of wheat farming:
- She has been able to purchase an ox plough.
- She has constructed a modern house.
- She is also a member of parliament as a result of farming.
- Shared & exchanged improved seeds with 17 other farmers
- She has food and income security

The farmer’s old House The Farmer’s new house
In order to give back to the society, she sells wheat seeds at a cheaper price than the market rate so that the other farmers can be able to uplift their lives. She also exchanges her improved seeds with the local seeds to assist other farmers get to where she has reached. Her son has also developed keen interest in farming after seeing her get a lot of money from wheat farming. She has become one among the many farmers in Ethiopia who can testify on EAAPP’s impact on their lives.

Future Plans
The farmer plans to;
- Purchase a tractor
- Purchase more land to expand the wheat acreage
- Invest in other profitable businesses in urban centres e.g construction of residential houses.

Conclusion
Women are able to transform lives from farming and hence she encourages more of them to practice agribusiness that will be able to increase the income from farming. People generally get interested where there is a lot of income and hence they are adopting wheat farming.

Discussion Session

Question: Does her promotion to regional parliament affect her farming?
Answer: Her son will be taking over from her in farming while she is engaged in parliamentary business. Therefore, her farm business will continue to grow since her family members are motivated.

Question: How sharing / bartering improved seeds with local ones from the business point of view?
Answer: She has been sharing the support of EAAPP with the needy community also selling the remaining at the market price (i.e doing social capital and business at a time).
Enhancing the adoption of improved wheat technologies, innovations and management practices through dissemination, up-scaling and knowledge management in Ethiopia

Mekonnen, M.1,*, Justa, K.2, Catherine, K.3 and Charles, A.4

1East African Agricultural Productivity Project (EAAPP), Ministry of Agriculture, Ethiopia; 2East Africa Productivity Project (EAPP), Tanzania; 3EAPP Kenya; 4EAAPP, Uganda; *Correspondence: alemeko@gmail.com

Abstract
Disseminating recommended technologies, innovations and management practices released by wheat research institutions in EAAPP countries (Ethiopia, Kenya, Uganda and Tanzania) is expected to contribute to increased productivity, improved food security and minimize wheat imports. Enhancing the capacity of wheat growers to commercialize wheat production, feed agro-processing industries and value addition is also necessary. Inventory of existing technologies, innovations and management practices in the three countries for scaling up was made through established centers of excellence (CoEs) i.e., wheat CoE in Ethiopia. Selection of relevant and effective implementation pathways for technology dissemination was identified and effective linkages among actors were created using different mechanisms.

Intensive training was given to implementers and facilitators, and joint monitoring was conducted on the performance of disseminated technologies. Fifteen (15) popular wheat cultivars and their production package were selected across countries for demonstrations and scaling up at the start of the project i.e., nine in Ethiopia, two in Kenya and four in Tanzania. Demonstrations in Farmers Training Centers (FTCs), Farmers Research and Extension Groups (FREGs), Farmers Innovation Groups (FIGs), farmers exchange tours, training, exhibitions and agricultural shows were some of dissemination pathways. Thousands of farmers have benefited from the indicated approaches in the EAAPP project countries. As a result, wheat productivity has increased in all the three Countries. (from 1.5 to 4.4 t ha-1 in Ethiopia, 3.2 to 4.5 t ha-1 in Kenya and from 0.9 to 3.0 t ha-1 in Tanzania).

More cultivated land was covered by improved varieties of wheat in all the three countries than before. Farmer to farmer seed exchanges, revolving seed system, and availability of certified seeds to farmers were some of additional benefits. Strengthening seed quality assurance, construction of seed laboratories, training for quality seed production, availing seed cleaning machines and construction of seed stores were some of farmers’ capacity building efforts. Strengthening the value chain approach, initiating agri-business groups supporting the value addition, processing and marketing functions were started, and these are recommended to continue in order to sustain high productivity.

Keywords: wheat technologies, innovations, scaling up, East Africa
**Introduction**

Wheat is a source of food and livelihoods for more than 1 billion people in developing countries. According to FAO production database, 715,909,258 tons of wheat was produced in the world in 2013 (FAOSTAT, 2013); Africa’s share is only 4% (28,285,941 tons). Many countries in Sub-Saharan Africa grow a small amount of wheat. Ethiopia is the largest wheat producer in terms of area (1.7 million ha), followed by Kenya (160,000 ha), and Uganda (14,200 ha) in 2013. The East African region is a net wheat importer, and much of the wheat enters through food aid programs. The recent rise in prices of local food staples has increased demand for wheat, mainly in urban areas. Not only the share of production is less as compared to the world production, the productivity of wheat in East Africa Agricultural Productivity Project (EAAPP) countries (Kenya, Tanzania, Uganda, Kenya) is lower as compared to world average of 3.2 tons ha⁻¹ (Figure 1). Kenya has the highest productivity of wheat 3.04 tons ha⁻¹ in 2013 followed by Ethiopia (2.37 tons ha⁻¹) and Uganda (1.41 tons ha⁻¹) tons ha⁻¹ (Figure 1). These results show that EAAPP countries must work to improve wheat production and productivity by using different approaches.

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**Figure 1: Wheat productivity by East African countries**

The low uptake of improved technologies and management practices; access to production inputs (seed, fertilizer and credit), machines and implements, and poor marketing systems are some of the challenges hampering increase of productivity and production of wheat commodity in the region.

Wheat Regional Center of Excellence (WRCoE) was established in Ethiopia at Kulumsa Agricultural Research Center (KARC) to coordinate the wheat research and development activities of Ethiopia, Uganda, Tanzania and Kenya. Afterwards the EAAPP countries started joint research and dissemination activities. According to Doss et al. (2003), extension is clearly the variable most highly correlated with the use of improved technologies. It is not always clear, however, what the extension variable is actually capturing. It may be related to the provision of both inputs and information. Therefore, to disseminate proven technologies generated, countries made inventories of existing wheat technologies. The objectives of this activity across the EAAPP countries were to:

- Disseminate proven wheat technologies, information and management practices to farmers in EAAPP countries;
- Improve productivity and increase the area under improved wheat varieties;
- Enhance capacity of wheat growers to commercialize wheat production, agro processing and value addition;
Increase availability of improved wheat seed to wheat growers;
- Promote the agricultural machines and implements to actors along the wheat value chain
- Improve knowledge, information management and sharing system

The expected outputs and outcomes were to increase number of farmers adopting improved wheat technologies and management practices, increase area under improved wheat, enhance productivity of wheat in selected areas, improve availability and access to seed of improved wheat varieties, increase adoption of new handling and processing methods, improve stakeholder satisfaction with the technologies, innovations and uptake pathways, facilitate dissemination of technologies in more than one EAAPP country, increase regional technology uptake pathways, and raise capacity of wheat growers to commercialize wheat production and agro-processing.

**Materials and methods**

The methods of training and dissemination (T&D) vary from country to country depending on the institutional arrangement and extension methods used. The approaches were based on participatory as well as client and market orientation with emphasis to value addition. These included preparation of manuals, guidelines, field days, exhibitions, leaflets and posters, and practical demonstration of management, practices and enhancing farmer innovations. The activities were implemented through intensive training of targeted communities where appropriate demonstration plots on smallholder farmers’ fields and Farmers Training Centers (FTCs) were used. In targeted areas, different working groups were organized which included men, women and youth and linked with research, extension and market. An exchange of experience in effective extension delivery methods were multiplied for further scaling up activities by communities and other actors.

**Results and discussion**

Different methods were applied to disseminate the proven technologies in each country using different pathways. Inventory of technologies, innovations and management practices (TIMPs) was done by each EAAPP Country at the start of the project. The achievements are described country by country below;

**Ethiopia**

Effective approaches for implementation were selected. Demonstration of TIMPs by FREGs, FTCs, supporting farmer innovations by establishing FIGs, establishing linkage platforms of actors along the value chain, and seed multiplication were selected as main dissemination pathways. Demonstrations of different varieties and management practices were conducted by establishing demos at FTCs and by establishing FREGs at farmers’ fields in 41 selected districts as indicated on Table 1 below;

<table>
<thead>
<tr>
<th>Table 1: Establishment of FREGs and FTCs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>2010-11</td>
</tr>
<tr>
<td>2011-12</td>
</tr>
<tr>
<td>2012-13</td>
</tr>
<tr>
<td>2013-14</td>
</tr>
<tr>
<td>2014-15</td>
</tr>
</tbody>
</table>

**Physical Capacity** Building: Strengthening the district agricultural offices and FTCs were implemented to 550 FTCs. The FTCs were equipped with furniture, demonstration materials and pedal cycles. Transportation and office equipment including motorbikes, computers, printers and photocopiers were procured and distributed to project
district agricultural offices to improve the efficiency of the extension delivery system. **Human Resource Capacity Building:** Various types of short term and awareness creation trainings were given on a number of wheat technologies to equip subject matter specialists (SMSs), development agents (DAs) and farmers. Trainings were conducted by researchers, seed experts and experts from regional bureaus of agriculture.

**Table 2: Trainees by gender**

<table>
<thead>
<tr>
<th>Trainees</th>
<th>Number of trainees</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>Farmers</td>
<td>20,747</td>
<td>16,790</td>
<td>3,957</td>
</tr>
<tr>
<td>DAs and SMSs</td>
<td>4,709</td>
<td>3,833</td>
<td>876</td>
</tr>
</tbody>
</table>

**Experience sharing visits:** Experience sharing events play a great role in popularizing proven technologies, serve as feedback forums for researchers, and facilitate the scaling up of proven technologies. On the other hand, organizing field days is important to showcase performance of new technologies to farmers. (Chimdo *et al.*, 2002). During Field days farmers discuss freely challenges facing them and point out issues they are dissatisfied with. It also provides an opportunity to researchers and extension staff to learn about farmers’ indigenous knowledge to be incorporated into the research system. Therefore, similar experience sharing events were conducted to facilitate the dissemination process. Significant number of participants was involved in different experience sharing events (Figure 2 and Table 3).

**Table 3: Number of participant in experience sharing**

<table>
<thead>
<tr>
<th>Year</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011-12</td>
<td>696</td>
<td>127</td>
<td>823</td>
</tr>
<tr>
<td>2012-13</td>
<td>4,506</td>
<td>846</td>
<td>5,352</td>
</tr>
<tr>
<td>2013-14</td>
<td>9,436</td>
<td>3,220</td>
<td>12,655</td>
</tr>
<tr>
<td>Total</td>
<td>14,638</td>
<td>4,193</td>
<td>18,830</td>
</tr>
</tbody>
</table>
Figure 2: Farmers’ Field days

New varieties were introduced to farmers, feedback was provided to researchers, and scaling up of technologies was enhanced because of the field days. The WRCOE hosted the visit of three (3) Tanzanian wheat extension and research specialists (one male and two females) on the status and operation of WRCOE, T&D and seed multiplication activities. As a follow up, 17 Tanzanian farmers visited the WRCOE and wheat farmers around the WRCOE and in Amhara region. The delegates were also briefed about how the extension system operates in Ethiopia and how effective the approaches were for technology dissemination and scaling up. Similarly, five delegates from Kenya also visited WRCOE and wheat growing parts of the Country with similar objectives.

In Ethiopia efforts have been made to facilitate linkages among research, extension and farmers by creation of joint planning and reviewing forums, production of training materials, training of extension staff and delivery of seeds and other inputs. Seed producers, wheat processing, value addition and marketing cooperatives were established. Efforts have been made to multiply certified seeds at farmer fields through the support of Ethiopian/Regional Seed Enterprises (ESE/RSEs) and Regional Bureaus of Agriculture (BoAs). The ESE/RSEs served as sources of basic seeds and potential buyers for farmers’ seeds while regional BoA took care of the quality assurance and linking producers with markets. Consequently, more than 768 tons of improved wheat varieties were distributed to farmers resulting to 11,849 tons of certified seeds being produced. The certified seeds produced were procured by ESE/RSEs, cooperatives, district agriculture offices (DAOs), BoAs and other farmers. Revolving seed system was also implemented at district level and framers were expected to return the amount they were issued with through...
EAAPP intervention. This assisted the DAOs to lend the produced seeds to other needy farmers for demonstration and production purposes. The effectiveness of community seed multiplication approach was also observed as good practice by Chimdo et al. (2002) on maize. The amount of wheat seed distributed for different activities increased from 26.7 tons to 483 tons. Accordingly, the average productivity of wheat increased from 1.5 ton ha$^{-1}$ (from base line survey) to 4.41 ton ha$^{-1}$ in project districts.

The average productivity of EAAPP districts was greater than the national average (Figure 3). EAAPP also contributed

**Figure 3:** Wheat Seed distributed (A) and average yields (B) in Ethiopia

Establishment of Agribusiness groups: To promote women participation in EAAPP activities and to fill the gap
created along the value chain of wheat, different agribusiness groups were organized through support of the project. The agribusiness groups comprised of women and youth and were involved in seed multiplication and marketing, bakery and similar activities.

**Strengthening the wheat seed sector:** A well-established and effective seed sector would help farmers to access new varieties and increase production by putting more area under improved cultivars (Wania et al., 2013). Building effective seed system is important when countries are working on regional bases. Therefore, WRCoE should have strong seed system that can provide quality seed for partner countries.

The following activities are carried out to strengthen the seed system in Ethiopia to serve as source of commercial wheat seeds:

**Strengthening seed quality assurance:** Two seed laboratories were constructed in two regional states to strengthen the seed quality control (Figure 4). The laboratory materials for the newly constructed laboratories at Assosa and Gambella were also being procured. Finances were also transferred to Amhara, Tigray, Oromia and SNNP regions.

**Figure 4: Some of the seed laboratories constructed**

**Strengthening quality seed production:** Three seed cleaning machines have been procured and transported to Amhara, Oromia and Tigray regions. Transportation, construction of shelter was also made to a seed cleaning machine procured previously in SNNP region.
Figure 5: Some of the seed-cleaning machine (Tigray)
- Construction of seed stores: Four seed stores (Hosaena-SNNP, Dodola-Oromia, Chagni-Amhara and Mekele-Tigray) with a capacity of 1000 tons were constructed and handed over to the respective Regional Seed Enterprises (RSEs).

Figure 6: Constructed seed store and offices at Hoseana, SNNPR
Generally, EAAPP has benefitted more than 263,100 farmers by involving them in FTC and FREG demonstrations, FIGs, community based seed multiplication and value chain grain production activities. A good number of farmers had benefitted from experience sharing events and farmer-to-farmer seed exchanges.
Kenya

EAAPP was promoting wheat production in Kenya by improving access to certified seeds of improved varieties, strengthening research extension linkages, building extension and farmers’ capacity. The project focused on small holder farmers who constitute 80% of wheat farmers. Five wheat project areas and twelve farmer groups were selected in consultation with stakeholders. Three pronged approach was adopted targeting increased production of certified seeds; promoting new wheat varieties and improving skills, knowledge and information. Licenced seed merchants were engaged through Memorandum of Understandings (MOUs) who were involved in contracting and training the groups on seed production. The groups were also trained on business development and preparation of five year business plans. Through enhanced research extension collaboration and dissemination, training materials were developed and joint training, field days and seed inspection activities were undertaken. Through such interventions, 290 tonnes of certified seed was produced through small holder seed producing groups. The new varieties namely ‘Robin’ and ‘Eagle 10’ have been popularised and adopted by both large and small scale farmers resulting in 80% replacement of old varieties. The total area under new varieties is now 30,000 ha while wheat productivity has increased from 3.2 to 4.5 tons ha⁻¹ in project areas. Demand for seed of the two varieties has also increased and the project has expanded hectareage under seed production from 64 ha (2012) to 278 ha (2014). Farmers groups have obtained information and improved skills in seed production, business development and have earned a total of US$167,000 from certified seed production.

Tanzania

Training and dissemination activities in wheat technology implemented under EAAPP for five years involved inventory of technologies, development of training manuals, capacity building/training of farmers and extension staff, study tours, exchange visits and establishment of demonstration plots. Other activities were monitoring, supervision and documentation of success stories.

*Inventory of wheat technologies*: Technologies identified for dissemination to address the challenge of low wheat production included improved wheat varieties, agronomic packages and farm implements. Varieties that are widely disseminated are Juhudi, Chiriku, Lumbesa, Riziki c1 and Riziki c2. These varieties are disseminated together with the agronomic package of fertilizer types and rates of application. Fertilizers commonly used for wheat are TSP, DAP with the rate of 20-25kg P ha⁻¹ and 50 kg N ha⁻¹, respectively and foliar application of 1-2 kg blue copper ha⁻¹.

Other technologies are farm implements related technologies: the use of Magoye ripper, which is animal driven, those manufactured by local companies including SEAZ in Mbeya and Nandra engineering in Moshi. It is a single tine implement (Figure 7) used for opening furrows for planting wheat on either ploughed or un-ploughed fields (Zero tillage).

Seed planters and wheat thresher are technologies important in reducing time and increasing efficiencies on farm operations. The use of green manure seems to be an alternative means of enriching soil nutrients. Commonly used nutrient alternatives are leguminous plant species as sources of nitrogen in wheat production; this technology is widely practiced in Mbeya District and proved to increase wheat yields significantly. The recommended rate is 5 ton/ha of *Sesbania sesban* or *Leucaena divosolia*. Apart from green manure, Poly feed is also recommended as foliar fertilizer in wheat production at a rate of 300g/20lts of water equivalent to 1kg/acre. Two applications are recommended with first application (starter) done at 3-5leaf stage and second application (finisher) applied at heading stage. Poly feed contains NPK 19: 19: 19 plus important micronutrients.
To reduce the incidence of wheat diseases the practice of Integrated Disease Management (IDM) was recommended. Septoria leaf blotch, stem rust, leaf rust and yellow/striped rust are major wheat diseases. Septoria alone can cause up to 50% of grain loss while Rusts can cause yield loss of up to 90% in different parts of Tanzania. Due to economic importance of these diseases to wheat industry, the research has developed integrated disease management of which early planting and single application of fungicide at heading stage is recommended.

Developing wheat training manual: Two training manuals in Swahili language were developed; one on Good Agricultural Practices (GAPs) and the second on Developing Agribusiness skills for wheat farmers. About 100 copies of GAP training manual were printed and distributed as a training guide to different stakeholders including extension staff, farmer facilitators, NGOs and other partners involved in training farmers along the value chain (production, harvesting, storage, marketing and group dynamics). To increase collaboration with other stakeholders, the manuals were developed in partnership with extension staff, researchers, training officers, Small Scale Industry Development Organization (SIDO), mechanization specialist and NGOs. For wider sharing, the manuals were displayed during Nane Nane Agricultural show held in Dodoma Tanzania in 2013 and during Agricultural show held in Kenya in September 2014.

Capacity building of farmers and extension staff: Training of Trainers (ToT) on improved wheat technologies was conducted to empower farmers and extension staff with knowledge and skills on wheat production, post-harvest handling and marketing. Trained farmers were facilitated to train other farmers. A total of 194 farmers (140M, 54F) and 74 Extension staff (female 6, male 68) were trained on wheat husbandry, agribusiness skills, safe use of chemicals, group dynamics and record keeping. The participants came from 31 villages in 9 Districts of Siha, Karatu, Hanang, Mbeya, Njombe, Sumbawanga Municipal, Nkasi, Sumbawanga, Njombe Town Council. The trained 194 farmers managed to train a further 970 (320 F and 650 M) others using Farmer-to-Farmer extension method.

Development of entrepreneurship skills: To develop entrepreneurship skills wheat farmers and extension staff were trained on agribusiness skills that involves profit margin analysis, farm budgeting, handling and managing of internal and external wheat markets, obtaining business license/permits and the use of mobile phones in obtaining agriculture information especially market information (Figure 8). A total of 56 (F 12 and M 44) farmers
and 23 (F 2 and M 21) extension staff from EAAPP intervention villages of Sihà, Karatu, Hanang, Njombe, Mbeya, Sumbawanga M, Nkasi and Sumbawanga Districts participated in the training. During training the participants (farmers) were linked with other service providers such as NMB, SIDO, RUDI and MVIWATA that could assist with the provision of credit, mobilizing farmer groups, processing and trading of wheat and wheat products.

Information sharing and knowledge gain

Study visit to Wheat Regional Centre of Excellence (WRCoE) - Ethiopia and Exchange Visit: As a strategy of knowledge and experience sharing among wheat farmers and extension staff, a team of 11 Farmers (3 F and 8 M), 8 Extension staff (3 F and 5 M) and one Researcher (1M) visited Wheat Regional Research Center of Excellence in Ethiopia (Figure 9). Participants visited different areas including Farmer Research Extension Groups (FREG), on farm research trials, processors, Focal Training Centers (FTC), farmers associations and Research Stations.

The knowledge/innovations and experience from WRCoE integrated in Tanzanian wheat farming practices include the establishment and management of Demo plot which is managed like FREG and GAP practices. Farmers appreciated the use of fertilizer in wheat cultivation and the production of wheat seeds by farmers and farmer groups.
Exchange visit was another initiative of increasing information and knowledge gain to wheat farmers on different practices for wheat production along the value chain. The visit was conducted to 40 farmers and 15 extension staff from Southern Highlands Zone (Mbeya, Njombe, S/wanga and Nkasi districts) to Northern Zone in Hanang District. Participants had an opportunity to visit Farmers Innovation workshop, District Demo Plots, Basutu Wheat Farm (private farm), farmers’ fields and demo plots at Gitting village. The participants gained knowledge and shared experiences on wheat production. The participants also assessed the progress on wheat farming.

**Establishment of wheat demonstration plots**: To make farmers appreciate the effect of GAPs on wheat production, 22 wheat demonstration plots were established in 9 Districts of Nkasi, S/wanga, Mbeya, Njombe/Wanging’ombe, Siha and Engarenairobi, Karatu and Hanang (Gitting). There were 620 farmers who participated to learn the applied practices such as improved varieties, fertilizer application and pest management (weed, insect and diseases). The performances of wheat in the demo motivated the application of GAPs in farmer’s fields (Figure 11). The practice in the demo was integration of GAPs available in the Country and innovations/practices learned from WRCoE (including tilling the land more than two times, fertilizer application, row planting and weed control).
Farmer field day: Other means to increase sharing of information with wheat stakeholders was to conduct farmers’ field days in Southern highlands regions of Mbeya (Ikhoho village), Sumbawanga (Msanda Muungano village), Sumbawanga Municipal (Mpanda and Ulinji village), Nkasi (Kipande village), Njombe (Igosi village). A total of 404 (149 F, 255 M) farmers and 18 farmers and extension staff from the villages participated.

Achievements: Technical backstopping was conducted to wheat farmers and extension staff who participated in various trainings and study tour to find out what happened on wheat fields after equipping them with various knowledge and skills on production and agribusiness. Through supervision and follow-up, success stories were documented.

Training of stakeholders: EAAPP managed to train 743 wheat stakeholders including farmers and extension staff compared to the project target of training 650.

Table 4: Stakeholders’ Trainings

<table>
<thead>
<tr>
<th>Type of Training</th>
<th>No of participants planned for training</th>
<th>No of participants trained</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short term training for extension staff and ToT</td>
<td>90</td>
<td>74</td>
<td>82</td>
</tr>
<tr>
<td>Short term training for farmers and ToT</td>
<td>160</td>
<td>194</td>
<td>121</td>
</tr>
<tr>
<td>Farmers study tour</td>
<td>30</td>
<td>16</td>
<td>53</td>
</tr>
<tr>
<td>Exchange visit</td>
<td>120</td>
<td>55</td>
<td>46</td>
</tr>
<tr>
<td>Demo plots</td>
<td>250</td>
<td>404</td>
<td>162</td>
</tr>
<tr>
<td>Total</td>
<td>650</td>
<td>743</td>
<td>114</td>
</tr>
</tbody>
</table>
Farmers’ Innovations

Adoption of GAP and improving production: Trained extension officers and farmers practiced the use of improved wheat technologies including land tilling (more than twice), use of improved seeds, and application of fertilizer and weed control techniques. Through these practices the production increased from 0.9 tons/ha to 3.5 tons/ha for Juhudi variety.

Improving farming practices and standards of living: Isaya Morel, a wheat farmer from Ngarenairobi Village, Siha District had an opportunity to attend residential training on GAPs and Agribusiness at Uyole Mbeya in 2012/2013. He participated in study tour at WRCoE in Ethiopia in 2013/2014 to learn wheat production technologies along the value chain. After acquiring knowledge and skills in 2013 he cultivated 20 ha (50 acres) and harvested 52 tons equivalent to 2.6 t/ha instead of 10 tons equivalent to 0.5t/ha he used to get before. In the year 2013 he managed to buy a tractor and its implement for 20,000,000/= (Figure 13). In 2014, he cultivated 15 ha and managed to harvest 40.3 tons (2.7 t ha-1), and managed to buy 4 surveyed plots for residential house, bought a new Toyota car and paid school fees in a private school for his daughter.

Figure 12: Sikabenga wheat farm during field day at Ikoh village
Isaya, after attending agribusiness training, was contracted as an agent to buy wheat in Ngarendore and Namwai villages. He bought a weighing scale and trained other farmers on the importance of using weighing scales. The wheat price increased because of the newly created linkages. Similar strategy/innovation was adopted in maize and beans production.

**Diversification of enterprise:** Mr. Daniel Nahumu from Namwai Siha District received GAP training and was involved in visit to WRCOE. He cultivated two acres of wheat and harvested 2.9 tons. He bought a digital camera, printer and scanner and constructed a two roomed house, which he used as a studio and rented out the other (Figure 14).

**Seed production**
After the study tour, a farmer Ms. Teresia Mzindakaya from Sumbawanga was motivated to start seed production and through Strategic Agricultural Research and Development (SARD-SC) assistance, she managed to cultivate 8 ha with a capacity of producing 24 tons of certified wheat seeds enough to plant 200 ha; and another farmer Mr. Paulo Mgao from Igosi village was also contracted to produce 3 tons of wheat seeds for distribution to farmers. This was expected to plant about 25 ha in 2014/2015.

**Conclusion**
From these achievements, it can be concluded that;
- The pace of dissemination of proven technologies is improved by using different approaches and extension methods to disseminate.
- Regional experience sharing contributed to flow of information and technologies among partner countries.
- The project created a good platform to link research and extension.
- Availing proven seeds within a short period was achieved through community based seed multiplication activities and by aligning the activities with seed enterprises.
Recommendations

- Policy harmonization on commercial seed exchange among EAAPP countries must be harmonized with technology generation and dissemination activities.
- Seed quality control laboratories and installation of seed cleaning machines should be completed before the end of the project.

Acknowledgement

The authors wish to acknowledge all those who contributed in one way or another in the preparation of this document. Special thanks to their respective ministries of agriculture, research institutes and the regional state branches that implemented the activities and provided information. This paper would have not been realized without the cooperation, leadership and support of the management and staff of WRCoE and EAAPP Ethiopia. We thank you all. Finally, we thank the role played by ASARECA in convening the research development activities of the region.

References


The incidence and distribution of insect pests in Rain-fed wheat in Eastern Africa

Munene, M., Tebkew, D., Agum, W. and Njuguna, M.

KALRO, Food Crops Research Centre- Njoro, P.O. Private Bag, 20107, Njoro, Kenya; Ethiopian Institute of Agricultural Research, Debre Zeit Center, P.O. Box 32, Debre Zeit, Ethiopia; National Agricultural Research Laboratories, (NARL) Kawanda, P.O. Box 7065, Kampala Uganda.

*Correspondence: munenewamacharia@yahoo.com

Abstract
Insect pests are one of the major constraints that limit yield of wheat in the East Africa region. Farmers’ fields in Ethiopia, Kenya and Uganda were surveyed to determine the species composition and distribution of insect pests and their natural enemies associated with wheat. Wheat fields along road sides were randomly selected at 2 to 10 km intervals and in each selected field several wheat plants in a cross diagonal line were examined for the presence or absence of insect pest and associate natural enemies. When insect infestation was encountered the type of insect was identified to species level and in situ population counts made. In the surveyed areas of Ethiopia, only 39% (n=28) of the fields were infested by tef epilachna, Chnootriba similis Thurnberg (Coleoptera: Coccinellidae), while the remaining wheat fields were free of insect infestation. However, the level of tef epilachna infestation was very low, which ranged from trace to two percent. The Russian Wheat Aphid (RWA), Diuraphis noxia Kurdjumov (Hemiptera: Aphididae) was the most prevalent insect pest of wheat both in Kenya and Uganda. The maximum number of RWA per tiller was 58 in Kenya and 38 in Uganda. Moreover, in Kenya the rose wheat (grass) aphid (Metopolophium dirhodum L.), oat-bird-cherry aphid (Rhopalosiphum padi Walker) and corn leaf aphid (R. maidis Fitch) were prevalent at low density ranging from 0.1 to 9 per tiller. The greenbug (Schizaphis graminum Rondani) and the green stink bug (Nezara viridula L.) were recorded only in Uganda. The general aphid predators Cheilomenes spp., spiders, lacewings and the parasitoid Aphidius spp were the natural enemies of aphid found in Kenyan wheat. However, the density of these natural enemies was too low to bring the aphid population to a level that does not cause economic damage.

Key words: Eastern Africa, wheat, insect pests, incidence, distribution, natural enemies

Introduction
Wheat is an important cereal crop in Eastern Africa region where it is grown by small - and large scale farmers. Average wheat yield in the region is low, about 2.4 t/ha in Ethiopia and 2.5t/ha in Kenya, which is less than the world average of 2.7 t/ha (Oerke 2005). Insect pests are one of the major constraints that limit yield of wheat in the region. According to Oerke (2005) the average worldwide yield losses in wheat due to insect pests is 8.7% (ranges 7 to 10%), depending upon the type of insect pest, control measure applied, type of variety grown and agronomic practices followed. Although there is no regional estimates in wheat in Eastern Africa, it is believed that the yield losses attributable to insect pests of wheat is much greater than the world’s average as the use of crop protection technology is limited in the region.

In the past, wheat insect pest surveys were made on country bases at different times and therefore, it is not known if the countries in the region have identical or different insect pest problems in wheat. Once information on the...
type, distribution and importance of insect pests of wheat are generated on region wide basis, this will be useful in prioritizing research needs, develop efficient insect pest management technologies and determine the efficacy of control measures. Besides, it is useful to index insect pests of wheat in the region to track shifts in pest status in the future, establish key germplasm screening and testing sites for each of the major insect pests and identify quarantine insects to the region. Survey data is also necessary for projecting insecticide requirements and distribution across different wheat growing areas in the region. The objectives of this survey, therefore, were to determine the current species composition, distribution, and measure the relative importance of wheat insect pests, and identify natural enemies associated with wheat insect pests in Eastern Africa (Ethiopia, Kenya and Uganda). This paper documents the insect pests found during the survey in wheat crops in farmers’ fields.

Materials and methods
Farmers’ wheat fields were surveyed in major wheat growing areas of Kenya, in East Shewa zone of Ethiopia and in Bukwo, Kween and Budadiri/ Bulambuli districts of Uganda in 2013 and 2014 cropping season. Stops were made at every 2 to 10 km intervals along accessible roads to visit the wheat crop. In each selected field several wheat plants in a cross diagonal line were examined for the presence or absence of insect pest and associated natural enemies. When insect infestation was encountered, the type of insect was identified to species level and in situ population counts were made or visual estimate of damage was taken.

In all areas covered by the survey, sampling of cereal aphids was extended to alternate host plants near the crop in order to identify the host plants that enable them to survive the offseason periods between crop harvest and the emergence of the next crop in the following season. The altitude of surveyed wheat fields ranged from 1600 to 2835 ma.s.l. The growth stage of the crop was between GS 17 (seven leaves unfolded) (Zadoks et al., 1974) in relatively high altitude areas and GS37 (flag leaf just visible) in the lower altitude areas.

Results and discussion
The Russian wheat aphid (RWA), *Diuraphis noxia* was the most predominant cereal aphid species in Kenya (Tables 1). Mount Kenya region had the highest incidence of RWA followed by West Mau and East Mau region (57.7, 11.7 and 10.2 aphids per tiller, respectively). Uasin Gishu had the lowest cereal aphid densities (1.0 aphids/tiller) recorded as most of the farmers planted seed dressed with insecticides (Gaucho 350FS and Cruiser 350FS). Other cereal aphid species recorded in Kenya were rose wheat (grass) aphid, *Metopolophium dirhodum* (Walker), corn leaf aphid, *Rhopalosiphum maidis* (Fitch) and the oat bird cherry aphid, *R. padi* (L.). However, the population intensity of these aphid species was much less than the population intensity of RWA (Table 1).
Table 1: Cereal aphid species intensity recorded on wheat in different wheat growing areas in Kenya

<table>
<thead>
<tr>
<th>Region</th>
<th>Mean number of cereal aphid species per tiller</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of farms surveyed</td>
</tr>
<tr>
<td>Mt Kenya</td>
<td>25</td>
</tr>
<tr>
<td>Laikipia</td>
<td>7</td>
</tr>
<tr>
<td>Nyandarua</td>
<td>4</td>
</tr>
<tr>
<td>East Mau</td>
<td>15</td>
</tr>
<tr>
<td>West Mau</td>
<td>8</td>
</tr>
<tr>
<td>Uasin Gishu</td>
<td>11</td>
</tr>
</tbody>
</table>

Although these aphid species occur in low intensity, other than the direct wheat damage caused, they are known to be vectors of many viral diseases in cereals including wheat (Irwin and Thresh, 1988; Gildow 1990). None of these cereal aphid species were found in Ethiopian wheat (Table 2).

Table 2: Incidence of insect pests on wheat in East and North Shewa zones in Ethiopia

<table>
<thead>
<tr>
<th>Zone</th>
<th>District</th>
<th>Number of farms surveyed</th>
<th>Pest</th>
<th>Infestation level (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Common name</td>
<td>Scientific name</td>
</tr>
<tr>
<td>East Shewa</td>
<td>Adaa</td>
<td>3</td>
<td>Tef epilachna</td>
<td>Chnootriba similis</td>
</tr>
<tr>
<td></td>
<td>Lume</td>
<td>12</td>
<td>Tef epilachna</td>
<td>Chnootriba similis</td>
</tr>
<tr>
<td></td>
<td>Dugdabora</td>
<td>3</td>
<td>Tef epilachna</td>
<td>Chnootriba similis</td>
</tr>
<tr>
<td>North Shewa</td>
<td>Minjar-Shenkora</td>
<td>10</td>
<td>Tef epilachna</td>
<td>Chnootriba similis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Field mice</td>
<td>Arvicanthisniloticus Desmarest</td>
</tr>
</tbody>
</table>

According to Hailu et al. (1989) in the main rainy season cereal aphids are not a problem of concern in Ethiopian wheat unless the crop is sown late and exposed to terminal drought. Therefore, the absence of cereal aphids in the surveyed area of Ethiopia might be due to the appropriate planting time used by farmers to sow wheat.

In Mt Kenya region most of the wheat was in the soft dough stage and most aphids tend to disappear as crops tend to head. However, symptoms of RWA infestation (leaf rolling and fishhook shaped ears) were evident. RWA was found in rolled leaves and trapped awns. The rolled leaves protect RWA and other cereal aphid species from unfavorable weather and natural enemies (Valialus, 1986). The leaf rolling effect also allows other cereal aphids (M. dirhodum, R. maidis, and R. padi), to stay longer on the crop. In addition, leaf rolling of some wheat varieties in response to drought conditions provided shelter for some of the cereal aphids, thereby allowing them to stay longer on the crop.
Continuous cropping of wheat was practiced by wheat growers in Mt Kenya region and West Mau areas. This enabled the cereal aphids to migrate from one field to another and survive from one season to the next. Similar observations have been reported by Mulatu and Gebremedhin (1994) in the highlands of Ethiopia.

Alternate host of RWA and other cereal aphids found during the survey in Kenya were wild oats *Avena fatua* L., brome grass *Bromus spp*, wild rye grass *Elymus spp* and foxtail grass *Setaria spp*. These grass weeds are common in the high altitude wheat growing areas of Ethiopia (Adugna and Tesema, 1987) and in Mt Kenya and West Mau regions of Kenya and serve as reservoirs for cereal aphids during the dry weather. Neglected volunteer wheat, barley and oats plants were also important for the survival of RWA and other cereal aphids. Volunteer wheat, barley and wild grasses have been reported by Armstrong et al., (1991) supporting RWA and thus provide a bridge for infestation of the next season wheat crop.

The *tef* epilachna, *Chnootriba similis* (Coleoptera: Coccinellidae) infested only 39% (n=28) of wheat fields in Ethiopia (Table 2). It was widely distributed both in the low- and high-land areas, although previously its distribution is believed to be limited to the mid and lowland (an altitude of 2000 m.a.s.l. or below) wheat growing areas of the country. Both the larvae and adults feed by scraping the upper leaf surface; however, the overall infestation level was very low. Symptoms of shoot fly damages i.e. dead heart were encountered in one wheat field in each district (Lume and Minjar-Shenkora). Moreover, localized rodent damage (probably by *Arvicanthis niloticus*) was recorded in the latter district. In these areas, crops are fenced with stone wall or live fences which usually harbor rodents and other small vertebrate animals.

The survey revealed that RWA was the most prevalent wheat pest in Uganda (Table 3) followed by greenbug *Schizaphis graminum*. The mean population density of RWA was 38 and 14.7 aphids per tiller, in 2013 and 2014, cropping season, respectively. The mean number of green bug per plant was 28 aphids per tiller. The green stink bugs *Nezara viridula* L. were the most prevalent in Budadiri district of Uganda and their population intensity was up to 4 bugs per tiller. The other insect pests were recorded at very low intensity.

### Table 3: Prevalence of insect pests and gastropods in wheat in Uganda

<table>
<thead>
<tr>
<th>Class</th>
<th>Order</th>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insecta</td>
<td>Hemiptera</td>
<td>Russian wheat aphid</td>
<td><em>Diuraphis noxia</em> (Kurdijumov)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Greenbug</td>
<td><em>Schizaphis graminum</em> (Rondani)</td>
</tr>
<tr>
<td></td>
<td>Thysanoptera</td>
<td>Thrips</td>
<td><em>Haplothrips tritici</em> (Kurd.)</td>
</tr>
<tr>
<td></td>
<td>Lepidoptera</td>
<td>Stem borers</td>
<td><em>Sesamia calamistis</em> (Walker)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pod borer</td>
<td><em>Helicoverpa armigera</em> (Hubner)</td>
</tr>
<tr>
<td></td>
<td>Isoptera</td>
<td>Termites</td>
<td><em>Marcotermes spp</em></td>
</tr>
<tr>
<td>Gastropoda</td>
<td>Stylommatophora</td>
<td>Slugs</td>
<td><em>Derofera leve</em> (Muller)</td>
</tr>
<tr>
<td></td>
<td>Stylommatophora</td>
<td>Slugs</td>
<td><em>Arion fasciatus</em> (Nilsson)</td>
</tr>
<tr>
<td></td>
<td>Pulmonata</td>
<td>Garden snails</td>
<td><em>Helix aspersa</em> (Muller)</td>
</tr>
</tbody>
</table>

Slugs and garden snails found infesting wheat are also pest of this crop in northern Africa and polyphagous, feeding on many other plant species. According to Douglas and Tooker (2012) slugs are serious pests of many crop species, including wheat, barley, oats, rye (*Secale cereal* L.); maize, and other crops in no- and reduced-tillage
field crop production. In many small grains, slugs feed on the seed or scrape strips in the leaves, leading first to window-pane damage, and then to leaf shredding.

**Natural enemies of cereal aphids**

Few types of predators and parasitoids attacked most of the cereal aphids (Table 4). The predators were the Coccinellid beetle (Cheilomenes spp.), spiders (Arachnidea) and lacewings (Chrysoppa spp), which are generalist predator occurring at very low density beginning from tillering and continues until the crop reached heading stage. These generalist predators are also known to prey on cereal aphid on wheat and barley in Ethiopia (Adugna and Tesema, 1987).

**Table 4: Predators and parasitoids attacking cereal aphids in wheat in Kenya**

<table>
<thead>
<tr>
<th>Predators and parasitoids</th>
<th>Cereal aphids species</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diuraphis noxia</td>
<td>Metopolophium dirhodum</td>
</tr>
<tr>
<td>Predators</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Coleopteran beetles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Cheilomenes spp)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2. Neuroptera (Lacewings)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3. Arachnoida (spiders)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Parasitoids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Hymenoptera</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Aphidius spp)</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

The only parasitoid emerged from mummified RWA was *Aphidius spp*, although the rate of parasitism was very low and appeared late in the season. Generally all these natural enemies occur at different times during the cropping season, but often when the aphid population had passed the damaging level. Therefore, they may not contribute to season long control of RWA and other cereal aphids in the wheat crop. For instance, the study noted that natural enemies of Russian wheat aphid were only present late in the crop season when damage to wheat crops had already taken place. The rapid population increase of cereal aphids in wheat was attributed to the absence of successful aphid predators and parasitoids. There is need to understand the population dynamics, including seasonal variation of these aphid species and their natural enemies for development of an integrated pest management (IPM) package.
Conclusion

The survey data revealed that the Russian wheat aphid is the most important and predominant cereal aphid in the region. Its feeding habit led to leaf rolling, which enabled the other cereal aphids to stay longer on the crop thereby increasing their inoculation period of viral diseases such as barley yellow dwarf virus. Leaf rolling particularly the rolling of flag leaf interferes with the pollination of wheat flowers. The survey also revealed that grass weeds support cereal aphids hence good control of grass weeds is essential. Moreover, though the number of predator and parasitoid species recorded were sufficient, because of their low density, they are unable to keep cereal aphid populations below damaging levels. However, efforts should therefore be made to conserve these natural enemies as they are of great importance in controlling the cereal aphids.

Acknowledgement

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References


Characterization of the seed supply and demand dynamism in wheat growing areas of Ethiopia

Bedada, B.1,* Karta, K.K.1, Tesfaye, S.1, Astawus, E.1, Abebe, A.2, Abera, G.3, Tilahun, D.4, Usman, S.5 and Awel, Z.6

1Wheat Center of Excellence (WCoE), Kulumsa Agricultural Research Center (KARC), Assela, Ethiopia; 2Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa; 3Debrezeit Agricultural Research Center (DZARC); 4Amahara Agricultural Research Institute (ARARI); 5Sinana Agricultural Research Center (SARC); 6Areka Agricultural Research Center (AARC).

*Correspondence: bedadabegna@gmail.com

Abstract

Availability and access to seed of improved varieties is a key factor contributing to the enhancement of wheat production in Ethiopia. Even though farmers have become aware of advantages of seeds of improved varieties through the consolidated efforts of the research and extension systems, seed supply and demand dynamism in the wheat seed system is noticeable in Ethiopia. Therefore, the present study was designed to characterize the seed supply and demand dynamics in major wheat growing areas and to indicate the possible options for improving its access and utilization by the smallholder farmers. The study was conducted in three purposively selected regional states of Ethiopia. Simple random sampling method was used to get a total of 756 wheat producer household heads for interview. Focus group discussions were held with the respective key informants to validate the data collected from the selected respondents. Results indicate that in the past five years 80% of the respondents used improved wheat seeds; however, the regular users were only 33.7%. Shortage of supply, high price, and untimely supply of quality improved wheat seeds were the factors that reduced its regular utilization. The farmers’ demand for improved wheat seeds varied over time because of the miss-match among variety preference, financial availability, change in rainfall pattern and shortage of seed supply. Accordingly, out of 756 respondents, 43.3% changed their demand for improved seeds sourcing through formal seed supply system in 2012. To enhance farmers’ utilization of improved wheat seeds to improve wheat production and productivity; facilitating credit services, improving wheat research for variety development, and improving timely supply of improved wheat seeds are the points that need due consideration in wheat producing regions of Ethiopia.

Key words: seed system, wheat, seed demand, Ethiopia

Introduction

In Ethiopia, sustainably enhancing wheat production and productivity is imperative to maintain food security for the rapidly growing population. Availability and access to seed of improved varieties is a key factor contributing to enhancement of wheat production in Ethiopia. Increasing quality and usage of improved seed (along with other best practices such as irrigation, fertilizer adoption, and mechanization) has the potential to dramatically increase Ethiopia’s annual crop production (IFPRI, 2010).

Failure to use appropriate seed, while investing sufficiently in other inputs and management practices, will not lead to improved productivity. This can be observed in the improved seed coverage and national wheat productivity in Ethiopia. During the main rainy season of 2012/2013, of 1.63 million
hectare of land covered with wheat, only 4.35% was sown with seeds from the formal sources (CSA, 2013) indicating that most of the seeds used by small farmers in the country is obtained from the farmers’ seed system. However, improvements have been observed in improved seed supply in recent years. Dawit Alemu and David (2006) had established that only 20% of the demand for improved seed was covered in the main rainy season of 2005 demonstrating that nearly 3000 tons of improved wheat seed is required to satisfy the existing demand.

Experience has shown that the predicted demand for wheat seed usually does not conform to the demand at planting times. When farmers revise their expectations of rainfall, prices and other factors, they incline to shift their interests. This frequently causes significant coordination problems for seed suppliers. This is well evidenced by the present national scaling up initiative by the EIAR and seed sale reports by seed suppliers. Hence, clearly defining demand dynamism for wheat seed has a crucial importance. Therefore, the study was initiated to characterize the wheat seed demand dynamics and identify options for targeted supply of early generation of certified seed to the producers.

### Materials and methods

#### Sampling technique

Multi-stage sampling procedures were employed to select the respondents. In the first stage, three regions (Oromia, Amahara and Southern Nation Nationality People (SNNP) potentially producing wheat were purposively selected among regions in Ethiopia and the administrative zones in the selected regions were stratified into two groups based on wheat production potentials, namely major producers and relatively less producers. In the second stage, two to three zones were selected purposefully based on accessibility among the listed major wheat producing zones in each selected regions. Thirdly, a team of researchers selected districts based on the wheat production potential within administrative zones. In the final stage, household heads in the selected Kebele Administration (KA) of the selected districts were listed and based on the limited resource and time at the disposal of the researchers, totally 756 farm households were selected randomly as per the district’s wheat producers size determined in the prior stage.

#### Method of data collection

Data needed by the study were collected from both primary and secondary sources. The primary data were collected through a household survey and focus group discussions (FGDs) held with farmers and concerned development stakeholders (key informants). A semi-structured questionnaire was used for the field interviews. In addition to the questionnaire survey, FGDs were made with randomly selected farmers and key informants including community leaders, development workers and representatives of governmental organizations. These informal techniques helped to acquire useful and detailed information, which would have been difficult to collect through the questionnaire survey. The FGDs were guided by checklists. Intensive review of secondary literature was made before and after the field survey so as to relate the results of the study with previous studies.

#### Data analysis

The survey data was coded, entered into computer software, cleaned and checked for consistency.
Descriptive statistics such as mean, percentage, cross-tabulations and graphs were used to present the results. Mean difference tests were used to estimate the significance of the key variables included in the study. Qualitative information collected from the FGD and key informants were used to describe the finding from a wider community perspective to complement the survey data.

**Results and discussion**

**Farmers’ knowledge and perception on improved wheat seeds**

More than 96% of the respondents confirmed their access to information on seeds of improved wheat varieties; however, the information level or knowledge on the improved varieties varied among the respondents. Local extension service (80%), relatives/neighbors (16.8%), cooperative unions (10%), agriculture research centers (9.5%) and seed enterprises (2.8%) were the sources of information on improved wheat varieties in the study areas (Table 4). About 98% of the respondents perceived that seed of improved wheat varieties from formal sources provided better yield than local seeds. Respondent farmers witnessed the possibility of obtaining 1.5t ha\(^{-1}\) more yield on average than from local varieties when improved wheat varieties were used together with good agronomic management. The finding is in conformity with previous reports that the direct contribution of quality seed alone to the total production is estimated at 15-20% depending on the crop type, and it can further be raised up to 45% with efficient management of other inputs (Abebe et al., 2012). As mentioned in FGDs, majority of the farmers had information on improved wheat seed from formal sources and had knowledge of its advantages. However, they lack direct access to seed of improved varieties from the formal sources (Abebe Atilaw and Lijalem Korbu, 2012) because the formal sector has limited coverage (less than 10%) of the seed needs of the farmers for the dominant staple crops in Ethiopia (FAO-CDMDP, 2010) and it is highly centralized (Dawit Alemu, 2011).

**Table 4: Percentage distribution of respondents by the sources of information on improved wheat varieties**

<table>
<thead>
<tr>
<th>Source of information</th>
<th>Oromia</th>
<th>Amhara</th>
<th>SNNP</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local extension contact</td>
<td>73.3</td>
<td>85.2</td>
<td>83.8</td>
<td>80.0</td>
</tr>
<tr>
<td>Agriculture Research centers</td>
<td>12.5</td>
<td>7.1</td>
<td>7.6</td>
<td>9.5</td>
</tr>
<tr>
<td>Seed enterprises</td>
<td>2.0</td>
<td>3.3</td>
<td>3.4</td>
<td>2.8</td>
</tr>
<tr>
<td>NGOs</td>
<td>4.5</td>
<td>5.2</td>
<td>6.8</td>
<td>5.4</td>
</tr>
<tr>
<td>Relatives and neighbors</td>
<td>22.2</td>
<td>9.1</td>
<td>16.6</td>
<td>16.8</td>
</tr>
<tr>
<td>Cooperatives/ unions</td>
<td>11.6</td>
<td>8.1</td>
<td>10.0</td>
<td>10.1</td>
</tr>
</tbody>
</table>

*Note: Percentages do not add up to 100 because of multiple responses; NGO-non-government organizations*
Farmers’ seed use and seed sources

The extent of use of seeds by farmers was influenced by several factors such as availability, finance, pricing, timing and awareness. About 80% of respondents, including regular and irregular users, utilized improved wheat varieties though the proportion of regular users was limited only to 33.7% in the past five years. The study revealed that huge volume of certified seed of improved varieties have been in the stock of seed companies and cooperatives every year as leftover seed which could attribute to the shortage of improved wheat seed for use by the smallholders. Possible reason could be timely distribution of the seeds to proximity of farmers and mis-match of the variety supplied with the farmers’ need and demand. Irregular seed use was attributed to shortage of supply (29%), lack of finance (24%), high seed price (22%), untimely supply (12%), lack of awareness on improved seed varieties (12%), and lack of trust on quality of improved seed or suppliers (12%) as shown in Table 5. In the past five years, the non-use of improved seed varieties could be due to lack of finance and awareness, untimely supply, lack of trust on improved seeds or suppliers and high price of related packages like fertilizer. The majority of the respondents (more than 90%) complained of irregular access to seed of improved wheat varieties which could be attributed to different factors like shortage, institutional factors related to transportation and distribution of seeds.

Table 5: Reasons that hindered utilization of seeds of improved wheat varieties in the past five years (percentage distributions)

<table>
<thead>
<tr>
<th>Reasons raised by irregular users</th>
<th>Orimia (n=311)</th>
<th>Amahara (n=210)</th>
<th>SNNP (n=235)</th>
<th>Total (N=756)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shortage of supply</td>
<td>28.0</td>
<td>33.3</td>
<td>27.6</td>
<td>29.4</td>
</tr>
<tr>
<td>Lack of finance</td>
<td>24.4</td>
<td>26.2</td>
<td>21.7</td>
<td>24.1</td>
</tr>
<tr>
<td>High price</td>
<td>22.0</td>
<td>22.0</td>
<td>22.5</td>
<td>22.1</td>
</tr>
<tr>
<td>Untimely supply</td>
<td>16.7</td>
<td>18.6</td>
<td>20.0</td>
<td>12.3</td>
</tr>
<tr>
<td>Lack of awareness/ interest</td>
<td>9.0</td>
<td>12.4</td>
<td>16.6</td>
<td>12.3</td>
</tr>
<tr>
<td>Lack of trust on improved seeds and suppliers</td>
<td>10.0</td>
<td>13.0</td>
<td>14.5</td>
<td>12.2</td>
</tr>
</tbody>
</table>

Farmers obtained seed from both formal and informal sources. Seed enterprises, research system, and cooperative unions were key players in the formal systems while the neighboring farmers, relatives, local markets and seed saving constitute the informal sector. Farmers accessed wheat seed from different sources among which cooperatives or unions (34.4%), seed enterprises (21%) and neighboring farmers (18.4%) were the major sources in Ethiopia. The predominance of cooperative unions in seed supply is due to the centralized seed marketing and distribution scheme prevailing in the country (Dawit Alemu, 2011). Smallholder farmers access agricultural inputs through unions in Ethiopia. In Oromia regional state, farmers mainly obtained improved wheat seed from cooperative/union (45%) and neighboring farmers (29%), as indicated in Table 6 below;
Table 6: Sources of seed of improved wheat varieties in major wheat producing regions of Ethiopia

<table>
<thead>
<tr>
<th>Wheat seed source</th>
<th>Oromia</th>
<th>Amhara</th>
<th>SNNPP</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed enterprises</td>
<td>5.1</td>
<td>30.5</td>
<td>33.6</td>
<td>21.0</td>
</tr>
<tr>
<td>Research centers</td>
<td>4.0</td>
<td>2.0</td>
<td>5.5</td>
<td>3.8</td>
</tr>
<tr>
<td>NGOs</td>
<td>2.3</td>
<td>1.0</td>
<td>6.0</td>
<td>3.2</td>
</tr>
<tr>
<td>Neighboring farmers</td>
<td>28.6</td>
<td>8.6</td>
<td>15.2</td>
<td>18.4</td>
</tr>
<tr>
<td>Relatives</td>
<td>4.5</td>
<td>0.0</td>
<td>4.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Local markets</td>
<td>4.0</td>
<td>9.0</td>
<td>4.8</td>
<td>5.2</td>
</tr>
<tr>
<td>Own saved seed</td>
<td>2.3</td>
<td>0.0</td>
<td>5.2</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Seed demand and its dynamism

The seed demand of wheat producers is correlated with the farmers’ trust or perception and level of awareness on the seed of improved wheat varieties. In line with this, about 98% of respondents in this study indicated their good perception on seeds of improved wheat varieties for better yield. Even though the farmers had high demand for improved wheat seeds, their demand varied from time to time.

Farmers’ original demand is collected by the development agents (DAs) at peasant association (kebele) level and presented to district agricultural office and the respective cooperative unions. The total demand for wheat seed from all districts is summarized at regional state Bureau of Agriculture (BoA) level and finally submitted to the Ministry of Agriculture (MoA). Based on the available certified seed stock at the seed enterprises, the Ministry of Agriculture makes appropriations to regions as per their demand gathered from the respective unions. The supply then flows down from Ministry to region then to cooperative unions, which distribute seed to farmers’ primary cooperatives. In this long chain, when improved seeds arrive at farmers’ village (primary cooperatives) a large number of farmers fail to take and use the seeds as per their original request. Similarly, among 756 respondents more than 43% changed their plan of seed request, and this was attributed to the loss of improved seeds in warehouses at different segments of seed supply chain. The reasons cited for the change of seed requested by farmers were change in rainfall pattern (19%), change in variety preference and lack of new varieties (26.6%), lack of finance and other complementary packages (25.5%), and shortage and untimely supply (7.5%) as shown in Table 7.

The existing wheat seed price is one important factor contributing to changing seed demand of farmers. However, evaluation of seed price varied among farmers depending on the farmer’s level of awareness and experience on improved seed utilization. Farmers’ evaluation of seed price during 2012 indicated that it was expensive for 51%, affordable for 31% and cheap for 5% of 756 respondents in wheat producing regions of the country.
Table 7: Percentage distribution of respondents based on reasons for changing seed demand

<table>
<thead>
<tr>
<th>Reasons for changing seed demand</th>
<th>Ormia (n=311)</th>
<th>Amahara (n=210)</th>
<th>SNNP (n=235)</th>
<th>Total (N=756)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change of trend of rainfall</td>
<td>3.8</td>
<td>24.8</td>
<td>33.6</td>
<td>18.9</td>
</tr>
<tr>
<td>Change of variety preference</td>
<td>11.1</td>
<td>34.8</td>
<td>39.2</td>
<td>26.6</td>
</tr>
<tr>
<td>Lack of finance</td>
<td>8.4</td>
<td>18.6</td>
<td>54.5</td>
<td>25.5</td>
</tr>
<tr>
<td>Shortage of supply and untimely supply</td>
<td>8.7</td>
<td>6.7</td>
<td>7.6</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Time of improved wheat seed availability determines the farmers’ level of seed utilization. The influence of timely availability of improved seeds was significant in enhancing the farmers’ adoption of improved wheat seeds according to the key informants included in FGD. The survey result indicated that few (2.5%) farmers requested improved wheat seed in December and January whereas majority (17.2%, 27.5% and 32.4%) of the respondents requested for improved seeds in April, May and June respectively. Because of unavailability of improved seed early on time of request, majority of the respondents actually purchased in May and June (Fig 1). Late seed supply contributed to a significant number of farmers to use own saved wheat seed as stated by the farmers in FGD.

Figure 1: Time when farmers’ demanded and purchased improved wheat seed

Conclusion

Availability of good quality seed of improved varieties at required amount and time and in affordable prices is necessary for improved wheat production. Failure to use appropriate seed, while investing sufficiently in other inputs and management practices results into lower yields. Farmers have adequate information on advantages of improved wheat varieties. The information about improved wheat technologies is mainly accessed by farmers with the help of agricultural extension system and information exchange with relatives/neighbors.

There was mismatch between demand for seed of improved varieties from formal sources compared with demand at planting times. When farmers revised their expectations of rainfall, prices and other factors combined with untimely supply of improved seeds, they inclined to shift their requests. Furthermore, the mismatch between time of actual seed availability and farmers’ seed request is the important factor attributed to seed demand dynamism among farmers. Farmers request for seed is high in March, April and May though the existing formal seed supply
system is not ready in those months. Formal supply is high in June, while farmers’ demand is low during this period.

Even though farmers have different perceptions on wheat seed quality, the major criteria used to determine wheat seed quality were freedom from variety and foreign materials mixture, field emergence, freedom from disease (discoloration) and yielding potential. In this regard a significant number of respondents complained about the quality of seeds supplied through the formal system.

**Recommendations**

To enhance the utilization of seed of improved varieties that contributes to boosting of wheat production and productivity the following is recommended from this study:

- Improve linkages among seed producers and processors like cooperatives and unions to enable timely supply of improved seeds to farmers.
- Farmers should have direct access to seed sources: seed sales should be allowed at any time of the year especially to farmers in close proximity to the sale points.
- Seed producers in the formal sector should reconsider their quality management system and ensure strict procedures in seed certification to safeguard the smallholder farmers from using poor quality seeds.
- Facilitate credit services, strengthening wheat research and new variety development.

**Acknowledgement**

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**References**


Transforming pastoral income of small scale wheat farmers in Kenya by enhancing soil and water management strategies in the face of changing climate

Nasirembe, W.W. 1,*, Ooro, P.A. 2, and Kirui, M. 2

1 Kenya Agricultural and livestock Research Organization (KALRO) - Molo, P.O. Box 100 Molo, Kenya; 2 KALRO - Njoro, P.O. Box, Njoro, Kenya

*Correspondence: wnjlwny@yahoo.com

Abstract
Poor crop yield have characterized arid and semi-arid lands (ASAL) of Sub Saharan Africa (SSA). Wheat water requirement is 450-600. This means rainfall in lower Narok is never sufficient under the circumstances. At optimum conditions expected wheat yield is over 3.3 tonnes. Rainfall intensity is the instantaneous amount of rain within a given period, while amount of rainfall is that which occurs during the year. The high rainfall intensity in lower Narok has led to soil erosion and consequently to loss of soil fertility that has led to yield to plummet. Land terrain in addition to pastoral lifestyle of the local community, offer a challenge to young fertile soils with low soil water aggregation stability.

Preliminary evaluation of the impact of rainfall trends, soil and water conservation structures and afforestation on livelihoods was accomplished by analysing historical rainfall data for 30 years to establish rainfall probabilities and rainfall patterns, construction of level terraces and establishing local friendly vegetation on terrace ridges as a mitigation trial laid on selected fields. After terracing, tilling, planting of wheat, applying recommended husbandry practices was undertaken. Data was collected on yield of crop with the assumption that the moisture retained, crop rate of growth and yield within the terrace ridges were a consequence of terracing.

There was an increase by up to 300% in yield due to this practice. Livelihoods of Smallholder wheat producers in lower Narok, can be enhanced by understanding rainfall patterns and probabilities, soil and water management strategies and appropriate bench terrace vertical height design.

Introduction
There has been low crop yield in arid and semi-arid lands (ASAL) of Sub Saharan Africa (SSA) (Creswell et al., 1993). Lower Narok in Kenya is one such area, where annual rainfall is enough to sustain wheat production, but its distribution and intensity adversely affect crop yield since only 250-300mm occur during the long rains from February to May and 100-200mm during short rains of October to December.

The amount is not adequate for wheat crop development. Wheat water requirement is 450-600 (William et al., 2010). This means rainfall in lower Narok is never sufficient under the circumstances. The problem is further compounded by random planting time which further depresses yield. At optimum conditions expected wheat yield is over 3.3 tonnes (Hassan 2004). Rainfall intensity is the instantaneous amount of rain within a given period, while the amount of rainfall is that which occurs during year. The high rainfall
intensity in lower Narok has led to soil erosion (Kenya Soil Survey, 1988) consequently to loss of soil fertility that has caused yield to plummet (Jetzold, et al., 2010).

This is why conservation structures and re-afforestation has been employed for soil and water conservation. Land terrain in addition to pastoral lifestyle of the local community (GEF and IFAD, 2007), offer a challenge to young fertile soils with low soil water aggregation stability. This can get worse if left unattended. It is very important to intervene because the population is growing rapidly while livestock and crop production remain the major economy drivers.

**Objective**

The main objective of the study was to carry out a preliminary evaluation of soil and water conservation structures and re-forestation on wheat yield of small holder farmers in lower Narok.

**Methodology**

Preliminary evaluation of the impact of soil and water conservation structures and afforestation on livelihoods was accomplished by analysing historical rainfall data from the last 30 years to establish rainfall patterns and probabilities, construction of level terraces of 1m vertical height and establishing local environmental friendly vegetation on the ridges on four selected fields.

The terrace laying experiment was set on plots of four land owners in the same catchment. Contour ploughing was undertaken using a disk plough, harrowed and planted with an identical variety of wheat. Neighbour fields that did not receive the treatment acted as control. After terracing, tilling, planting and applying recommended husbandry practices, data was collected on yield of crop with the assumption that the moisture retained, crop rate of growth and yield within the ridges of the terrace were consequences of the terraces.

Four sites were selected and subjected to terrace treatment with known and consistent vertical interval. It is essential to calculate the VI; it not only shows roughly the height of future terraces but also provides the basis for further designing. The simple equation using slope and the width of the bench as the main inputs was as follows: $VI = \frac{(S \times Wb)}{(100 – S \times U)}$ (1) Where S is land slope in percent (%), Wb is the width of the bench, and U is the slope of the terrace riser or side slope. Horizontal to vertical ratio puts is substituted into the equation such as 1 for machine built terraces.
Results

Rainfall Probabilities

Probability diagram with a regression curve for rainfall series, February to June period at Narok Meteorological station from which probabilities of exceedance of a rainfall value of a specific magnitude were obtained by direct reading or by use of the curve characteristic function, \( R = 732.9e^{-0.008P} \). This function can be used to assess rainfall probabilities.

![Probability diagram with a regression curve for rainfall series.](image)

**Figure 1: Annual rainfall Probability curve**

It was observed that the rainfall reliability for the study area was 60% and seasonal average rainfall was found to be 255mm that lasted 41 days during the main season. The date of sowing was established to be not later than mid-March.

Ridge Vertical Interval

Vertical interval, VI, is the elevation difference between two succeeding terraces that determines runoff flow rate which is a function of moisture retained, amount and rate of soil particle displacement and fertility loss. Field conditions did not enable collection of data on these aspects except VI. (Table 1)

**Table 1: Vertical Heights**

<table>
<thead>
<tr>
<th>Farm Owner</th>
<th>Land Size (ha)</th>
<th>% Slope</th>
<th>Width (m)</th>
<th>Vertical Height(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nkuruna</td>
<td>10.5</td>
<td>3</td>
<td>21.3</td>
<td>1.0</td>
</tr>
<tr>
<td>Terere</td>
<td>19.4</td>
<td>4</td>
<td>12.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Naikuni</td>
<td>15.0</td>
<td>5</td>
<td>8.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Londari</td>
<td>18.2</td>
<td>3</td>
<td>21.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Wheat Yield

Terracing had an effect on crop yield having impact of over 300%, Table 2: The yield of other farmers that did not practice the system remained as low as previous. Other factors that could have contributed to the increase in yield but data was not collected include timing of planting time, crop husbandry activities and use of recommended certified seed variety.

Table 2: Effect of terracing on yield of Wheat

<table>
<thead>
<tr>
<th>Farm Owner</th>
<th>Before intervention</th>
<th>After intervention</th>
<th>% increase in Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year0</td>
<td>Year1</td>
<td>Year2</td>
</tr>
<tr>
<td>Nkuruna</td>
<td>0.89</td>
<td>4.00</td>
<td>4.22</td>
</tr>
<tr>
<td>Terere</td>
<td>0.67</td>
<td>2.67</td>
<td>2.67</td>
</tr>
<tr>
<td>Naikuni</td>
<td>1.33</td>
<td>2.89</td>
<td>3.11</td>
</tr>
<tr>
<td>Londari</td>
<td>1.78</td>
<td>3.34</td>
<td>3.34</td>
</tr>
</tbody>
</table>

Discussion

Rainfall documented by many scientific papers is normally presented as annual rainfall but this study shows that although rainfall is recorded across the year, useful rain for establishing a wheat crop is that during the 4 months February to May. It is on this basis that the probability curve has been drawn to inform the smallholder farmers on the risks of rainwater unavailability. This information helps the farmer to plan. Chances of getting 435mm of rainfall and above are 60%. The land terrain is not found to be uniform so every farm has its unique slope. Using the simple formula (Critchley et al., 2001):

\[ V.I. = x s + y \]

Where V.I. = Vertical interval
x=0.4 (value of x varies by geographical location from 0.4-0.8)
s=land slope in percentage
y=a variable with values from 1.0 to 4.0

bench width was found to vary on differing slopes. Steep slopes had shorter widths and gentle slopes had longer bench widths. Short widths do not allow accumulating runoff to gain momentum which would have a destructive (erosive) force. The yield increased from by 88 -275% due to the soil and water conservation efforts that were applied on the farms. There may be other underlying factors that could have been a source of variation but were not documented.
Conclusion and recommendation

Livelihoods of Smallholder wheat producers in lower Narok, Kenya can be enhanced by understanding rainfall patterns and probabilities, soil and water management strategies and appropriate bench terrace vertical height design. This intervention has been found to increase wheat yield by 88-275%.

Actual dates of rainfall onset should be determined to maximize on water utilization. Early land preparation and dry planting is one of the areas that can be perfected for maximum water utilization. Most wheat varieties take over 125 days to mature so varieties that take a shorter period can benefit more and greatly contribute to improving livelihoods through increased yields.

References


Machito Mihara 1, Janya Sang-Arun 2 and Hisashi. Terrace Structure Designing Based on Rainfall Erosivity and Soil Erodibility Mori 1 Tokyo University of Agriculture, Faculty of Regional Environment Science 1-1-1 Sakuragaoka Setagaya-ku, Tokyo 156-8502, Japan


Dairy research and development

Dr. Jean Ndikumana, Dairy Consultant

Abstract
The paper maps out and discusses the Dairy Value Chain, the importance of dairy for the socio-economic development of ECA, Challenges and opportunities, Priorities for investment for the transformation of the dairy industry in ECA and Future prospects. Promotion of research for the sector (in relation to generation and adoption of productivity enhancing technologies) and value addition are discussed with a view of improving sector productivity and increased market access. Diagrammatic mapping of the Dairy value chain is given; Pictures are given and illustrations Tables are given on selected commodity trends. It is concluded that with regional policy harmonization, intensification of research for development and supporting the Public Private partnerships, opportunities for a bright future are abound.

Key words: Dairy Value Chain, ECA, Public-Private- Partnerships, market access, Value addition

Introduction
The Diary sector has been recognised as a major contributor to growth and development in the Eastern and Central African (ECA) countries. Through a study conducted by IFPRI and ASARECA to identify strategic priorities for investment in ECA, conclusions indicate that when ECA is viewed as a region, milk emerges as the most important commodity/sub-sector for growth-inducing investments in research and development among the 15 most important commodities in the region. Milk is followed by Cassava, maize and bananas to mention but a few.

The Growth of demand for livestock products is higher than the production due to factors that include; human population growth with increased incomes and urbanisation followed with change in nutrition/feeding habits. People in towns tend to consume more milk and milk-products. The supply of milk and the milk products is not matching the demand. So deficiency is reported across the region. All ECA member countries except Kenya are net importers of milk and the situation is expected to worsen as indicated by the imports trend.

Harmonisation of quality, safety and standards at regional level has the potential to enhance regional integration and to boost growth in the dairy sector.

The Contribution of Dairy to agricultural GDP
The figure below shows the contribution to the Agricultural GDP for selected commodities/sub-sectors.

Figure 1: Regional AgGDP Gains to 2015 from Growth in Selected Commodity Sub-Sectors
From the figure above, it is clear that Milk contributes significantly (> 400 million USD) to the AgGDB almost doubling contribution from maize, bananas, and vegetables/fruits. Milk too by the nature of its production accords families with daily income unlike other agricultural products which are seasonal. Despite the huge potential dairy industry potends in the region, productivity continues to be hampered by a series of challenges along the dairy value chain. These have resulted in increasing milk deficit in Africa from 913,000 metric tons in 1970 to 3,602,000 now and a projected 5,226,000 tons in 2030. In the ECA region, other than Kenya, all other countries are net importers for milk. In order to upgrade the performance of the value chain, and off-set the huge deficits, key challenges (among them, inadequate feed, diseases and poor markets and marketing) must be addressed. Dairy is therefore a very important commodity within the region to warrant attention to increase productivity, value addition and market access.

The Dairy Value Chain
The Dairy value chain (DVC) is characterised with a number of segments from input supply to final consumers. Sometimes the chain is very short from primary producers straight to the consumers or longer through a number of intermediate stages that include “middlemen: only 20% of the milk is handled through what is a recognised as the formal sector and the 80% is through the informal sector. An effort to increase formal sector contribution is a key intervention area. The performance of the DVC in terms of commodity flow, return on investment, profitability and competitiveness are affected by the following factors and challenges: The subsector is faced with upstream challenges of production levels and productivity and middle stream concerns of value addition and market access.
Mapping of the Dairy Value Chain

The figure below shows the different segments and the recognised pathways from input supply through primary production to the final consumer.

Challenges to increased livestock productivity (up-stream issues)

1. **Low genetic potential**: It’s reported that more than 90% of ECA livestock population are the unselected low production potential indigenous breeds but with excellent adaptive traits. The adaptive traits seem to be negatively correlated to production levels. The regional researchers are called upon to develop/identify suitable dairy breeds (with high productivity while utilising the observed adaptive traits).

2. **Inadequate nutrition**: There is poor availability of feed both in quantity and quality. This has been reported as the single most important constraint to livestock production across countries and across production systems. This challenge is partly occasioned by low efforts by producers to adequately feed their cows, due to lack of economic incentives (e.g. poor milk prices and marketing).
Challenges to value addition and market access (down-stream issues)

1. Unidentified niche markets
2. Inappropriate standards and sanitary regulations
3. Inappropriate tax incentives
4. Poor infrastructures and services
5. Poor access to market information
6. Poor value addition in input output markets
7. Trade barriers and effects of globalisation
8. Poor utilization of innovations
9. Poor organisation and institutional arrangements

The above challenges notwithstanding, there are major opportunities for investment to enhance dairy production and trade in ECA. These opportunities are for both increased productivity and increased market accesses.

Opportunities to increase productivity

The key area with all the different facets is investing in Research to enhance generation and adoption of productivity-enhancing technologies (feeds, trees, health and intensification) and innovations including tapping on the potential of biotechnology, there is potential for exponential growth of the sub-sector. There is a huge productivity gap from using science based technologies/innovations and not using. While in Israel, Dairy Cattle yields average 12,000 litres per animal per year, within this region few animals give up to 4000 litres per year. The Majority of Dairy animals within the region, however give less than 1000 litres per year. Research can produce the Technologies required to close the Gaps and make a difference.

Research for development approach

The research for development should aim at building capacity of actors along the value chain including linking our universities to develop expertise beyond production (Beyond Biology and Farming). The curriculum of universities should be revised to include other critical areas like Dairy technologists. There should be the strengthening the Agricultural Innovation System (AIS) for action research, knowledge management, participatory Monitoring and Evaluation and learning (ME&L), and communication for development. There should be Gender mainstreaming and Environmental and Social safeguards management to ensure sustainability.

Opportunities to enhance market access

Investment in value addition to increase shelf life of milk and its products and responding to consumer demand (quality, standards and safety) are reported to enhance market access. The ECA Countries should endear policies and regulations that increase the quantity of milk on the formal market. The informal sector is handling about 80% of the milk, and this presents challenges of how to maintain the statutory hygiene, quality, and other food-related standards. Governments should support policies that will increase the milk available through the formal sector without necessarily eliminating or “killing” the informal sector. Despite its inadequacies, the informal sector is still important in helping some farmers and the industry as a whole. The adoption of a change from informality to formality can be supported through regulations and giving incentives.
In order to increase access to markets, the current research should focus on (1) supporting the development and harmonization of standards and regulations that affect market access of dairy and dairy products, (2) strengthening policy and regulations to improve market access, (3) market analysis to inform policy and investment options and (4) strengthening organizational and institutional arrangements to enhance market access through the creation of a stronger voice.

**Future Prospects**

There are prospects for transforming the dairy industry which include strengthening of Research to improve productivity through investment in modern technologies including mechanization, automation, and fodder irrigation. The other prospect is the strengthening the research for development innovation system (AIS) approach along the dairy value chain to ensure/ support increased adoption of technologies and innovations. Finally, the future will be brighter if there will be strengthening the public private partnership for investment in post harvesting handling and value addition of dairy and dairy products. The PPP will be supported through

- Strengthening producers’ organizations and organization of other actors along the dairy value chain to ensure they are major actors in the market.
- Enhance partnership with credit and other inputs and services providers for the transformation of smallholder dairy into a modern industry.
- Policies and regulations for channeling more milk from informal into formal sector.
- Strengthen women and youth participation as major actors along the dairy value chain.
- Promote an integrated dairy industry in ECA through policies harmonization.
Preferred phenotypic traits by zebu cattle breeders for dairy production in selected Counties of Kenya

Ilatsia, E.D.1*, K’Oloo, T.O1, Mbuthia, J.M1, Ole Pulei, R.N1, Mbuku, S.M2, Nyambati, E.1 and Indetie, D.3

1Kenya Agricultural and Livestock Research Organization, KALRO-Naivasha Centre, P.O. Box 25 – 20117, Naivasha; 2Kenya Agricultural and Livestock Research Organization, KALRO, Nakuru Centre; 3Eastern Africa Agricultural Productivity Project, Project Coordination Unit
*Correspondence: evansilatsia@yahoo.com

Abstract

This study provides the findings of a broad project that aims to improve Zebu cattle for dairy production through targeted selection and systematic crossbreeding programs in Kenya. The study aimed at analysing the existing farmers’ trait preference of indigenous cattle for milk production through a household survey in Kitui, West Pokot, Busia and Homa Bay Counties of Kenya. Logistic regressions were carried out using SAS computer package and comparisons done across counties. Body frame for bulls and udder size and placement for cows, were the most important traits in selection decisions across counties. Other important traits in cow selection included; teat size, tail length and rumen depth. Traits considered important in bull selection were; appearance, tail length and scrotal size. Despite lack of performance records, performance of relatives was considered important while selecting bulls. Traits like backline and coat colour were perceived to be of lower importance. Drought and disease tolerance were ranked as important attributes preferred by farmers across the counties. Basically, there was a lower perception of indigenous over exotic cattle traits for mature weight, watering frequency and feed requirements. There was no difference in the perception for reproductive performance in Busia and West Pokot and watering frequency in the latter between indigenous and exotic cattle. Improving indigenous cattle productivity will improve the farmers’ options to select and develop breeds adapted to existing diversity in the diverse production environments.

Keywords: Kenya, Selection, Traits Preference, Zebu

Introduction

Despite the growing demand for livestock products and the subsequent response by farmers to increase productivity, about 70% of the cattle in the Eastern Africa region are indigenous and unimproved. This is because there has been no deliberate breeding programme for improvement of indigenous stock (Ouma et al., 2005). This has been compounded by non-existence of herd recording, lack of efficient breed improvement programmes and non-availability of proven superior quality breeding animals thus contributing to the slow progress for genetic merit of local cattle populations (Rege and Wakhungu, 1992). According to Trivedi, (1998) animal recording is very important because it provides information that can enable farmers to compare performance of their own herds and those of other farmers in the community in order to stimulate competition and provide incentives to improve production.

Most of the countries in the region are implementing crossbreeding programmes to upgrade the local cattle
population towards exotic genotypes. However the challenges of adequate and quality feeding, animal health
and other allied services are lacking to support optimal production from these improved breeds. In Kenya, the
trend has been that in the high rainfall Kenya highlands, most of the livestock keepers have opted to change from
indigenous breeds to exotic *Bos Taurus* dairy breeds such as Friesians, Ayrshires, Guernsey and Jersey breeds and
their crosses with *Bos Indicus* cattle with increasing intensification (Bebe *et al*., 2003). In the Southern rangelands
of Kajiado, Narok and Trans Mara, most of the Maasai pastoralists have opted to upgrade from the indigenous East
African Zebu to the Sahiwal which has its origins in India and Pakistan (Ilatsia *et al* 2012).

Most of the farmers in the medium rainfall areas have also been upgrading towards exotic dairy breeds. However,
a vast majority of cattle in Kenya have not been upgraded. The State Department of Livestock estimates that 72% (9
million out of 12.5 million) of cattle in Kenya are Zebu (MoLD 2010). However, in some production systems, the
pace of introgression has been too rapid to the extent of endangering the indigenous breeds with threats of extinction
(FAO, 2007; Rege *et al*., 2011). Since 1990, 300 out of 6,000 breeds identified by FAO have become extinct and
many more are at risk, mainly because of unplanned intensive selection and cross-breeding (Cardellino, 2006).
Traditional breeds which have evolved over generations and have become well adapted to the local conditions are
being lost in the process of cross-breeding. The resultant short term increase in productivity of marketable products
such as milk and meat from these exotic breeds and their crossbreds have often resulted in genetic erosion of
adaptability traits that allow the very existence of these cattle in these harsh environments (Conway and Waage,
2010). This is largely due to lack of proper design and implementation and management of breeding programs and
management of breeding programs and schemes for the indigenous breeds. There is therefore need for better understanding of the livestock genetic characteristics, to inform their proper improvement (Gamba, 2006).

The livestock systems are faced with a myriad of production constraints such as harsh environmental conditions,
prevalence of pests and diseases, frequent droughts and low input management hence lowered productivity.
Understanding the traits preference among cattle keepers will support improvement of indigenous cattle genotypes
that are well adapted to the environment and capable of dairy production and performing the multiple roles that
cattle play in these production systems. The national programs can also prioritize local needs for productivity,
adaptability and genetic conservation and find ways of extending this information to the local owners. This study
evaluates different traits and breed preferences for indigenous and crossbred cattle in selected arid and semi-arid
lands (ASAL) counties in Kenya.
Materials and methods

Study areas

A household survey was conducted by way of personal interviews using a structured questionnaire by a team of trained enumerators in four selected counties of Kenya. The counties; Kitui, West Pokot, Busia and Homa Bay were selected because of the significant proportion of indigenous cattle. Kitui County is located in Eastern part of Kenya. The climate of Kitui County is semi-arid with very erratic and unreliable rainfall. Most parts of the county are hot and dry resulting in very high evaporation rates. The daily temperatures range from 14 °C to 34 °C and the rainfall is distributed in two seasons and ranges from 500mm to 1050mm per annum in different parts of the county with about 40% reliability (FAO, 2008).

West Pokot County is located in the Northern part of the Rift Valley. The vast majority of the County is arid and semi-arid with the erratic and unreliable rainfall patterns. However, there are some parts of the county that are highly elevated and receive a considerable amount of rainfall. The rainfall in the county is two seasonal and ranges from 400mm in the lowland areas to 1500mm in the highlands. The daily temperatures range from 10 °C to 30 °C.

Busia County is located in Western part of Kenya and borders Uganda to the West and Lake Victoria to the South. It is a medium potential agricultural area with annual rainfall ranging from 750mm to 1,800mm per annum and an average daily temperatures of 22 °C. The proximity of West Pokot and Busia to Uganda would offer an excellent opportunity for future exchange of germplasm through cross-border livestock trade among communities living along the border regions of both Kenya and Uganda. The last target county was Homa Bay County which is located in the South Western part of Kenya. The annual rainfall ranges from 250mm to 750mm per annum with daily temperatures ranging from 17.1 °C to 34.8 °C.

Data collection and analysis

This study was conducted using a household survey of 360 randomly selected households. Survey questionnaire was designed to collect information on farm characteristics, production and breeding objectives and practices. Optional answers were provided and where appropriate, the farmer was asked to rank ordinal responses on a scale ranging from (1) for less important to (3) for very important. For the questions pertaining to traits preference and selection criteria, the farmer was asked to rank the traits that he/she considers to be either less important, important or very important.

Descriptive statistics and logistic regression were carried out in SAS, (2003) and results presented in tabulated summaries. Logistic regression in terms of trait preference and selection criteria was used to compare the preferences across counties. A cumulative logit model was used to analyse the importance of the animal characteristics on selection or preference of various traits across the regions. Indices were calculated to provide an overall ranking for constraints to production in each county. The indices represent weighted averages of all rankings for a particular constraint. The following equation adopted from Bett et al (2009) was used to calculate the index (Ii) for each trait or purpose

\[
I_i = \frac{\left( \sum_{j=1}^{3} X_j \right)^3}{\sum_{i=1}^{n} \left( \sum_{j=1}^{3} X_j \right)^2}
\]
Where $X_i$ is the percentage of respondents ranking the trait $i$ in the $j$th rank and $k$ is the sum of ranks for $n$ number traits or purposes.

**Results**

**Household socio-economics and characteristics:**

Out of the 360 households surveyed, 60% of the respondents were males and 40% females. However, 87% of the sampled households were headed by men. Only 13% were female headed household with Kitui reporting the highest percentage of female headed households at 22% and West Pokot reporting the least number of female headed households at 6% (Table 1). The proportion of female headed households in Busia and Homa Bay were reported to be 12% and 13% respectively.

**Table 1: Distribution of socio-economic characteristics of respondents in terms of the percentages (N=360)**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Category</th>
<th>Kitui</th>
<th>West Pokot</th>
<th>Busia</th>
<th>Homa Bay</th>
<th>Overall %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender of respondent</td>
<td>Male</td>
<td>51</td>
<td>77</td>
<td>45</td>
<td>69</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>49</td>
<td>23</td>
<td>55</td>
<td>31</td>
<td>40</td>
</tr>
<tr>
<td>Gender of the household head</td>
<td>Male</td>
<td>78</td>
<td>94</td>
<td>88</td>
<td>87</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>22</td>
<td>6</td>
<td>12</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Age group of household head</td>
<td>&lt;25</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>25 to 35</td>
<td>8</td>
<td>37</td>
<td>30</td>
<td>20</td>
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<td></td>
<td>46 to 65</td>
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<td>32</td>
<td>41</td>
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<td></td>
<td>&gt; 65</td>
<td>16</td>
<td>5</td>
<td>9</td>
<td>15</td>
<td>11</td>
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<td>Education level of household head</td>
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<td>10</td>
<td>16</td>
<td>5</td>
<td>7</td>
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<tr>
<td></td>
<td>Lower Primary</td>
<td>11</td>
<td>9</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Upper Primary</td>
<td>46</td>
<td>51</td>
<td>38</td>
<td>37</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>Secondary</td>
<td>30</td>
<td>19</td>
<td>39</td>
<td>38</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>College/</td>
<td>4</td>
<td>5</td>
<td>12</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>University</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean household size</td>
<td>7±3</td>
<td>9±5</td>
<td>7±3</td>
<td>8±3</td>
<td>8±4</td>
<td></td>
</tr>
</tbody>
</table>

Most of the sampled household heads (37%) were aged between 46 to 65 years old, followed by those aged between 36 to 45 years, (26%). West Pokot had the highest proportion of youth household heads (37%) aged between 25 and 35 years old, while Kitui had the highest proportion of old household heads (16%) aged over 65 years of age and 52% of household heads aged between 46 and 65 years. The highest proportion of household heads with higher level of education was recorded in Busia County with 12% having attained post-secondary level of education and a total of 51% of the household heads having attained secondary school and above. However, the situation was rather different in West Pokot County where 16% of the household were illiterate and up to 60% had only basic primary education.
The household sizes were found to be highest in West Pokot with an average household size of 9±5 members. This was followed by Homa Bay County with an average household size of 8±3. Busia and Kitui Counties had smaller household sizes both at 7±3.

Livestock breeding systems:
Most of the farmers (60%) across all the counties mainly use borrowed bull or communal bull for breeding. However, the practice is more prevalent in Busia and West Pokot where up to 69% and 56% of the farmers respectively used borrowed bulls for breeding purposes as presented in Table 2: There are also high chances of inbreeding as 24% of the farmers both in West Pokot and Homa Bay use bulls that were born and bred within their homes.

Table 2: Livestock breeding systems practiced by various farm households (%)

<table>
<thead>
<tr>
<th>Source of breeding bull</th>
<th>Kitui</th>
<th>West Pokot</th>
<th>Busia</th>
<th>Homa Bay</th>
<th>Overall % in all the counties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Own bull (bred)</td>
<td>19</td>
<td>24</td>
<td>13</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>Own bull (bought)</td>
<td>27</td>
<td>15</td>
<td>8</td>
<td>26</td>
<td>18</td>
</tr>
<tr>
<td>Donated bull</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Borrowed bull</td>
<td>49</td>
<td>56</td>
<td>69</td>
<td>35</td>
<td>53</td>
</tr>
<tr>
<td>Communal bull</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>11</td>
<td>6</td>
</tr>
</tbody>
</table>

Access to breeding services

<table>
<thead>
<tr>
<th>Access to breeding services</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9</td>
<td>91</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>89</td>
</tr>
</tbody>
</table>

Source of breeding service

<table>
<thead>
<tr>
<th>Source of breeding service</th>
<th>Bull scheme</th>
<th>AI service</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.6</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>2.8</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>2.2</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>6.4</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Sale of milk

<table>
<thead>
<tr>
<th>Sale of milk</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>49</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>49</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>59</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>37</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>49</td>
<td>51</td>
</tr>
</tbody>
</table>

Average land holding (SD/SE)

| Average land holding (SD/SE) | 10±1±6.5 | 12.9±16.1 | 4.8±4.3 | 5.2±6.9 | 8.2±12.5 |

Average Herd size

| Average Herd size | 5±4 | 13±19 | 4±3 | 10±12 | 8±12 |

Access to improved breeding services by the farmers across all the counties was relatively poor (11%). It is only in Busia and Homa Bay Counties where there was about 14% and 12% access to breeding services respectively. The level of access to such services in the other Counties was less than 10%. However, most of the people who had access to breeding services used the bull services rather than artificial insemination as only 3.6% used A.I. services. The results indicate that more farmers in Busia County (59%) sell milk as compared to their counter parts in the other Counties (Table 2).

The largest herd sizes were reported in West Pokot County where the average herd size was 13 heads of cattle with some households having a herd of more than one hundred heads of cattle. This was followed by Homa Bay County with an average herd size of 10 heads of cattle. The County with the lowest herd size per household was Busia with an average herd size of 4 heads of cattle per household. The herd size seems to be directly related to the average land holding where households in West Pokot are reported to have the highest land holding at around 13 acres per household and the smallest land holding being reported in Busia with an average land holding of 4.8 acres per household (Table 2).
Traits preference:

In ranking the important criteria for cattle selection, farmers were provided with phenotypic characteristics considered important in selection for milk production. Tables 3 and 4 presents the odds ratio estimates and their 95% confidence intervals from logistic regression for the ordinal ranks of traits considered while selecting for bulls and cows respectively across the various counties. Essentially, if the odds ratio exceeds one (1) then there is no difference in the stated perception of the traits. There is a better perception when the odds ratio is greater than one and a lower perception when it is less than one (Bebe et al., 2003). The odds ratio is significant when its 95% confidence interval excludes one. The odds ratio estimates for bulls represent a measure of the relative importance when ranking a characteristic relative to body frame which was the most highly ranked characteristic across all the Counties.

Table 3: Odds Ratio Estimates and their 95% Confidence Intervals for Phenotypic characteristics for Bulls

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Kitui</th>
<th>West Pokot</th>
<th>Busia</th>
<th>Homa Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body frame†</td>
<td>Ref</td>
<td>Ref</td>
<td>Ref</td>
<td>Ref</td>
</tr>
<tr>
<td>Scrotal size</td>
<td>1.17 (0.80, 1.69)</td>
<td>1.08 (0.77, 1.52)</td>
<td>1.37 (0.96, 1.95)</td>
<td>1.67 (1.13, 2.47)</td>
</tr>
<tr>
<td>Appearance</td>
<td>1.39 (0.96, 2.01)</td>
<td>1.56 (1.12, 2.19)</td>
<td>1.80 (1.28, 2.53)</td>
<td>2.08 (1.41, 3.04)</td>
</tr>
<tr>
<td>Tail size</td>
<td>1.18 (0.81, 1.71)</td>
<td>1.27 (0.91, 1.78)</td>
<td>1.69 (1.19, 2.41)</td>
<td>1.73 (1.16, 2.56)</td>
</tr>
<tr>
<td>Performance of relatives</td>
<td>1.26 (0.87, 1.82)</td>
<td>1.30 (0.93, 1.82)</td>
<td>1.59 (1.13, 2.24)</td>
<td>1.90 (1.30, 2.78)</td>
</tr>
</tbody>
</table>

†Body frame was the reference characteristic in the model comparison because it was the most frequently ranked criteria for bull selection.

In all the Counties, body frame ranked highly as criteria for bull selection, hence its assignment as the reference body characteristic in the model. Bulls were selected more based on their appearance than on performance of relatives and phenotypic characteristics such as scrotal size and tail length in all counties. Despite the lack of records, farmers had a high preference for bulls whose lineage and performance can be traced (Table 3).

While selecting cows for dairy purposes, farmers in Kitui and Homa Bay Counties ranked highly teat size as a very important trait as opposed to West Pokot and Busia Counties where body shape took precedence (Table 4). In addition to a well-placed udder, farmers associate big teat size to more milk and ease of milking. Rumen depth was ranked highly in Kitui and West Pokot Counties compared to Busia and Homa Bay. Farmers perceived that cows with big rumen capacities would tend to eat more and probably convert the feed to more milk and meat. However, this may be a challenge in areas facing frequent droughts.
Table 4: Odds Ratio Estimates and their 95% Confidence Intervals of Phenotypic Characteristics for Selection of cows

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Kitui</th>
<th>West Pokot</th>
<th>Busia</th>
<th>Homa Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Udder and teat Placement b</td>
<td>ref</td>
<td>ref</td>
<td>Ref</td>
<td>ref</td>
</tr>
<tr>
<td>Tail Length</td>
<td>1.32 (0.91, 1.91)</td>
<td>1.35 (0.96, 1.90)</td>
<td>1.18 (0.83, 1.66)</td>
<td>1.18 (0.82, 1.71)</td>
</tr>
<tr>
<td>Teat Size</td>
<td>1.67 (1.15, 2.43)</td>
<td>1.38 (0.98, 1.93)</td>
<td>1.34 (0.96, 1.87)</td>
<td>1.39 (0.96, 2.01)</td>
</tr>
<tr>
<td>Dewlap Size</td>
<td>1.44 (0.10, 2.07)</td>
<td>1.39 (0.99, 1.95)</td>
<td>1.30 (0.93, 1.83)</td>
<td>1.26 (0.87, 1.83)</td>
</tr>
<tr>
<td>Rumen Depth</td>
<td>1.63 (1.13, 2.36)</td>
<td>1.49 (1.06, 2.10)</td>
<td>1.26 (0.990, 1.75)</td>
<td>1.28 (0.89, 1.85)</td>
</tr>
<tr>
<td>Body Shape</td>
<td>1.49 (1.02, 2.17))</td>
<td>1.56 (1.11,2.20)</td>
<td>1.59 (1.13, 2.24)</td>
<td>1.11 (0.76, 1.61)</td>
</tr>
<tr>
<td>Back line</td>
<td>1.42 (0.99, 2.01)</td>
<td>1.29 (0.93, 1.80)</td>
<td>1.26 (0.90, 1.77)</td>
<td>1.05 (0.72, 1.52)</td>
</tr>
<tr>
<td>Coat colour</td>
<td>1.12 (0.77, 1.62)</td>
<td>0.91 (0.65, 1.29)</td>
<td>1.05 (0.74, 1.47)</td>
<td>0.99 (0.68, 1.45)</td>
</tr>
</tbody>
</table>

*b* Udder and placement was the reference body characteristic in the model comparison because it was the most frequently ranked criteria in cow selection.

In all counties, coat colour was mainly ranked as less important in selecting for dairy characteristics. Other traits such as tail length, dewlap size and backline were perceived to have little influence when selecting for dairy traits. However, some farmers associate a long tail with a thick tail brush to more milk.

Farmers were asked to state whether they prefer the indigenous to exotic cattle. The preference was 58%, 37%, 46% and 23% in Kitui, Homa Bay, West Pokot and Busia respectively. Table 5 presents the odds ratio estimates and their 95% confidence intervals from logistic regression for the ordinal ranks of farmers’ preference for Zebu to exotic genotypes. The odds ratio represents a measure of the relative importance when ranking characteristics relative to drought tolerance. Results indicate an overlapping ranking of both drought and disease tolerance, traits which make farmers prefer zebu to exotic or crossbred cattle. Preference for different indigenous over exotic or crossbred cattle traits varied with region as shown in Table 5.

Table 5: Odds Ratio Estimates and their 95% Confidence Intervals for Preference of Zebu to Exotic Genotypes

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Kitui</th>
<th>West Pokot</th>
<th>Busia</th>
<th>Homa Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature Weight</td>
<td>0.79 (0.55, 1.15)</td>
<td>0.84 (0.57, 1.23)</td>
<td>0.84 (0.54, 1.31)</td>
<td>0.83 (0.56, 1.22)</td>
</tr>
<tr>
<td>Watering Frequency</td>
<td>0.93 (0.65, 1.34)</td>
<td>1.00 (0.69, 1.44)</td>
<td>0.96 (0.90, 0.58)</td>
<td>0.96 (0.67, 1.37)</td>
</tr>
<tr>
<td>Feed Requirements</td>
<td>0.71 (0.49, 1.04)</td>
<td>0.87 (0.59, 1.27)</td>
<td>0.90 (0.58, 1.38)</td>
<td>0.85 (0.56, 1.24)</td>
</tr>
<tr>
<td>Reproductive Performance</td>
<td>0.91 (0.64, 1.31)</td>
<td>1.00 (0.70, 1.46)</td>
<td>1.00 (0.68, 1.46)</td>
<td>0.97 (0.68, 1.39)</td>
</tr>
</tbody>
</table>

^ Drought tolerance was the reference Trait of comparison in the model because it was the most frequently preferred characteristic for Zebu Cattle.
Livestock keepers perceive that exotic cattle perform well in terms of mature body weight, and unexpectedly, feed requirements. Considering region-wise comparisons, results for Kitui could be influenced by the frequent droughts. From the results, it follows that there was no difference in preference for reproductive performance in Busia and West Pokot counties and watering frequency in the later for indigenous over exotic cattle (Table 5).

**Challenges to production:**

Farmers are faced with a number of production constraints ranging from lack of feeds, disease prevalence to lack of breeding materials as well as poor market access. Some of the constraints to production facing farmers in the study counties are provided in Table 6:

<table>
<thead>
<tr>
<th>Constraint</th>
<th>Rank Index</th>
<th>Kitui</th>
<th>West Pokot</th>
<th>Busia</th>
<th>Homa Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of Feed</td>
<td>0.28</td>
<td>0.23</td>
<td>0.21</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Frequent Drought</td>
<td>0.26</td>
<td>0.12</td>
<td>0.03</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Lack of Water</td>
<td>0.26</td>
<td>0.12</td>
<td>0.04</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Disease Prevalence</td>
<td>0.09</td>
<td>0.28</td>
<td>0.33</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>Breeding Stock</td>
<td>0.02</td>
<td>0.14</td>
<td>0.12</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Inadequate Extension Services</td>
<td></td>
<td>0.04</td>
<td>0.10</td>
<td>0.24</td>
<td>0.14</td>
</tr>
<tr>
<td>Lack of Market</td>
<td>0.01</td>
<td>0.05</td>
<td>0.03</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Cattle Theft</td>
<td>0.00</td>
<td>0.00</td>
<td>0.03</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Lack of Credit</td>
<td>0.04</td>
<td>0.06</td>
<td>0.08</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

*1=less important, 2=important, 3=Very important

These constraints should be understood so that improvement programmes should be set within their context. In Kitui County, lack of feed, water and frequent droughts were reported to be the major constraints. These factors reflect the harsh environmental conditions experienced in this semi-arid region. On average in the other Counties disease prevalence was cited as the main constraint. Diseases mentioned were mainly tick-borne such as East Coast Fever (ECF) and anaplasmosis and frequent Foot and Mouth Disease (FMD) outbreaks. This aspect of disease prevalence can be supported by the ranking of inadequate extension and veterinary services as a constraint preceding disease prevalence. Lack of quality breeding animals was also viewed as a constraint in West Pokot and Busia Counties.

**Discussion**

Understanding of the gender roles is important in planning gender sensitive livestock breed utilization and conservation schemes. The generally higher proportion of male respondents in the sample size is understandable because cattle production and ownership have always been culturally associated with the male gender in most African communities. Such association has been reported by a number of studies (Amimo et al., 2011; Ilatsia et al., 2012). Men are also the heads of most households, therefore it is only natural that they respond to matters pertaining to livestock, save for the exceptional situations when they may not be present at home. However, the glaring disparity between the female headed households in Kitui and West Pokot Counties is worth noting.
This disparity can be attributed to the socio-cultural attributes of the communities living in those counties. The Pokot people come from a pastoral background where polygamy is acceptable and there is male dominance in livestock farming activities. This observation is consistent with what was reported in earlier studies by Mwacharo and Drucker (2005); Kosgey et al., (2008); Ilatsia et al., 2012). Most of the Pokot men have a special attachment to livestock that is why very few of them migrate to urban areas in search of jobs. Most men in Kitui County on the other hand move to the nearby towns in search for jobs, some of whom leave their women to take care of their homes, giving rise to the high proportion of female headed households (22%) as compared to other counties.

Many studies have shown that education can play a very important role in the livelihoods of the livestock keeping households. It influences their judgement and decision making process at the household level. Education levels of the household heads in the study Counties varied, with people from Busia County having on average higher levels of education as compared to their counterparts in West Pokot County. Tambi et al., (1999) reported education to significantly influence the type of decisions made at the household level including adoption of livestock upgrading programs. This could explain the slightly higher level of adoption of improved breeds and use of AI and other breeding services in Busia County compared to other counties where education levels of household heads is comparatively lower. Similar observations were made by Ilatsia et al., (2012) between the Maasai pastoralists of Kajiado County and those of Narok County. In this study, it was evidenced that farmers who had higher levels of education had higher rate of adoption of the improved cattle genetic resource.

Farmers have been selecting for useful traits in their herds for thousands of years since the first domestication of animals (Conway and Waage, 2010; Rege et al., 2011). Cattle have been selected for such obvious characteristics as size, colour, shape of their horns and in some cases, resistance to diseases. Understanding the breed and trait preferences is useful in making informed decisions on developing interventions to improve the contribution of cattle to livelihoods of the farmers (Garoma et al., 2013).

From the results, a big body frame which also translates to heavier body seems to be the main focus in bulls preference. Bulls provide draught power in the crop-livestock systems. Here, good traction ability is important since bulls are used for ploughing crop fields and pulling carts (Ouma et al., 2005). In addition to high traction ability, a bigger bull would also mean a higher market value during sale. This is important during sale either for slaughter or to other farmers for production which is common practice (Bebe et al., 2003). Similar observations were made by Ilatsia et al., (2012) among the Maasai pastoralists of Kajiado and Narok Counties who have a higher preference for the sahiwal breed of cattle which are relatively bigger in size than the East African short horn zebu (EASZ). However, farmers still feel that indigenous cattle do not match the exotics in terms of mature weight (Table 5). In most of the study areas, all categories of livestock are communally grazed, where cows are mixed with bulls. Castration of bulls is not common and therefore controlled mating becomes difficult to implement. This hampers efforts to utilize bulls with preferred traits. This form of communal grazing is a major hindrance to the traceability of performance of bull sibs and their relatives.

In cow trait preference, traits that farmers associate with high milk yield had the highest odds ratios. These traits included udder size and placement which was the reference body characteristic and teat size. It has been reported that high preference for milk traits is common among many traditional African cattle owners because they keep cattle primarily for milk with accumulation of stock as a form of investment playing secondary role (Garoma et al., 2013). Milk sales were considered as a possible incentive for the farmers to upgrade their livestock to higher milk producing breeds. More farmers (59%) in Busia County were selling milk as compared to their counterparts...
in the other counties. This was seen to have a positive correlation with access to breeding services, however it had a negative correlation with the number of people owning bulls for breeding purposes. This can only be a clear indication that milk is a major production objective for the cattle keepers in this region and most of the farmers are keeping female cows mainly for this purpose.

Considering that a large herd size is an indicator of wealth, reproductive performance becomes highly valued because it ensures fast herd increases (Ouma et al., 2005). Cows that can produce a calf per year become more valued than a cow yielding more milk per lactation. According to Tada et al., (2003) in Burkina Faso, reproductive performance of cows is the most preferred trait compared to milk yield and disease resistance.

In all counties, coat colour was mainly ranked as less important in selecting for dairy characteristics. This is in contrast to Garoma et al., (2013) who reported high preference for coat colour in Kereyu cattle citing ecological significance in the region. Although not mentioned, this was observed in the current study whereby most of the cattle in Kitui are light coloured. Most of the study areas are infested with tsetse flies which are a nuisance to livestock. They disrupt feed and transmit diseases and therefore preference should be for colours that do not attract tsetse flies i.e light coloured cattle. Although farmers indicated that this has no major inclination to milk yield, the disruption and sickness is expected to affect the livestock’s productivity adversely.

It was only in Kitui County where a large proportion of farmers still prefer rearing indigenous cattle. This is probably due to ecological suitability and demand for draught animals, in mixed crop-livestock systems. According to Otieno, (2013), this may be explained by the adaptation of the local breeds to the limited pasture and water supply and harsh conditions as a result of the relatively dry and hot climate. In Busia and West Pokot the climate is not harsh and supports improved breeds. Crossbreeding is rife in all counties where farmers use large exotic breeds to upgrade their indigenous cattle. The transition of West Pokot’s topography from high altitude areas where crop agriculture and livestock production are the major economic activities to undulating plains which are predominantly pastoral lands offer a variety of production systems. The high potential areas producing exotic dairy cattle and lowlands hosting indigenous cattle has exposed farmers to uncontrolled crossbreeding activities. In Busia, the tendency is to upgrade mainly using the Ayrshire. This has been propelled by the support from Heifer Project International in the region which promotes dairy productivity using exotic breeds. Unless conditions are favourable, the use of large exotic breeds in smallholder systems is discouraged because of their high nutritional demand, poor milk yield under these conditions and adaptability and production inefficiency (Kahi et al., 2000; Bebe et al., 2003).

The constraints reported here are in line with other reports in the Kenyan ASALs (e.g. Mwacharo and Drucker, 2005; Otieno, 2013). Due to these constraints, rearing of exotic breeds has been low in the ASALs because of their low adaptability. Lack of appropriate policies and failure to effectively implement existing policies are major constraints to the development of the smallholder livestock sector in developing countries. This limits the potential of the sector to reach its full potential to contribute to economic growth and poverty alleviation through trans-boundary trade (Rege et al., 2011).
References


Cardellino R 2006 Status of the World’s livestock genetic resources: preparation of the first report on the state of the World’s animal genetic resources. In: The role of biotechnology in exploring and protecting agricultural genetic resources. FAO.

Conway G and Waage J 2010 Science and Innovation for development. UK. Collaborative on development science.


FAO 2008 Food security outlook, Kitui District


Ouma E, Abdulai A and Drucker A 2005 Assessment of farmer preferences for cattle traits in cattle production systems of Kenya. 11th congress of the European Association of Agricultural Economists. (pp1-14). Copenhagen, Denmark.


Tada O, Muchenje V and Dzama K 2013 Preferential traits for breeding Nguni cattle in low-input in-situ conservation production systems. SpringerPlus, 2, 195


The use of Assisted Reproductive Techniques in multiplication of Small East African Zebu cattle in Makueni County, Kenya.

Kihurani, D.*; Mburu, J.^; Kosgei, I.; Mbuku, S.; Ngigi M.; Katiku, P. and Wambulwa, L.

*University of Nairobi; ^Egerton University; †Laikipia University, KALRO, ‡Lanet and #Kiboko.

Abstract:
The use of modern technologies in rapid multiplication of livestock germplasm is important in availing breeding stock, particularly cattle which have a long generation interval. Two such technologies are Multiple Ovulation and Embryo Transfer (MOET) as well as Estrous synchronization and Artificial Insemination (ES & AI). They are Assisted Reproductive Techniques (ARTs) that were used for genetic improvement in a Small East African Zebu (SEAZ) herd at the Kenya Agricultural and Livestock Research Organization (KALRO), Kiboko, Makueni County. The cattle were selected on the basis of a relatively high milk yield, fertility as shown by regularity of oestrus and calvings, adaptability to the semi-arid environment, and good health. Four MOET programs were performed, each with 4 donors and 16 recipient cattle. In addition, one ES & AI program was done using 30 SEAZ. From the MOET programs 23 transferable embryos were obtained and implanted into suitable recipients. Pregnancy diagnosis was thereafter done using ultrasound, out of which 8 were confirmed pregnant. Of this lot, several calves have already been born. The cattle on the ES & AI program have also been examined and a further 6 confirmed pregnant. Of this lot, several calves have already been born. The cattle on the ES & AI program have also been examined and a further 6 confirmed pregnant. Challenges encountered during these programs included drought periods with inadequate pasture and water, competition for the available pasture with illegal cattle and camel grazers, irregular concentrate supplementation due to funding constraints, and a Foot and Mouth Disease outbreak. Nevertheless, these results demonstrate that ARTs, particularly MOET which is being performed for the first time in SEAZ in Kenya, can be utilised with some success. This exercise is also creating a SEAZ nucleus herd with heifer and bull offspring which can be availed to local farmers for breeding.

Key words: Donors, Estrous Synchronization, Kenya, Multiple Ovulation and Embryo Transfer, Recipients, Small EA Zebu.

Introduction
Kenya has a total cattle population of 17,467,774 (National Census 2010). Indigenous cattle constitute 77% of this cattle population, with most of it being reared in the dry parts of the country, such as Makueni County. These cattle mostly have a thoracic hump and are either classified as Small or Large East African Zebu (i.e. SEAZ or LEAZ). The number of this group of cattle is much higher, in comparison to the exotic breeds, because they are able to thrive and breed well in arid and semi-arid regions that constitute a big portion of Kenya (Rege et al., 2001).

In spite of the large numbers of EA Zebu cattle and their wide distribution in the country, little work has been carried out to improve their genetics through selection along production lines e.g. milk
production. The reason being that the breed is small in stature, produces little quantities of milk and is owned primarily by low income farmers, hence considered uncompetitive economically. Nevertheless, in the semi-arid regions the Zebu are valued for their adaptation to the harsh environment, hardy nature, disease resistance and as draught animals (Rege et al., 2001). It is therefore important to improve this group of cattle through selection of superior (i.e. higher milk producing) indigenous cattle and then shorten the time of multiplication through use of available reproductive technologies.

The Assisted Reproductive Techniques (ARTs) used in breeding of cattle include: (i) Multiple Ovulation and Embryo Transfer (MOET); (ii) Estrous synchronization and Artificial Insemination (ES & AI); (iii) Sexed semen utilization; and (iv) In-vitro embryo production (IVEP)(Seidel and Seidel, 1991; Davis, 1998). The techniques selected to multiply the desired SEAZ traits in this project were MOET, ES and AI.

Artificial Insemination (AI) is the most widely used ART and the one that has made the most significant contribution to genetic improvement in Kenya and globally. It is also an integral part of both MOET and ES. On its own though, it has mainly been used in cross breeding programs between the SEAZ and exotic breeds. However, it is argued that this cross breeding makes these indigenous breeds vulnerable to genetic erosion of the special reservoir of adaptive genes for tolerance/resistance to extreme environments, parasites and diseases (Rege et al., 2001).In addition, the main semen production center in Kenya (the Kenya Animal Genetics Resource Center) does not have SEAZ bulls, hence does not supply its semen. Natural breeding using local bulls is therefore practiced by farmers, including those of Makueni County (Mbure et al., 2013). This project sought to conserve the purebred SEAZ genetics with AI using the same breed. The use of AI also reduced the risk of disease transmission that is more likely with the traditional use of bulls.

In addition, MOET was selected as a breeding tool to amplify the reproductive rates of genetically superior cows. An initial baseline survey was done in Makueni County and the majority (84%) of the SEAZ cattle produced less than 3 liters of milk per day at peak lactation (Mbure et al., 2013; Ngige et al., unpublished data). Cows producing 4-6 liters of milk per day (4% of population, N = 339) were therefore considered superior in this trait. This group of higher milk producing cows was targeted for breeding using MOET, where they would be enabled to have more offspring than would be possible naturally. For example, a cow normally produces one calf in a year, but using MOET, this can be increased exponentially depending on the number of embryos harvested and the conception rates following embryo transfer into surrogates. A donor cow can also be bred every 2 months using MOET, further increasing the number of offspring. The technique uses superior bulls too so both the genetic potential of the male and female are tapped hence maximizing production (Seidel and Seidel, 1991; Davis, 1998; Baruselli et al, 2006). In addition, embryo transfer is used for preserving genetic material of valuable indigenous breeds by cryopreservation of embryos (Seidel and Seidel, 1991).

The advantages of ES prior to AI include improving the efficiency of heat detection and therefore timely service of the cows. It also reduces the professional labour requirements when large numbers of cattle are synchronized, to be inseminated at the same time (O’Connor, 2014). This technique was therefore used to complement MOET and increase the breeding stock for the nucleus herd of SEAZ to be availed to the local community.

Materials and methods
**MOET**

**Study design**

The MOET was performed in 4 phases as illustrated in Table 1:

<table>
<thead>
<tr>
<th>Phase</th>
<th>Period</th>
<th>Groups</th>
<th>No. of Donors</th>
<th>No. of Recipients</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>July 2014</td>
<td>1</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>August 2014</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>November 2014</td>
<td>5</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>January 2015</td>
<td>7</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>2</td>
<td>8</td>
</tr>
</tbody>
</table>

These MOET programs were all carried out at facilities (Cattle boma and lab) constructed at the Kenya Agricultural and Livestock Research Organization (KALRO), Kiboko, Makueni County. Some donors utilized during the first 2 phases were re-used during phase 3 and 4. In addition, those recipients that did not conceive during the first 2 phases were re-used in phases 3 and 4.

Eight steps were followed in MOET process as indicated below:

**i. Selection of donor cattle**

Donors are the cattle from which the embryos were harvested. The SEAZ that were relatively high milk producers (4-6 litres / day) from previous KALRO Kiboko data were selected (Mwacharo et al., 2006; and unpublished data). They were also fertile, having already had between 1 to 4 normal calvings, between 5 and 10 years of age, with no genetic or health defects on examination. The SEAZ had typical Kamba Zebu physical features such as black, red, fawn or grey coat colour, a cervico-thoracic hump, pendulous dewlap and small to medium body size (Rege et al., 2001; Mwacharo et al, 2006). These phenotypic traits were used in the absence of genotypic tests (e.g. genotyping by sequencing) as the funding to do this was not provided as originally proposed.
ii. Selection of recipient cattle

Recipients are the surrogate cows into which the embryos are implanted. They were selected based on their good body condition, high fertility (regular oestrus cycles), ability to calve easily, sound health as well as good mothering ability based on previous calvings. These recipients were from the SEAZ breed as well as other breeds (e.g. Boran, Sahiwal, Cross-breeds, etc.). They did not need to be pure SEAZ as this does not affect the genetic composition of the embryo.

iii. Super-ovulation of donors

Normally, the ovary of a cow releases one ovum (egg) during oestrus (heat). However, following hormonal stimulation, using Follicle Stimulating Hormone (sold as Folltropin®), the ovary can release many ova (i.e. super-ovulation). The super-ovulation process that was used in this study is detailed out in the donor program in Table 2 below.

Table 2: Donor and recipient programs in MOET.

<table>
<thead>
<tr>
<th>Day</th>
<th>Time</th>
<th>Donor Program</th>
<th>Recipient Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>am</td>
<td>Multimin 5ml</td>
<td>Multimin 5ml</td>
</tr>
<tr>
<td>7</td>
<td>a.m</td>
<td>2 ml Estrumate</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>p.m</td>
<td>Heat observation</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>a.m</td>
<td>Heat observation + 2ml Fertagyl</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>a.m</td>
<td>Heat observation</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>a.m</td>
<td>CIDR in + 2 ml Ciderol</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>8 a.m</td>
<td>CIDR in + 2ml Ciderol + 20 ml Kyrophos</td>
<td>-</td>
</tr>
<tr>
<td>17</td>
<td>6 p.m</td>
<td>Folltropin 4.0 ml</td>
<td>2.5 ml Chronogest (300 iu)</td>
</tr>
<tr>
<td>18</td>
<td>6 a.m</td>
<td>Folltropin 4.0 ml</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 p.m</td>
<td>Folltropin 4.0 ml</td>
<td></td>
</tr>
</tbody>
</table>
iv. Synchronization of donor and recipient cattle

Synchronization is the process of ensuring the donor and recipient cattle come on heat at the same time. In this way, surrogate cows would be ready to receive and accept the embryos that are harvested from the donor as the uteruses of both the donors and surrogates will be at a similar stage of hormonal influence. This process (see Table 2) is primarily achieved using 2 hormones (Progesterone and Prostaglandin). Progesterone was administered to both donor and recipient as an intra-vaginal device (CIDR), while Prostaglandin (Estrumate®) was injected intra-muscularly.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>6 a.m</td>
<td>Folltropin 3.0 ml</td>
</tr>
<tr>
<td></td>
<td>6 p.m</td>
<td>Folltropin 2.0 ml</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>6 a.m</td>
<td>Folltropin 1.5 ml + 3ml Estrumate</td>
</tr>
<tr>
<td></td>
<td>6 p.m</td>
<td>Folltropin 1.0 ml + 1 ml Estrumate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CIDR out + 2 ml Estrumate</td>
</tr>
<tr>
<td>21</td>
<td>6 a.m</td>
<td>Folltropin 1.0 ml + CIDR out</td>
</tr>
<tr>
<td></td>
<td>6 p.m</td>
<td>Folltropin 1.0 ml</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 ml Ciderol</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heat observation</td>
</tr>
<tr>
<td>22</td>
<td>6 a.m</td>
<td>1st A.I. (On standing Heat)</td>
</tr>
<tr>
<td></td>
<td>6 p.m</td>
<td>2nd A.I.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heat observation</td>
</tr>
<tr>
<td>23</td>
<td>6 a.m</td>
<td>3rd A.I.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heat observation</td>
</tr>
<tr>
<td>29</td>
<td>a.m</td>
<td>Flush Embryos</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transplant Embryos</td>
</tr>
</tbody>
</table>

Figure 2: The process of insertion of CIDRs into donor and recipient SEAZ.
v. Artificial insemination of donors

Subsequently, the donor cows that showed heat (i.e., standing to be mounted by another cow, and a mucoid vaginal discharge) were inseminated artificially using bull semen from 2 KALRO, Kiboko bulls (KAZ 111 and P MAZ 105). These Kamba Zebu bulls were selected using similar phenotypic traits as those described for the Donors above. The bull semen had previously been collected by staff of the Kenya Animal Genetic Resources Centre (KAGRC), processed and stored in Liquid Nitrogen at the Centre.

![Artificial Insemination.](image)

vi. Flushing of donor cattle

After artificial insemination of the donors, the embryos were harvested 7 days later through the process of flushing. This involved the administration of a special flush medium (Complete flush solution) into the uterus, via a silicone catheter. An inflated cuff (balloon) near the tip of the catheter blocked the internal diameter of the uterus, allowing recovery of the administered fluid together with the dislodged embryos. This recovered fluid was then passed through an embryo filter and the excess drained off. Both uterine horns were flushed separately to ensure optimum recovery of embryos.

Figure 3: Artificial Insemination of Donor cattle

vi. Flushing of donor cattle

After artificial insemination of the donors, the embryos were harvested 7 days later through the process of flushing. This involved the administration of a special flush medium (Complete flush solution) into the uterus, via a silicone catheter. An inflated cuff (balloon) near the tip of the catheter blocked the internal diameter of the uterus, allowing recovery of the administered fluid together with the dislodged embryos. This recovered fluid was then passed through an embryo filter and the excess drained off. Both uterine horns were flushed separately to ensure optimum recovery of embryos.
Figure 4: The process of flushing donors

vii. Searching for and grading embryos.

After flushing, the embryo filter was searched for embryos using a stereoscopic microscope. When embryos were observed, they were picked up using a micro-pipette and transferred to an embryo holding medium in a 5 well plate. In this medium, they were further examined using the microscope and graded with regard to the stage observed and quality. The embryo stages seen on day 7 after AI are Morulae or Blastocysts. Only those of good quality (see Figure 5) were subsequently transferred into the recipients.
viii. Transfer of embryos into the recipients.

Prior to implantation, the recipient cattle were examined by rectal palpation to ensure they had a suitable ovarian corpus luteum and hence determine which uterine horn the embryos would be transferred into. Thereafter, a single embryo was picked up again using a ¼ ml straw attached to a syringe. The straw was then disconnected and loaded into an embryo transfer gun. To ensure proper hygienic conditions during transfer, the gun was covered by a sheath and shield. The embryo was then inserted into the relevant uterine horn via the cervix, in a process similar to artificial insemination.
Figure 6: The process of transfer of embryos to the recipients.

Nutrition of the SEAZ herd

All the cows were grazed on natural pasture within the KALRO, Kiboko ranch and at least allowed nine hours of grazing on a daily basis. When the pasture was insufficient, such as during the drought period (November, 2014), the cattle were supplemented using hay preserved from a previous season’s growth. Where available, different crop residues (e.g. pigeon pea, maize stovers and sweet potato vines) were fed too. However, these crop residues did not last long, especially during the drought periods, hence were inadequate.

The cattle on the MOET programs were also supplemented using concentrate feed (Dairy meal from local Agro-Vet shops) and minerals mixed with this. Donors were fed on 2 kg per day of the concentrates during the 29 day MOET program. Some donors that were not used to the concentrates refused to eat this initially. The feed was then mixed with pigeon pea crop haulms, which the cattle liked, to ensure uptake.

The recipients, on the other hand, were fed on 1 kg concentrate per day due to funding constraints. This began 1 week before the transfers and continued for a further 3 weeks for the recipients that received embryos.

Water was provided in a trough at the cattle boma in which they were housed. The cattle would then graze during the day and return to the boma in the afternoon to obtain water. This water was available ad-lib.
during the night.

**Estrous synchronization and Artificial Insemination (ES & AI).**

The two procedures were carried out on 30 SEAZ in a process similar to that of the recipient program for MOET above (Table 2). The only additional step was insemination of the cows 12 and 24 hours after they showed standing heat. The semen used was from bulls (identification numbers KAZ 111 and P MAZ 105) that were also used in the MOET program.

**Results**

**MOET**

**Embryo yields**

The embryo yields obtained from flushing the donors in the 8 groups are shown in Table 3 below. The number of embryos harvested ranged from 1 to 7 each from 9 donors. This is out of a total of 16 donors that were flushed. The total number of embryos obtained was 23, with an average yield of 3 embryos per donor. The embryos comprised 10 Blastocysts and 13 Morulae which were all of good quality hence transferred to 23 recipients.

However, almost half the donors (7) yielded no embryos on flushing. The worst groups were 5 and 6 (in phase 3, November 2014) where only 1 donor out of the 4 yielded an embryo. In the other 3 phases at least 2 or 3 donors gave embryos.

Another setback was cases of degenerate embryos, a total of 7, most of which (6) were obtained from one donor (KO 29). These embryos were of poor quality and could not be transferred to recipients. One ovum (unfertilized egg) was also obtained but not transferred.

**Table 3: Embryo yields from SEAZ donors.**

<table>
<thead>
<tr>
<th>No.</th>
<th>Group</th>
<th>Donor Cow ID</th>
<th>No. of Embryos</th>
<th>Embryo type*</th>
<th>Degenerate embryos</th>
<th>Ovum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>92</td>
<td>1</td>
<td>M</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>P MAZ 100</td>
<td>2</td>
<td>B1, M1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>95</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>P MAZ 96</td>
<td>2</td>
<td>M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>KO 48</td>
<td>7</td>
<td>B5, M2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>KO 146</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>7197</td>
<td>1</td>
<td>M</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>7231</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>100</td>
<td>0</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>6089</td>
<td>1</td>
<td>B1</td>
<td></td>
<td></td>
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<tr>
<td>11</td>
<td>6</td>
<td>96</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>6</td>
<td>KKR 9031</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>7</td>
<td>KO 48</td>
<td>1</td>
<td>B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conception rates among the recipients

A total of 23 embryos were transferred to recipients. The cattle were then monitored to observe for signs of oestrus (heat) after 14 days and thereafter in the recipients that did not conceive. Pregnancy diagnosis was performed by rectal palpation and Ultrasound (Figure 7) after 2 months. This way, 8 cows were detected to be pregnant which translated to a conception rate of 35%. Out of these 8 pregnancies, four (i.e. 2 each) were from two donors (KO 48 and 6138), while the others were from different donors (PMAZ 96, PMAZ 100, KO146 and 6089). Four calves were subsequently born in the months of May and June, 2015 (Table 4 and Figure 8). At the time of publication, the rest of the calves had not yet been born.

![Figure 7: An Ultrasound image of a foetus in a SEAZ recipient.](image-url)
Table 4: SEAZ calves born following MOET at KALRO, KIBOKO.

<table>
<thead>
<tr>
<th>Calf No./ ID</th>
<th>Sex</th>
<th>Donor</th>
<th>Sire</th>
<th>Embryo type</th>
<th>Recipient ID</th>
<th>Date implanted</th>
<th>Date Of Birth</th>
<th>Birth weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P MAZ 1501</td>
<td>M</td>
<td>P MAZ 096</td>
<td>P MAZ 105</td>
<td>Morula</td>
<td>KKR 9023</td>
<td>7.8.2014</td>
<td>6.5.2015</td>
<td>18</td>
</tr>
<tr>
<td>P MAZ 1502</td>
<td>M</td>
<td>P MAZ 100</td>
<td>P MAZ 105</td>
<td>Blastocyst</td>
<td>KKR 1171 (1st calving)</td>
<td>6.8.2014</td>
<td>17.5.2015</td>
<td>22</td>
</tr>
</tbody>
</table>

Estrous Synchronization and Artificial Insemination

A total of 30 SEAZ were bred using these techniques, of which six were declared pregnant using rectal palpation and Ultrasound after 2 months, giving a conception rate of 20%.

An additional group of 14 Boran and Dairy cattle crosses were synchronized and inseminated using exotic dairy (Friesian, Ayrshire and Guernsey) bull semen. Out of 14 cows, 4 were diagnosed as pregnant, which was a conception rate of 29%.

Discussion and conclusions

The embryo yields in these Zebu cattle ranged from 1 to 7 with an average of 3 in those that produced embryos. This is an acceptable yield for Zebu cattle where other authors have also reported an average of 3-4 embryos per Zebu donor (Siddiqui et al, 2002; Tegegne et al, 1994). There are, however, variations in embryo yields in different Bos indicus breeds, depended on feeding regimes, body condition scores and seasons (Donaldson, 1984; Siddiqui et al, 2002; Bastidas and Randel, 1987).

However, almost half (7) the donors did not yield embryos, particularly in the MOET program carried out in November, 2014 (Phase 3). Three out of the 4 donors did not yield embryos while the 4th had 1 embryo recovered. This was also the period at the height of the drought season at Kiboko. Therefore the cattle were most likely in a negative energy balance with inadequate nutrition to meet both maintenance and reproduction requirements (Butler, 2000).
Even when nutritional requirements are adequate, between 20-30% of donors do not yield embryos (Seidel and Seidel, 1991). This would probably explain why the other SEAZ donors did not yield embryos. There was adequate pasture and supplementation of the donors with concentrates during the other 3 phases of the MOET programs, apart from the November 2014 program. However, it was difficult to ensure the cattle were on a rising plane of nutrition, a necessary factor for optimum embryo yields and conceptions (Davis, 1998; Lamb, 2005). In particular, donors should not be losing weight at the time of superovulation (Seidel and Seidel, 1991; Siddiqui et al, 2002).

One cow (KO 29) yielded 6 embryos but they were all degenerating hence could not be transferred to the recipients. Degeneration is part of the process of cell death. There are many causes of embryonic mortality in cattle including: - (a) Genetic factors- breed, family, inbreeding and blood groups, and (b) Environmental factors—nutrition, age, climate, infections, hormonal imbalance and uterine environment (Ayalon, 1978). It was not possible to investigate all these factors. However, these cattle were treated using an intra-uterine douche of diluted Povidone Iodine which is suitable for uterine infections (endometritis).

The conception rate for the embryos transferred to the recipients was rather low (35%). This was most probably due to inadequate supplementation, as indicated in the materials and methods. The recipients were only supplemented with concentrates from 1 week prior to the transfers and for 3 weeks thereafter for those receiving embryos. This occurred due to funding constraints.

Other factors that could have contributed to the low conception rates in the recipients include: (i) Asynchrony between the recipients and donors of more than 24 hours; (ii) Uterine trauma during the transfer; and (iii) Endometritis (uterine infection).

Asynchrony between donors and recipients was a setback during the first 2 phases (Groups 1-4) of the MOET programs. In 4 cases a Morula (6 day old embryo) was transferred to a recipient 8 or 9 days after it was reportedly observed on standing heat.Apparently the available recipients were coming on heat earlier than expected, while the embryos obtained on the day of transfer were Morulae. Asynchrony of more than 24 hours between embryo and recipient results in a significant reduction in conception rates (Lamb, 2005).

Uterine trauma was another probable factor reducing the conception rates. Some recipients had a narrow cervix, creating difficulties in passage of the ET gun, as well as difficulties in placing the embryo beyond the external bifurcation of the uterine horn, as required. The manipulation most likely resulted in some cervical and uterine trauma (despite attempts in utmost care) which reduces conception rates (Seidel and Seidel, 1991).

Endometritis was another factor noted in 1 recipient during the Ultrasound examination for pregnancy, 2 months after the transfer. Such a cow would not be able to conceive or retain a pregnancy due to the infection. Treatment was effected in this case using an Intra-uterine douche with diluted Povidone Iodine. The same treatment was done for donors in the last 2 MOET programs, as well as any recipients showing a muco-purulent vaginal discharge, to forestall the likelihood of infection.
The effect of disease on conception was also noted during the ES & AI program where the conception rate was even lower (20%). An outbreak of Foot and Mouth disease (FMD) occurred at the Kiboko ranch with clinical signs observed in some of the cattle selected for the program. Prior vaccination against this disease had been done for the cattle on the MOET programs, but not the additional ones required for the ES & AI. A persistent high fever, commonly observed in FMD, is a common cause of lack of conception or abortion, as the uterine environment is too hot for the developing embryo or foetus (Thomas, 2007).

Despite the challenges indicated, four calves have been born to date while a further 4 cows have been confirmed pregnant, following the use of MOET. The value of MOET is that a superior cow is enabled to have more offspring than would be possible naturally (Seidel and Seidel, 1991; Davis, 1998; Baruselli et al., 2006). In this study and in a period of 6 months, 2 donor cows (KO 48 and 6138) have bred 2 calves each via their surrogates, which would not have been possible otherwise. Another reason set out for performing MOET in this study was the cryopreservation of embryos from these superior SEAZ. However, the embryos obtained were few hence all transferred to recipients.

In addition to MOET, ES & AI used in this study, another possible breeding tool would have been in-vitro embryo production (IVEP). In Brazil, on a large scale commercial program the mean number of embryos produced and the pregnancy rates were 3.2 (12,243/3,778) and 40% for Gir (Bos indicus) cows, 2.1 (2,426/1,138) and 36% for Holstein cows (Pontes et al., 2010). In Kenya, the method has been used to produce embryos from ova collected from slaughtered Boran cows. A total of 1,658 cumulus oocyte complexes were collected to produce in vitro blastocysts, out of which 17 calves were born following transfer to recipients (Mutembei et al., 2015). As observed, large numbers of embryos are obtained but ultimately the mean embryo yields, conception rates and number of calves born can also be low, while many excess embryos are discarded/wasted. In addition, this breeding tool was not selected for use in this study due to the large capital outlay required in laboratory equipment for production of embryos.

**Way Forward**

The aims of this investigation was to demonstrate how these 2 ARTs can be used to multiply superior SEAZ cattle and thus increase the number of such animals in the Eastern region of Kenya, where they are well adapted and therefore an important indigenous cattle genetic resource. However, even though the number of cattle produced was small, this group can be used to initiate the Nucleus herd that would be availed to local farmers for breeding. A number of the calves born are male and when mature their semen could be distributed for use by AI.

Going forward, the SEAZ cattle identified phenotypically as superior during the Baseline survey (Mburu et al., 2013; Ngige et al., 2013) could be bred using ES & AI to further increase this population of animals. In addition, genotyping of these selected animals would be important to ensure proven animals are multiplied and distributed.

**Acknowledgement**

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References


Abstract
A study to determine brucellosis prevalence in livestock and incidence in humans amongst pastoralists and agro-pastoralists communities was carried out in selected areas of Kenya and Tanzania from 2012 to 2014. A total of 1702 ruminants were screened using different serological techniques in the selected areas. Serum samples were from Southern Highlands Zone (SHZ), Northern Zone (NZ) and Eastern Zone (EZ). were screened using Rose Bengal Plate Test (RBPT) antigen and later positive samples were confirmed using competitive enzyme linked immune-sorbent assay (c-ELISA) showing prevalence of 11.4% in the SHZ (n=799), 2.4% in the EZ (n=169) and 1% in the NZ (n=408). Whereas milk samples from Migori, West Pokot and Mwingi were screened by Milk ring test showing prevalence of 17.9% (n=56) in 2012 and 11.7% (n=77) in 2014 in cattle in Migori, 21.9% (n=96) in 2012 and 21.2% (n=52) in 2014 in cattle, 4.7% (n=43) in 2012 and 16.7% (n=6) in 2014 in goats in West Pokot and 2.2% (n=45) in 2012 and 4.3% (n=70) in 2012 in cattle and goats in Migori. A total of 578 human cases were followed up, where 28.2% of the suspected cases were confirmed in health facilities. While using Compliment Fixation Test (CFT) the prevalence was 0.9% (n=212) in cattle in Migori, 4.0% (n=101) in cattle, 4.0% (n=100) in goats and 13.8% (n=29) in sheep in West Pokot and 4.75% (n=43) in cattle and 9.5% (n=21) in goats in Mwingi in 2014. A total of 1140 Human cases were followed up in selected study areas where livestock samples were collected and an overall incidence of 22.7% (n=1140) was confirmed in health facilities. Selected areas in Tanzania had an incidence of 28.2% (n=578) and in Kenya an incidence of 17.1% (n=562) was recorded. Results from this study have shown that Brucellosis is still endemic in many areas of Tanzania and Kenya and pose a high risk to human health. Human beings also seem to be affected by the disease and livestock are the potential source of human infections through consumption and or handling of infected animals and animal by-products. Control of the disease in livestock through vaccinations of all susceptible animals and knowledge dissemination on transmission methods, proper handling of aborted fetuses and afterbirths and importance of consuming proper boiled and or processed milk highly advocated to rollback the prevalence of brucellosis in these selected areas of East Africa.

Key words: Brucellosis, Incidence, Kenya, Pastoral and Agro-pastoral, Public health, Prevalence, Tanzania, Zoonoses.
Introduction

Brucellosis is amongst the most widely distributed zoonoses of economic importance in developing countries. Most of these zoonotic diseases are poorly controlled and endangers poor peoples’ lives (Perry et al., 2001 and WHO, 2006). In livestock, brucellosis results in reduced productivity, abortions and weak offspring and is a major setback to international trade. Estimates of losses in meat and milk production as a result of the disease were $800 million annually in the USA (Richey and Harrell, 2008). Despite of productivity losses in Africa and Asia being not well documented, are associated with abortions, reduced milk production, hampered external trade and reduced work capacity ((Mangen et al., 2002). In Nigeria the annual losses were estimated to be US$575.605 per year (McDermott et al., 2013). Almost all species are affected and this causes a major challenge in prevention, control and eradication (Smits and Cutler, 2004).

Humans are infected through ingestion of infected animal products such as untreated milk or cheese, and by direct contact with contaminated materials through handling of abortions, dystocia and retained placentas (Racloz et al., 2013). Brucellosis in humans is characterized by intermittent fever accompanied by generalized pain (WHO, 1997). The disease may present as acute, subacute or chronic (Corbel et al, 2006 and Roop et al, 2009). However, clinical signs are non specific and the disease can be confused with typhoid fever, malaria, rheumatic fever and relapsing fever. It is debilitating and requires prolonged treatment with a combination of antibiotics (Kunda et al., 2010). Although many Brucella species can cause disease in human, Brucella abortus and Brucella melitensis are the mostly implicated (Franco et al., 2007). Brucella melitensis is the more common and more virulent species causing human disease (Pappas et al., 2005).

This paper reports on the sero-prevalence of brucellosis in milk and serum samples of bovines, caprine, ovines and camels and incidence of human cases in selected areas of Tanzania and Kenya and provides data on the current situation of this disease that is considered to be re-emerging. Results from this study forms a basis for strategizing control measures in preventing further spread of the disease. Despite of the efforts being made to understand and control the disease, there are clear evidences that the efforts give low returns as the spread of the disease among livestock and across to humans are still observed. This study therefore aims at establishing the current disease prevalence in livestock and the magnitude of spread to humans in pastoral and agro-pastoral communities of Kenya and Tanzania.

Materials and Methods

Study area

The study was conducted in pastoral and agropastoral communities of Tanzania and Kenya. Samples were collected from Southern Highland Zones (SHZ), Eastern Zone (EZ) and Northern Zone (NZ) in Tanzania and from counties of West Pokot, Mwingi and Migori in Kenya. In Tanzania where a typical tropical climate (ICID, 2010) is experienced, SHZ receives an average of 1250 mm rainfall per annum (Mbululo and Nyihirini, 2012), in the county of Migori in Southern west area of Kenya as it is NZ particularly in Northern East area of Tanzania climatic condition is semi desert receiving an average of 600 mm per annum and EZ with an average of 1000 mm rainfall per annum (Kabede et al., 2010; Geutjes and Knutsson, 2014) the amount of rainfall similar to the larger area of the arid to semi arid land of West Pokot county that records 700mm to 1600mm per annum (Geutjes and Knutsson, 2014). Majoreconomyin these communities is heavily depended on agriculture (including livestock keeping) contributing 56% of the GDP, employing 80% of the work force and provides 60% of the total earnings (NAPA, 2006). The occurrence of Livestock diseases is also influenced by climate.
Study design

Epidemiological studies were employed and an observational cross sectional study design was carried out in livestock populations in Tanzania and Kenya. In order to reduce potential variations in the study results, studies included in the final data were restricted to sero-epidemiologic field surveys on traditionally managed animals with a known number of sampled and positively tested animals between 2012 and 2014 (Mangen et al., 2002).

Sample collection

Sample size was calculated using the standard formula for estimation of proportions (Martin et al., 1987) and the population was considered infinite. In livestock 2401 samples were to be collected considering an infinite population, 19% to 21% confidence interval at 95% confidence level where as in humans 1067 considering an infinite population, 15% to 18% confidence interval at 95% confidence level. Blood samples from animals were collected from jugular veins in plain vacutainer tubes and stored in iced cool boxes, decanted after 90 minutes and serum was preserved in cryotubes, labeled and kept at 4°C in Tanzania and -20°C in Kenya (WHO. 2005).

Sample laboratory analysis

Some serum samples were screened using Rose Bengal Plate Test (RBPT) as described by Díaz et al. (2011). Positive samples were labeled and confirmed using competitive Enzyme Linked Immunosorbent Assay (c-ELISA) test (Perret et al., 2001) in Tanzania and Compliment fixation Test in Kenya (OIE, 2009) Other samples in Kenya were tested in the field using Milk Ring Test (MRT). Because the test detects false positive (Low sensitivity) due to positive reactions from samples taken shortly after parturition, near the end of lactation period or from mastitic quartered (MacMillan, 1990), animals in these conditions were avoided during sampling. In humans’ case follow up were carried out in health centres in Korogwe-Tanzania and Ortum-Kenya. Based on c-ELISA, CFT and MRT results, farmers were advised accordingly. The advice targeted to control further spread of the disease among animals and possibilities of the disease affecting human beings.

Data management analysis

The data were recorded and organized using Microsoft Excel 2007; statistical analysis was carried out using Epi Info 7 statistical software. MedCalc® statistical software was used to compare proportions of the variables. Statistical significance between variables was examined using P-value at critical probability of P<0.05

Results

In Tanzania a total of 1,376 cattle were screened in the three zones and Brucellosis prevalence confirmed by c-ELISA was 11.4% (n=799) in SHZ, 1% (n=408) in NZ and 2.4% (n=169) in EZ. These results were obtained from samples that tested positive to RBPT screening. RBPT recorded 12.6% (n=799) in SHZ, 1.7% (n=408) in NZ and 2.4% (n=169) in EZ. The percentage of accuracy between the tests was 90.1% (n=101) in SHZ, 57.1% (n=7) in NZ and 100% (n=4) in EZ (Table 1). This indicates that in all agroecological zones and RBPT picked more samples to be positive as compared to c-ELISA.

Table 1: Cattle c-ELISA results and RBPT screening in different ecological zones in Tanzania

<table>
<thead>
<tr>
<th>Ecological zones</th>
<th>Confirmed brucellosis c-ELISA</th>
<th>Positive for brucellosis RBPT Screening</th>
<th>Percentage of c-ELISA / RBPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHZ</td>
<td>11.4 % (n = 799)</td>
<td>12.6% (n = 799)</td>
<td>90.1% (N = 101)</td>
</tr>
<tr>
<td>NZ</td>
<td>1% (n = 408)</td>
<td>1.7% (n = 408)</td>
<td>57.1% (N = 7)</td>
</tr>
<tr>
<td>EZ</td>
<td>2.4% (n = 169)</td>
<td>2.4% (n = 169)</td>
<td>100% (N = 4)</td>
</tr>
</tbody>
</table>

Key: n=Number of animals at Risk in respective zones. N=Number of animals tested positive to RBPT
In Kenya, antibodies to Brucella were detected in bovines, caprines and ovines. In Migori, results from MRT in bovine declined from 17.86% (n=56) in 2012 to 11.69% (n=77) in 2014. One (1) caprine was screened in 2012 and was negative, where as the other two species ovine and camels were not screened due to lack of farmers’ cooperation. Results in West Pokot indicated that there was decline in diseases prevalence in bovines recording 21.88% (n=96) in 2012 and 21.15 (n=52) in 2014. However, an increase in brucellosis prevalence was recorded in caprine where prevalence increased from 4.65% (n=43) in 2012 to 16.67% (n=6) in 2014. In 2012, there were no positive cases in both ovines (n=13) and camels (n=5), and no screening was done in both species 2014 as some farmers were not willing to allow sampling the animals and the low number of animals kept. Only bovines and caprine were screened in 2012 in Mwingi with results showing prevalence of 2.22% (n=45) and 4.29% (n=70). Generally from MRT results indicates that higher prevalences were recorded in West Pokot in bovines 21.88% (n=56) while lower prevalence were recorded in Mwingi in bovines 2.22% (n=45). No cases were recorded in caprine (n=1) in 2012, ovine (n=13) in 2012 and camels (n=5) in 2012 (Table 3)

**Table 2: Brucellosis prevalence by species (milk Ring Test – MRT) – 2012 and 2014 in Kenya**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Migori</td>
<td>17.86% (n=56)</td>
<td>11.69% (n=77)</td>
<td>0.00 (n=1)</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td></td>
</tr>
<tr>
<td>West Pokot</td>
<td>21.88% (n=96)</td>
<td>21.15% (n=52)</td>
<td>4.65% (n=43)</td>
<td>16.67% (n=6)</td>
<td>0.00 (n=13)</td>
<td>Nil</td>
<td>0.00 (n=5)</td>
<td></td>
</tr>
<tr>
<td>Mwingi</td>
<td>2.22% (n=45)</td>
<td>Nil</td>
<td>4.29% (n=70)</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td></td>
</tr>
</tbody>
</table>

Key: n=Number of animals at Risk in respective counties

The other samples were tested using Compliment Fixation Test (CFT) and prevalences were higher in caprine 20% (n=100) and ovine 13.79% (n=29) in West Pokot as compared to bovine that recorded the lowest prevalence of 0.94% (n=212) in Migori. Similar to MRT higher values were recorded in West Pokot than in Migori and Mwingi (table 4). However generally MRT recorded higher prevalences than CFT in bovines while it was the reverse for caprine and ovines (Table 2 and 3)

**Table 3: Brucellosis prevalence by species CFT – 2014 in selected counties in Kenya**

<table>
<thead>
<tr>
<th>Location / Species</th>
<th>Bovine</th>
<th>Caprine</th>
<th>Ovine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Migori</td>
<td>0.94% (n=212)</td>
<td>0.00 (n=2)</td>
<td>0.00 (n=1)</td>
</tr>
<tr>
<td>West Pokot</td>
<td>3.96% (n=101)</td>
<td>20% (n=100)</td>
<td>13.79% (n=29)</td>
</tr>
<tr>
<td>Mwingi</td>
<td>4.65% (n=43)</td>
<td>9.52% (n=21)</td>
<td>Nil</td>
</tr>
</tbody>
</table>

Key: n=Number of animals at Risk in respective counties

Prevalence of human brucellosis were recorded in both Tanzania and Kenya. Results showed that the incidence was higher in Tanzania 28.2% (n=578) as compared to Kenya 9.36% (n=342). In Tanzania the suspected cases were recorded from January 2014 to July 2014 and in Kenya suspected cases were recorded from June 2013 to April 2014.
Table 4: Brucellosis prevalence in human beings in Ortum – Kenya and Korogwe - Tanzania

<table>
<thead>
<tr>
<th>Location</th>
<th>Time interval</th>
<th>Brucellosis prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tanzania (Korogwe)</td>
<td>January 2014 to July 2014</td>
<td>28.2% (n=578)</td>
</tr>
<tr>
<td>Kenya (Ortum)</td>
<td>May 2013 to April 2014</td>
<td>9.36% (n=342)</td>
</tr>
</tbody>
</table>

Key: n=Number of people screened in the specified time and locations

Discussion

Brucellosis is endemic in Africa but only a few studies have been carried out to understand the status of the disease in selected areas of Tanzania and Kenya. The findings from this study indicates that the disease still posses a big threat to human health and possibilities of increasing economic losses to livestock keepers. Although the disease has been confirmed in human beings, little emphasis is put to control the spread of the disease through limiting possible movement of livestock (McDErmont et al., 2013). In Tanzania, the he disease spreading pattern seems to be from North to South of Tanzania, following paths of animal movement towards the South (Mwambene et al., 2014), which results in animals meeting frequently in different water sources, the types of livestock farming are being practiced despite the efforts to modernize livestock farming through agro-pastoralism (Msalale 2007). Other studies performed resulted in isolation of *Brucella melitensis* biovar 1, and *Brucella abortus* biovar 3 from milk and aborted fetus materials respectively (Muendo et al., 2012) in central Kenya. In the r previous study by Waghela et al. (1978) reported 11 reactors in RBPT, 11 in SAT and 21 in CFT out of 172 samples from camels, in the current study sampled camels showed negative results, however this could possibly be due to few samples collected as most farmers were not willing to let their animals be sampled.

Brucellosis prevalence in this study ranged from 1% in NZ of Tanzania from c-ELISA results to 21.88% in West Pokot in MRT. Generally there is a clear indication that all screening techniques picked up positive reactors, the results are in line with those by Kangethe et al. (2000) who reported prevalences of 4.9% and 3.9% by ELISA and 2.4% and 3.4% by MRT at milk consumer-level and informal market level respectively. In all these studies the positives were picked in milk or in sera collected from bovines, ovines and caprine with no evident clinical signs findings that are concurrent with those by Shirima et al. (2014). Similarly, the ranges of disease prevalence 1% NZ to 11.28% in SHZ in bovines by c ELISA, 2.22% in Mwingi to 21.88% in West Pokot by MRT in bovines and 0.94% in Migori to 4.65% in Mwingi in bovines are in line with the ranges reported by Waghela and Karstad (1986). Free range production system practiced in most parts of these countries also helps to maintain the disease in both animal and human populations. The cultural practices of some communities that encourage consumption of raw livestock products e.g. whole blood and raw milk favour spread of the disease. Obtaining milk from the market (p value <0.00001, odds ratio 7.3, 95% confidence interval 2.5-21.1) and drinking of unboiled milk (p value <0.0001, odds ratio 8.5, 95% confidence interval, 4.2-17.3) were significantly associated with brucellosis (Kiambi, 2011).

Human brucellosis has been reported in this study where Tanzania reported more incidences compared to Kenya. In both countries, screening of the disease is usually considered in patients who have not responded to treatment for malaria. This was reflected in the much longer duration of illness of brucellosis as compared to malaria; clearly, earlier diagnosis of brucellosis is required (Muriuki, 1994, Kunda et al., 2007). Muriuki et al. (1997) studying in Narok classified 0.8% (n= 1,037,875) of all ‘flu-like’ syndromes in man as Brucellosis. 21.2% of these tested positive for Brucellosis on RBT. The results from the current study are relatively higher than the ranges of 3% to 8% recorded in Sub-Saharan African countries (Baba et al., 2001). However, there is still a need for using much sophisticated techniques.
in places where the disease prevalence is thought to be much higher, because, despite the usefulness of diagnostic techniques used in hospitals, these techniques appear have low sensitivity thus at times not able to give a clear picture of the true disease prevalence. In a study by Kiambi, 2011 the detected sero-prevalence of brucellosis using Febrile Rapid Diagnostic Kit was 31.8% while the true prevalence detected by PCR method was 15.4%.

Conclusion and Recommendations
Brucellosis is still an endemic disease in Tanzania and Kenya and affects both livestock and humans and in this study has been shown that there is a possibility of brucellosis spread between the two species. Little knowledge of livestock keepers on the disease and uncontrolled movement play a role in disease existence and spread. It is therefore recommended that stakeholders’ sensitization and education cooperation, change of some cultures, control of livestock movements, screening and vaccination should be efforts emphasized in control of the disease.

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References
Kiambi, S.G. 2011. Prevalence and factors associated with brucellosis among febrile patients attending Ijara District Hospital, Kenya MSc Thesis, Jomo Kenyatta University of Agriculture and Technology


WHO (2005) Manual on the management, maintenance and use of blood cold chain equipment: Marketing and Dissemination, World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland (Fax: +41 22 791 4857; e-mail: bookorders@who.int), pg5-12
Geographic structure of sub-clinical *Theileria parva* infection among distinct morphometric cattle populations in Uganda derived in a landscape approach

Fredrick Kabi¹,2*, Vincent Muwanika¹ and Halid Kirunda², Charles Masembe³

¹Molecular Genetics Laboratory, Department of Environmental Management, Makerere University, P.O. Box 7098, Kampala, Uganda; ²National Livestock Resources Research Institute (NaLIRRI), P.O. Box 96, Tororo, Uganda; ³Department of Biosciences, Makerere University, P.O. Box 7062, Kampala, Uganda

*Correspondence: freddykabi@gmail.com, Mob +256 776 212 292

Abstract

Indigenous cattle populations in Uganda kept under the stewardship of rural smallholder farmers have over time developed useful traits for agro-ecological fitness (AEF). They thrive under continuous *Theileria parva* challenge upon recovery from primary East Coast Fever (ECF), a trait enhanced by repeated exposure to homologous parasite strains. They also exhibit high levels of morphometric AEF to facilitate endurance of harsh conditions. This study used a landscape approach to examine the trends of the sub-clinical ECF geographic structure and linear morphometric trait patterns among indigenous cattle in the diverse agro-ecological zones (AEZs) of Uganda. Blood from 925 apparently healthy indigenous cattle spread out in 10 AEZs were assayed using a nested PCR to ascertain their *T. parva* infection status. Ten discriminant linear morphometric traits were subsequently measured among female cattle of the same study herds. In this study, *Theileria parva* was present in 30% of the surveyed cattle, exhibiting a steady upsurge from 17% (95% CI: 0.03 – 0.23) to 43% (95% CI: 0.3 – 0.55) in North Eastern Savannah Grasslands (NESG) and in Western Highland Ranges (WHR) AEZs respectively. A correspondingly associated 18% (95% CI: 0.07 – 0.28) and 35% (95% CI: 0.3 – 0.39) sub-clinical ECF prevalence was observed among the East African shorthorn Zebu (EASZ) and Ankole cattle respectively. Likewise, the linear morphometric traits varied significantly by AEZ and breed exhibiting a gradient of low to high dimensions among the EASZ and Ankole cattle respectively. Sub-clinical ECF and linear morphometric traits exhibited similar trends, implying that indigenous cattle AEF embraces resilience to ECF infection. These findings guide deployment of sustainable and integrated control strategies, indigenous cattle improvement and conservation programs.

Keywords: Agro-ecological fitness, Indigenous cattle breeds, Linear morphometric structure, Sub-clinical ECF geographic structure, Uganda

Introduction

Rural smallholder farmers and pastoralists have patronised indigenous cattle populations for millennia in the tropics (Hoffmann 2010). The Ankole (*Bos taurus-indicus*), East African Shorthorn Zebu (EASZ) (*B. indicus*), and their intermediate varieties are the main indigenous cattle breeds constituting about 93.3% of the national cattle herd in Uganda (Balikowa, 2011). Their custodians rear them by tethering and open grazing on communal or privately owned land. They also practice selective breeding to boost Agro-Ecological Fitness (AEF), endemic disease resilience and cultural identity of subsequent cattle generations (Kugonza et al., 2011; Ndumu et al., 2008a). In...
return, indigenous cattle are critical sources of livelihoods to 26.1% households in Uganda through delivery of several goods and services (Kugonza et al. 2011; Hanotte et al., 2010). The Food and Agricultural Organisation of the United Nations (FAO) has observed that indigenous cattle populations have for millennia thrived under continuous endemic disease challenges and low quality feed resources enabling the utilization of marginal resources where no other type of agricultural capitalisation is viable (Anderson, 2003; FAO, 2007).

Indigenous cattle populations in Uganda have been shown to harbour *T. parva* without manifesting acute clinical ECF, a trait cherished by rural cattle keeping communities especially in marginal lands where animal health services may not be readily accessible (Kabi, et al., 2014; Magona et al., 2011). This innate attribute developed as a result of host parasite evolutionary co-existence, developed when cattle pastoralists migrated into the disease endemic areas of eastern and southern Africa (Gachohi et al., 2012). Magona, et al. (2011 and 2008), have provided evidence for endemic stability, a phenomenon enabled by high levels of *T. parva* infection and sero-conversion, accompanied by minimal disease occurrence among indigenous cattle populations measured over time (Jonsson, et al., 2013). Exotic cattle are cherished for high productivity but easily succumb to ECF resulting into high mortalities, necessitating high investment to control ticks and tick-borne diseases using acaricides, chemotherapy and vaccines (Gachohi et al., 2012).

Although use of acaricides to control ticks which are ubiquitous in all the different AEZs decreases primary ECF stress and favours cattle growth vigour, it is associated with reduced *T. parva* challenge, sero-conversion and loss of endemic stability among indigenous cattle. This may result into ECF outbreaks during prolonged dry season stress (Marcelino, et al., 2012; Rodriguez-Vivas et al., 2011; Mugisha, et al., 2008). This countrywide study determined the relationship between the geographic structure of sub-clinical ECF and linear morphometric structure to establish whether indigenous cattle AEF include resilience to clinical ECF. The findings provide additional evidence for conservation, improvement and sustainable utilisation of indigenous cattle resources while promoting resilience to *T. parva* infection and reduction of acaricide use for tick control.

**Materials and methods**

**Study area**

This study had a nationwide coverage as previously described in Kabi et al. (2014). Concisely, Uganda has a total size of about 241,550.7 square kilometres (sq.km), lies astride the equator in Eastern Africa between longitudes 29 ½° East and 35° East and between latitudes 4 ½° North and ½° South. Uganda has an average altitude of 1,100 meters above sea level, varying from 620 metres (Albert Nile) to 5,111 metres (Mt. Rwenzori peak). Numerous lakes which are drained by rivers (Aswa, Kagera and the Nile) subsequently influencing the agro-ecological climatic features (UBOS, 2013). Ten AEZs were included in this study defined by a fairly similar socio-economic attributes and ecological settings, farming systems and practices (MAAIF, 2004).

**Sample size and sampling approach**

A landscape sampling approach guided by 50 grid cells enabling an inclusive sample and data collection across the 10 AEZs as previously explained (Kabi et al. 2014) was adopted in this study. Samples and data for this study were collected from January 2011 to April 2012.

The sample size for the study will be determined by the following formula given by Thrusfied (2005).
n = Z² (Pexp) (1-Pexp)/d²
Where n=sample size, Z=1.96, value of CI at 95%
d= desired absolute precision

Where n is the sample size, Z at 95% confidence interval (CI) is 1.96, p is expected prevalence (estimated at 50%, a priori) and d is margin of error (5%) (Thrusfield, 2003)

Given this formula, a minimum of 384 head of cattle per EASZ and Ankole breed was considered adequate. Going by the wide variation in size and cattle statistics within each AEZ, the sample size obtained per zone varied from 50 to 150 head of cattle and was guided by grid cells to ensure an even distribution of sample collection. Sample and data was collected from 50 grid cells (approximately 50 × 50 sq. km each). Four to six indigenous cattle herds were randomly selected per grid cell and four to five head of cattle were randomly selected from each herd. The 10 AEZs, grid cells and locations of the 209 sample herds are shown in Figure 1.

**Figure 1:** Distribution of indigenous cattle sample herds (n = 209) in the AEZs of Uganda
Blood sample and linear morphometric data collection

Blood samples were obtained from 925 apparently healthy cattle (410 Ankole - *B. taurus- indicus*, 465 EASZ and 50 Nganda - *B. indicus*) by venepuncture into appropriately labelled Ethylenediaminetetraacetic acid (EDTA) coated vacutainer tubes (Becton-Dickinson, Vacutainer System, UK) and stored on ice in a cool box. Matching records of location, ownership, age and sex were entered onto a field data sheet. The iced cool box with samples was transported to Makerere University Molecular Genetics Laboratory in the department of Environmental Management within 36 hours. At the laboratory, blood was stored at −20°C before DNA extraction. Total genomic DNA was extracted using a Qiagen QIAmp® DNA extraction kit (Qiagen-GmbH Hilden Germany) according to the manufacturer’s instructions. The quality of DNA was checked by electrophoresis on 1% agarose gel. Linear morphometric data was collected from same cattle situated on a relatively even surface, 10 discriminant linear morphometric traits were recorded to the nearest centimetre (cm) using a flexible tape before the cattle were taken for grazing by the first author to minimize in between-individual variations according to Mwacharo et al. (2006) and Alderson (1999).

Description of the linear body measurements taken on each animal were: horn length (HL) – the distance from the base of the horn to its tip, animal length (AL) – the distance from the top of the head to the base of the tail, fore arm length (FAL) - the distance from the elbow joint to the extreme end of hoof, fore arm circumference (FAC) - the perimeter distance of the metacarpal joint of the fore arm, face length (FL) - the distance from the muzzle to the top of the head, horn base circumference (HBC) – the perimeter distance at the base of the horn, length between the horn bases (LHB) – the distance between one horn base to the other, length between the horn tips (LHT) - the distance between one horn tip to the other, muzzle circumference (MC) – the perimeter distance of the muzzle and tail length (TL) - the distance from the base of the tail to the end of tail switch.

Gestating females were excluded from this study. The number of samples used in this study per breed and sex for *T. parva* and morphometric analysis is shown in Table 1: The age groups were estimated by dentition and clustered into four categories 7 - 24, 25 – 36, 37 – 72 and 73 – 192 based on minimal differences observed within the categories (Carles and Lampkin. 1977).

<table>
<thead>
<tr>
<th>Samples and morphometric data type</th>
<th>Ankole</th>
<th>Nganda</th>
<th>EASZs</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>M</td>
<td>F</td>
<td>M</td>
</tr>
<tr>
<td>Blood samples tested for <em>T. parva</em></td>
<td>387</td>
<td>13</td>
<td>46</td>
<td>4</td>
</tr>
<tr>
<td>Morphometric trait data</td>
<td>387</td>
<td>0*</td>
<td>46</td>
<td>0*</td>
</tr>
</tbody>
</table>

*F – females, M – males, * Males were not included in the morphometric data analyses due to their lower numbers among the 209 cattle surveyed*

**Nested PCR amplification of T. parva**

The nested PCR assay using p104 primers has been detailed (Kabi et al., 2014). The primer set for detection of *T. parva* based on the p104 antigen gene (Genbank M299954) was imported from Oligo™ Macrogen Seoul Korea. The primary forward and reverse primers sequences were 5’-ATT TAA TAA ACC TGA CGT GAC TGC-3’ and 5’-TAA GAT GCC GAC TAT TAA TGA CAC C-3’ respectively. The nested forward and reverse primers sequences were 5’-GAA CAA GGT CTC CTT CAG ATT ACG-3’ and 5’-TGG GTG TGT TGC CTC GTC ATC TGC-3’ respectively.
These primers were intended to amplify a 277 bp fragment, a highly conserved segment of p104 gene, a specific and sensitive target for *T. parva* detection. Primary and nested PCR assays were performed in 20 μl AccuPower® PCR PreMix Bioneer® tubes (USA) according to Odongo, *et al.* (2010) with slight adjustments. The PCR products were electrophoresed on 1.5% agarose (Bio Tolls Inc. Japan), stained with 5% Ethidium bromide™ (Biotium, Inc., USA) Agarose gel for 30 minutes and the positive samples were visualised as a 277 bp band on the agarose gel under UV trans-illuminator.

**Data management and statistical analyses**

Raw data on *T. parva* prevalence, age group, sex, breed were entered into Microsoft Excel® 2010, exported to Stata® ver. 12 (2012) statistical package, cleaned and coded for computation. Mean prevalence of *T. parva* among the different AEZs breed, sexes, age groups were computed at 95% confidence interval (CI). A multivariate mixed logistic regression model was used to estimate the odds ratio (OR) for the risk of *T. parva* infection with adjustment for AEZ, breed, gender and age group.

Similarly, raw data on morphological traits were entered into Microsoft Excel® 2010, exported to Stata® ver. 12 (2012) statistical package, cleaned and coded for computation. The means with their standard errors (SE) and statistically significant differences between morphological traits based on the study cattle breeds, age groups and AEZs were calculated. Descriptive statistics of the morphometric traits and Analysis of Variance (ANOVA) were used to establish significant differences at *p* ≤ 0.05.

Linear statistical regression models to determine the trend of the 10 linear morphometric trait variations among age groups, AEZs and breeds were computed. The linear multiple regression models used took the format of

\[
Y_{ijk} = \mu + B_i + AEZ_k + A_l + (BAEZ)_{ij} + (BA)_{jk} + (BAAEZ)_{ijk} + E_{ijk}
\]

\[
Y_{ijk} = \text{morphometric trait on the animal of } i^{\text{th}} \text{ breed, sampled from the } j^{\text{th}} \text{ AEZ, categorised to the } k^{\text{th}} \text{ age group; } \mu = \text{overall mean, } B_i = \text{effect of } i^{\text{th}} \text{ breed (} i = \text{Ankole, Nganda, EASZ), } AEZ_k = \text{effects of the } k^{\text{th}} \text{ AEZ (} k = \text{NED, NESG, NWSG, KP, LVC, WSG, WHR, PR, SWF, PS), } A_l = \text{effect of } l^{\text{th}} \text{ age group (} l = 7 - 24, 25 - 36, 37 - 72, 73 - 192 \text{ months), } (BAEZ)_{ij} = \text{interaction effect of } i^{\text{th}} \text{ breed and } j^{\text{th}} \text{ AEZ, } (BAAEZ)_{ijk} = \text{interaction effect of breed, AEZ, age, } E_{ijk} = \text{random error peculiar to each animal.}
\]

**Results**

**Trend of sub-clinical *T. parva* in cattle in the different Agro-ecological zones (AEZs)**

This study has revealed an estimated prevalence of sub-clinical *T. parva* to be 30% (248/925) among indigenous cattle of Uganda. The herd level prevalence was variable ranging from 0.0% to 100%. However a mean herd prevalence of 28% was observed. The prevalence of sub-clinical *T. parva* among indigenous cattle from the ten AEZs were categorised into three: - low (17 – 18%), medium (22 – 27%) and high (36 – 43%) based on the prevalence value, location and breed. Cattle exhibiting low prevalence were EASZ based in the NESG and NED zones with 17% (95% CI: 0.1 – 0.23) and 18% (95% CI: 0.08 – 0.27) respectively. Cattle which exhibited medium sub-clinical *T. parva* prevalence [KP, NWSG, PSG (EASZ cattle) and WSG (Ankole cattle) thus: - 22% (95% CI: 0.14 – 0.28), 25% (95% CI: 0.17 – 0.31), 25% (95% CI: 0.03 - 0.46) 26% (95% CI: 0.17 - 0.33) and LVC (Nganda cattle) - 27% (0.15 - 0.38) respectively]. Cattle which showed high sub-clinical *T. parva* were Ankole from PR, SWF
and WHR (36% (95% CI: 0.28 – 0.43), 39% (95% CI: 0.22 – 0.55), 43% (95% CI: 0.3 – 0.55) respectively (Table 2). The structure of sub-clinical T. parva infections exhibited a gradual decrease from southwestern highlands to eastern savannah grasslands and semi-arid drylands zone.

**The occurrence of sub-clinical T. parva by age, sex and breed**

The prevalence of sub-clinical T. parva infection decreased with the increase in age (months) [36% (7 – 24), 30% (25 – 36), 28% (37 – 72) and 25% (73 – 192)]. The parasite prevalence among the female (26%) and males (27%) was similar, while it was significantly higher among the Ankole (35%) as compared to the Nganda (18%) and EASZ (21%) cattle, even though the sample size of Nganda cattle was low (Table 3).

**Table 2: Distribution and risk of sub-clinical T. parva infection among the 10 AEZs**

<table>
<thead>
<tr>
<th>AEZ</th>
<th>Districts sampled</th>
<th>T. parva prevalence (95% CI)</th>
<th>Odds ratio (OR)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NESG</td>
<td>Pader, Kitgum, Katakwi, Abim</td>
<td>17 (0.1 - 0.23)</td>
<td>Reference</td>
<td></td>
</tr>
<tr>
<td>NED</td>
<td>Northwestern Kotido, eastern Kitgum, northern Nakapiripiriti</td>
<td>18 (0.08 - 0.27)</td>
<td>1.05</td>
<td>1.00</td>
</tr>
<tr>
<td>KP</td>
<td>Iganga, northern Bugiri, Tororo, Kaberamaido</td>
<td>22 (0.14 - 0.28)</td>
<td>1.27</td>
<td>0.53</td>
</tr>
<tr>
<td>NWSG</td>
<td>Adjumani, western Nebbi, Arua, Yumbe, northern Gulu, northern Apac</td>
<td>25 (0.17 - 0.31)</td>
<td>1.55</td>
<td>0.14</td>
</tr>
<tr>
<td>PSG</td>
<td>Eastern Nebbi, southwestern Gulu, western Masindi</td>
<td>25 (0.03 - 0.46)</td>
<td>1.59</td>
<td>0.49</td>
</tr>
<tr>
<td>WSG</td>
<td>Hoima, Kibaale, Kyenjonjo</td>
<td>26 (0.17 - 0.33)</td>
<td>1.64</td>
<td>0.15</td>
</tr>
<tr>
<td>LVC</td>
<td>Southern Masaka, Bukomansimbi, Buikwe, Mpigi, Jinja, Mayuge</td>
<td>27 (0.15 - 0.38)</td>
<td>1.74</td>
<td>0.16</td>
</tr>
<tr>
<td>PR</td>
<td>Masindi, Nakasongola, southern Mubende, eastern Mbarara, southern Ntungamo</td>
<td>36 (0.28 - 0.43)</td>
<td>2.70</td>
<td>0.0004***</td>
</tr>
<tr>
<td>SWF</td>
<td>western Mbarara, northern Ntungamo, Rukungiri</td>
<td>39 (0.22 - 0.62)</td>
<td>3.03</td>
<td>0.0110***</td>
</tr>
<tr>
<td>WHR</td>
<td>Kabale, Kasese, western Kyenjonjo</td>
<td>43 (0.3 - 0.73)</td>
<td>3.55</td>
<td>0.0003***</td>
</tr>
</tbody>
</table>

AEZ - Agro-Ecological Zone, NESG - North Eastern Savannah Grasslands, NED - North Eastern Drylands, KP - Kyoga Plains, NWSG - North Western Savannah Grasslands, PSG - Para-Savannah Grasslands, WSG - Western Savannah Grasslands, LVC - Lake Victoria Crescent, PR - Pastoral Rangelands, SWF - South Western Farmlands, WHR - Western Highland Ranges, **Significantly different from the reference (p < 0.05).

**Table 3 Multivariate regressions for the distribution and risk of T. parva infection by age, sex and breed type**

<table>
<thead>
<tr>
<th>Study population attributes</th>
<th>Number of T. parva positives</th>
<th>Prevalence (Ref) 95% CI</th>
<th>Odds ratio (OR)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (months)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-24</td>
<td>25</td>
<td>36 (Ref)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-36</td>
<td>46</td>
<td>30 (0.29 - 1.29)</td>
<td>0.71</td>
<td>0.24</td>
</tr>
<tr>
<td>37 - 72</td>
<td>94</td>
<td>28 (0.4 - 1.28)</td>
<td>0.61</td>
<td>0.21</td>
</tr>
<tr>
<td>73 - 192</td>
<td>108</td>
<td>25 (0.33 – 1.04)</td>
<td>0.59</td>
<td>0.05***</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>216</td>
<td>27 (Ref)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>32</td>
<td>26 (0.68 – 1.69)</td>
<td>1.06</td>
<td>0.82</td>
</tr>
</tbody>
</table>
The trend of morphometric traits among indigenous cattle

The results of the morphometric trait variations are based on female cattle due to the low numbers of their counter males as observed during sample collection. The age, breed and AEZs significantly influenced variations of linear morphometric traits of the female cattle studied. Age significantly influenced all traits except HBC, FAL and FAC, while AEZs and breed significantly influenced all the traits. Interactions of breed with AEZs influenced all traits except FAC, while interaction of breed with age, and AEZs with age significantly influenced FL and FAL respectively. Interactions of age, breed and AEZs significantly influenced FL only. The summary of ANOVA for the variation of linear morphometric traits and levels of significance is shown in Table 4:

Generally, the study linear morphometric traits exhibited significant gradual increase from low, intermediate to high dimensions among the EASZ, Nganda and Ankole cattle breeds respectively. All the study traits of Ankole cattle significantly differed among the age groups with exception of HBC. All the study traits of EASZ cattle exhibited significant differences among the age groups with exception of LHB, FAL and FAC. Among the Nganda cattle, the HL, FL, MC and AL exhibited significant differences within the different age groups. The traits generally increased along the age gradient, with older age groups exhibiting higher linear dimensions and providing a suitable source of breed differentiation (Table 5).

Linear morphometric traits from SWF, PR and WHR showed comparatively higher dimensions than traits from PS, NED, NESG and NWSG.

### Table 4: Summary ANOVA for linear morphometric traits of indigenous cattle

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>DF</th>
<th>HL</th>
<th>LHT</th>
<th>LHB</th>
<th>HBC</th>
<th>FAL</th>
<th>FAC</th>
<th>FL</th>
<th>MC</th>
<th>TL</th>
<th>AL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>3</td>
<td>6559***</td>
<td>3447**</td>
<td>242*</td>
<td>59 NS</td>
<td>69 NS</td>
<td>19 NS</td>
<td>271***</td>
<td>268***</td>
<td>103***</td>
<td>9531***</td>
</tr>
<tr>
<td>Breed</td>
<td>2</td>
<td>162419***</td>
<td>124961***</td>
<td>5298***</td>
<td>8018***</td>
<td>1739***</td>
<td>741***</td>
<td>1617***</td>
<td>564***</td>
<td>3498***</td>
<td>40950***</td>
</tr>
<tr>
<td>AEZ</td>
<td>9</td>
<td>31702***</td>
<td>25609***</td>
<td>1354***</td>
<td>1112***</td>
<td>325***</td>
<td>208***</td>
<td>367***</td>
<td>231***</td>
<td>1193***</td>
<td>8377***</td>
</tr>
<tr>
<td>Breed x AEZ</td>
<td>7</td>
<td>5616***</td>
<td>3788***</td>
<td>199***</td>
<td>492***</td>
<td>41***</td>
<td>6NS</td>
<td>63***</td>
<td>53***</td>
<td>480***</td>
<td>1170***</td>
</tr>
<tr>
<td>Breed x Age</td>
<td>6</td>
<td>975NS</td>
<td>282NS</td>
<td>73NS</td>
<td>38NS</td>
<td>12NS</td>
<td>11NS</td>
<td>25*</td>
<td>21 NS</td>
<td>82 NS</td>
<td>1108***</td>
</tr>
<tr>
<td>AEZ x Age</td>
<td>26</td>
<td>647NS</td>
<td>707NS</td>
<td>70NS</td>
<td>99NS</td>
<td>22***</td>
<td>9NS</td>
<td>16NS</td>
<td>7NS</td>
<td>58NS</td>
<td>475*</td>
</tr>
</tbody>
</table>

**Significantly different compared to the reference (Ref)**
Mean squares and levels of significance for the various linear morphometric traits

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>DF</th>
<th>HL</th>
<th>LHT</th>
<th>LHB</th>
<th>HBC</th>
<th>FAL</th>
<th>FAC</th>
<th>FL</th>
<th>MC</th>
<th>TL</th>
<th>AL</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEZ x age x breed</td>
<td>11</td>
<td>486NS</td>
<td>518NS</td>
<td>36NS</td>
<td>78NS</td>
<td>7NS</td>
<td>8NS</td>
<td>24*</td>
<td>10NS</td>
<td>160NS</td>
<td>169NS</td>
</tr>
<tr>
<td>Residual</td>
<td>736</td>
<td>373</td>
<td>461</td>
<td>55</td>
<td>64</td>
<td>10</td>
<td>6</td>
<td>9</td>
<td>10</td>
<td>70</td>
<td>278</td>
</tr>
</tbody>
</table>

AEZ – Agro-ecological zone, DF – Degrees of freedom, EASZ – East African shorthorn zebu, HL – Horn length, LHT – Length between the horn tips, LHB – Length between the horn bases, HBC – Horn base circumference, FAL – Fore arm length, FAC – Fore arm circumference, FL – Face length, MC – Muzzle circumference, TL – Tail length, AL – Animal length, NS – Not significant (p > 0.05), *** - Very highly significant (p < 0.001), ** - Highly significant (p < 0.01), *significant (p ≤ 0.05).

Table 5: Variation of linear morphometric traits of indigenous cattle breeds among the different age groups

| Breed         | Age group | Morphometric traits (mean ± SE) | HL ± SE | LHT ± SE | LHB ± SE | HBC ± SE | FAL ± SE | FAC ± SE | FL ± SE | MC ± SE | TL ± SE | AL ± SE |
|---------------|-----------|---------------------------------|--------|----------|----------|----------|----------|----------|--------|--------|--------|--------|--------|
| Ankole (n = 387) | 7 – 24    | 35.7 ± 5.1⁹ | 56.4 ± 5.8⁹ | 17.8 ± 1.3⁹ | 23.9 ± 2.2⁹ | 33.7 ± 0.7⁹ | 21.1 ± 0.4⁹ | 43.0 ± 1.0⁹ | 35.8 ± 0.7⁹ | 69.2 ± 2.1⁹ | 193.5 ± 3.5⁹ |
|               | 25 – 36   | 44.0 ± 4.7⁹ | 58.1 ± 4.8⁹ | 22.1 ± 1.7⁹ | 23.3 ± 1.6⁹ | 36.3 ± 0.7⁹ | 22.4 ± 0.5⁹ | 45.8 ± 0.7⁹ | 37.2 ± 0.4⁹ | 70.0 ± 1.4⁹ | 203.8 ± 4.0⁹ |
|               | 37 – 72   | 56.8 ± 2.3⁹ | 69.3 ± 2.3⁹ | 21.8 ± 0.8⁹ | 22.7 ± 0.8⁹ | 35.8 ± 0.3⁹ | 22.3 ± 0.3⁹ | 47.5 ± 0.3⁹ | 39.0 ± 0.2⁹ | 75.2 ± 0.7³ | 216.7 ± 1.8⁹ |
|               | 73 – 192  | 66.8 ± 2.4³ | 69.6 ± 2.4³ | 19.9 ± 0.7³ | 23.5 ± 0.8³ | 35.9 ± 0.3³ | 22.8 ± 0.2³ | 48.9 ± 0.3³ | 40.4 ± 0.2³ | 76.3 ± 0.7³ | 225.3 ± 1.5³ |
| Nganda (n = 46)  | 7 – 24    | 8.0 ± 5.0⁹ | 22.8 ± 5.0⁹ | 11.9 ± 1.0⁹ | 12.0 ± 4.0⁹ | 34.5 ± 2.5³ | 19.0 ± 1.0⁹ | 42.5 ± 0.5³ | 34.5 ± 3.5³ | 70.0 ± 10³⁹ | 186.5 ± 26.5⁹ |
|               | 25 – 36   | 25.8 ± 4.9³ | 50.8 ± 7.0⁹ | 18.5 ± 2.0³ | 17.3 ± 2.7³ | 34.0 ± 0.8³ | 21.3 ± 0.6³ | 44.7 ± 1.0³ | 35.5 ± 0.7³ | 68.0 ± 4.8³⁹ | 194.0 ± 4.0³⁹ |
|               | 37 – 72   | 26.7 ± 4.3³ | 43.5 ± 5.8³ | 15.0 ± 1.6³ | 17.6 ± 2.1³ | 34.3 ± 0.6³ | 23.3 ± 0.9³ | 46.4 ± 0.4³ | 38.0 ± 0.4³ | 76.9 ± 1.5³⁹ | 208.2 ± 1.8³⁹ |
|               | 73 – 192  | 39.2 ± 4.7³ | 48.9 ± 5.1³ | 17.6 ± 1.6³ | 17.9 ± 1.3³ | 32.7 ± 0.6³ | 22.0 ± 0.3³ | 46.3 ± 0.4³ | 37.7 ± 0.3³ | 76.2 ± 1.3³⁹ | 209.1 ± 2.6³⁹ |
| EASZ (n = 368)  | 7 – 24    | 8.9 ± 1.4³ | 22.8 ± 2.4³ | 11.9 ± 1.0³ | 11.4 ± 1.2³ | 31.5 ± 0.5³ | 19.4 ± 0.6³ | 41.2 ± 0.6³ | 34.7 ± 0.7³ | 64.0 ± 2.3³⁹ | 180.7 ± 3.5³⁹ |
|               | 25 – 36   | 12.1 ± 2.5³ | 26.1 ± 3.7³ | 11.6 ± 1.3³ | 12.0 ± 1.6³ | 32.3 ± 0.6³ | 19.1 ± 0.2³ | 42.1 ± 0.5³ | 34.6 ± 0.4³ | 65.9 ± 1.6³ | 193.3 ± 3.3³ |
|               | 37 – 72   | 15.3 ± 0.9³ | 30.9 ± 1.4³ | 13.3 ± 0.5³ | 13.4 ± 0.6³ | 31.8 ± 0.3³ | 19.9 ± 0.2³ | 43.9 ± 0.2³ | 37.5 ± 0.3³ | 70.7 ± 0.8³ | 199.3 ± 1.2³ |
|               | 73 – 192  | 20.6 ± 0.9³ | 33.2 ± 1.0³ | 13.7 ± 0.3³ | 14.6 ± 0.4³ | 31.4 ± 0.2³ | 19.8 ± 0.1³ | 43.9 ± 0.2³ | 37.2 ± 0.3³ | 69.3 ± 0.6³ | 199.0 ± 0.9³ |

SE – Standard Error, HL – Horn length, LHT – Length between tips, LHB – Length between the horn bases, HBC – Horn base circumference, FAL – Fore arm length, FAC – Fore arm circumference, FL - Face length, MC – Muzzle circumference, TL – Tail length, AL - Animal length, age is measured in months, linear morphometric traits are measured in centimetres, EASZ – East African short horn Zebu, * ⁻⁹ refer to very highly significant (p ≤ 0.000) differences, highly significant (p ≤ 0.00) differences and significant (p ≤ 0.05) differences respectively. NS – Not significantly different. The linear morphometric traits for each breed were compared among the different AEZs in the same column indicated with the same superscript.
### Table 6: Variation of linear morphometric trait of indigenous cattle breeds sampled from the different AEZs

<table>
<thead>
<tr>
<th>Breed</th>
<th>AEZ</th>
<th>Morphometric traits (mean ± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HL ± SE</td>
</tr>
<tr>
<td>Ankole (n = 378)</td>
<td>NWSG</td>
<td>44.1 ± 6.0 a</td>
</tr>
<tr>
<td>Anco (n = 378)</td>
<td>KP</td>
<td>48.1 ± 4.7 a</td>
</tr>
<tr>
<td>LVC</td>
<td>28.0 ± 3.3 a</td>
<td>40.6 ± 2.9 a</td>
</tr>
<tr>
<td>WSG</td>
<td>51.0 ± 3.5 a</td>
<td>61.3 ± 3.5 a</td>
</tr>
<tr>
<td>WHR</td>
<td>52.0 ± 3.0 a</td>
<td>67.9 ± 3.0 a</td>
</tr>
<tr>
<td>PR</td>
<td>76.9 ± 2.3 a</td>
<td>81.9 ± 2.5 a</td>
</tr>
<tr>
<td>SWF</td>
<td>80.7 ± 3.9 a</td>
<td>85.0 ± 4.8 a</td>
</tr>
<tr>
<td>Ngada (n = 46)</td>
<td>NED</td>
<td>29.1 ± 2.5 a</td>
</tr>
<tr>
<td>LVC</td>
<td>29.4 ± 2.4 a</td>
<td>44.9 ± 2.2 a</td>
</tr>
<tr>
<td>PR</td>
<td>33.8 ± 5.5 a</td>
<td>47.9 ± 7.8 a</td>
</tr>
<tr>
<td>EASZ (n = 465)</td>
<td>KP</td>
<td>23.3 ± 1.8 a</td>
</tr>
<tr>
<td>LVC</td>
<td>20.0 ± 3.0 a</td>
<td>40.1 ± 4.0 a</td>
</tr>
<tr>
<td>NED</td>
<td>14.6 ± 1.6 a</td>
<td>26.6 ± 2.3 a</td>
</tr>
<tr>
<td>NESG</td>
<td>16.1 ± 1.0 a</td>
<td>29.3 ± 1.6 a</td>
</tr>
<tr>
<td>NWSG</td>
<td>17.0 ± 0.9 a</td>
<td>32.5 ± 1.3 a</td>
</tr>
<tr>
<td>PS</td>
<td>13.5 ± 1.6 a</td>
<td>31.1 ± 2.5 a</td>
</tr>
<tr>
<td>PR</td>
<td>11.6 ± 1.3 a</td>
<td>29.8 ± 2.9 a</td>
</tr>
<tr>
<td>WSG</td>
<td>31.6 ± 5.4 a</td>
<td>41.9 ± 5.1 a</td>
</tr>
</tbody>
</table>

AEZ – Agro-ecological zone, SE – Standard Error, HL – Horn length, LHT – Length between tips, LHB – Length between the horn bases, HBC – Horn base circumference, FAL – Fore arm length, FAC – Fore arm circumference, FL - Face length, MC – Muzzle circumference, TL – Tail length, AL - Animal length, EASZ – East African Short horn Zebu, NED – North Eastern drylands, NESG – North Eastern Savannah Grasslands, NWSG – North Western Savannah grasslands, KP – Kyoga Plains, LVC – Lake Victoria Crescent, WSG – Western Savannah Grasslands, WHR – Western Highland Ranges, PR – Pastoral Rangelands, South Western Farmlands, PS - Para Savannahs. a, b, c refer to very highly significant (p≤ 0.000) differences, highly significant (p≤ 0.00) differences and significant (p≤ 0.05) differences respectively. The linear morphometric traits for each breed were compared among the different AEZs in the same column indicated with the same superscript.
The variations of morphometric traits within same cattle breeds sampled from different AEZs were observed. Similar traits of Ankole cattle from different AEZs were significantly different. Among the EASZ cattle similar traits exhibited significant differences with exception of LHB, while the LHB, HBC, FAL and MC of Nganda cattle exhibited significant differences (Table 6).

**Discussion**

This study was aimed at relating the structure of sub-clinical *T. parva* among indigenous cattle populations with the linear morphometric trait variations in the different AEZs in Uganda based on samples and data collected from January 2011 to April 2012 in a landscape approach. The prevalence of sub-clinical *T. parva* at individual and herd level of 30% and 28% established in this study was within limits given the fact that the ECF is endemic in Uganda and indigenous cattle are associated with its sub-clinical syndrome. Similar observations of 25.3% to 27.1% *T. parva* were observed by (Bazarusanga et al., 2007) in neighbouring Rwanda during nationwide surveys carried out between 1998 and 2003.

The prevalence of sub-clinical *T. parva* was widely varied among the different AEZs [low 17% to high 43% in the northeastern (NESG, NED) and southwestern (SWR, WHR, PR) AEZs respectively. The diverse AEZs attributes and weather conditions, coupled with farmers’ management practices influence tick abundance. Higher rainfall patterns, suitable environmental temperatures and abundant wildlife coupled with pastoral and open grazing systems practiced in southwestern and western Uganda favours increased cattle – tick activity (Kabi et al., 2014).

Linear morphometric structures of indigenous cattle populations including the Ankole, Nganda and EASZ vary with age, breed types and AEZs (Kabi et al., 2015). These variations foster indigenous cattle populations’ adaptation to different AEZs (Kugonza et al., 2011). These structures have resulted from selection of unique morphometric traits to improve AEF and enrich socio-cultural identities among cattle keeping communities.

While, the Ankole cattle breed nurtured in western, southwestern and some parts of central Uganda exhibited significantly higher linear morphometric traits. The availability of comparatively higher natural pasture and water resources in western and southwestern region of Uganda combined with the possibility of hybrid vigour of Ankole (*B. taurus x B. indicus*) cattle (Hannote et al., 2010) could have resulted into higher morphometric traits of the Ankole compared to EASZ cattle. Additionally, the Ankole cattle keepers’ selective breeding criteria based on customary knowledge to enhance higher productivity, socio-cultural identity and beauty could be fostering the ability their cattle to endure *T. parva* challenges (Kugonza et al., 2012, 2011; Ndumu et al., 2008a). The reverse was exhibited in the southwestern and northeastern savannah grasslands inhabited by the EASZ cattle. This implies that agro-ecological attributes which favour higher *T. parva* infection prevalence will also favour superior morphometric traits exhibited among the Ankole cattle population.

The EASZ cattle exhibited comparatively low linear morphometric trait dimensions which occurred in the NED, PS, NESG and NWSG AEZs. The northeastern, northern and northwestern regions are characterised by lower altitudes, higher ambient temperatures and lower precipitation patterns (< 500 mm) which consequently lower the availability of pasture and water resources (Balikowa, 2011). Consequently, indigenous livestock farmers’ selection criteria tend to favour cattle’s ability to survive under lower feed and water availability (Nalule, 2010; FAO, 2007) which in turn influences lower body sizes of EASZ cattle breed types. Selection of smaller body measurements have enabled the comparatively smaller EASZ cattle to thrive under the less privileged climatic, feed and water resource conditions (FAO, 2009; Loquang and Köhler-Rollefson, 2005). The EASZ cattle also exhibited lower sub-clinical *T. parva* prevalence. This too strengthens the fact that cattle keeping communities selectively breed for disease tolerance in addition to AEF.
Conclusions

This study has revealed that high prevalence of *T. parva* infection occurred among indigenous cattle populations with similarly high linear morphometric traits in Uganda. The two gradients of sub-clinical *T. parva* and linear morphometric structures are influenced by AEZ, breed and farmer cattle management activities. These baselines are critical for development, deployment and monitoring of integrated tick control strategies. These results further motivate indigenous cattle improvement and conservation with *T. parva* infection tolerance.

Acknowledgements

We thank the Eastern Africa Agricultural Productivity Project (EAAPP) of NARO Uganda and Next generation methods to preserve farm animal biodiversity (NEXTGEN) project for providing the logistics for this study. The Uganda National Council for Science and Technology (UNCST) granted permission to undertake this study to which we are grateful. We acknowledge the DVOs, veterinary staff and farmers for granting us permission to undertake this study in their districts.

References


Discussion Session

Question: Whether the study considered production/management systems in the different agro ecological zones and whether this would have added value to the discussion.

Answer: Yes vector control use of Acaricides was considered. However, the study discovered that there was a lot of misuse of Acaricide which opens up more questions.
Study on bovine tuberculosis in selected areas of Tanzania and Kenya


1Veterinary Research Centre Muguga, Veterinary Sciences Research Institute P.O. Box 32-00902 Kikuyu, KENYA, 2Central Veterinary Laboratories Private Bag 00625 Kangemi, KENYA 3Tanzania Veterinary Laboratory Agency (TVLA), Veterinary Complex, 131 Nelson Mandela Road, P. O. Box 9254, 15487 Dar es Salaam, TANZANIA

* Corresponding author: jommugambi@gmail.com Tel +254721433783

Abstract
The zoonotic Mycobacterium bovis is a pathogen of significance in the dairy industry. Although the pathogen primarily affects cattle it has a wide host range including humans. Mycobacterium bovis can be shed in milk and therefore un boiled milk from infected cattle is a major source of infection to humans. A cross-sectional study was carried out in three agro-ecological zones of Tanzania namely the Southern Highlands Zone (SHZ), Eastern Zone (EZ) and Northern Zone (NZ) to check current status of the disease in cattle in order to inform control measures. A total of 391, 169 and 401 cattle were tested for bovine tuberculosis (bTB) in the SHZ, EZ and NZ respectively using the single intradermal comparative cervical tuberculin test (SICTT). Results showed that the prevalence of bTB was higher (p<0.05) in EZ 2.37% (n = 169) as compared to SHZ 1.3% (n=391) and NZ where no positive result was recorded (n = 401). Thirty three cattle from SHZ and seven cattle from EZ showed inconclusive results. In Kenya 625 cattle from four sites within agro-pastoral and pastoral production systems were tested. In one area of Mwingi County, Eastern Kenya, all the 161 cattle tested were negative while in the other three sites of Migori, in Nyanza, WestPokot and Laikipia in Rift Valley, prevalence of 4-6% was obtained with SICTT. Bovine TB occurs in the region and may pose a public health threat through occupational activities and/or consumption of animal products especially because no obvious clinical signs were observed in positive animals. Policy issues on how to deal with positive cases, creation of awareness on this important zoonotic disease and a simple test to quickly identify sick animals in the field require urgent attention.

Key words: Agro-ecological zones, Bovine, Kenya, Prevalence, Tanzania, Tuberculosis, Zoonoses

Introduction
Bovine tuberculosis (bTB) is caused by Mycobacterium bovis bacterium. The disease is found most commonly in cattle but it is also found in other domestic animals. It is zoonotic, which means that it is transmissible between animals and humans (PAHO, 2001). The primary signs of bTB infection include persistent coughing, weakness and loss of weight. Symptoms result from the formation of tuberculous nodules in the lungs or the lymph nodes particularly of the lungs and the mammary glands but tubercles can be found in any organ (OIE, 2009). The symptoms usually take months to develop in cattle and infections can also remain dormant for years only to reactivate during periods of stress or in old age. Infected animals may develop a chronic, debilitating disease whose severity varies with the dose of infectious organisms and individual immunity (OIE, 2009).
Although bTB is distributed worldwide some countries have managed to control it by testing and slaughter. In Africa, bTB represents a potential health hazard to both animals and humans, as nearly 85% of cattle and 82% of the human population live in areas where the disease is prevalent or only partially controlled (Thoen and Steele, 1995). It also is present in wildlife (Cleaveland et al., 2005; Lekolool, 2011). A significant correlation between the prevalence of M. bovis infection in humans and that in local cattle populations was reported thus highlighting the potential threat of this disease to humans (Daborn et al., 1996). The estimated prevalence of bTB in animals in Tanzania has been reported to range across regions from 0.2% to 13.3% (Katale et al., 2012).

Lack of public awareness about the disease is considered to increase the risk of acquiring and spreading it in animals and man (Lienhardt, 2001; Lienhardt et al., 2005). Lack of knowledge on disease transmission, clinical signs and proper animal husbandry as well as pastoralists’ eating behaviour not only expose animal and human populations to an increased risk of contracting bTB but also affect the control strategies (Shirima et al., 2003; Mfinanga et al., 2003; Onoja et al., 2010).

Much more work on bTB has been published in Tanzania (eg Shirima et al., 2003; Cleaveland et al., 2007; Mwakapuja et al., 2013) than in Kenya where studies are limited. The most recent one in Kenya was carried out in abattoirs and a prevalence of 2.05% of M. bovis was obtained using molecular techniques although isolates of M. bovis were made from 19 out of 176 carcasses that had lesions suggestive of tuberculosis (Gathogoet et al., 2012). The aim of this study was to assess knowledge on tuberculosis amongst pastoralists and agro-pastoralists and to document the presence or absence of disease in these communities in selected areas of Tanzania and Kenya as a basis for taking appropriate action including surveillance which is either inadequate or non-existent (Cosivi et al., 1998). The findings on the knowledge and perceptions of farmers on bTB are presented in a separate paper.

**Materials and Methods**

This cross-sectional study was conducted in selected areas of Tanzania and Kenya where pastoral and agro-pastoral livestock keeping are practiced. Sample size was calculated using the standard formula for estimation of proportions (Martin et al., 1987) and the prevalence was expected to have a maximum of 50% with 95% confidence level.

**Kenya**

**Study area**

Kenya is located between latitudes 5° N and 4°S and longitudes 33° E and 42° E. The equator divides the country into two almost equal portions. Migori County covers 2,596.5km², is situated in the South-Western part of Kenya and forms part of the border with Tanzania. The altitude of Migori rises from 1140m at the shores of Lake Victoria in Nyatike to 4,625m in Uriri. Climate is inland equatorial that is modified by altitude, relief and Lake Victoria. The long rains occur between March and May and the short rains between September and November. Rainfall varies from 700 to 1800m (Hitaji Development Initiative, 2015). Indigenous breeds and some crosses constitute up to 95% of the cattle population in Migori. A more sedentary farming system is picking up in the County.
Mwingi is in Kitui County. The area has four agro-ecological zones in this arid and semi-arid region (Ministry of Devolution and Planning, 2013). The county is predominantly a livestock rearing area but water scarcity and diseases pose formidable challenges. Rainfall pattern is bimodal with the long rains which are often erratic falling from March to May. The short rains come in October to December. The annual rainfall ranges from 300 to 1050mm (Ministry of Devolution and National Planning, 2013).

West Pokot County is in the western zone of Kenya. It covers an area of 8418.2km² andforms part of the border with Uganda. Livestock farming is a favoured cultural practice. The county is mainly semi-arid to arid (Jaetzold et al., 2011).

Laikipia County covers 9462km² and lies between an altitude of 1500m above sea level at Ewaso Nyiro basin in the North and 2611m around Marmanet forest in the South. The Rift Valley, the Mt. Kenya and the Aberdares have significant effects on the climatic conditions of the County. The County is suitable for grazing and ranching besides having abundant wildlife (Laikipia County, 2013). It experiences a relief type of rainfall due to its altitude and location. The average annual rainfall varies from 400mm to 750mm with areas bordering Mt. Kenya and the Aberdares receiving the higher rainfall. The long rains are experienced from March to May and the short rains, in October and November (Laikipia County, 2013).

Site selection in Kenya
The study was conducted in sites within four counties. The reasons for selecting the areas are shown in Table 1:

Table 1: Reasons for selection of County to include in the study in Kenya

<table>
<thead>
<tr>
<th>Area</th>
<th>Reason(s) for choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laikipia</td>
<td>Earmarked as a disease free zone and flagship county for livestock export in government plans</td>
</tr>
<tr>
<td>Mwingi</td>
<td>Situated along an important cattle route</td>
</tr>
<tr>
<td>Migori</td>
<td>Anecdotal information of a TB problem in the area</td>
</tr>
<tr>
<td>Pokot</td>
<td>Milk is not necessarily boiled before consumption</td>
</tr>
</tbody>
</table>

Farm selection
Farms to be visited were randomly selected with the assistance of field veterinary personnel. A maximum of three cattle were tested in each of the test farms. Majority of the tested animals were females. A total of 625 cattle were screened of which 124 were from Migori, 78 from West Pokot, 262 from Laikipia and 161 from Mwingi.

Tanzania
Study area
Tanzania lies between longitudes 30E and 43E and latitudes 10S and 110S. It is close to the equator and has a typical tropical climate (ICD, 2010). However, there are variations between different agro-ecological zones and this cross-sectional study was conducted in three agro-ecological zones namely Southern Highlands Zone (SHZ), Eastern Zone (EZ) and Northern zone comprising different regions with varying cattle populations. Generally, altitude modifies climatic conditions; SHZ and NZ receive an average of 1250mm rainfall and in EZ rainfall ranges between 750 and 1250 mm per annum whereas the mean temperature ranges from 20-26°C in January and 16 – 22°C in July, the coolest being
in Northern and Southern Highlands and the warmest being in the Eastern zone along the coast (Mbululo and Nyihirini, 2012).

Cattle were randomly picked from selected villages. Milking cows and heifers were targeted during selection. In a few exceptional cases bulls (such as bulls owned by a group of farmers) were also screened. A total of 961 cattle were screened and of these, 391 were from SHZ, 401 from NZ and 169 from EZ.

**bTB Screening**

**Preparation of cattle for injection with protein derivatives**

Cattle were restrained in crushes and prepared for intradermal inoculation as recommended by the tuberculin test kit’s manufacturer. Briefly, the cattle were visually examined for any obvious skin swellings or clinical signs of tuberculosis. An area within the middle third of the neck was then marked for shaving. On each animal, two areas about 10 cm apart were shaved and the cut hair and any debris brushed off in order to allow for the injection of avian as well as bovine purified protein derivatives (PPD) of *Mycobacterium avium* and *Mycobacterium bovis* respectively. The proteins were injected on either of the two shaved skin sites.

**Injection**

Before injecting the proteins, a fold of skin at each of the intended clipped injection sites was accurately measured in mm with a pair of callipers. A 0.1 ml volume of avian PPD and of bovine PPD was delivered intra-dermally using a 1 ml tuberculin syringe. The area was palpated to feel the presence of a small swelling indicative of intradermal injection (OIE, 2009).

**Reading of results**

The skin fold thickness at each injection site was measured at 72 hrs post inoculation. The same person carried out all the measurements at any one study site. Differences in the magnitude of swellings between the avian and the bovine PPD injection sites were recorded in mm. All inconclusive results were to be re-tested after 42 to 60 days as recommended (OIE, 2009). However, in this study re-testing was only done in Migori County – Kenya.

**Interpretation of results**

Table 2 shows the criteria of interpreting the results.
Table 2: Criteria of interpreting the comparative intradermal tuberculin test results (adapted from Annex B of Council Directive 64/432/EEC and OIE, 2009)

<table>
<thead>
<tr>
<th>Result</th>
<th>Difference between thickness (mm) of bovine and avian PPD injections after 72hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>A reaction to bovine tuberculin PPD which is more than 4mm compared to the reaction to avian PPD</td>
</tr>
<tr>
<td>Inconclusive</td>
<td>A reaction to bovine tuberculin PPD of at least 2mm which is 1-4mm greater than the reaction to avian PPD</td>
</tr>
<tr>
<td>Negative</td>
<td>A reaction to bovine tuberculin PPD which is equal to or less than 1mm the reaction to avian tuberculin PPD</td>
</tr>
</tbody>
</table>

Data analysis
The data was recorded and organised using Microsoft Excel 2010. Statistical analysis was carried out using Epi Info 7 statistical software. MedCalc® statistical software was used to compare proportions of the variables. Statistical significance between variables was examined using P-value at critical probability of P<0.05 for the Tanzanian data.

Results
In all cattle screened in Tanzania and Kenya there was no report of obvious clinical signs of bTB. However, upon testing with SICTT, while some animals had hardly any discernible swellings, others had diffuse, oedematous, warm and painful swellings at the injection sites. In Kenya prevalences of 4%, 5% and 6% were recorded in Migori, Laikipia and West Pokot counties respectively while no positive cases were obtained in Mwingi (Table 3).

Table 3: Summary bTB test results in Kenya and Tanzania of inconclusive results

<table>
<thead>
<tr>
<th>Site</th>
<th>No. tested</th>
<th>No. positive</th>
<th>No. inconclusive</th>
<th>Prevalence (%)</th>
<th>% Inconclusive</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHZ (Tanzania)</td>
<td>391</td>
<td>5</td>
<td>7</td>
<td>1.28</td>
<td>8.44</td>
</tr>
<tr>
<td>NZ (Tanzania)</td>
<td>401</td>
<td>0</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>EZ (Tanzania)</td>
<td>169</td>
<td>4</td>
<td>33</td>
<td>2.37</td>
<td>4.14</td>
</tr>
<tr>
<td>Total (Tanzania)</td>
<td>961</td>
<td>9</td>
<td>40</td>
<td>0.93</td>
<td>4.16</td>
</tr>
<tr>
<td>Migori (Kenya)</td>
<td>124</td>
<td>5</td>
<td>25</td>
<td>4.03</td>
<td>20.16</td>
</tr>
<tr>
<td>West Pokot (Kenya)</td>
<td>78</td>
<td>5</td>
<td>26</td>
<td>6.41</td>
<td>33.33</td>
</tr>
<tr>
<td>Laikipia (Kenya)</td>
<td>262</td>
<td>13</td>
<td>0</td>
<td>4.96</td>
<td>0</td>
</tr>
<tr>
<td>Mwingi (Kenya)</td>
<td>161</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total (Kenya)</td>
<td>625</td>
<td>23</td>
<td>51</td>
<td>3.68</td>
<td>8.16</td>
</tr>
</tbody>
</table>

In Tanzania, prevalences of 2.37% and 1.28% were recorded in EZ and SHZ respectively (Table 3). No positive cases were recorded in NZ where 401 cattle were screened. Relatively high percentages of inconclusive results were also recorded: 20.16% and 33.33% in Migori and West Pokot and 8.44% and 4.14 % in SHZ and EZ respectively. Retesting of 26 animals in Migori showed that six more (24%) out of 25 cattle were positive, raising the prevalence to 8.9%. One animal was not presented for reading after 72hr following re-testing.
Discussion

*Mycobacterium bovis* has been reported for many years in Tanzania (Markham, 1952; Kazwala, 1996; Mwakapuja *et al.*, 2013) and this study confirms that the disease still persists. The prevalence was 1.28% in SHZ and 2.37% in EZ and it is the first report of bTB in the two areas. The prevalences are lower than those reported by Shirima *et al.* (2003) and Mwakapuja *et al.* (2013) in different parts of the country but they are within the estimated prevalence of 0.2% to 13.3% across regions in the country (Katale *et al.*, 2012).

In Kenya bTB is classified as notifiable under the Animal Diseases Act. The results showed that the disease is present in three of the Kenyan study sites with prevalences of 4 to 6%. They indicated the occurrence of the disease in additional areas in Kenya. Re-testing by SICTT in Migori resulted in 24% of positive reactors from the re-tested animals suggesting that the prevalences might be higher than what is reported here. Similar findings were reported in Brazil when six out of seven inconclusive cases by the skin test were shown to be positive by PCR and culture (Zarden et al., 2013). Medeiros *et al.* (2010) reported that anergic animals may be harbouring TB and yet be unreactive to the skin test while delayed hypersensitivity may take 3 to 6 weeks following infection (OIE, 2009). These are probable reasons for obtaining inconclusive results in this study.

Lekolool (2011) investigated the epidemiology of *M. bovis* in the wildlife-livestock interface to determine the prevalence and spatial distribution in Masai Mara and Amboseli ecosystems. With the gamma interferon assay the overall prevalence in wildlife was 14.8% compared to 2.3% among the livestock. This is of epidemiological significance since some wild animals may have a role in the spread of the disease to other wild and domestic animal species (Shitaye *et al.*, 2007).

*Mycobacterium bovis* has been associated with human extra pulmonary tuberculosis. *M. bovis* accounts for only 1% of all human TB in developed countries as compared to 10% in the developing world (Etchechoury *et al.*, 2010). In Tanzania, one of the few developing countries with quantitative data on the prevalence of *M. bovis* there was a significant increase (116.6%) of extra-pulmonary cases reported between 1995 and 2009, suggesting the possibility of widespread *M. bovis* infection. In the southern highlands region of the country, *M. bovis* was isolated from 1/23 (4%) cases of pulmonary TB, from 6/21 (28.6%) cases of cervical adenitis and from 7/65 (10.8%) of culture-positive cases of cervical adenitis in the Arusha region. Since extra-pulmonary TB cases comprise 15–20% of new cases of TB recorded each year in Tanzania, *M. bovis* may not be a negligible component of the human tuberculosis epidemic (Cleaveland *et al.*, 2007). That bTB contributed substantially to the burden of human extra-pulmonary tuberculosis in Tanzania is worrying given that *M. bovis* is resistant to pyrazinamide, one of the four first line TB antibiotics and prognosis is often poor (WHO, 2010). In Tanzania, ignorance of farmers about the disease and how its spreads coupled with culture and uncontrolled movement of animals are important risk factors (Chota personal communication). The lack of clear policies on how bovine tuberculosis can be controlled and the failure of health authorities to associate cattle with tuberculosis hinder the control of the disease. Furthermore the disease which is considered neglected has not even been classified as notifiable in the country (Kazwala *et al.*, 2006). However, the present results indicate a rather low prevalence of bTB and imply a low risk to humans in the study areas.

Findings have shown that pastoral and agro-pastoral communities were at greatest risk from bTB and brucellosis and people with poor levels of knowledge living in remote, marginalised areas are particularly at high bTB risk (WHO, 2010). Public awareness of hygienic measures that can substantially reduce the risk of diseases in these settings is often very limited (World Bank, 2010a). A questionnaire study that preceded the SICTT showed that indeed awareness was very limited (Omwenga *et al.*, in press). The hygienic conditions and sanitary services available to
dispose wastewater and organic material in slaughterhouses was found wanting in some places within the study sites. During this study sensitization meetings were held and more of these need to be held.

Success in reducing the public health significance of zoonotic diseases greatly depends on the level of cooperation between medical and veterinary sectors in the diagnosis of zoonoses, exchange of information, organization of shared surveillance systems, common training of staff and creation of community awareness (WHO, 2003).

Hygienic measures are recommended universally for the control of TB among cattle. The infected animal which is a potential source of infection should be identified through periodic application of the intradermal tuberculin test and removed from the herd by destruction or by segregation. However the policy to support this action is not in place in either country. Lately, the practice has received severe criticism because of costs and chances of falsely condemning healthy, high value cattle and of missing infected ones. Coupled with this is the view that the reaction to the skin test could actually be a sign of immunity rather than of sickness (Ritchie et al., 2011). Vaccination is an important tool to help control bTB but the efficacy of the BCG vaccine was reported to vary from 56 to 68% depending on the parameter measured (Ameni et al., 2010) and it has not been approved for use. The presence of maintenance hosts in wildlife populations also impedes bTB eradication programmes (Etter et al., 2006) and wild animals too have to be considered in the programmes. However, it is prudent to control the disease because of the high pay-off and cost-effectiveness of control interventions for zoonotic diseases (Coleman et al., 2004; Budke 2006; Fevre et al., 2008). Significant benefits that accrue from improved prevention and control measures of a disease outweigh the cost of investing in the necessary animal health services (OIE 2007). For example in Africa it has been estimated that an investment of €14.7 million to control CBPP could save €30 million annually in losses from morbidity/mortality, leading to a net benefit of €15.4 million (World Bank, 2010b).

From the observations made during the course of this study it is necessary to use knowledge dissemination methods that account for poor literacy or illiteracy and poor visual literacy. It is also important to involve and interest political leaders and other advocates, establish and implement regulatory structures for sale of milk and develop an integrated national policy for control of bovine tuberculosis. Bovine-induced human tuberculosis, brucellosis, and echinococcosis are major causes of morbidity and mortality among poor people although they are also almost certainly the most under-reported diseases (World Bank, 2010b).

The intradermal tuberculin skin test is recommended by the OIE for international trade (OIE, 2009) although it is not 100% reliable. However delayed hypersensitivity may not develop for a period of 3–6 weeks following infection. Thus, if a herd/animal is suspected to have been in recent contact with infected animals, testing should be delayed in order to reduce the probability of false-negatives (OIE, 2009). A number of blood tests are available. These include the gamma interferon and the lymphocyte proliferation assays that test cellular immunity and the ELISA that tests humoral immunity. Due to the cost and the more complex nature of laboratory-based assays, they are usually used as ancillary tests to maximise the detection of infected animals, or to confirm or negate the results of an intra-dermal skin test (OIE, 2009). PCR based tests using geneXpert machines are now available in the human diagnostic laboratories.
Conclusions
The prevalences of bTB of 1.28% and 2.37% in Tanzania were lower than the 4-6% obtained in Kenya. The study areas had not been sampled before. The relatively high number of inconclusive results was thought to indicate anergy or a delay in reactions and it likely to understate the real prevalence. A more accurate, easy to use test is required. In the positive animals no obvious clinical signs of the disease were evident, making it difficult for farmers to easily appreciate the significance of bTB. No policies appear to be in place to effectively control bTB in either country. The test and slaughter policy that is used in other countries as a means of controlling and possibly eradicating the disease has lately come under scrutiny as to its effectiveness and rationale and efficacious vaccines are required.

Acknowledgements
This study was conducted with funds from the East African Agricultural Productivity Project (EAAPP). In Kenya the support of the Director General of KALRO is acknowledged with thanks. Technical inputs were provided by Esther Muendo and Eunice Nganga of the office of the Director of Veterinary Services assisted by Samuel Mungai of KALRO. Thanks to the Chief Executive officer (CE) of Tanzania Veterinary Laboratory Agency (TVLA) for granting permission for sample storage and analysis. We appreciate the TVLA centres in SHZ and Veterinary Officers in the study areas of both countries for hosting, supporting and being involved in the sampling teams. Last but not least thanks to all livestock keepers who were involved in the study.

References


ICID (2010). Tanzania country profile. Website: http://www.icid.org


Mbululo, Y. and Nyihirani, F. (2012). Climate characteristics over Southern Highlands Tanzania. Atmospheric and Climate Sciences 2: 454 – 463


Ministry of Devolution and Planning 2013. Kitui County Development Profile


OIE (2009). Bovine Tuberculosis Ch. 2.4.7 OIE Terrestrial Manual


WHO (2010). Global tuberculosis control, Global, region and country-specific for key indicators. Website: http://www.who.int/tb/data


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**Discussion Session**

*Question:* Methodology – since there is distinct weather conditions in a year would have been appropriate to collect data based on those. Other factors that could have been considered are farming systems, agro-ecology etc. It is also important to investigate the source of differences in disease prevalence

*Answer:* Comment is valid. However for this study we were not comparing prevalence between the 2 countries. Ours was to generate additional data to inform actions like surveillance given that bovine TB in a trade sensitive disease

*Question:* What control measures apart livestock movement are being effected to control tuberculosis in cattle in Kenya. If it is done is it routine?

*Answer:* The other important action actions are pasteurization and boiling of milk and also meat inspection. Attempts have been made to produce a BCG vaccine for use in cattle but the efficacy is about 50%-65% at present and it has not even been approved for commercial use.
Screening Napier grass (*Pennisetum Purpureum*) accessions for dry matter yield and tolerance to napier stunt disease in Uganda

Kabirizi, J.1,*; Kawube, G.2; Mulaa, M.3; Namazzi, C.1; Mugerwa, S.1; Lukwago, G.4; and Nampijja, Z.5

1National Livestock Resources Research Institute, P.O. Box 96, Tororo, Uganda; 2Kenya Agricultural Research Institute, P.O. Box 450-30200, Kitale, Kenya; 3National Crops Resources Research Institute, P.O. Box 7084, Kampala, Uganda; 4Eastern Agricultural Productivity Programme, PCU-NAROSEC, P.O. Box 265, Entebbe, Uganda; 5Makerere University, P.O. Box 7062, Kampala, Uganda.

*Correspondence: jmkabirizi@gmail.com

Abstract

Napier grass (*Pennisetum Purpureum*) fodder contributes 60-80% of the forages in smallholder dairy systems in Eastern and Central Africa. However, production is threatened by the emergence of Napier stunt disease (NSD) leading to a reduction in dry matter yield (DMY) of over 40%. A study was conducted at the National Crops Resources Research Institute, Namulonge in Central Uganda, to screen 22 Napier grass accessions found to be tolerant to NSD in Kenya.

The accessions were planted in a Randomized Complete Block Design replicated three times with spreader rows of diseased plants. At each harvest, scoring for NSD incidence was done using a scale of 1 to 5 where 1 = no symptoms, 2 = very mild symptoms, 3 = medium mild symptoms, 4 = severe symptoms and 5 = very severe symptoms. Data were collected at intervals of 8 weeks. Herbage DMY was estimated using methods described by Mannetje (1978). The trial lasted for one year (September 2012 to September 2013). Results for 5 harvests (40 weeks) showed that accessions 97, 112, 16702, Kakamega 1 and Kakamega 2 produced highs DMY (31-46 t/ha) and showed no disease symptoms up to the 5th harvest. Accessions with a high disease build-up such as River Bank, 104, 79 Napier +Sugar had very low DMY (12-17 ton/ha). Based on DMY and tolerance to NSD, Kakamega 1, Kakamega 2, 97, 112 and 16702 were recommended for multiplication in NSD “hot spots” to improve feed availability. There is need to continue collecting data for more than 3 years since farmers maintain Napier grass fields for more than 5 years, and also to assess the effect of fertilizer application on NSD incidence.

Key words: Dry matter yield, Disease score, Napier stunt disease, Tolerance

Introduction

Napier grass (*Pennisetum Purpureum*) also known as elephant grass fodder contributes 60-80% of the forages in smallholder dairy systems in Eastern and Central Africa (ECA) (Kabirizi et al., 2006; Orodho, 2006). The grass, whose herbage dry matter yield (DMY) ranges between 16 and 30 t/ha/year is grown by over 80% of smallholder farmers in ECA. Indirectly, some farmers earn cash incomes from selling napier grass fodder to dairy farmers. The grass is also being used as a trap plant in the integrated management of stem borers (*Chilo partellus*) of maize and sorghum (Ahmed et al., 2008).

Napier grass production in ECA is threatened by Napier stunt disease (NSD) caused by 16SrXI group phytoplasma (*Candidatus Phytoplasma oryzae*) (Nielsen et al., 2007). Studies conducted in Uganda have shown that all locally...
available napier grass accessions are susceptible to NSD (Kawube et al., 2014; Nielsen et al. 2007). Affected shoots become pale yellow in colour and seriously dwarfed (Mulaa et al., 2010). Often the whole stool is affected, with yield reductions of 40-100% and eventual death of the plants. Consequently, the disease has reduced feed availability for livestock, increased price of napier grass in the worst affected districts, forcing some farmers to sell off their livestock.

Research efforts on napier grass diseases have intensified in the last 5 years through the Regional Dairy Centre of Excellence (RDoE) under EAAPP at Kenya Agricultural and Livestock Research Organization (KALRO), and the International Centre for Insect Physiology and Ecology (ICIPE) in Kenya (Mulaa et al. 2010). As a result some resistant/tolerant accessions have been identified (Mulaa et al. 2010).

These accessions were introduced in Uganda for evaluation of various attributes to assess their suitability as a fodder. If found superior to the existing accessions, these accessions will improve the performance of the smallholder dairy sector, alleviate the current feed shortages and environmental crises associated with NSD. This will contribute to food and nutritional security, social and gender protection, improved incomes, poverty alleviation, environmental sustainability and sustainable natural resource use in the region. Therefore, this study was conducted to determine the level of resistance/tolerance to NSD and DMY of introduced Napier grass accessions in Uganda.

Materials and methods

Description of study site:

The study was conducted at the National Crops Resources Research Institute (NaCRRI), Namulonge in Central Uganda. Namulonge lies at an elevation of about 1150m above sea level, 03°20’N and 32°35’E. The study site experiences an average temperature of 22.0°C. The area lies in a sub-humid zone of Uganda with a bimodal annual rainfall of about 1127mm.

The rainfall seasons are approximately of the same length, March to June and September to November being the rainy seasons, and the dry seasons being December to February and July to August (Figure 1).

![Figure 1: Monthly rainfall totals for NaCRRI (2012)](image-url)
The soils are ferralitic, sandy clay loams, low in phosphorus (about 4 ppm P) with a pH of 5.4-6.0 (Anon, 2014). The vegetation is wooded savannah with tall trees and tall grasses dominated by *Pennisetum purpureum* and *Panicum maximum*.

**Experimental procedure:**
Twenty two Napier grass accessions were collected from the Regional Dairy Centre of Excellence (RDCoE), Kenya Agricultural and Livestock Research Organization (Alupe Research Station) in Kenya for screening for DMY and tolerance to NSD. The plants were established in plots of 3m x 3m allowing for 2m between replicates and 1m between plots. Plots had an intra and inter row spacing of 1m x 1m giving a total of 9 stools per plot. Each Napier grass accession was replicated three times in a Randomized Complete Block Design. Infected Napier grass plants were planted around the experimental plots to enhance transmissibility (Muyekho et al., 2008) using a spacing of 0.45m from the healthy plants and 1m between the infected stools.

**Herbage biomass yield:**
Two months after planting, the plots were harvested to determine the herbage biomass yields, and the subsequent harvestings done at two months (8 weeks) interval for a period of one year. Total biomass yield was estimated by harvesting all the plants in a plot at a height of 10cm from the ground. Three stems were randomly chosen from a plot from which leaves were plucked to measure leaf and stem biomass which were added up to obtain total biomass yield from the plot. For determination of Dry Matter Yield (DMY) two tillers were selected from each plot, cut into small pieces of about 2cm that were packed into paper bags. The weight of each sample was taken and recorded. There after the samples were oven dried at 60°C to a constant dry weight in about 72 hours in an air-circulating electric oven to determine the dry matter (Mannetje, 1978).

**NSD incidence and severity:**
The incidence and severity of NSD was determined by site observation of any diseased plants in the plots. Napier stunt disease symptoms used included yellowing, leaf curling, stunting of plants and tiller proliferation. A score card was developed for the severity of Napier stunt disease. Scores from 1–5 were used as follows; 1= no symptoms, 2= very mild symptoms (when approximately 25% of the stool is affected), 3= medium mild symptoms (when approximately 50% of the stool is affected), 4 = severe symptoms (when approximately 75% of the stool is affected), 5= very severe symptoms (when the whole the stool, 100% is affected) (Muyekho et al., 2008).

**Data analysis:**
The data collected was subjected to Analysis of Variance (ANOVA) using Genstat statistical package 14th edition and means separated using Least Significant Difference (LSD) at 5% level of significance. Data were collected during the period of September 2012 to September 2013. Data collected during 40 weeks are reported in this study.

**Results**

**Herbage dry matter yield (DMY) of Napier grass:**
Mean herbage DM yield of napier grass accessions for five harvests was 23.4±13.15 ton/ha and varied between 12.5 t/ha and 46.9 t/ha (Figure 2).
Figure 2: Mean herbage dry matter yield (ton/ha) of Napier grass accessions for 5 harvests

Accession 97 produced the highest mean DM yield in all harvests (46.9±13.2 t/ha) whereas Napier + Sugar (SN) had the lowest mean DM yield (12.5±13.2 ton/ha) (Figure 2). There was no significant difference in the interaction between different accessions and harvests (p= 0.343) whereas a very significant difference existed between accessions (p < 0.0001) and levels of harvests (p < 0.0001) (Table 1).

Table 1: Analysis of variance for DMY of Napier grass accessions at different levels of harvests

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>F</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Napier grass accessions</td>
<td>21</td>
<td>748543206.8</td>
<td>3564914.6</td>
<td>6.3</td>
<td>&lt; 0.0001</td>
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<td>Harvest</td>
<td>4</td>
<td>119089861.1</td>
<td>29772470.3</td>
<td>52.9</td>
<td>&lt; 0.0001</td>
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<tr>
<td>Napier accession*Harvest</td>
<td>84</td>
<td>506639536.4</td>
<td>6031423.1</td>
<td>1.1</td>
<td>0.343</td>
</tr>
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</table>

Napier stunt disease severity among Napier grass accessions:

Napier stunt disease severity was significantly different among the different Napier accessions at different levels of harvests (Table 2). Some of the accessions such as 104, 79 Sugar + Napier, 117 and 103 showed disease symptoms as early as at 2nd harvest while others such as Kakamega 1, Kakamega 2, 112, 97, 16702 did not show symptoms up to 5th harvest (Table 3). By the 5th harvest out of the 22 accessions, seven accessions: 117, 79 Sugar + Napier, Kakamega 3, 76, 104 and 103 showed very severe symptoms. Accessions with a high disease build-up such as River Bank, 104, 79 Napier + Sugar had very low DMY (12-17 ton/ha). (Figure 2 and Table 3).

Table 2: Analysis of Variance for NSD severity at different levels of harvest

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of squares</th>
<th>Mean squares</th>
<th>F</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest 2</td>
<td>21</td>
<td>3.590</td>
<td>0.171</td>
<td>2.820</td>
<td>0.002</td>
</tr>
<tr>
<td>Harvest 3</td>
<td>21</td>
<td>3.830</td>
<td>0.183</td>
<td>1.510</td>
<td>0.04</td>
</tr>
<tr>
<td>Harvest 4</td>
<td>21</td>
<td>18.500</td>
<td>0.881</td>
<td>3.880</td>
<td>0.0001</td>
</tr>
<tr>
<td>Harvest 5</td>
<td>21</td>
<td>26.000</td>
<td>1.240</td>
<td>3.714</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
Table 3: Mean dry matter yield and NSD severity score for Napier grass accessions at different times of harvest

<table>
<thead>
<tr>
<th>Napier Accession</th>
<th>Level of harvest (weeks after planting)</th>
<th>1(8 wk)</th>
<th>2(16 wks)</th>
<th>3(24 wks)</th>
<th>4(32 wks)</th>
<th>5(40 wks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kakamega 1</td>
<td>DMY (t/ha)</td>
<td>31.9&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
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<tr>
<td>Kakamega 2</td>
<td>33.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
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<tr>
<td>Kakamega 3</td>
<td>21.7&lt;sup&gt;efgh&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>97</td>
<td>46.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>16805</td>
<td>24.8&lt;sup&gt;bdefgh&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>16815</td>
<td>17.5&lt;sup&gt;hi&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>112</td>
<td>46.9&lt;sup&gt;abcd&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>16702</td>
<td>32.4&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>16789</td>
<td>18.6&lt;sup&gt;ijk&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.7</td>
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<tr>
<td>41</td>
<td>20.4&lt;sup&gt;ijk&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>19</td>
<td>21.5&lt;sup&gt;ijk&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>75</td>
<td>27.7&lt;sup&gt;bdef&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>105</td>
<td>24.5&lt;sup&gt;bdefgh&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.7</td>
</tr>
<tr>
<td>River Bank</td>
<td>13.6&lt;sup&gt;i&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.7</td>
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<tr>
<td>Alupe Napier Field</td>
<td>23.2&lt;sup&gt;bdefgh&lt;/sup&gt;</td>
<td>1.0</td>
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<tr>
<td>16814</td>
<td>20.0&lt;sup&gt;ijk&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>104</td>
<td>17.4&lt;sup&gt;i&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.7</td>
<td>1.7</td>
<td>2.7</td>
<td>3.0</td>
</tr>
<tr>
<td>79 Sugar + Napier</td>
<td>12.5&lt;sup&gt;i&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.7</td>
<td>1.7</td>
<td>2.3</td>
<td>2.7</td>
</tr>
<tr>
<td>76</td>
<td>29.4&lt;sup&gt;bcd&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0</td>
<td>1.3</td>
<td>2.3</td>
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<tr>
<td>117</td>
<td>20.5&lt;sup&gt;ijk&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.3</td>
<td>1.3</td>
<td>2.0</td>
<td>2.3</td>
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<tr>
<td>103</td>
<td>26.3&lt;sup&gt;bdefg&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.7</td>
<td>1.3</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>79</td>
<td>20.6&lt;sup&gt;ijk&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.3</td>
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<tr>
<td>LSD</td>
<td>13.2</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Means followed by different superscripts along the column are significantly different at p ≤ 0.05

1 = no symptoms, 2 = very mild symptoms (when approximately 25% of the stool is affected), 3 = medium mild symptoms (when approximately 50% of the stool is affected), 4 = severe symptoms (when approximately 75% of the stool is affected), 5 = very severe symptoms
Discussion

Effect of Napier stunt disease on Napier grass dry matter yield:

The significant difference in DMY of Napier accessions could be attributed to genetic differences (Muyekho et al., 2008) and effect of NSD since different Napier grass accessions are affected differently with yield losses of 55% to 100% being reported in some accessions (Kabirizi et al., 2015).

Napier stunt disease severity:

Results of this study also revealed that Napier grass accessions differed significantly in their tolerance to NSD. This observation is similar to what was observed by Mulaa et al., 2010; and Muyekho et al., 2008. The reason for the difference in severity scores at the different harvest levels might have been that the accessions succumbed to NSD at different times which results agree with the findings of Mwendya et al., 2006. Napier accessions 103, 104 and 79 Sugar + Napier that succumbed first had the highest disease score. Some Napier grass succumbed to the disease as early as the second harvest while others were tolerant up to the fifth harvest (97, Kakamega 1, Kakamega 2, 16702, 16815, 112, 16805). The results on the reaction of Kakamega 1 contradicted the findings of Muyekho et al., 2008, who reported that in Kenya the accession succumbed to NSD after the third harvest with very mild symptoms.

Similarly, Kakamega 3 succumbed to NSD by the fourth harvest, which results differed from the findings of Muyekho et al., 2008 who reported the same accession to succumb to the disease after the first harvest in Kenya. The difference in the results could have been due to variation in soil fertility as napier growing on fertile soils tends to be more tolerant to the stunt disease (Mulaa et al., 2007). No fertilizers were applied to the plots during the study period, in Uganda.

There was an increasing trend in incidence and severity of NSD with level of harvests, with the first mild symptoms appearing at the second harvest. These results are in agreement with findings of Muyekho et al. 2008 and Mulaa et al. 2010 who reported that NSD affects plots that have been cut more than twice. The reason for the increase in severity and incidence with increased number of harvest could be that when the grass is harvested, the leaf hoppers that spread NSD tend to move to alternative hosts for survival. When the plants start regenerating, the hoppers then move back to the young soft and juicier plants thus spreading the disease. It could also be attributed to the fact that as a result of cutting, the plant becomes more stressed, thus succumbing to the disease.

Conclusions

This study has shown that napier stunt disease tolerance exhibited by the accessions such as 105, 16789, 16825, 19 and 75 despite having relatively low yields, can be very useful candidates in breeding programmes for resistance against NSD. Accessions Kakamega 1, Kakamega 2, 97, 16702 and 112 were among the accessions with the highest DMY and were tolerant to NSD up to the 5th harvest, therefore these accessions can be grown in NSD “hot spot” areas to improve feed availability.
References


Mannețe Lj., (1978). Measurement of grassland vegetation and animal production. CSIRO Division of tropical agronomy, Cunningham Laboratory, Brisbane, Queensland, Australia


Discussion Session

Question: Why napier stunt disease is expresses earlier in some varieties than the others? Does it relate to the mode of transmission (Tebkew Damte)

Answer: This is linked to 2 factors; 1) Difference in resistance/tolerant level of different clones 2) Environmental factors as the disease occurrence vary depending on the agro-ecological conditions

Question: What could be mode of transmission for the occurrence at second harvest to the sixth harvest, the materials are useful candidates for NSD tolerant programme, was ouma variety considered? (Dr. Bwin JMN)

Answer: Ouma is still under evaluation in Kenya at Kitale. It was not yet developed in 2014 when the material was moved to Uganda. The occurrence at the second harvest for some accessions and not for other is due to the differences in level of tolerance or resistance of the different accessions.
III. Feeds and Feeding

The performance of dairy cattle fed a high density total mixed ration feed block based on crop residue in western Kenya

Okitoi, L.O.1,*, Khatsasili, M.1, Muyekho, F.N.1, Mudeheri, M.A.1, Onyango, T.A.2 and Wandera, F.P.3

1Kenya Agricultural and livestock Research organization (KALRO), Kakamega
P.O. Box 169-50100, Kakamega, Kenya; KALRO, Naivasha, P.O. Box 25-20117 Naivasha, Kenya; 3 KALRO Headquarters P.O. Box 57811, Nairobi.
*Correspondence: oriana_okitoi@yahoo.com

Abstract
Inadequate feed for dairy cattle particularly during the dry season is the main challenge dairy farmers face in Western Kenya. A home-made compacted feed blocks using a combination of local ingredients comprising maize stover/sugarcane tops, urea, molasses, minerals and concentrates formulated using the principle of the Total Mixed rations (TMR) was developed. The objective of this study was to test the performance of dairy cows fed using the feedblock. On-station and on-farm validation trials were conducted using Friesian cows. On-station results showed that dry matter intake and milk yield per cow per day for animals fed sugarcane tops and maize stover based feed blocks though similar to those fed Napier grass were significantly (P<0.05) higher compared to those fed on sugarcane tops alone or maize stover alone. At farm level, milk yield for animals fed compacted feed block, dairy meal and mineral block supplement (Test diet) and chopped Napier grass, dairy meal and mineral block supplement (Positive Control) was similar (P>0.05). Percent milk increase from initial milk production was highest (147%) for cows fed the feed block. Farmers preferred the feed block size in the current standard compared to basal diet of Napier grass because the amount fed daily, time and cost involved in acquiring dry matter was low. The feed block is easy to handle and more friendly even to the elderly. In conclusion, crop residue based feed blocks fed to dairy cows increased their dry matter intake and milk yield per cow per day. Dry matter intake and milk yield per cow per day for animals fed crop residue based feed blocks and Napier grass was similar indicating that the feed block could replace Napier as a basal diet.

Introduction
Droughts and floods result in total or partial crop failure as well as forage and water scarcity that reduce livestock productivity, and in severe cases leads to livestock losses. A densified total mixed ration feed block based on crop residue could be the feeding strategies to manage such climatic extremities. A densified total mixed ration feed block made from proportions of crop residues, a concentrate mixture: oil cakes/meals as protein source; molasses, grains, grain by-products as energy sources; and supplements such as bypass protein or bypass fat was made. Other ingredients included strategic and catalytic supplements, such as micronutrients and other feed additives, for example vitamins, minerals, lime (binder), probiotics, enzymes, antioxidants, immune-protective agents, antitoxins and herbal extracts.

The densified total mixed ration feed block increases the efficiency with which crop residues are used as
Recent studies identified the densified TMR feed blocks based on crop residues as potential innovative technology to supply balanced feeds to dairy and other livestock (Okitoi et al. 2012). The challenge of densification resulted in development of a prototype machine that applies a compaction pressure up to 425 kg/cm². It can form compressed blocks in the sizes appropriate and economical for handling. The machine has the capacity to apply a vertical load up to 420 kg/cm² on crop residues filled in a square cross section cylinder up to 0.25 m height. (Okitoi et al. 2012).

This study evaluated the milk yield from dairy cattle fed the feedblock as a total ration. It was hypothesized that the milk yield from dairy cattle fed the feedblock and those fed the basal diet comprising Napier grass was not the same. This was done by first conducting a controlled on-station feeding trial and later a validation feeding trial at farm level.

### Materials and Methods

#### Experimental animals

For the on-station study, five lactating Friesian cows were selected from a Friesian herd at KALRO Kakamega, based on live weight (mean of 367 ± 13 kg), lactation phase (mid lactation) and milk yield prior to the feeding trial (mean of 9.9 ± 3.1 kg milk day⁻¹). The Friesian herd at KALRO was grazed on natural pasture. For the on-farm validation study, Six lactating Friesian cows were selected based on similarity in their breed, milk yields, live body weights (Mean 316 ± 11 kg and were producing 6.9 ± 5.1 kg of milk/d at the beginning of the trial and lactation period from farmers in Karemo and Nyalgungu in Siaya county prior to the beginning of the trial. The reasoning was that cows with the same yielding ability would likely show similar responses in milk yields. The animals were fed on Napier grass with no supplementation prior to imposing treatments.

#### Feed

**Table 1:** The nutritive value of ingredients used in making a densified feedblock

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>DM (%)</th>
<th>ME (Mcal/KG)</th>
<th>Digestibility (%)</th>
<th>Crude protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane tops</td>
<td>23</td>
<td>2.55</td>
<td>60</td>
<td>3.8</td>
</tr>
<tr>
<td>Soya bean meal</td>
<td>87</td>
<td>3.16</td>
<td>89</td>
<td>42</td>
</tr>
<tr>
<td>Molasses</td>
<td>74</td>
<td>2.57</td>
<td>68.7</td>
<td>5.7</td>
</tr>
<tr>
<td>Maize stover</td>
<td>87</td>
<td>1.78</td>
<td>50</td>
<td>5.9</td>
</tr>
<tr>
<td>Salt</td>
<td>96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lime</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Proportions and calculated nutrient composition of a crop residue based densified TMR feedblock

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percentage</th>
<th>Calculated nutritive value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soya bean meal</td>
<td>21</td>
<td>DM (%) 84.9</td>
</tr>
<tr>
<td>Molasses</td>
<td>15</td>
<td>ME (MJ/kg DM) 2.01</td>
</tr>
<tr>
<td>Maize stover/sugarcane tops</td>
<td>52.6</td>
<td>DMD (%) 55.2</td>
</tr>
<tr>
<td>Salt</td>
<td>2.1</td>
<td>CP (%) 15.6</td>
</tr>
<tr>
<td>Lime</td>
<td>8.4</td>
<td>Price/kg (KES) 14.9</td>
</tr>
<tr>
<td>Urea</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>

Experimental diets

For the on-station trial, two types of crop residue based blocks (Sugar cane tops block and maize stover block) were selected from those produced on-station and tested alongside sugar cane tops dry, maize stover dry and Napier grass as shown below:

- Napier grass + Dairy meal
- Sugar cane tops based block + Dairy meal.
- Sugar cane tops dry + Dairy meal
- Maize stover based block + Dairy meal
- Maize stover dry + Dairy meal

For the on-farm validation trial, a test diet (A crop residue based densified feed block, dairy meal and mineral block supplement) was tested alongside a positive control/farmer’s feeding practice (Chopped Napier grass, dairy meal and mineral block supplement).

Preparation of ingredients in the diets

- For on-station studies, the napier grass (Kakamega I), sugarcane tops and the maize stover were chopped using a poulverizer, the soya bean meal was milled to pass through 2 mm sieve, and the molasses was diluted with water at a 1:2 ratio.

- For on-farm validation studies, Napier grass was chopped using machetes daily. The resultant basal feed was mixed to known amount of molasses. A crop residue based densified feed blocks were smashed by hand and placed in feeders daily.

- A software Live-sim dairy – a dairy production simulation model version 10.1 (c.leon velarde, R et al. 2005) or EXRATION (Okitoi et al 2012) used to determine the proportions of the ingredients in the TMR.
Experimental design

- For the on-station study, the design used was a 5x5 Latin square change over design (Experimental units=Pens, Replications=animals, diets=treatments), each cow receiving each ration for a period of 25 days, consisting of 10 days for ration adjustment and 15 days for data collection, with a 3 day cross-over period.

- For the on-farm validation study, the animals were randomly assigned to receive the dietary treatments according to a randomized completed design:

In order to elicit the perception of stakeholders on use of a densified TMR feed block in feeding dairy cattle during on-farm validation, a questionnaire was administered to capture the knowledge, constraints and perceptions on feed block. The questionnaire was administered to farmers, extension agents and up and downstream agro-businesses through their inclusion in multi-stakeholder feedback workshop.

Data Collection

For on-station study, milk yield was recorded daily and the amount of feed given was weighed daily. Feed refusals were weighed each day in the morning before offering known amounts for that day. Each animal was weighed at the beginning and the end of each period.

For on-farm validation trial, animals were adjusted to the new feeds for one week, after which feed block intakes were measured daily during a further two week period. Feed refusals were weighed each day in the morning before offering known amounts for that day. During the last days of trial animals were weighed using a weighing band.

Statistical analysis

The data was analyzed using the General Linear Model (GLM) of the ANOVA option in the SAS (1998) software. Treatment means were compared using Duncan’s New Multiple Range Test (Steel and Terrie 1980).

The model was:

\[ Y_{ijk} = \mu + T_i + E_{ij} \]

Where \( Y_{ijk} \) = Observed value from row \( i \) column \( j \) treatment \( k \)

\( \mu \) = Overall sample mean

\( T_i \) = Effect of treatment \( i \)

\( E_{ij} \) = Experimental error of the mean

Results

Table 3 presents the effects of feeding crop residue based TMR feedblocks on Dry matter intake and milk yield of Friesian dairy cows. Milk yield for cows fed Napier grass, Sugarcane based feed block, maize stover feed block, maize stover and sugarcane tops was not found significant (\( P>0.05 \)). Sugarcane tops based feedblock, maize stover based feed block and Napier grass showed better milk yield than Maize stover alone and sugar cane tops alone. Sugarcane tops alone showed the lowest performance values which may be due to a number of reasons.
Table 3: Effects of feeding crop residue based TMR feedblocks on Dry matter intake and milk yield of Friesian dairy cows.

<table>
<thead>
<tr>
<th>Crop Residue Feedblock</th>
<th>DMI (kg/day)</th>
<th>Milk yield (Litres/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Napier grass</td>
<td>8.6 c</td>
<td>9.3 a</td>
</tr>
<tr>
<td>Sugar cane based blocks</td>
<td>9.5 a</td>
<td>9.5 a</td>
</tr>
<tr>
<td>Maize stover based blocks</td>
<td>9.1 b</td>
<td>9.0 a</td>
</tr>
<tr>
<td>Maize stover dry</td>
<td>8.5 c</td>
<td>8.5 a</td>
</tr>
<tr>
<td>Sugar cane tops dry</td>
<td>8.4 c</td>
<td>8.4 a</td>
</tr>
</tbody>
</table>

Table 4 presents the effects of feeding crop residue based TMR feedblocks on Dry matter intake and milk yield of Friesian dairy cows at farm level. Milk yield for cows fed Compacted feed block, dairy meal and mineral block supplement (Test diet) and Chopped Napier grass, dairy meal and mineral block supplement (Positive Control) was not different (P > 0.05). Percent milk increase from initial milk production was highest (147%) for cows fed the feed block. Percent increase in body weight gain from the initial body weight was highest (21%) with animals fed the feedblock.

Table 4: Effects of feeding crop residue based TMR feedblocks on Dry matter intake and milk yield of Friesian dairy cows at farm level

<table>
<thead>
<tr>
<th>Source of feed block</th>
<th>Milk yield kg/cow/day (kg)</th>
<th>Percent milk increase from initial milk production (%)</th>
<th>Dry matter intake kg/cow/day</th>
<th>Body weight gain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compacted feed block, dairy meal and mineral block supplement (Test diet)</td>
<td>10.3</td>
<td>147.7</td>
<td>5.7</td>
<td>21</td>
</tr>
<tr>
<td>Chopped Napier grass, dairy meal and mineral block supplement (Positive Control)</td>
<td>10.4</td>
<td>97.8</td>
<td>4.6</td>
<td>6.5</td>
</tr>
<tr>
<td>LSD</td>
<td>0.34</td>
<td>12.5</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>Significance</td>
<td>Ns</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

Table 5 presents the cost of dry matter from densified feedblocks and Napier grass and that of producing a litre of milk. The cost of dry matter was higher by KES 1.50 compared to that of the densified feedblocks. The cost of producing a litre of milk from a densified TMR feedblock based on sugar cane tops was cheaper by about 20 cents per litre compared to producing from Napier grass. While that of producing milk from a densified TMR block based on maize stover was cheaper by about 10 cents per litre of milk.

Table 5: The cost of dry matter and that of producing a litre of milk

<table>
<thead>
<tr>
<th>Source of feeds</th>
<th>DMI</th>
<th>Cost/kg DM</th>
<th>Milk yield (Litres/day)</th>
<th>Cost/litre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Napier grass</td>
<td>8.6</td>
<td>16.5</td>
<td>9.3</td>
<td>1.77</td>
</tr>
<tr>
<td>Sugar cane based blocks</td>
<td>9.5</td>
<td>15</td>
<td>9.5</td>
<td>1.58</td>
</tr>
<tr>
<td>Maize stover based blocks</td>
<td>9.1</td>
<td>15</td>
<td>9</td>
<td>1.67</td>
</tr>
</tbody>
</table>

The perception of stakeholders of use of TMR feed block in feeding dairy cattle

All farmers participating in the focused group discussion (FGD) agreed that feed block is necessary for improved dairy production. The farmers were convinced that the feed blocks addressed issues of fodder shortage and nutrients levels. The blocks were observed as fast in making the cows full. They also created a thirst and the cows drunk...
almost 3 times more than usual amounts of water. This led to increased milk yield per cow per day. Dairy cattle feeding on blocks reduced the quantity of daily napier grass requirement, time and labour involved in acquiring Napier grass. Farmers who used the densified feed block stated that they had more free time for other farm activities and to attend to community meetings. The densified feed blocks were easy to handle hence even the elderly were convinced they could venture into dairy farming. Feeding dairy cattle with the densified feedblock reduced the unnecessary stress caused by high labor turnover among workers in the farms. On level of technology (densified TMR feedblock) satisfaction, 36% of the farmers were highly satisfied while 64% were satisfied.

Dairy cows fed on densified feed blocks increased in body weight, looked healthy, ate to their fill, drunk enough water, laid down to rest, had an upward milk yield trend and an observed increase in milk cream in all the units where on farm trials were carried out. On presentation of the densified feed block, farmers preferred feed block size in its current size. The farmers were of the opinion that dairy meal should be used to sweeten the block and for color and scent.

**Discussion**

Results demonstrated that the feeding of densified TMR feedblock improved dairy cattle performance (Milk yield and growth rate). These results are supported by Sehgal and Jha 2008, Lailer et al (2009) and Jha (2008). The explanation for these improved performance was because of improved utilization of the crop residue as indicated by kashongi et al 2013 who explained that Urea in the maize and sugarcane tops based feed blocks boosted the non-protein nitrogen level of the crop residues and perhaps could have provided alkali effect when compacted that helped break down the lingo-cellulose bond of the crop residues. Secondly, Samanta et al 2003 explained that the feeding of densified feedblock generally allowed for synchronised supply of nutrients to microbes resulting in the synergy between nutrients demand of rumen microbes and the release of adequate levels of the nutrients bringing stability in the rumen ecosystem for optimal fermentation.

In the first experiment, Milk yield from animals fed maize stover alone and sugarcane tops alone was lower than the blocks and Napier grass. These findings are similar to those of Walli, 2008 and therefore suggest that maize stover alone and sugarcane tops alone could be dry season diets to cope with feeds scarcity. This also suggests that crop residue feed blocks could be used in intensive feeding systems.

The advantages of densified feedblocks as expressed by farmers included that feedblocks were balanced and one expected improved supply of nutrients. Secondly, the feedblocks reduced feed wastage thus were efficient in delivery of nutrients. Thirdly that by feeding feedblocks the expenditure on labour with respect to feeding was reduced. These are supported by walli 2008 who demonstrated that feeding feedblocks reduced labour by 30-40% and that a farmer indicated that it took 20-30 minutes to feed 20 animals as opposed to several hours of feeding the same animals using cut and carry method.
Conclusion and Recommendations

Crop residue based feed blocks improved the milk yield and growth performance of dairy cattle.

Feeding Crop residue based feed blocks to dairy cattle reduced the expenditure on labour with respect to feeding. Feeding Crop residue based feed blocks reduced the cost of producing a litre of milk.

With the advent of crop residue based feed block technology, it is possible to set up feed banks nearer to feed deficit areas. Because of easy handling, transportation and storage of the crop residue based feed blocks, the technology could improve preparedness against natural calamities, and save animals from hunger and death during the emergency situations. The crop residue TMR blocks can even be air lifted to the remotest places to avert disasters.

There is substantial room for improving the quality of crop residue TMR blocks. Its value addition could be a continuous exercise through extended research, trying different supplements, newer feed additives, anthelmintics and herbal extracts to improve their overall nutritional quality. However, it has to be ensured that the non-nutritive additives are used within the specified limits, so that they do not cause any major dilution of macro- or minor-nutrients in the feed blocks, which could reduce nutritional quality of the blocks.

The benefit provided by easier storage of feed blocks makes it possible to supply uniform quality of the feed throughout the year, with lesser price fluctuation, as against the large price fluctuation and irregular supply of crop residues and other feed ingredients in different seasons. This could also have an impact on stabilizing milk prices, irrespective of seasons, and produce milk of the same quality throughout the year. Better performance of the animals obtained on feeding the CRTMRB would obviously bring better returns to the farmer.

References


Discussion Session

Question: What is the weight of the block; what is used for making the block; affordability and cost of production.
Answer: Adoption study was undertaken and data analysis is in progress. Capacity for local fabrication was not considered. Access to spare parts for some machines e.g transplanters is a problem.
Biomass production and forage quality of head-smut disease resistant Napier grass accessions in highland and lowland environments of Kenya

Kariuki, I.W.¹,*, Mwendia S.W.¹, Muyekho, F.N², Ajanga, S.I.³ and Omayio, D.O.²

¹Kenya Agricultural and Livestock Research Organization Food Crops Research Institute-Muguga Centre Department of Animal Production P.O. Box 30148-00100 Nairobi, Kenya; ²Masinde Muliro University of Science and Technology Department of Biological Sciences P.O. Box 190-50100, Kakamega, Kenya; ³Kenya Agricultural and Livestock Research Organization Non-Ruminant Research Institute-Kakamega Department of Crop Protection P.O. Box 169-50100, Kakamega, Kenya

*Correspondence: iwkariuki2002@yahoo.com.au

Abstract

The aim of this study was to determine the biomass yield and forage quality of head-smut resistant/tolerant Napier grass accessions in highland and lowland environments of Kenya. Field trials were undertaken at two contrasting environments. The first site was in the highlands at KARI-Muguga, while the second site was in the lowlands at KARI-Katumani. The trials were initiated in November 2011 using canes to plant ten Napier grass accessions (ILRI numbers 16790, 16791, 16783, 18448, 16806, 16808, 16809, 16796, 16835, 16837) in separate 4 m x 4 m plots in four replicates. The plots were arranged in a Completely Randomised Block Design. The grasses were first harvested at week 23 after planting when they attained an approximate height of 0.5 m at KARI-Muguga and 0.3 m at Katumani. Subsequent harvests occurred at a shorter interval of about 8 weeks after regeneration. There were eight growth cycles at each site. At the end of each cycle several growth variables were measured. The results showed differences (P<0.05) between the accessions in biomass dry matter production that ranged from 28.8 – 51.2 tons/ha at KARI-Muguga and 18.1 – 26.7 tons/ha at KARI-Katumani.

The cumulative biomass yields during the study period reflected total rainfall received at the sites resulting in a remarkable similarity in rain use efficiency for the two sites of 20.71 kg/ha/mm at KARI-Muguga and 20.73 kg/ha/mm at KARI-Katumani. There were differences (P<0.05) between the accessions in neutral detergent fibre that ranged from 62.4 – 66.7% at KARI-Muguga and 62.4 – 67.2% at KARI-Katumani. There were no differences (P>0.05) in nitrogen content (mean 2.5%, range 2.2–2.7%) between the accessions at KARI-Katumani. However, there were differences (P<0.05) in nitrogen content (mean 2.6%, range 2.3–2.9 %) at KARI-Muguga. The accession no. 16806 was confirmed resistant to head smut disease, while accession nos. 16783, 16796 and 16835 were tolerant to head smut disease in concurrent glass house screening/molecular studies. These four accessions are suitable candidates for further on-station studies (in vitro digestibility, rumen degradability and animal performance) and farmer-managed (fodder and animal performance) on-farm trials before final recommendation/wide dissemination to the farming community.

Key Words: *Pennisetum purpureum*, Rain Use Efficiency, ILRI, PCR, Tolerant
Introduction

Napier grass (*Pennisetum purpureum* Schumach) is a tropical grass that grows in relatively moist areas (750—2500 mm annual rainfall) in tropical and subtropical ecological zones (Lowe *et al*., 2003). The forage crop is popular in Eastern and Central Africa (Valk, 1990) for its enormous biomass production and ability to tolerate frequent cuttings (Lowe *et al*., 2003; Nyambati *et al*., 2011). In Kenya, the crop is used by smallholder dairy farmers as fresh or as silage forms of livestock feed (Martha *et al*., 2004; Orodho, 2006). These smallholder dairy farmers supply 80% of the total marketed milk in the region (Omore *et al*., 1999).

Despite its importance as a fodder crop in boosting the milk industry, the crop faces some production challenges with pests and diseases being the most prevalent (Farrell *et al*., 2002; Mwendia *et al*., 2007). Napier head-smut, Napier stunt and snow white mold are the most common diseases (Farrell *et al*., 2002; Orodho, 2006). Stunt disease reduces Napier grass yields by 100% (Mulaa *et al*., 2010), while head-smut disease reduces Napier grass yields by up to 46 percent (Farrell *et al*., 2000). The two diseases are also major problems in Uganda, Tanzania, Ethiopia, Rwanda and Burundi (Mulaa *et al*., 2010).

Napier head-smut disease is widespread in the central region of Kenya where over 70% of the smallholder dairy farmers grow Napier grass (Mwendia *et al*., 2007). Moreover, of concern is the spread of the disease to other parts of the country (Lukuyu *et al*., 2012). Napier head-smut disease is caused by a fungus [*Ustilago kamerunensis* P. & H. Sydow] - (Farrell, 1998; Farrell *et al*., 2000; Orodho, 2006; NAFIS, 2012). The disease firstly manifests itself in susceptible hosts through induced premature flowering covered in a black mass of ustilospores commonly referred to as smut as shown on Figure 1.

This occurs even in plants that are below 1.5 metres in height which is not usually the case in healthy plants that usually flower at heights above 1.5 to 8 metres depending on the variety of the grass (Farrell, 1998). This visual sign is later compounded by other severe symptoms such as slow regrowth after cutting, withering and chlorosis setting in with gradual browning leading to drying and death of the entire stool of the crop within the subsequent 2-3 cuttings in severe cases (ASARECA, 2010; NAFIS, 2012). Besides the above primary signs, other secondary characteristics of the disease are induced dwarfing (characterized by short internodes with distorted leaves in shape that are reduced in number and size on stools), increased tillering and eventually the total dry matter of the affected crop is reduced (Farrell *et al*., 2002; Mwendia *et al*., 2007; NAFIS, 2012).
Figure 1: A smutted Napier grass crop head (Source; Omayio et al., 2014)

The two ways through which the disease spreads to new areas are; first, through the spores from smutted heads of susceptible cultivars and; second, through exchange and transfer of planting materials (infected canes and cuttings) between farmers unaware that the systemic intercellular pathogen is within the tissues (Mwendia et al., 2007; ASARECA, 2010; NAFIS, 2012).

Therefore, to mitigate this disease’s spread via the mentioned ways; non-smutting cultivars have been developed and the most common cultivars are Kakamega 1 and 2. However, the two cultivars are over-relied upon and are highly susceptible to Napier stunt disease (Arocha et al., 2009). Moreover, these two cultivars provide a narrow range of resistance genes to the head-smut pathogen with an imminent threat of a likely evolving pathogen (NAFIS, 2012). Furthermore, the on-going expansion of the dairy industry have been almost entirely into drier zones which demands deployment of suitable Napier grass cultivars with resistance/tolerance to drought conditions and head-smut disease.

The aim of this study was to determine the biomass yield and forage quality of head-smut resistant/tolerant Napier grass accessions in highland and lower midland dry environments of Kenya.

Materials and methods

Sites description

Field trials were undertaken at two contrasting environments in Kenya. The first site was in the highlands at KALRO-Muguga [01° 12.663’ S; 036° 38.286’ E; 2,052 metres above sea level] while the second site was in the lowlands at KALRO-Katumani [01° 35.212’ S; 037° 14.407’ E; 1,600 metres above sea level] (Jaetzold et al. 2006). KALRO-Muguga has a mean daily temperature of 17.6°C and an annual rainfall of 878 mm
KALRO-Katumani experiences mean daily temperature of 24.7°C and an annual rainfall of 655 mm (Jaetzold et al. 2006). Table 1 presents some properties of the soils at KALRO-Muguga and KALRO-Katumani as assessed through the procedures of Okalebo et al. (2002).

Table 1: Selected chemical properties, texture and bulk density of the topsoil at the trial sites at KALRO-Muguga and KALRO-Katumani

<table>
<thead>
<tr>
<th>Site</th>
<th>Soil layer (m)</th>
<th>Sand (%)</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Soil texture</th>
<th>Bulk density (kg m⁻³)</th>
<th>pH</th>
<th>N (%)</th>
<th>OC (%)</th>
<th>EC (dS m⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KALRO-Muguga</td>
<td>0 — 0.2</td>
<td>20.3</td>
<td>50.3</td>
<td>29.5</td>
<td>Clay</td>
<td>1,030</td>
<td>5.81</td>
<td>0.18</td>
<td>2.72</td>
<td>0.183</td>
</tr>
<tr>
<td></td>
<td>0.2 — 0.4</td>
<td>21.0</td>
<td>53.5</td>
<td>25.5</td>
<td>Clay</td>
<td>1,160</td>
<td>5.92</td>
<td>0.13</td>
<td>1.61</td>
<td>0.231</td>
</tr>
<tr>
<td>KALRO-Katumani</td>
<td>0 — 0.2</td>
<td>56.0</td>
<td>38.3</td>
<td>5.75</td>
<td>Sandy-clay</td>
<td>1,220</td>
<td>5.79</td>
<td>0.07</td>
<td>1.23</td>
<td>0.145</td>
</tr>
<tr>
<td></td>
<td>0.2 — 0.4</td>
<td>51.3</td>
<td>44.0</td>
<td>4.75</td>
<td>Sandy-clay</td>
<td>1,510</td>
<td>5.95</td>
<td>0.06</td>
<td>1.13</td>
<td>0.105</td>
</tr>
</tbody>
</table>

N, nitrogen; OC, organic carbon; EC, electrical conductivity and each value is a mean of 4 measurements.

Treatments and Experimental design

The treatments were ten Napier grass accessions at each site. The Napier grass accessions used, were obtained from the field gene bank at the International Livestock Research Institute (ILRI) in Ethiopia. Their origin and accession numbers were: Swaziland (16790), Tanzania (16783 and 18448), USA (16806, 16808 and 16809), Zimbabwe (16796), and unknown origin (16835 and 16837). Accession no. 16791 (Kakamega 1) is resistant to head-smut disease and was used as the negative check at each site.

At each site, the ten accessions were planted in separate 4 m x 4 m plots arranged in a randomized complete block design (RCBD) in four replicates. Hence, the total number of plots was forty.

Trial establishment and maintenance

Land preparation was undertaken in mid-October 2011 and it involved ploughing with a tractor-drawn disc plough to 0.25 m depth followed with harrowing. Each plot was supplied with diammonium phosphate (DAP) fertiliser (18: 46: 0 of N, P, K) at a rate of 26 kg P ha⁻¹ at planting. The Napier grass canes with at least three nodes were planted on 1st November 2011 by pushing the canes into the soil at an angle of about 45° to bury two nodes. Planting was done at a spacing of 1 x 1 m i.e. from row to row and cane to cane and hence each plot had 16 canes/stools. The plots were kept weed-free manually with a hand hoe when needed. Calcium ammonium nitrate (CAN) top-dress fertilizer (26% N) was applied at a rate of 13 g per stool (equivalent to 33.8 kg N ha⁻¹) after each harvest (cycle). No symptoms of disease and/or pest infestation were observed during the entire trial period. The grass was first harvested at week 23 when it attained an approximate height of 0.5 m at KALRO-Muguga and 0.2 m at KALRO-Katumani. Subsequent harvests occurred at a shorter intervals of about 8 weeks after regeneration. Data collection in each of the eight growth cycles (from 1st November 2011 to 9th May 2013) at each site involved measurements of growth variables.
Data Collection

Weather data

Key weather variables consisting of temperature and humidity were logged every three hours and rainfall every 24 hours at 2 m height using solar powered self-logging weather stations (Weather station, ICO348, China). The weather stations were installed at the study sites.

Plant height and number of tillers

Measurements of plant height and number of tillers were taken a day before harvest at the end of each of the first five growth cycles. These were made on two stools that were randomly selected from each of the 40 plots; the tillers on the stools were counted, while plant height was determined as the distance from the base to the apical meristem on two randomly selected tillers per stool.

Dry matter yields

The above ground dry matter (DM) yields was determined at the end of every growth cycle, which was at 23 weeks after planting for the first growth cycle and eight weeks of re-growth for subsequent cycles as mentioned earlier. At each harvest, the four stools at the middle of each plot were cut at 2 cm above the ground. The stools were weighed fresh using a spring balance; then sub-samples of about five tillers were taken from the stools and weighed fresh after which they were oven dried. These fresh and dry weights were used to calculate total dry matter yields for each plot.

Neutral detergent fibre and nitrogen content

Some oven-dried forage samples (from the stools used for determination of dry matter yields) were ground to pass through 1 mm sieve. The ground samples were used to determine neutral detergent fibre (NDF) using an Ankom fibre analyzer (Ankom Technology Fairport, NY, USA) following a published procedure (AOAC, 1975). Likewise, nitrogen (N) percentage was determined on the ground samples according to AOAC (1980) with a segmented flow analyser (Skalar segmented-flow autoanalyzer, VW Scientific, York).

Data analysis

All data were checked for entry errors in Microsoft excel. The data from each site was analysed independently through analysis of variance (ANOVA) using Genstat version 14 (VSN International Ltd). Where statistical significance (P<0.05) was observed, pairs of means were compared using the least significant difference (LSD) test.

Results and discussion

Weather

The climatic parameters during the eight growth cycles (from 1st November 2011 to 9th May 2013) were; KALRO-Muguga (1,977 mm total rainfall, 12.9°C mean minimum temperature, 23.8°C mean maximum temperature) and KALRO-Katumani (1,054 mm total rainfall, 14.6°C mean minimum temperature, 25.1°C mean maximum temperature).
Plant height and number of tillers

As shown in Table 2, the mean plant height and tiller density at harvesting of Napier grass accessions at KALRO-Muguga was higher than at KALRO-Katumani, most likely due to higher moisture and better soil fertility available at KALRO-Muguga.

Table 2: Mean plant height and tiller density at harvest of Napier grass accessions at KALRO-Muguga and KALRO-Katumani

<table>
<thead>
<tr>
<th>Napier grass accession</th>
<th>Plant height (m)</th>
<th>Tiller density (Number of tillers per m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KALRO-Muguga</td>
<td>KALRO-Katumani</td>
</tr>
<tr>
<td>16783 §</td>
<td>0.51</td>
<td>0.25</td>
</tr>
<tr>
<td>16790</td>
<td>0.51</td>
<td>0.26</td>
</tr>
<tr>
<td>16796 §</td>
<td>0.45</td>
<td>0.27</td>
</tr>
<tr>
<td>16806 §</td>
<td>0.38</td>
<td>0.22</td>
</tr>
<tr>
<td>16808</td>
<td>0.37</td>
<td>0.27</td>
</tr>
<tr>
<td>16809</td>
<td>0.54</td>
<td>0.27</td>
</tr>
<tr>
<td>16835 §</td>
<td>0.37</td>
<td>0.21</td>
</tr>
<tr>
<td>16837</td>
<td>0.44</td>
<td>0.28</td>
</tr>
<tr>
<td>18448</td>
<td>0.46</td>
<td>0.28</td>
</tr>
<tr>
<td>16791 § (Kakamega 1)</td>
<td>0.56</td>
<td>0.35</td>
</tr>
<tr>
<td>LSD</td>
<td>0.18</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Significance level | P<0.05 | P<0.05 | P<0.05 | P<0.05 |

§ Napier grass accession resistant/tolerant to head-smut disease as per concurrent glass house screening/molecular studies (Omayio et al., 2014). LSD = Least Significant Difference.

Dry matter yields and forage quality

There were differences (P<0.05) between the accessions in biomass dry matter production that ranged from 28.8 – 51.2 tons/ha at KALRO-Muguga and 18.1 – 26.7 tons/ha at KALRO-Katumani (Table 3)

Table 3: Cumulative dry matter yield (t/ha), neutral detergent fibre (%) and nitrogen (%) of Napier grass accessions at KALRO-Muguga and KALRO-Katumani.

<table>
<thead>
<tr>
<th>Napier grass accession</th>
<th>Dry matter (t/ha)</th>
<th>Neutral detergent fibre (%)</th>
<th>Nitrogen (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>KALRO-Muguga</td>
<td>KALRO-Katumani</td>
<td></td>
</tr>
<tr>
<td>16783 §</td>
<td>47.9</td>
<td>65.3</td>
<td>2.5</td>
</tr>
<tr>
<td>16790</td>
<td>20.6</td>
<td>62.4</td>
<td>2.8</td>
</tr>
<tr>
<td>16796 §</td>
<td>42.1</td>
<td>66.1</td>
<td>2.4</td>
</tr>
<tr>
<td>16806 §</td>
<td>51.2</td>
<td>63.7</td>
<td>2.4</td>
</tr>
<tr>
<td>16808</td>
<td>28.8</td>
<td>64.5</td>
<td>2.6</td>
</tr>
</tbody>
</table>
Napier grass accession | Dry matter (t/ha) | Neutral detergent fibre (%) | Nitrogen (%) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>KALRO-Muguga</td>
<td>KALRO-Katumani</td>
<td>KALRO-Muguga</td>
<td>KALRO-Katumani</td>
</tr>
<tr>
<td>16809</td>
<td>50.0</td>
<td>26.7</td>
<td>63.1</td>
</tr>
<tr>
<td>16835 §</td>
<td>44.2</td>
<td>20.9</td>
<td>66.7</td>
</tr>
<tr>
<td>16837</td>
<td>41.5</td>
<td>18.1</td>
<td>63.9</td>
</tr>
<tr>
<td>18448</td>
<td>41.2</td>
<td>26.0</td>
<td>65.0</td>
</tr>
<tr>
<td>16791 § (Kakamega)</td>
<td>42.0</td>
<td>22.1</td>
<td>66.7</td>
</tr>
</tbody>
</table>

LSD 12.9 8.3 0.96 1.77 0.44 0.56

Significance level P<0.05 P<0.05 P<0.05 P<0.05 P<0.05 P>0.05

§ Napier grass accession resistantholerant to head-smut disease as per concurrent glass house screening/molecular studies (Omayio et al., 2014). LSD = Least Significant Difference. Dry matter yields are totals over eight growth cycles while neutral detergent fibre and nitrogen means are over five growth cycles. Eight growth cycles = 1st November 2011 to 9th May 2013. Five growth cycles = 1st November 2011 to 22nd November 2012.

The cumulative biomass yields during the study period reflected total rainfall received at the sites (Table 3). The average total yield at KALRO-Katumani of 21.9 t/ha was about 53.4% of the 41.0 t/ha obtained at KALRO-Muguga, consistent with rainfall at KALRO-Katumani (1,054 mm) being 53.3% of the rainfall (1,977 mm) obtained at KALRO-Muguga. This resulted in a remarkable similarity in rain use efficiency, calculated as amount of biomass produced/total amount of rainfall, for the two sites of 20.73 kg/ha/mm at KALRO-Katumani and 20.71 kg/ha/mm at KALRO-Muguga. Unfortunately, the rain use efficiency was not derived under controlled conditions hence other variables e.g. differences in soil fertility between the sites may have influenced the values calculated.

Elsewhere, in Ghana (average rainfall 1,194 mm and temperature 21.0 – 34.0°C), the annual biomass yields of four Napier grass provenances ranged from 28.9 – 45.0 t/ha on sandy loam soils (Ansar et al., 2010). It is apparent that Napier grass productivity is influenced by the environment and management in addition to traits inherent in the provenances that can be selected to contribute to increased productivity.

The chemical composition of forage is a major determinant of animal production (Skerman & Riveros, 1990). In this study, there were differences (P<0.05) between the accessions in neutral detergent fibre (NDF) that ranged from 62.4 – 66.7% at KALRO-Muguga and 62.4 – 67.2% at KALRO-Katumani (Table 3). Unfortunately, in vitro digestibility and rumen degradability studies were not carried out on the Napier grass forage samples from the two sites in order to assess the effect of differences in NDF on the above parameters.

Tissue nitrogen is a good measure of crude protein (Claessens et al., 2005; Moran, 2012). There were no differences (P>0.05) in nitrogen content (mean 2.5%, range 2.2–2.7%) between the accessions at KALRO-Katumani (Table 3). However, there were differences (P<0.05) in nitrogen content (mean 2.6%, range 2.3–2.9%) at KALRO-Muguga. The more than double the nitrogen (N) percent in the soil at KALRO-Muguga (Table 1) at the start of the trial could explain the slightly higher tissue nitrogen at this site compared with KALRO-Katumani. The forage nitrogen percent values registered in this study translate to crude protein values (N% x 6.25) of 15.4% at KALRO-Katumani and 16.0% at KALRO-Muguga. These crude protein values are higher than the average 9.7±4.3% (mean±SD) but within

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the range 2.8-22.7% reported in literature (Feedipedia, 2015).

Besides assessing the productivity and forage quality of the Napier grass accessions, it was necessary to establish their resistance/tolerance to head-smut disease in concurrent glasshouse screening experiments following artificial inoculation with *Ustilago kamerunensis* spores (Omayio et al., 2014). In the glasshouse experiments, besides accession no. 16791 (Kakamega 1) which was the negative check, only accession numbers 16806, 16783, 16835 and 16796 were still free of head smut disease at the 11th growth cycle. Thereafter, the resistance/tolerance needed to be validated by a discriminative molecular method using primers in conventional Polymerase Chain Reaction (PCR) analysis. The molecular study at KALRO Biotechnology Research Institute Headquarters at Muguga (former KARI-TRC, Muguga) confirmed Napier grass accession no. 16806 to be resistant to head-smut disease, while accession nos. 16783, 16835 and 16796 were tolerant to head-smut disease (Omayio et al., 2014). In the molecular study, the detection of the pathogen in the accessions despite them being smut-free under glasshouse screening experiments upon artificial inoculation, could be due to internal resistance mechanisms that do not favour the aggressive establishment of the pathogen in these accessions unlike in the susceptible accessions in a classic case of polygenic (quantitative) resistance (Keane, 2012). An example of such internal mechanisms has been reported in sugarcane attacked by the sugarcane smut (*Ustilago scitaminea* Sydow), where the crop produced increased levels of glycoproteins with cytoagglutination properties as a defence against the pathogen's proliferation (Blanca et al., 2002; Ana-Maria et al., 2005). Furthermore, in pearl millet (*Pennisetum glaucum* [L.] R. Br.) similar biochemical defences have been observed against downy mildew infection (Niranjan et al., 2012). Accession no. 16806 had no pathogen detected in its tissues which can be attributed to complete resistance or immunity which is the top most level of resistance that is characterized by complete absence of the pathogen and disease (Van der Plank, 1975).

**Conclusion and Recommendations**

Productivity at the two sites was apparently largely driven by rainfall since the magnitude in the dry matter yield difference was similar to that in the amount of rainfall received during the study period. Rain use efficiency (biomass productivity per unit rainfall) was almost identical for the two sites.

The four accessions (16806, 16783, 16835 and 16796) were high yielding in the study reported here. The accession no. 16806 was confirmed resistant to head smut disease, while accession nos. 16783, 16835 and 16796 were tolerant to head-smut disease in concurrent glass house screening/molecular studies. These four accessions are suitable candidates for further on-station studies (*in vitro* digestibility, rumen degradability and animal performance) and farmer-managed (fodder and animal performance) on-farm trials before final recommendation and wide dissemination to the farming community.

**Acknowledgement**

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**References**

Ana-Maria M., Blanca F., Maria-Estrella L. and Carlos V. (2005). Glycoproteins from sugarcane plants regulate cell polarity of *Ustilago*


Lowe A.J., Thorpe W., Teale A. and Hanson J. (2003). Characterization of germplasm accessions of Napier grass (*Pennisetum purpureum* and *P. purpureum* × *P. glaucum* hybrids) and comparison with farm clones using RAPD. *Genetic Resources and Crop Evolution*, 50: 121-132


IV. Value Addition and Socio-Economics

Quality and consumer acceptability of goat milk with respect to goat breed and lactation stage

Wanjekeche, E.1,* MacOsore, Z.1, Kiptanui, A.2 and Lobeta, T.1

1 Kenya Agricultural and Livestock Research Organization, Food Crops Research Institute, P.O. Box 450, Kitale. 2 University of Eldoret, P.O Box, Eldoret, Kenya.

*Correspondence: elizawanjekeche@gmail.com

Abstract

Lack of information on the quality of goat milk and the belief that the milk has an undesirable “goaty” flavor have been major challenges to its wider utilization and commercialization. An on-station study was carried out at KALRO-Kitale to determine the yield and quality of goat milk from the Kenyan Alpine, Toggenburg, and Saanen breeds during their first and second lactation stages. The quality of milk from farmers’ goats in Trans Nzoia County was also determined. The milk was analyzed for fat, protein, solids-not-fat (SNF) contents, the density and added water. Consumer acceptability of the colour, taste and smell of fresh milk, yoghurt and tea made using goat milk was assessed and compared with similar products from cow milk. The results showed significant differences in yield and quality of milk from different breeds. Milk from the Saanen goats had the highest levels of fat, SNF and density. The protein content did not differ significantly between the three breeds. There was great variation in the composition of the milk obtained from farmers’ fields which may be attributed to differences in the breeds, stage of lactation and feeding regime. Consumers showed higher preference for goat milk than cow milk products.

Key Words: Dairy goat breed, milk yield and composition, consumer acceptability.

Introduction

The potential of dairy goats in providing nutritional and financial sustenance to the economically weaker sections of the society, which cannot afford a cow, is well recognized (Okeyo, 2001; Lusweti et al., 2011). Goats require little space and feed and have the ability to thrive under diverse climatic conditions (CTA, 2007). They can be acquired by the poor and easily tended to by even the old and young members of a household or those weak victims of the HIV/AIDS virus. They can be owned by disadvantaged members of the society including women and the youth. Hence focusing on them can help to bridge gender disparities in resource ownership.

Lack of information on the quality of goat milk and the belief that the milk has an undesirable “goaty” flavor have been major challenges to wider utilization and commercialization of the milk (Okeyo, 1997). However goat milk that has been well handled, has a delicious slightly sweet taste with sometimes a salty tint. It is indistinguishable in taste and odour from cow milk.

In Kenya, most of the research to improve dairy goat milk production has focused on issues related to breeding and general animal husbandry (Ruvuna et al., 1988; Ogola et al., 2010), but issues of milk composition and quality and if differences exist between breeds have not been well investigated yet these attributes affect consumer acceptability.
hence market potential. Studies done elsewhere show that goat milk has superior nutritional quality than cow milk. Jenness, (1980) reported that goat milk is a very good source of protein, calcium, phosphorus, potassium, riboflavin (vitamin B2), vitamin A, and the amino acid - tryptophan. Further, the vitamin A in goat milk exists exclusively in its true form and not as carotenoid pigments as in cow milk. Nutritional superiority of goat milk can therefore be used as a basis for promoting marketing and consumption of goat milk products.

**Objectives**

- To determine and compare the nutrient composition of goat milk from different breeds in Kenya with respect to lactation stage.
- To assess consumer perception and acceptability of goat milk products

**Materials and Methods**

The study was conducted on-station at the Kenya Agricultural and Livestock Research Organisation (KALRO) at Kitale and on-farm in Trans Nzoia County. The on-station study used three dairy goat breeds; the Kenya Alpine, Toggenburg and Saanen. For each breed, three does were used for the study. The goats were kept under zero grazing and each goat was provided with napier grass (15kg) and 5kg sweet potato vines (fresh weight basis). Dairy meal (1kg) was also given to the goats while mineral supplements and water were provided *ad libitum*. Other recommended management practices including deworming, tick control, proper housing separating the does from the bucks and clean milk handling were observed. Milking was done twice a day (morning and afternoon). For quality analysis, only the morning milk was sampled starting from the fourth day after kidding. Milk samples were collected daily throughout the first and second lactation periods. Milk samples were also collected from 15 farmers’ fields in Trans Nzoia county and analysed for quality. The farmers’ goats were the Kenya Alpine breed although they were not pure breeds because of cross breeding with local breeds. Analysis of the milk was done using the milk Analyzer. The parameters measured were fat, protein, solids-not-fat (SNF), density and added water. The data collected were subjected to Analysis of Variance (ANOVA) to determine if there were differences in the quality of milk among breeds and the variation throughout the lactation stage.

Consumer acceptability of fresh milk, yoghurt, and tea made using goat milk was determined by 15 taste panellists from the research centre. The panellists indicated their degree of liking for colour, taste, odour of the products using a five point Hedonic scale as follows; 1- like extremely, 2-like slightly, 3-Dislike slightly, 4- Dislike extremely.

**Results and Discussion**

**Milk yield**

The average milk yield (litres/day) for the 3 breeds over the first and second lactation periods is shown in Table 1: The Kenya Alpine had the highest milk yield during both lactation periods while the Saanen had the lowest milk yield. The milk yield for all breeds increased during the second lactation period although it was much lower than the potential yield of 4 litres per goat per day quoted in literature.
Table 1: Average milk yield of dairy goats (litres/day)

<table>
<thead>
<tr>
<th>Goat breed</th>
<th>1st Lactation period</th>
<th>2nd Lactation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya Alpine</td>
<td>1.02</td>
<td>1.85</td>
</tr>
<tr>
<td>Toggenburg</td>
<td>0.75</td>
<td>1.5</td>
</tr>
<tr>
<td>Saanen</td>
<td>0.65</td>
<td>1.0</td>
</tr>
<tr>
<td>Mean</td>
<td>0.81</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Milk quality

Table 2 shows the quality of milk from the K.Alpine, Toggenburg and Saanen goats during the first lactation periods. The fat content of the milk generally increased while the protein content reduced in all breeds with lactation stage.

Table 2: Quality of goat milk from 3 breeds during the 1st Lactation period

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lactation stage (Months after kidding)</th>
<th>0*</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat (%)</td>
<td>K.Alpine</td>
<td>5.06</td>
<td>5.93</td>
<td>6.03</td>
<td>6.33</td>
<td>6.82</td>
<td>6.03±0.62</td>
</tr>
<tr>
<td></td>
<td>Toggenburg</td>
<td>3.52</td>
<td>5.81</td>
<td>5.80</td>
<td>5.90</td>
<td>6.44</td>
<td>5.50±0.68</td>
</tr>
<tr>
<td></td>
<td>Saanen</td>
<td>4.30</td>
<td>4.74</td>
<td>5.38</td>
<td>6.91</td>
<td>7.79</td>
<td>6.30±1.08</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>K.Alpine</td>
<td>4.30</td>
<td>3.84</td>
<td>3.77</td>
<td>3.65</td>
<td>3.89</td>
<td>3.89±0.04</td>
</tr>
<tr>
<td></td>
<td>Toggenburg</td>
<td>3.90</td>
<td>3.70</td>
<td>3.61</td>
<td>3.57</td>
<td>3.68</td>
<td>3.69±0.80</td>
</tr>
<tr>
<td></td>
<td>Saanen</td>
<td>4.17</td>
<td>4.17</td>
<td>4.18</td>
<td>4.17</td>
<td>4.02</td>
<td>4.14±0.04</td>
</tr>
<tr>
<td>Solids not fat (%)</td>
<td>K.Alpine</td>
<td>9.53</td>
<td>9.60</td>
<td>9.74</td>
<td>9.86</td>
<td>9.90</td>
<td>9.74±0.11</td>
</tr>
<tr>
<td></td>
<td>Toggenburg</td>
<td>9.49</td>
<td>9.33</td>
<td>9.28</td>
<td>9.03</td>
<td>8.98</td>
<td>9.22±0.15</td>
</tr>
<tr>
<td></td>
<td>Saanen</td>
<td>11.00</td>
<td>10.80</td>
<td>10.50</td>
<td>10.20</td>
<td>10.10</td>
<td>10.47±0.30</td>
</tr>
<tr>
<td>Milk density (g/cm³)</td>
<td>K.Alpine</td>
<td>35.60</td>
<td>33.50</td>
<td>30.70</td>
<td>32.40</td>
<td>32.50</td>
<td>32.73±1.20</td>
</tr>
<tr>
<td></td>
<td>Toggenburg</td>
<td>34.00</td>
<td>30.90</td>
<td>30.50</td>
<td>32.30</td>
<td>32.20</td>
<td>31.73±1.10</td>
</tr>
<tr>
<td></td>
<td>Saanen</td>
<td>35.90</td>
<td>33.90</td>
<td>33.30</td>
<td>34.40</td>
<td>34.70</td>
<td>34.37±0.63</td>
</tr>
</tbody>
</table>

* - Milk sampled 4 days after kidding

The milk from the Saanen goats had the highest levels of fat (6.30%), protein (4.14%), SNF (10.47%) and density (34.37g/cm³). The Toggenburg had the lowest levels of all nutrients. In all breeds, the nutrients reduced with lactation stage.

Table 3 shows the quality of milk from the Kenya Alpine, Toggenburg and Saanen goats during the second lactation period. A similar trend as in the first lactation period was observed in the fat and protein contents. Milk from the Saanen was again superior to the milk from the Kenya Alpine and Toggenburg. No significant differences were observed between milk from Toggenburg and Kenya Alpine.
Table 3: Quality of goat milk from 3 breeds during the 2nd Lactation period

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Breed</th>
<th>Lactation stage (Months after kidding)</th>
<th>0*</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat (%)</td>
<td>Kenya Alpine</td>
<td>5.94</td>
<td>5.78</td>
<td>5.56</td>
<td>5.93</td>
<td>5.70</td>
<td>5.78±0.29</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Toggenburg</td>
<td>5.34</td>
<td>6.59</td>
<td>7.32</td>
<td>4.71</td>
<td>5.40</td>
<td>5.87±0.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Saanen</td>
<td>5.38</td>
<td>5.36</td>
<td>6.03</td>
<td>6.86</td>
<td>6.30</td>
<td>6.00±0.44</td>
<td></td>
</tr>
<tr>
<td>Protein (%)</td>
<td>Kenya Alpine</td>
<td>4.06</td>
<td>4.14</td>
<td>4.31</td>
<td>4.00</td>
<td>3.70</td>
<td>4.04±0.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Toggenburg</td>
<td>4.07</td>
<td>3.89</td>
<td>4.14</td>
<td>3.57</td>
<td>3.73</td>
<td>3.88±0.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Saanen</td>
<td>4.18</td>
<td>4.02</td>
<td>4.17</td>
<td>4.01</td>
<td>3.90</td>
<td>4.06±0.09</td>
<td></td>
</tr>
<tr>
<td>Solids not fat (%)</td>
<td>Kenya Alpine</td>
<td>9.79</td>
<td>10.20</td>
<td>10.20</td>
<td>9.36</td>
<td>9.10</td>
<td>9.73±0.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Saanen</td>
<td>10.10</td>
<td>9.75</td>
<td>9.08</td>
<td>9.95</td>
<td>9.67</td>
<td>9.71±0.23</td>
<td></td>
</tr>
<tr>
<td>Milk density (g/cm³)</td>
<td>Kenya Alpine</td>
<td>32.80</td>
<td>32.30</td>
<td>32.40</td>
<td>32.00</td>
<td>30.40</td>
<td>31.98±0.53</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Toggenburg</td>
<td>32.50</td>
<td>32.30</td>
<td>32.20</td>
<td>30.40</td>
<td>30.70</td>
<td>31.62±0.77</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Saanen</td>
<td>34.40</td>
<td>33.00</td>
<td>32.90</td>
<td>32.00</td>
<td>32.00</td>
<td>32.86±0.68</td>
<td></td>
</tr>
</tbody>
</table>

* - Milk sampled 4 days after kidding

The quality of milk from 15 farmers’ fields is shown in Table 4: There was great variation in the composition of the milk which may be attributed to differences in the breeds, lactation stage and feeding regime. Although farmers in the study site were initially given the Kenya Alpine goats by several development agents, a lot of cross breeding with the local goats has occurred due to limited access to quality bucks.

Some of the milk samples from farmer’s fields had added water which may have contributed to low levels of some nutrients. Some farmers add water to goat milk to increase volume, hence have more milk to sell.

Table 4: Quality of goat milk from farmers fields in Trans Nzoia County

<table>
<thead>
<tr>
<th>No</th>
<th>Fat (%)</th>
<th>SNF (%)</th>
<th>Protein (%)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.70</td>
<td>9.72</td>
<td>4.03</td>
<td>31.8</td>
</tr>
<tr>
<td>2</td>
<td>3.38</td>
<td>9.18</td>
<td>3.70</td>
<td>32.4</td>
</tr>
<tr>
<td>3</td>
<td>0.96</td>
<td>8.47</td>
<td>3.30</td>
<td>31.6</td>
</tr>
<tr>
<td>4</td>
<td>3.79</td>
<td>8.42</td>
<td>3.26</td>
<td>28.5</td>
</tr>
<tr>
<td>5</td>
<td>3.91</td>
<td>9.50</td>
<td>3.87</td>
<td>33.3</td>
</tr>
<tr>
<td>6</td>
<td>1.94</td>
<td>10.3</td>
<td>4.21</td>
<td>38.0</td>
</tr>
<tr>
<td>7</td>
<td>0.91</td>
<td>9.52</td>
<td>3.82</td>
<td>35.9</td>
</tr>
<tr>
<td>8</td>
<td>1.60</td>
<td>8.76</td>
<td>3.45</td>
<td>32.2</td>
</tr>
<tr>
<td>9</td>
<td>7.12</td>
<td>9.53</td>
<td>3.85</td>
<td>29.9</td>
</tr>
<tr>
<td>10</td>
<td>9.60</td>
<td>8.34</td>
<td>3.40</td>
<td>23.8</td>
</tr>
<tr>
<td>11</td>
<td>1.43</td>
<td>8.25</td>
<td>3.20</td>
<td>30.3</td>
</tr>
<tr>
<td>12</td>
<td>1.84</td>
<td>9.09</td>
<td>3.62</td>
<td>33.4</td>
</tr>
<tr>
<td>13</td>
<td>1.12</td>
<td>8.28</td>
<td>3.21</td>
<td>30.7</td>
</tr>
<tr>
<td>14</td>
<td>7.55</td>
<td>11.8</td>
<td>5.08</td>
<td>39.4</td>
</tr>
<tr>
<td>15</td>
<td>2.22</td>
<td>9.35</td>
<td>3.76</td>
<td>34.1</td>
</tr>
<tr>
<td>MEAN ± SD</td>
<td>3.80± 2.0</td>
<td>9.23± 0.56</td>
<td>3.72±0.28</td>
<td>32.35 ±2.35</td>
</tr>
</tbody>
</table>
Consumer acceptability of goat milk

Table 5 shows the panelists’ scores for colour, taste, odour and overall acceptability of fresh goat milk, yoghurt and tea compared to similar products made using cow milk. Consumers showed higher preference for tea made using goat milk than cow milk and did not reject the odour of the products. The milk used in the study was hygienically produced hence had no off flavours. Literature shows that goat milk produced under good hygienic conditions is indistinguishable in taste and odour from cow milk. Consumers also preferred the colour of goat milk compared to cow milk. Goat milk has a pure white colour while cow milk is cream.

<table>
<thead>
<tr>
<th></th>
<th>Fresh Milk</th>
<th>Tea</th>
<th>Yoghurt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Goat</td>
<td>Cow</td>
<td>Goat</td>
</tr>
<tr>
<td>Colour</td>
<td>3.75</td>
<td>3.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Taste</td>
<td>3.75</td>
<td>3.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Odour</td>
<td>3.75</td>
<td>3.75</td>
<td>4.00</td>
</tr>
<tr>
<td>Overall acceptability</td>
<td>3.75</td>
<td>3.75</td>
<td>4.00</td>
</tr>
</tbody>
</table>

*Scale – 1 = Dislike very much, 2 = Dislike slightly, 3 = Like slightly, 4 = Like very much

Conclusion and recommendations

The study established that milk quality did not differ significantly between breeds although from the Saanen breed had the highest contents of protein, solids not fat and density during both lactation stages. However the milk yield for this breed was the lowest. The Toggenburg had the lowest levels of all nutrients. For all the breeds, the protein, fat, solids not fat and density reduced with lactation stage. The quality parameters also reduced during the second lactation. More data however needs to be taken for more lactation cycles to confirm the trend in the quality parameters. The color, taste and smell of goat milk products were highly acceptable to consumers. This shows that if goat milk is produced under hygienic conditions, it will not have any off-flavors. The study also observed that milk yields for the three breeds were far much below the potential production cited in literature despite feeding the recommended feed rations. There is need to upgrade the current breeds preferably through Artificial Insemination to increase milk yields and satisfy the demand for milk. Further research should evaluate the effect of improved fodders on the milk yield and quality in order to identify the best fodders for recommendation to farmers.

Acknowledgement

The Authors are very grateful for the financial support from the East African Agricultural Productivity Project (EAAPP) to carry out this study. Special thanks go to the Centre Director, KALRO-Kitale for logistical support, the Laboratory Technologists (G. Malenya and P. Sifuna) for analyzing the milk samples and the farmers in Gitwamba, and Salama Dairy Goat farmers’ umbrellas for providing samples of milk for analysis.

References


Discussion Session

Question: How does goat milk compare to cow milk? What is the return to investment? Availability of milk to the goat - kids given the low production levels.

Answer: The nutrient content in goat milk is higher than that of cow milk; it is reported that goat milk is closer to human milk than cow milk. The milk yield of dairy goats is below the potential and therefore returns to investment low. Milk available to the kid is low since the farmer has to retain some milk for sale or household consumption.

Question: What is the reason for the low yield of milk produced under zero grazing?

Answer: The reason for the low milk yield of the goats is the low genetic quality which has resulted from continued use of the same buck for breeding leading to some element of inbreeding.

Question: In your study did you contemplate any guidelines for management and nutrition of dairy goats that can deliberately lead to high yields for the breeds studied (Saanen, Toggenburg, Alpine)?

Answer: The recommended management and nutrition guidelines were followed.

Question: What was the original source of your breeding stock. This could be the reason for the lower levels of milk production?

Answer: The goats used in the study were obtained from the farmers in Embu (Alpine), Meru (Toggenburg), Nyeri (Saanen), through the dairy goat association of Kenya (DGAK). There is need to improve the quality of breeds through AI.

Question: In your study, did you make specific findings on medicinal ability of zero grazed goat milk as one of the qualities that can attract consumer acceptability

Answer: The medicinal role of goat milk is largely due to the physiochemical properties. A study is being undertaken by MSc student at the University of Eldoret to characterise the major physio-chemical properties of goat milk and how different forages feed to the goat during zero grazing and affect this compound to the milk from goats that browse naturally.
Exposure of children 4 to 6 months of age to aflatoxin in Kisumu County, Kenya

Obade, M.1,*, Andang’o, P.2, Obonyo, C.3 AND Lusweti, F.4

1Maseno University, P.O Box 3803-40100, Kisumu, Kenya; 2Maseno University., Department of Nutrition and Health. P.O. Box 333, Maseno- Kenya; 3Kenya Medical Research Institute (KEMRI), Centre for Global Health Research, P.O Box 1578, Kisumu, Kenya; 4Kenya Agricultural and Livestock Research Organization. P.O. Box 450-30200, Kitale, Kenya.

*Correspondence: mobade2002@yahoo.com

Abstract

Contamination of foods by aflatoxins is a global health problem in both developed and developing countries. Exposure to the toxins is associated with a range of effects on health including growth faltering in children. Commodities at high risk of aflatoxin contamination include cereals, legumes, milk, fish and meats. Being genotoxic, levels of aflatoxins in foods should be kept as low as possible, given that there is no known threshold at which they may pose a health risk. Children are more vulnerable to effects of aflatoxin exposure compared to adults. This study investigated the potential exposure of young children to aflatoxin contamination in Kisumu County, Kenya. Kisumu County may have the potential for low to high levels of aflatoxin contamination due to prevailing weather conditions as well as reliance on maize, sorghum, cassava and rice as the main staple foods, groundnuts as snack and omena (Rastrienobola argentea) – common name Silver cyprinid. and milk as cheap sources of protein. These foods are also used as weaning foods in the County. Samples of omena, rice, groundnuts, cassava, maize, and sorghum were collected from Kibuye wholesale market, Kibuye open air market, Ahero market, Oile market and Mamboleo market in Kisumu County using a combination of cluster and systematic sampling. Processed cow’s milk samples were collected from supermarkets and raw cow’s milk samples from 3 market milk bars in the County. Analysis of solid foods was done using HELICA Total Aflatoxin Assay, intended for quantitative detection of aflatoxin B1, B2, G1 and G2. Milk sampling was done using the European model outlined in the Codex Alimentarius. Aflatoxin M1 levels in milk were analyzed using HELICA Aflatoxin M1 Assay. Aflatoxin levels ranged from 0 to 34.5 ppb aflatoxin B1 in solid foods, 0.012 to 0.127 ppb aflatoxin M1 in processed milk and 0.0002 to 0.013 ppb aflatoxin M1 in raw milk. All the food products, except cassava, had samples with detectable aflatoxin levels. Daily aflatoxin consumption ranged from 35 ng (4.43/kgBW/day) to as high as 872 ng (110.4 ng/kg BW/day). These findings indicate that weaning children in Kisumu County are potentially exposed to low to high levels of aflatoxins, given that the food stuffs that were analyzed are the commonly used weaning food items. Effects on their health should be assessed and efforts taken to reduce potential exposure both from the commonly suspected sources as well as from milk.

Key Words: Aflatoxin, exposure, infant, weight, height.

Introduction

Aflatoxins are a naturally occurring group of mycotoxins that are produced by Aspergillus flavus and Aspergillus parasiticus (Yu, et al., 2004) and are of public health importance because of their effects on human health and food safety (Williams, et al., 2004)et al., 2004. About 4.5 billion people in developing countries have chronic exposure to large amounts of aflatoxins in their diets (Shephard, 2008). Some of the foods prone to aflatoxin contamination include maize, wheat, rice, millet, sorghum, beans, soya beans, peanuts, and spices. The toxins are
also found in milk, eggs, and meat products due to consumption of contaminated feeds by animals (Lanyasunya, 2008)

Studies carried out in Kenya reveal that more than 40% of diets in both rural and urban communities are comprised of maize and maize products and are likely to be contaminated by aflatoxins (Mwihia, et al., 2008). Aflatoxin poisoning resulting from consumption of contaminated maize has been reported in Eastern Kenya (Muthomi et al., 2009) the worst having occurred in 2004 (Lewis, et al., 2005). Recent research findings revealed mean aflatoxin levels ranging from 37 ppb to 54 ppb in maize in Nyanza Region compared to 21 ppb to 44 ppb in Eastern Region (Collins et al., 2010). These findings point to wide spread contamination of food with aflatoxin in Kenya.

Consumption of both high and low aflatoxin levels is associated with negative health outcomes (Okoth and Kola, 2012). Exposure to aflatoxins has been reported as a causative factor in child stunting and underweight, neurological impairment, immune-suppression and child mortality (Henry et al., 2001, Gong et al., 2008, Turner et al., 2007, Cardwell and Henry, 2004). Aflatoxin exposure may affect child growth through immune suppression resulting in increased susceptibility to infectious diseases (Williams, et al., 2004 et al., 1994; Williams, et al., 2004). Stunting during childhood has been associated with a reduction in adult size, reduced work capacity and adverse reproductive outcomes (Gibson, 2005).

Aflatoxin B<sub>1</sub>, found mainly in cereals and groundnuts is considered the most toxic and most potent (Keskin, et al., 2009). Aflatoxin AFM<sub>1</sub> is a marker of AFB<sub>1</sub> intake, being detectable in milk 12-24 hours after ingestion and poses a health risk to breast-feeding infants, as well as infants being weaned on cow’s milk (Galvano, et al., 2008). Both AFM<sub>1</sub> and AFB<sub>1</sub> have been found in breast milk samples from Ghana and Nigeria (Gürbay, et al., 2010). Studies carried out in The Gambia, Guinea, Kenya, Benin, Togo, and Senegal, revealed that about 85% to 100% of children had either detectable levels of serum aflatoxin albumin adducts or urinary aflatoxins (Polychronaki, et al., 2008). These findings indicate that high proportions of infants in tropical Africa may have prenatal and postnatal exposure to aflatoxins.

Most children in Kenya are breastfed until at least the latter part of the second year and begin to receive cereal-based gruel before the age of 3 months (Onyango et al., 2002), which could increase their exposure to the toxin. Reports indicate that stunting rate among children < 5 years of age in Nyanza Province was 35.4% according to Kenya Multiple Indicator Cluster Survey 2002; 31.1% according to Kenya Demographic and Health Survey (KDHS), 2003 (Food and Agriculture Organization (FAO) 2005) and 26.9% according to (KDHS), 2008/2009 (KNBS, & Macro, 2010). High stunting figures have also been recorded in all the Counties in Nyanza Region; Kisii 35.3%, Homa Bay 37.0%, Kisumu 33.1%, Migori 46.2%, and Siaya 38.4% (Food and Agriculture Organization (FAO) 2013).

This study aimed to investigate the potential exposure of children of weaning age (4 to 6 months of age) to aflatoxin contamination in Kisumu County, Kenya. Certain characteristics make Kisumu County prone to aflatoxin contamination; some of the foods grown and consumed in the County, including maize, sorghum and groundnuts, are high risk commodities for aflatoxin contamination; results of KDHS 2008/2009 reveal stunting figures of 26.9% among children < 5 years of age in Nyanza Province (KNBS, & Macro, 2010); prevailing climatic conditions in Kisumu County including drought, erratic rainfall (1200mm and 1300mm per annum), high temperatures ranging between 20°C and 35°C and high humidity (40-89%), provide a favorable environment for growth of mould and production of aflatoxins (Onyango et al., 2002).
Material and Methods

A cross sectional survey study was conducted in Kisumu East and Nyando Districts, Kisumu County, Kenya. Markets were selected for inclusion in the survey based on geographic location of the population served by the market, having enough vendors with a variety of food products of interest to the study; and the availability of maize, sorghum, cassava, rice, ‘omena’ (*Rastrienobola argentea*) and milk. The markets selected were: Kibuye wholesale market, Kibuye open market, Oile Market, Mamboleo market and Ahero market.

Two hundred and nine (209) dried food samples (500g each) including: 50 omena, 31 rice, 22 groundnuts, 37 cassava, 41 maize, and 28 sorghum, were collected from Kibuye wholesale market, Kibuye open air market, Oile market, Ahero market and Mamboleo market. Sampling of dry foods was done using a combination of cluster and systematic sampling. Five hundred grams each of available maize, sorghum, rice, cassava, groundnuts and omena was collected from each bag of consenting sellers. The foods were sampled based on the number of bags available in the market. If there were ≤10 bags, sampling was done on all the bags and if there were >10 bags, the square root of the extra bags was calculated and added to the 10 bags. The products were scooped from selling bags at different points of the bags to ensure uniformity, using respective vendor tools such as tins, and double packaged in paper envelopes to avoid cross contamination and moisture entry (Njapau, 2008). The packages were labeled and the sources recorded and stored for two days before being analyzed for aflatoxins at KARI Kitale, Kenya.

A total of 80 milk samples were collected as follows: 50 processed milk samples from the 5 most common milk brands from the major supermarkets in Kisumu City; and 30 raw milk samples were collected from Ahero, Mamboleo, and Guba market milk bazaars. The milk samples were analyzed for aflatoxin M<sub>1</sub>. The European model, which recommends that a 500g sample composed of five 100 g portions of milk is taken from a batch, be used for the minimum sample size and sample selection method was applied (Codex Alimentarius, 2001). The milk samples were transported in cooler boxes and immediately frozen and stored at -20°C before being transported in coolers to KARI Kitale for analysis.

Aflatoxin B<sub>1</sub> levels in staple food samples were analyzed using HELICA Total Aflatoxin Assay. An aflatoxin specific antibody optimized to cross react with Aflatoxin B<sub>1</sub>, B<sub>2</sub>, G<sub>1</sub> and G<sub>2</sub>, was coated to a polystyrene microwell. The toxins were extracted from a ground sample of 20g portion and 100 ml of 70% methanol. The extracted samples and hydrogen peroxidase preservative conjugate (HRP) Aflatoxin B<sub>1</sub> were mixed and added to the antibody coated microwell. Microwell contents were decanted and nonspecific reactants were removed by washing. An enzyme substrate TMB was added and the colour blue developed. The intensity of the color was inversely proportional to the concentration of Aflatoxin in the sample or standard. The sample had been diluted at a ratio of 5 to 1 with 70% methanol, and so the aflatoxin shown by the standard was multiplied by 5 in order to indicate the ng of aflatoxin per gram of commodity. Dietary exposure to aflatoxin (ng/ kgBW/day) of a child 6 months (7.9 kg) of age with a daily consumption of 60g of mixed cereal flour and 500mls of milk per day in Kisumu County was calculated using the formula: Exposure (ng/kgBW/day) = (Contamination level) (amount consumed)/ body weight (Table 2) (Shephard, 2008).

Aflatoxin M<sub>1</sub> levels were analyzed using Helica Aflatoxin M<sub>1</sub> Assay (Aflatoxin M<sub>1</sub> ELISA Quantitative) with high affinity for aflatoxin M<sub>1</sub>. Helica Aflatoxin Assay is a solid phase competitive enzyme immunoassay used for detection of aflatoxin M<sub>1</sub> in milk and milk products. In this procedure, an antibody with a high affinity for aflatoxin M<sub>1</sub> was coated onto polystyrene microwells. 200µL of milk sample was added to the appropriate microwell and aflatoxin M<sub>1</sub> was bound to the coated antibody. Subsequently, aflatoxin bound to horseradish peroxidase (HRP)
was added and it bound to the antibody not already occupied by aflatoxin M₁ present in the sample or standard. After 15 minutes of incubation, the contents of the wells were decanted, washed and an HRP substrate was added which developed a blue color in the presence of an enzyme. The intensity of the color was directly proportional to the amount of bound conjugate and inversely proportional to the amount of aflatoxin M₁ in the sample. An acidic stop solution was added which changed the chromogen colour from blue to yellow. The microwells were measured optically by a microplate reader with an absorbance filter of 450nm (OD450). Results were determined by comparing the optical density of the sample to the optical density of the kit standards.

Aflatoxin contamination of food samples was calculated as average aflatoxin levels in all samples of a specified food. Potential exposure of children to aflatoxin was determined by calculating the absolute amount of aflatoxin a weaning child would consume assuming intake of 60g of solid food and 500 ml of milk and the amount of aflatoxin consumed in ng/kg body weight/day using the formula:

\[
\text{Exposure (ng/kg body weight/day)} = \left( \frac{\text{Contamination level} \times \text{amount consumed}}{\text{body weight}} \right) \quad (\text{Shephard, 2008})
\]

In a similar approach, aflatoxin intake through milk was determined by assessing median aflatoxin M₁ concentration in milk samples, then multiplying by milk consumption of the population (Henry et al., 2001). These formulae have been applied to arrive at data in Table 2: Data was analyzed using Statistical Package for Social Sciences (SPSS) software (IBM SPPS Statistics® (Pallant, 2003).

**Results and Discussion**

Aflatoxin levels in the dried foods ranged between 0 to 34.5 ppb aflatoxin B₁ and 0.0002 to 0. 13 ppb aflatoxin M₁ in milk samples (Table 1). All the solid food products, except cassava, had aflatoxin levels above the Kenyan regulatory limit of 10 ppb for aflatoxin B₁. Exposure of the children to aflatoxin ranged from 4.33 – 110.38 ng/kg body weight/day and total aflatoxin intake by the children ranged from 35 – 872 ng per day.

**Table 1: Descriptive statistics:Aflatoxin B1/M1 levels (ppb) in market foods**

<table>
<thead>
<tr>
<th>Food Item</th>
<th>Maximum</th>
<th>Median(IQR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver cyprinid (Omena)</td>
<td>2.76</td>
<td>0.6 (0, 2.08)</td>
</tr>
<tr>
<td>Rice</td>
<td>11.70</td>
<td>0.5 (0,1.2)</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>27.6</td>
<td>1.5 (1.5,2.0)</td>
</tr>
<tr>
<td>Cassava</td>
<td>3.5</td>
<td>0.5 (0,5,1,0)</td>
</tr>
<tr>
<td>Maize</td>
<td>34.50</td>
<td>0.5 (0,5,1,0)</td>
</tr>
<tr>
<td>Sorghum</td>
<td>24.50</td>
<td>14.2 (8.5, 19)</td>
</tr>
<tr>
<td>Processed milk *</td>
<td>0.127</td>
<td>0.04 (0.03, 0.07)</td>
</tr>
<tr>
<td>Raw milk *</td>
<td>0.013</td>
<td>0.008 (0.005,0.01)</td>
</tr>
</tbody>
</table>

*AFM₁

This study showed that the potential for aflatoxin exposure in Kisumu County, depending on the combination of contaminated foods consumed, could range from minimal consumption of aflatoxin to consumption of levels as high as 34.5 ng/g of food. At these levels, if the food items were used as weaning foods for infants, assuming consumption of cereal and tubers, and milk, infants could have aflatoxin intakes as high as 115 ng/kg body weight per day, which could translate to 0.115μg/kg body weight/day. Concern on aflatoxin mainly focuses on exposure
to very high levels of aflatoxin as occurs during aflatoxicosis outbreaks. However, chronic exposure to low levels is associated with liver cancer and malnutrition including micronutrient deficiencies and stunting (Williams et al., 2004).

The highest level of aflatoxin contamination in the food samples analyzed in our study was 35.4 ppb. Recent research findings revealed high mean aflatoxin levels in maize in Homa Bay and Rongo compared to Makueni, Mbeere North and Mbooni East respectively (Collins et al., 2010). It is also documented that 40% of food samples from farmers in Nyanza Province had aflatoxin levels above the regulatory limit of 10 ppb (Mwihia et al., 2008). These findings reveal the prevalence of high levels of aflatoxin in Nyanza region compared to areas previously known to be prone to aflatoxin contamination.

Maize has previously been reported as the major source of aflatoxin exposure in Kenya. However, our findings reveal higher median aflatoxin levels in sorghum compared to maize although maize had the samples with the highest aflatoxin levels (34.5 ppb). Furthermore, the proportion of sorghum samples with detectable aflatoxin contamination was higher than that of maize, indicating more widespread contamination in sorghum. Other foods analyzed in this study which show potential for aflatoxins exposure include omena (Rastrineobola argentea) and rice. Cassava had the lowest range of aflatoxin levels among the dried foods. Maize, sorghum, dried cassava, rice, groundnuts, fish and milk are among the major foods produced and consequently, consumed in Kisumu County.

Aflatoxin B₁ (AFLB₁) is known to occur in most foods, especially in cereals and groundnuts, which are among the common staples foods in Kisumu County. Sorghum, maize and groundnuts had the highest levels of aflatoxin B₁ based on the findings of this study. These foods are also likely to be used as weaning dishes by most households in Africa, Kenya and in Kisumu County (Gong et al., 2008, Okoth and Ohingo, 2004). Therefore, measures should be put in place to minimize aflatoxin levels in the foods in order to protect young children from the negative effects of the toxin.

Low levels of aflatoxin were found in both processed and raw milk samples in Kisumu County. Our findings concurred with levels indicated in the Codex Alimentarius on concentration of aflatoxin M₁ in milk (µg/kg) by regional diet giving a concentration of 0.0018 µg/kg for the African region (Henry et al., 2001). Based on the findings of our study, milk may not be a major source of aflatoxin exposure to children in Kisumu County. However, it is important to note that in attempting to keep aflatoxin contamination at levels as low as possible, feeds consumed by dairy animals should be taken into account. This is because aflatoxin B₁ in such feeds is converted to aflatoxin M₁ in the animals and excreted in milk. Additionally, aflatoxin is found in other animal products. A study carried out on animal feeds in Nairobi Province, showed aflatoxins levels ranging from 5.13 to 1123 ppb, with the largest proportion being between 11-99 ppb (Okoth and Kola, 2012). Aflatoxin contaminated animal feeds have been identified as a major source of aflatoxin exposure in animal based products consumed by man.

**Exposure of weaning children to aflatoxins**

Observations from our study confirm that weaning children onto family foods represents a period of increasing aflatoxin exposure. As indicated earlier, more than 40% of diets in both rural and urban communities in Kenya are comprised of maize and maize products (Mwihia et al., 2008). Flour from maize is one of the main ingredients commonly used in preparing weaning porridge in most Kenyan communities including Kisumu County. However, other foods like sorghum, cassava, rice, groundnuts and omena are also used separately or mixed with other cereal flours to prepare weaning gruel. The author found potential aflatoxin exposure in children ranging from 4.43 ng/
kg BW/day in a combination of maize flour and raw milk to 110.38 ng/kgBW/day in a combination of sorghum and raw milk (Table 2).

Table 2: Dietary exposure to aflatoxin (ng kg⁻¹ body weight/day) of a child 6 months (7.9 kg) of age with a daily consumption of 60g of solid food stuff and 500mls of milk per day in Kisumu County

<table>
<thead>
<tr>
<th>Food Item</th>
<th>Median Aflatoxin levels (ng/g)</th>
<th>Aflatoxin intake (ng) from food*</th>
<th>Meal1</th>
<th>Meal2</th>
<th>Meal3</th>
<th>Meal4</th>
<th>Meal5</th>
<th>Meal6</th>
<th>Meal7</th>
<th>Meal8</th>
<th>Meal9</th>
<th>Meal10</th>
<th>Meal11</th>
<th>Meal12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice (g)</td>
<td>0.5</td>
<td></td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
<td>(30g) 18.0</td>
</tr>
<tr>
<td>Cassava (g)</td>
<td>0.5</td>
<td></td>
<td>(5g) 2.50</td>
<td>(5g) 2.50</td>
<td>(5g) 2.50</td>
<td>(5g) 2.50</td>
<td>(5g) 2.50</td>
<td>(10g) 5.00</td>
<td>(10g) 5.00</td>
<td>(30g) 15.0</td>
<td>(30g) 15.0</td>
<td>(30g) 15.0</td>
<td>(30g) 15.0</td>
<td>(30g) 15.0</td>
</tr>
<tr>
<td>Maize (g)</td>
<td>0.5</td>
<td></td>
<td>(60g) 3.00</td>
<td>(60g) 3.00</td>
<td>(35g) 17.50</td>
<td>(35g) 17.50</td>
<td>(15g) 7.50</td>
<td>(15g) 7.50</td>
<td>(20g) 10.0</td>
<td>(10g) 5.0</td>
<td>(10g) 5.0</td>
<td>(10g) 5.0</td>
<td>(10g) 5.0</td>
<td>(10g) 5.0</td>
</tr>
<tr>
<td>Sorghum (g)</td>
<td>14.2</td>
<td></td>
<td>(20g) 284.0</td>
<td>(20g) 284.0</td>
<td>(20g) 142.0</td>
<td>(20g) 142.0</td>
<td>(40) 568.00</td>
<td>(40) 568.00</td>
<td>(30g) 284.0</td>
<td>(30g) 710.0</td>
<td>(30g) 710.0</td>
<td>(30g) 710.0</td>
<td>(30g) 710.0</td>
<td>(30g) 710.0</td>
</tr>
<tr>
<td>Processed milk</td>
<td>0.04</td>
<td></td>
<td>(500ml) 20.0</td>
<td>(500ml) 20.0</td>
<td>(500ml) 20.0</td>
<td>(500ml) 20.0</td>
<td>(500ml) 20.0</td>
<td>(500ml) 20.0</td>
<td>(500mls) 20.0</td>
<td>(500mls) 20.0</td>
<td>(500mls) 20.0</td>
<td>(500mls) 20.0</td>
<td>(500mls) 20.0</td>
<td>(500mls) 20.0</td>
</tr>
<tr>
<td>Raw Milk (ml)</td>
<td>0.01</td>
<td></td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
<td>(500ml) 5.00</td>
</tr>
<tr>
<td>Total aflatoxin intake (ng)</td>
<td>35.00</td>
<td>50.00</td>
<td>324.00</td>
<td>309.00</td>
<td>190.00</td>
<td>175.00</td>
<td>598.00</td>
<td>327.00</td>
<td>735.00</td>
<td>53.00</td>
<td>464.00</td>
<td>872.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*For individual foods the value indicated refers to the amount in the g of food consumed, indicated in the brackets above the aflatoxin level

** Exposure (ng kg⁻¹ body weight/day) = (Contamination level)(amount consumed)/body weight [3].

Our data record a higher aflatoxin consumption of 0.6 ng/kg body weight/day for a child at 6 months weighing 7.9 kg compared to that indicated by the Codex Alimentarius Committee of 0.1 ng/person/day aflatoxin M₁ through milk for the African region. Weighted mean concentration of 0.05 μg aflatoxin M₁ in milk and a consumption of 0.25ng/kgBW/day have been associated with a prevalence of between 3.2 to 20 cancer cases/year/10⁶ (Henry et al., 2001). Therefore, even low levels of aflatoxin exposure may have negative health effects on consumers.

Conclusion

Children in Kisumu County are potentially exposed to low and high levels of aflatoxin contamination through weaning diets from a variety of sources. The larger community may also be exposed to varying levels of aflatoxin through consumption of staple foods such as maize, sorghum, omena, milk, groundnuts and cassava.

Recommendation

Given the potential adverse health effects of this dietary toxin on children, the County Government should carry out routine surveillance of food market outlets for control and management of aflatoxin in all foods and feeds.

Acknowledgement
The authors highly appreciate the Kenya Agricultural and Livestock Research Organization (KALRO) Kitale for the special role in aflatoxin analysis of the food samples, with special gratitude to the laboratory technicians, Mr. Sifuna and Mr. Wafula. We are grateful to Maseno University, Kenya, for the opportunity to undertake the study at the institution. Our gratitude also goes to Eastern Africa Agricultural Productivity Project (EAAPP) for funding the research work. Special thanks to Mrs. Jane Muriuki and Mr. Ndegwa of EAAPP for the role they played.

References


Question: Taking into consideration the WHO recommendation that children under 6 months be fully under exclusive breast feeding, was breast milk considered for analysis on the level of carcinogenic substance, bearing the risk factor?

Answer: In this study, the author did not incorporate breast milk, but in the bigger study, effects of exclusive breast feeding have been considered and results show no difference between breast feeding and control on aflatoxin exposure.

Question: Why only assess effects of aflatoxin other than assessing the root causes for effective interventions?

Answer: This is because a lot of research has been undertaken on root causes and little on effect.

Question: Has anybody sampled breast milk for aflatoxin M1 as this is the main source of feed for the children 4-6 months?

Answer: Yes, some studies have been done in Kenya. The Gambia, Benin etc and an association has been established between aflatoxin M1 and growth outcomes (Turner 2008, Gong et al 2002, 2004 & 2008).

Question: What is the effect of heat / cooking on the aflatoxin levels in the foods you tested? And for how long can the children be exposed to them so as to get sick?

Answer: Cooking, Heat or processing has no effect on aflatoxin levels. Exposure to large amounts is fatal and will cause death. Half-life of aflatoxin is 3 to 6 months. Effect has been established in uterus, at birth and it increases with exposure.

Question: To what extent can you attribute the percentage of stunting to aflatoxin exposure only?

Answer: In adjusted analysis, in our bigger study, aflatoxin was the main predictor of stunting in infants 0 -3 months of age.

Comment: It would be appropriate also to collect data at the household level because the farmers produce, store and consume at home. The prevalent source of contamination is at storage.

Response: This has financial implications but is a good proposal for future study.

Comment: Please look at the time of harvesting and handling of sorghum (time of harvesting, drying and threshing)

- Sample the sorghum in the field,
- Sample at the market
- Sample at farm storage and handling level,

Response: Honestly, humidity, drying of sorghum (post-harvest management) was beyond the scope of my study. It requires another well designed study.
Determinants of milk market participation among Sahiwal farmers in Kajiado and Narok Counties, Kenya

Mukundi, J.M., Obare, G.A., Murage, A.W. and Ilatsia E.D.

Abstract

The livelihood of the pastoralists is dependent more on livestock and less often on small scale crop production. However, the productivity of livestock particularly milk has been low due to the harsh climatic conditions and poor livestock breeds. The Sahiwal cattle were introduced by Kenya Agricultural and Livestock Research Organization (KALRO), as a measure to increase the productivity and therefore the livelihoods of households in the pastoral areas. With the high potential for increased milk production with adoption of Sahiwal breed, milk market profiles both in terms of quantity and channels are likely to change as the milk market develops in the pastoral areas. In view of this, underlying factors of this change must be understood. Using a random sample of 384 pastoralist households from Narok and Kajiado Counties, this study analyzed the factors that influence milk market development in pastoral areas, using Double hurdle (DH) model. The main significant variables were found to be age of the farmer, education, number Sahiwal in the herd, TLUs, quantity of milk produced per herd, income from livestock sales, group membership and the county dummy which either had a positive or negative influence on farmers’ decision to sell their milk, and how much they sold. The findings are relevant in designing intervention strategies geared towards improvement of milk market development in the region.

Keywords: Double hurdle, Milk market participation, Pastoralists, Sahiwal.

Introduction

With its adaptability to the ASAL climate, Sahiwal genetic resources can contribute to increased milk production and hence offer a source of livelihood. For this to be realized, access to market for the surplus milk is inevitable. Nonetheless, access to rural markets is characterized by many factors that determine the ability of farmers to participate in these markets or not. Several studies have evaluated the factors that determine market participation and the extent to which farmers involve themselves in different markets. In these studies, various factors have been observed to influence decisions on market participation. For example Bellemare and Barret (2004) in their study on determinants of livestock market participation in Kenya and Ethiopia, found that high transaction costs that was determined by market accessibility negatively influenced the decisions by farmers to participate in the market. This was emphasized by Ehui et al. (2009), Omiti et al. (2009) and Makhura et al. (2001) who noted that factors that lowered transaction costs were likely to influence farmers to participate in markets. Conditions and circumstances in different areas vary and also with different products in the market.

This shows that decisions on market participation are likely to be influenced by environment and situations that surround the farmer. Unfortunately, most of the market participation studies have not been conducted in areas where the Sahiwal genetic resource has been introduced as a dual purpose breed, and one that have
a likely effect on market participation. Although livestock dynamics are expected to allow the rural poor to contribute to the growing market, most pastoralists lack reliable marketing outlets that could provide full benefit especially from Sahiwal cattle genetic resources (Devendra, 2001; Omore et al., 2004). There are constraints that restrain farmers in pastoral areas from selling cattle milk thereby failing to get the benefits from the market. To achieve these benefits it is necessary to address constraints within the milk marketing system and ensure that the farmers participate in milk markets. This study therefore aims at determining the factors that influence participation in milk markets among the pastoralists. The information generated from this study can be used to draw insight on relevant interventions to ensure pastoralists participation in milk market enhancing market development.

Methodology

Study area

Narok County lies within latitude 0° 50’ and 2° 05’ South and within longitudes 35° 58’ and 36° 05’ East. It has a population of about 850,920 persons with poverty rate of 38.3% (GoK, 2009). About 70% of the people in Narok have primary education and only about 7% have attained secondary education (GoK, ibid). Kajiado County lies within latitude 01° 53’ South and within longitudes 36° 47’ East. It has a population of about 687,312 persons with poverty rate of 11.6% (GoK, ibid). About 62% have primary education and about 12% have attained secondary education (GoK, ibid).

Sampling and data collection

Narok and Kajiado Counties were purposively selected because of the presence of pastoralists having a priority of keeping Sahiwal cattle. Multistage sampling technique was used. The sample unit constituted of individual households from pastoralist and 384 households were sampled. Data was collected between December 2012 and January 2013 using a pretested structured questionnaire through personal interviews.

Empirical model

To determine the factors influencing decision and extent of market participation a Double hurdle model was used. The choice of this model was based on the fact that the decisions to participate in the market and how much or the level of participation can be made jointly or separately by the farmer (Berhanu and Swinton, 2003). Other models such as Tobit model assumes that the two decisions are affected by the same set of factors (Greene, 2000). When censored data models such as Tobit are used in market participation analysis, the factors leading to participation are assumed to be the same as those that determine the intensity of participation. If a given farmer characteristic is known to have positive influence on decision to participate in the market then it may lead to prediction that a farmer will choose to participate in the market (Teklewold et al., 2006). Double-hurdle model generalizes the Tobit model by allowing for a separate first hurdle which represents a farmers’ decision to participate in market, and a second hurdle which represents the decision about how much to sell in the market. A sale is realized only after both hurdles are cleared, the two decisions can be modeled as dependent on or independent of each other (Cragg, 1971). Explanatory variables may appear in both equations or in either of one and a variable appearing in both equations may have opposite effects in the two equations (Teklewold et al., 2006).

In the double hurdle model, it is assumed that if a household makes a decision to participate in
the market, the resulting observation for sale is positive and the Double-hurdle model is then represented as;

\[ P(Y_i = 1) = P(Q_s > 0) = Z_i a + e \]  \hspace{1cm} (1)

\[ Y_i \] defines the market participation decision and takes the value of 1 if the household made a decision to participate in the market and a value of 0 if no participation, \( Q_s \) represents quantity or value sold in the market, \( Z_i \) is the set of variables that enter the first hurdle defining factors that affect the discrete probability of market participation, \( a \) is a parameters to be estimated and \( e \) is an error term that is normally and independently distributed with a mean of zero. When \( Y_i = 1 \) then the quantity sold is represented in an equation as;

\[ Q_s = X_i b + u \]  \hspace{1cm} (2)

where, \( Q_s \) represents quantity or value sold in the market, \( X_i \) are set of variables that enter the second hurdle defining factors that affect the discrete probability of intensity of participation, \( b \) is a parameter to be estimated, \( u \) is an error term that is normally and independently distributed with a mean of zero. The dependent variable (participation) refers to whether the farmer had sold milk or not and the dependent variable in the second hurdle refers to the amount of milk that was sold.

**Description of variable used in the analysis**

*Herd size:* the total number of cattle owned by the household (\( \text{HerdSize} \)) is a continuous variable measured by number of cattle kept. A marginal increase in herd size is expected to positively influence decision on market channel choice and market participation because of the expected marketable surplus. Bardhan *et al.* (2012) found that increased production of milk positively influenced market participation among the smallholder dairy farmers in Uttarakhand.

*Education Level* (the education level of the household head) is a categorical variable indicating the number of years that the household head has schooled. Households with more years of education are more likely to accept new ideas to improve household income as well as find information on production and market therefore enhancing market participation. In a study by Holloway *et al.* (2000) education was found to have a positive effect on quantity of milk supplied to the markets in Ethiopian highlands. The variable *Occupation* (the main occupation of the household head) is a categorical variable showing various activities that farmers engaged in to earn their livelihoods. Main occupation of the household head is likely to influence the level of income thereby positively or negatively influencing the choice of marketing channels and market participation. Age (age of the household head) is a categorical variable and is often used as a proxy for experience in farming. Studies by Tiunza *et al.*, (2001) and Ouma *et al.*, (2010) reported positive effect of age on market participation.

*Land ownership:* Total land size owned by the household in acres (\( \text{TldSize} \)) is a continuous variable measured in acres. Land may have a positive influence on participation by enabling pastoralists to produce more milk generating surpluses for selling as observed by Omiti *et al.* (2009). A study by Bardhan *et al.* (2012) noted a negative influence on market participation with more land for the household because dependence on dairying as supplementary income decreased with increase in land size.
Group membership: household member belonging to a group or association (Grupmebersp) is a dummy with 1 indicating group membership and 0 indicating non membership to groups. Participation of household to groups increases access to information important both in production and marketing. Variable Totacattle_milkprod (total amount of milk produced per day) is a continuous variable measured by litres of milk produced by the household. A marginal increase in amount of milk produced is expected to have significant effect on amount of milk surplus marketable and consequently have an influence on decision to participate in the market. Femaleown_milk (who make decision on use of milk) is a dummy variable with value of 1 for wife, 0 others. Women have been observed to own and market most of the milk among the pastoralists and therefore women ownership of milk is likely to positively influence participation in the milk market.

Income: Total income from live animal sales plus milk sale per year is a continuous variable measured in KES with the annual income from sale of all livestock and livestock products. Pastoralists with high total incomes are likely to participate in markets because they are able to meet transaction costs such as transportation of milk to the market. Increased income is also likely to enable farmers invest on Sahiwal cattle and other input leading to increased production positively influencing market participation. Tdist (total distance covered to the point of milk sale) is included in the model to capture transaction costs and its role in influencing market participation. Many studies have found distance to influence decisions in market participation. For example Omiti et al. (2009) and Ouma et al. (2010) noted that long distances reduced market participation and the amount sold due to increased transaction costs. It is expected that farmers located far from the markets increase travel time and costs which impact negatively on market participation.

Sahiwal ownership: total number of Sahiwal cattle owned (Tsah) is a continuous variable, the higher the number of Sahiwal breed a farmer has the more likely they are to participate in the market and to have marketable surplus. Acs_road (access to all weather roads) is a dummy variable introduced to capture effect of market access on milk marketing decisions expected to influence market participation positively. Markets are sources of information and likely centers for milk collection by the buyers. Ease of access to marketing points increases interaction between farmers and buyers reducing transaction costs. Narok (Narok County) is a location dummy introduced to get the effect of location of the farmer. The influence on market participation is likely to be positive or negative. The variable buyer (milk sell points) is a categorical variable representing marketing channel choices by the farmers. Presence of different types of buyers is expected to influence farmers differently in their participation in milk markets.
Results and discussion

Descriptive statistics for farmers’ socio-economic characteristics

This section provides descriptive summaries of farmers’ socio-economic factors. Tables 1 and 2 present the descriptive statistics of key variables used. Chi2 () or t-test were used where appropriate for statistical significance or else, for differences between Counties. Several variables showed significant mean differences between Counties in the study area. Table 1 presents the means and standard deviations of socio-economic characteristics of the respondents.

Table 1: Descriptive statistics for variables used in the Market Participation analysis in Narok and Kajiado Counties

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of milk sold</td>
<td>30.090</td>
<td>45.373</td>
</tr>
<tr>
<td>Age Below 35</td>
<td>0.177</td>
<td>0.382</td>
</tr>
<tr>
<td>Age 35-45 years</td>
<td>0.260</td>
<td>0.439</td>
</tr>
<tr>
<td>Age Over 45 years</td>
<td>0.564</td>
<td>0.497</td>
</tr>
<tr>
<td>Distance to the market</td>
<td>4.305</td>
<td>6.975</td>
</tr>
<tr>
<td>Access to good roads</td>
<td>0.275</td>
<td>0.447</td>
</tr>
<tr>
<td>ln income</td>
<td>13.223</td>
<td>1.185</td>
</tr>
<tr>
<td>Female milk use decision</td>
<td>0.826</td>
<td>0.380</td>
</tr>
<tr>
<td>Retailer buyer</td>
<td>0.195</td>
<td>0.397</td>
</tr>
<tr>
<td>Processor buyer</td>
<td>0.086</td>
<td>0.280</td>
</tr>
<tr>
<td>Middlemen buyer</td>
<td>0.379</td>
<td>0.486</td>
</tr>
<tr>
<td>Neighbor buyer</td>
<td>0.096</td>
<td>0.295</td>
</tr>
<tr>
<td>Average milk price</td>
<td>34.036</td>
<td>11.096</td>
</tr>
<tr>
<td>ln amount of milk sold</td>
<td>3.102</td>
<td>1.028</td>
</tr>
<tr>
<td>ln total number of cattle sold</td>
<td>3.445</td>
<td>0.966</td>
</tr>
<tr>
<td>ln total Number Sahiwal</td>
<td>3.677</td>
<td>1.471</td>
</tr>
<tr>
<td>ln total land size</td>
<td>4.249</td>
<td>1.708</td>
</tr>
<tr>
<td>ln Herd size</td>
<td>4.275</td>
<td>0.973</td>
</tr>
<tr>
<td>Group membership</td>
<td>0.468</td>
<td>0.500</td>
</tr>
<tr>
<td>Occupation farmer</td>
<td>0.849</td>
<td>0.358</td>
</tr>
<tr>
<td>Agro-pastoralist</td>
<td>0.636</td>
<td>0.482</td>
</tr>
<tr>
<td>No formal education</td>
<td>0.400</td>
<td>0.491</td>
</tr>
<tr>
<td>Primary education</td>
<td>0.249</td>
<td>0.433</td>
</tr>
<tr>
<td>Secondary education</td>
<td>0.184</td>
<td>0.388</td>
</tr>
<tr>
<td>Tertiary education</td>
<td>0.166</td>
<td>0.373</td>
</tr>
</tbody>
</table>

The data revealed varied trend in the mean and standard deviation of the variables considered.
Econometric results

The results from the empirical analysis are presented below in two sub-sections. In the first section determinants in milk market participation are presented and discussed. Then, the determinants of level of participation in milk market are presented and discussed in the second section. STATA version 11 was used in data management and analysis.

Factors influencing milk market participation

Table 3 presents the double hurdle results on market participation. The variable representing income earned from livestock sales had positive significant influence on milk market participation. The households with high levels of income from livestock sales had a higher probability of participating in milk markets. Lapar et al. (2003) observed that farmers with high level of income participated in milk markets because they could bear risks associated with marketing. This suggests that well-off households in terms of high income levels participated in milk markets possibly because they could meet the transaction costs of participating in markets.

There was positive significant relationship between amount of milk produced and the decision to participate in milk market as presented in Table 3: Households that produced more milk had a higher probability of participating in milk markets. This indicated that with increase in amount of milk produced the pastoralists were likely to make a decision to sell milk possibly because of increased marketable surplus. The results are consistent with findings by Bardhan et al. (2012) in their study among smallholder dairy farmers in Uttarakhand who found that increase in production increased farmers participating in markets.

Table 3: Double hurdle coefficients of factors influencing milk market participation in Narok and Kajiado Counties

<table>
<thead>
<tr>
<th>Variables</th>
<th>Whole sample</th>
<th>Kajiado</th>
<th>Narok</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neighbor buyer</td>
<td>1.935 (0.612)*</td>
<td>1.982 (1.153)***</td>
<td>7.648 (8.858)***</td>
</tr>
<tr>
<td>Middlemen buyer</td>
<td>2.154 (0.364)*</td>
<td>2.693 (0.728)*</td>
<td>2.690 (0.787)*</td>
</tr>
<tr>
<td>Processor buyer</td>
<td>1.461 (0.542) *</td>
<td>1.013 (0.834) ***</td>
<td>2.036 (1.068)</td>
</tr>
<tr>
<td>Retailer buyer</td>
<td>1.734 (0.529)*</td>
<td>2.234 (0.792)*</td>
<td>6.435 (7.473)**</td>
</tr>
<tr>
<td>Female owner</td>
<td>-0.192 (0.412)</td>
<td>0.693 (0.690)</td>
<td>-1.307 (0.957)</td>
</tr>
<tr>
<td>Narok county</td>
<td>0.631 (0.245) *</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Age over 45yrs</td>
<td>0.473 (0.377)</td>
<td>1.874 (1.332)</td>
<td>0.391 (0.662)</td>
</tr>
<tr>
<td>Age 35_45yrs</td>
<td>0.167 (0.436)***</td>
<td>0.950 (1.364)</td>
<td>-0.454 (0.807)</td>
</tr>
<tr>
<td>Primary education</td>
<td>-0.103 (0.330)</td>
<td>1.415 (1.456)</td>
<td>-0.696 (0.538)</td>
</tr>
<tr>
<td>Secondary education</td>
<td>-0.272 (0.383)**</td>
<td>-0.617 (0.895)**</td>
<td>-0.507 (0.587)</td>
</tr>
<tr>
<td>Access to good roads</td>
<td>0.591 (0.283) **</td>
<td>1.164 (0.476)*</td>
<td>0.371 (0.442)</td>
</tr>
<tr>
<td>In Income</td>
<td>0.161 (0.188) *</td>
<td>0.2238 (0.313) *</td>
<td>0.289 (0.326)**</td>
</tr>
<tr>
<td>Distance to market</td>
<td>0.719 (0.172)</td>
<td>0.925 (0.242)</td>
<td>0.994 (0.311)</td>
</tr>
<tr>
<td>Number of Sahiwal</td>
<td>0.012 (0.001) *</td>
<td>0.001 (0.000) ***</td>
<td>0.051 (0.000) *</td>
</tr>
</tbody>
</table>
The location of the farm had a positive significant influence on decisions of the farmers to participate in the milk markets. From the result farmers from Narok County were more likely to participate in milk markets. This is probably because farmers in Narok County produced more average milk as observed in differences between county means and this was likely to increase amount of milk available for marketing positively influencing market participation.

There was a positive significant relationship between the neighbours, middlemen, processors and the retailer buyers on farmer’s decision to participate in milk market in the whole sample. The middlemen had the highest influence followed by the neighbours. The plausible reason could be that the neighbours and the middlemen were easily accessible to the farmers and they provided an easily accessible market for sale of the surplus milk. These findings were in tandem with Enete (2009) who found that presence of buyers who were easily accessible to the farmers made them to sell surplus produce. These buyers also offered average higher prices and this could possibly influence the farmers to participate in milk markets. This indicated that presence of milk buyer influenced decision of the pastoralists in participating in milk markets.

The education level (secondary education) of the household head had a negative significant influence on decision to participate in the milk market as compared to farmers with no formal education. This is probably because with more education the farmers are able to look for other jobs and diversify income sources and consequently use milk for consumption at home. This was in line with Lapar et al. (2003) in a study on smallholder livestock producers in Philippines who established that educated farmers had opportunities for off-farm employment. These findings were inconsistent with Holloway et al. (2000) in a study on Transaction Costs, Cooperatives and Milk-Market Development in the Ethiopian highlands and found that educated farmers were able to gather more information influencing market participation.

Ownership of Sahiwal cattle significantly influenced the decision to participate in milk markets positively;
the influence was highest in Narok County because on average they had higher numbers of Sahiwal breeds than their counterparts in Kajiado. Farmers in Narok County had large number Sahiwal cattle as observed from the means in Table 2, consequently farmers in Narok County produced more milk than their counterparts in Kajiado. High milk production from Sahiwal cattle was likely to influence marketing of surplus milk. Sahiwal cattle represent an asset base for milk production in pastoralist area and an increase in asset base is likely to influence participation. This was in line with Dovonan and Poole (2014) and Amanikwah et al. (2012) who indicated that investment in assets scaled up the level of production positively influencing participation.

Access to all weather roads had a significant positive influence on market participation significant in Kajiado County as presented in Table 3: The households that had access to good roads that were accessible at all times were likely to participate in milk markets. Buyers in the rural areas bulk milk from various households or collection points, ease of access to this households and collection points maximizes on the profits by reduction of transaction costs associated with poor road infrastructure.

Pastoralists’ membership to groups and associations positively and significantly influenced the decision to participate in the milk markets as presented in Table 3: The households that were members of organized groups had a higher probability of participating in milk markets. This implied that groups were a source of market information and this reduced the level of information asymmetry between the farmers and milk traders. Barret and Christopher (2008) stated that smallholder farmer participation to groups influenced the decision to sell farm produce.

The herd size negatively and significantly influenced participation in whole sample and Narok County. Households with large herd sizes were unlikely to participate in milk markets. This indicated that dependence on dairying as additional source of income decreased with increase in herd size. Herd size indicated level of wealth in a household and the higher the income from cattle sale the less likely a household was to look for supplementing incomes. Bardhan et al. (2012) in their study noted that farmers with low incomes sold more milk to supplement their lower incomes.

The age between of 35 to 45 years had a positive and significant influence on market participation as presented in Table 3: With increase in age of the household heads it was likely that the farmers would sell milk. The possible reason could be that with increase in age farmers were likely to be more experienced and needed more resources to cater for the growing family needs. With increase in age farmers were likely to have high capital which increases level of production, positively influencing market participation.

Factors influencing the level of participation in milk

Table 4 presents the double hurdle results on extent of milk market participation. The household income had positive significant influence on amount of milk sold in the market in whole sample and Narok County. This indicated that poor households sold little amount of milk in the market. This could be explained by low level of production among the poor households or inability to meet the transaction costs that are associated with increased volumes marketed.

The amount of milk produced had a positive significant relationship with amount of milk sold as presented in Table 4 This indicated that increased milk production increased the amount that was sold. This was in
tandem with the findings by Omiti et al. (2007) who found that increased production led increased level of market participation.

**Table 4: Double hurdle coefficients of factors influencing the level of participation in milk market in Narok and Kajiado Counties**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Whole sample</th>
<th>Kajiado</th>
<th>Narok</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neighbor buyer</td>
<td>-43.542 (13.505)*</td>
<td>-39.801 (22.032)***</td>
<td>-44.183 (18.454)**</td>
</tr>
<tr>
<td>Processor buyer</td>
<td>3.302 (5.194)***</td>
<td>7.072 (3.273) **</td>
<td>0.272 (4.591)</td>
</tr>
<tr>
<td>Retailer buyer</td>
<td>-13.616 (10.856)***</td>
<td>3.166 (11.212)</td>
<td>-23.984 (17.030)***</td>
</tr>
<tr>
<td>Female owner</td>
<td>-2.222 (9.000)</td>
<td>17.622 (13.068)</td>
<td>-8.465 (12.712)</td>
</tr>
<tr>
<td>Narok county</td>
<td>-4.23 (3.130)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Age over 45 yrs</td>
<td>4.047 (9.283)***</td>
<td>13.782 (13.285)***</td>
<td>5.489 (11.474)***</td>
</tr>
<tr>
<td>Age 35-45 yrs</td>
<td>4.980 (10.429)</td>
<td>5.343 (14.709)</td>
<td>3.041 (12.626)</td>
</tr>
<tr>
<td>Primary education</td>
<td>10.893 (8.168)</td>
<td>19.384 (12.152)</td>
<td>3.624 (10.034)</td>
</tr>
<tr>
<td>Access to good roads</td>
<td>6.502 (7.621)***</td>
<td>-2.722 (8.411)</td>
<td>7.676 (11.320)</td>
</tr>
<tr>
<td>Income</td>
<td>12.099 (6.086)***</td>
<td>5.037 (7.378)</td>
<td>16.011 (8.718)***</td>
</tr>
<tr>
<td>Distance to market</td>
<td>-0.483 (3.430)***</td>
<td>2.020 (3.942)</td>
<td>-1.827 (5.530)</td>
</tr>
<tr>
<td>Number of Sahiwal</td>
<td>7.878 (3.988)***</td>
<td>4.812 (3.786)</td>
<td>13.107 (7.275)***</td>
</tr>
<tr>
<td>Herd size</td>
<td>-0.037 (0.019)*</td>
<td>-0.023 (0.015) ***</td>
<td>-0.041 (0.029) **</td>
</tr>
<tr>
<td>Group member</td>
<td>2.603 (7.225)</td>
<td>-1.075 (8.897)</td>
<td>3.440 (10.258)</td>
</tr>
<tr>
<td>Milk produced</td>
<td>101.400 (8.881)*</td>
<td>91.094 (9.140)*</td>
<td>107.262 (14.922)*</td>
</tr>
<tr>
<td>Land size</td>
<td>-0.073 (2.228)*</td>
<td>-0.401 (3.558)</td>
<td>-1.144 (3.300)*</td>
</tr>
<tr>
<td>Constant</td>
<td>-513.630 (76.023)*</td>
<td>-393.081 (96.421)*</td>
<td>-556.117 (105.899)*</td>
</tr>
<tr>
<td>sigma cons</td>
<td>34.484 (2.243)*</td>
<td>25.803 (2.395)*</td>
<td>37.815 (3.285)*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Whole sample</th>
<th>Kajiado</th>
<th>Narok</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of obs</td>
<td>334</td>
<td>148</td>
<td>186</td>
</tr>
<tr>
<td>Wald chi2 (17)</td>
<td>71.250</td>
<td>32.070</td>
<td>18.980</td>
</tr>
<tr>
<td>Prob &gt; chi2</td>
<td>0.000</td>
<td>0.001</td>
<td>0.089</td>
</tr>
<tr>
<td>Log likelihood</td>
<td>-1214.004</td>
<td>-484.705</td>
<td>-708.164</td>
</tr>
</tbody>
</table>

Source: Survey data

Note: *, ** and *** denote significance at 1%, 5% and 10% confidence level. Standard errors are in parenthesis

Though land size did not significantly influence decision to participate in milk market in whole sample and Narok
County as presented in Table 3 in previous section, it had a negative significant influence on amount sold as presented in Table 4: Pastoralists are likely to keep breeds that produce meat if they had large land sizes and this is likely to explain the inverse relationship between extent of participation and land size.

The number of Sahiwal cattle owned per household had a positive significant relationship with amount of milk sold. Farmers who had large numbers Sahiwal cattle were likely to produce more milk consequently having more marketable surplus. When farmers raise their asset base in production in increasing number producing units, more is likely to be produced for sale. These findings are in tandem with those of Amanikwah et al. (2012) who found that increased capital base led to increased level of market participation which resulted from increased production.

The amount of milk sold in the market was positively and significantly influenced by the age of the household head (age category of over 45 years) as presented in Table 4: Level of investment and experience is highly correlated with age. Farmers are likely to have high level of production and networks for milk market with age. This corroborated with findings Staal et al. (2006) who established that experience which was highly correlated with age influenced the level of market participation.

When the available buyers for the surplus milk were the neighbors, middlemen and the retailer buyers, their influence on amount of milk was negative and significant. This implied that these buyers could not buy large quantities of milk because of possibly their low handling capacity and they were not in a position to trade with large milk capacities. The processors had a positive relationship with amount of milk sold in the market probably because of their capability to handle large amount of milk.

The distance covered to the market had a negative significant influence on amount of milk sold. The distance increases the cost of transaction that the farmers incur in delivering milk to the market and this is likely to reduce amount sold. Barret and Christopher (2008) in their study on Smallholder Market Participation in Eastern and Southern Africa found that reduced cost of transaction by improvement of market infrastructure positively influenced amount sold.

**Conclusion**

In enhancing market participation among the pastoralist actors should note that household total income play a significant role. This therefore indicates that innovations to increase income among the poor households can be instrumental in exploiting marketing opportunities. Interventions to reduce risk of household reduced income are pivotal by training farmers on diversification of income generating enterprises. Increasing number of Sahiwal cattle breeds owned by the farmers through breeding programs and awareness is essential. The groups provided information and financial services to the farmers and these are critical in accessing market opportunities. Increasing social capital among the pastoralists is therefore of great value in enhancing access to markets. Development agencies need to focus on infrastructure development to ensure that farmers can easily access the markets.

**Acknowledgements**

The authors greatly acknowledge the Department of Agricultural Economics and Business Management of Egerton University, for providing a favorable environment for doing this work. We would like to appreciate Kenya Agricultural Research and Livestock Research Organization through East African Agricultural Productivity Project for financial support during the field research and all the staff, enumerators and farmers who made data collection a success.


A testimony from Erick Mwatuni, a farmer from Balambala Group- Kenya

Introduction

Balambala Sub-county is in Garissa County. It is divided into four administrative Wards (Balambala, Sankuri, Saka and Danyere). It is bordered to the West by Garbatula Sub-county of Isiolo County, to the North by Lagdera Sub-county and East by Garissa Sub-county of Garissa County and to the South by River Tana. The Sub-county covers an area of 3797.3 km² with an estimated population of 62,390 (2009 census figures). The District has a flat topography with altitude ranging from 450 – 700 meters above sea level. Balambala is classified as arid with temperatures ranging between 33°C to 42°C. It is in AEZ 6 and receives bimodal rainfall with annual average of between 250-300mm. The long rains are received in April to May while the short rains fall in November – December. It is characterized mainly with hot and dry weather.

Livestock population is estimated to be; 122,900 camels, 188,000 cattle, 460,000 goats, 200,000 sheep and 25,000 Donkeys in the Sub county. Livestock production is the main source of food and income in the Sub-county and provides for 95% of household income. It is a predominantly nomadic pastoralism area although there are two pastoral livelihood zones in the sub-county.

Pastoral system of production is characterized with Camel milk production, deteriorating range condition, high vulnerability to drought and floods, lack of market infrastructure, lack of market information and over-dependence on marketing of livestock and unprocessed livestock products. Agro-pastoralists are found along the Tana River while farms are owned by farmer groups. Farming along the river is mainly done under open canal system of irrigation for crops and fodder production. The Agro-pastoralists form 6% of the total population.

Before EAAPP intervention farmer groups in Balambala were using traditional methods and containers to process and keep their milk, respectively. These had challenges of short shelf-life and hygiene and therefore the groups could not access far flung markets. The formal markets including supermarkets were also inaccessible due to similar reasons.

EAAPP Intervention

In the Sub-county, camel milk production and marketing was the main focus for EAAPP intervention. The main success story is based on the activities related to camel milk promotion through EAAPP intervention as follows;

■ Capacity building of farmers on camel milk hygiene and handling, Camel milk bulking and marketing,
■ Camel milk value addition and marketing
■ Dairy health management and sensitization on zoonotic diseases prevention-Camel milk
■ Camel disease control
Examples of EAAPP Intervention in the Sub-county

- One Camel milk outlet opened in Garissa town by a co-operative group arising from the trained farmers’ groups who came together. At the outlet, 350-450 litres of value added milk was sold daily earning an average daily income of Kshs. 38,000 (US$ 361).
- Ten women and four youths are now Trainers of Trainers (TOT) in Camel milk value addition and are being used by other organizations to train groups and they earn income, hence job creation.
- Three Products have been launched officially, Garol – Yoghurt, Sousa – Sweetened soured milk and gal’hanan - Chilled fresh camel milk and were by then retailing in Garissa town.

Achievements
Examples of EAAPP Achievements in the Sub-county

New Camel milk Outlet Opening /Women and youth TOT in milk value addition

Official opening of Towfiq Camel milk Outlet and Launch of products in Garissa town

A ToT training in Garissa town

The camel group members with extension staff at the exhibition in KICC, Nairobi
Seven groups are bulking and cooling milk for sale after they adopted the technologies trained on. Clean milk production is evident from the quality of milk the groups are taking to the markets.

Three groups have taken up the opportunity in milk value addition and started producing other types of Camel milk value added products (Yoghurt, Sweet Mala, Camel ghee, butter and Ice cream) for sale in markets. They also take advantage of exhibitions and ceremonies where they sell their products. The groups have increased their daily milk sales from an average 80 liters when they started to a daily average of 450 liters of value added products. They earn a daily income of about Kshs. 29,000 (US$ 276).

Women and men earlier on trained have taken up a pastoral field school approach and are training other groups on milk value addition and fodder production which is very encouraging in technology dissemination. They have been involved in the trainings to improve adoption levels.

The groups have been able to exhibit in various exhibitions and shows as follows; All African Conference on Animal Agriculture at KICC- Nairobi, Nairobi International Trade Fair, Garissa County Open Day organized by Garissa County Government, which has earned them a lot of commendations.

**Conclusion**

The project has transformed lives in Balambala Sub-county which is in a remote far flung area with no communication networks and no electricity connection. The women groups have adopted modern milk handling techniques and are carrying out value addition, something that they could only imagine of before EAAPP intervention. Farmer to farmer extension has also worked quite well and more and more farmers are getting involved in the activities.
A testimony by Mohammed Serem of Mindililwo Youth Group, Marakwet County, Kenya

Introduction

Mindililwo Development Youth Group was formed and registered in 2011 comprising of 24 members (9 females and 15 males). It is located at Mindililwo village at Kapchemutwa ward, Keiyo North sub-county, Elgeyo Marakwet County in Kenya. The goal of forming the group was to contribute towards their income generating activities. The main economic activity for majority of members is dairy production. The group has a feed business whose specific objectives are:

- To provide services as a one stop shop for dairy farmers
- To address shortages and address feed quality
- To expand feed production and supply
- To be a dairy learning centre for farmers

Group activities that deliver on the group objectives are;

- Production, processing and formulation of animal feeds (plate 2)
- Selling of feeds and dairy mineral supplements
- Providing dairy extension dairy services to farmers
- Providing Artificial Insemination services to farmers at affordable fees
- Tick control services
- Sale of Rhodes grass hay and maize stovers (packed in 50 kg)

Plate 1: Signpost at Mindililwo youth group premises at Keiyo
Key achievements made by the groups are:

- Each member has been able to acquire an exotic dairy cow for milk production and sales for income generation.
- Hiring 7 acres piece of land and established pasture.
- Relocation of feed centre to a more accessible area within the Iten town.
- The group has expanded operations and managed to own trading premises in Iten town.
- Growth in stock from KShs 40,000 to 400,000
- Employment of six staff to assist in their activities.
- Successfully operating a milk bar which serves as the main market outlet for their milk (plate 3).

The success of the group has been attributed to good management and cohesiveness among members. Future prospects of the group include acquisition of Kenya Bureau of Standards (KEBs) certification, construction of a feed store, acquisition of a pickup track for marketing of processed products and expansion of pasture and fodder production.
A testimony by Cyrus Mwaniki of Umoja Dairy Society Ltd, Kenya, on successful adoption of improved dairy technologies

Introduction

Umoja Dairy Society is located at Mairo – Inya trading centre in Ndaragwa, Nyandarua County, Kenya. It was registered on 17th February 2012. The Idea of starting the society was initiated by the Nyahururu Umoja Sacco Society Limited Board of Directors in June 2010. Most of the Sacco Members were dairy farmers. Board of directors went on a study tour on value addition and marketing to Kinangop, Mbooni and Machakos in June 2012. During the same year members attended Agricultural and Livestock Conference exhibition (ALICE) at Safari Park Hotel and learnt about total mixed ration (TMR) technology through EAAPP.

Successful adoption of TMR technology has assisted the farmers to realize increased milk production at their farms. It has also improved the quality of milk (e.g. higher butter content), improved consistency in milk supply throughout the year and enhanced members’ confidence in the society.

The chairman reported that due to the training obtained through EAAPP, members had registered 120 cows and another 70 were in the process of registration with Kenya Stud Book. He reported that the youth were now more involved in dairy farming since TMR feeding was less labour intensive compared to previous cut and carry system.

In June 2012, the society came up with a five year strategic plan 2013 – 2018 that is reviewed quarterly. The Vision statement is to be a competitive dairy co-operative society of choice offering quality and quantity services for sustainable economic and social empowerment of members. The Mission statement is to promote modern dairy commercial farming practice and ensure a sustainable market for members produce.

Towards fulfilling the co-operative mission, the activities involve;  
- Milk bulking, processing and marketing  
- Training of farmers through pasture/fodder demonstration Plots, TMR, crop residue utilization  
- Dairy cattle recording and registration  
- Farmers’ exchange tours for cross learning
Key achievements by the co-operative are:

- Higher milk productivity per cow per day due to improved feeding
- Established three (3) demonstration plots on Columbus grass and Lucerne, two tree nurseries on Sesbania sesban and Lucerne fodder shrubs.
- The society held 8 trainings last financial year through collaboration with Ministry of Agriculture, Livestock and Fisheries where 720 farmers attended.
- Society held two farmers tours for cross learning in Nyeri.
- Four members of staff were trained on milk value addition, milk quality and hygiene.
- The society has complied with Kenya Bureau of Standard (KBS).
- The society acquired a feeds store for members to produce TMR materials at subsidized prices and about 70 farmers have adopted TMR and were preparing 1800kgs per week.
- About 200 dairy cattle have been registered with the Kenya Stud Book
- More youths getting involved in dairy farming since feeding using TMR is easier than cut and carry system involving napier grass.
- The society was adding value to milk through yoghurt making (Vanilla and Strawberry flavours) retailing as Umoja yoghurt and Pasteurized milk.

Factors leading to the Success of the Society are:

- Committed staff, Board of Directors and supervisory committee
- Exchange tours and information sourcing embraced by members.
- Collaboration with our partners and stakeholders e.g. EAAPP, KAPAP, UMOJA Sacco, Cooperative Bank, CIC insurance, Nyandarua County Government among others.
- Prompt milk payments to the farmers enhancing royalty
- Payment of bonuses and dividends to members
- Advance of credit facility to members to source inputs
Plate 1: Milk bulking process at the factory

From the operations of the co-operative, impacts realized are;

- Increased returns raising the standards of living.
- Improved value of dairy animals due to recording and registration.
- Reduced cost of production (TMR produces 1 ltr at @14/= while feeding using other methods produces 1 ltr @ 16/=)
Plate 2: Milk marketing operations at Umoja dairy

Future Prospects for the Society involves:

- Vigorous marketing and recruitment exercise of more members / milk suppliers.
- Constructing a milk processing plant and a feeds manufacturing plant.
- Expansion of milk collection area and milk chilling points.
- Continuous training of staff and members’ on safe handling of milk and dairy production management.
- Recruit more skilled staff commensurate to expansion needs.
- Invest in milk processing technologies to enhance efficiency.
- Establish an Agro vet shop and a dairy products consumer shop.
- Involve more dairy farmers in improved animal breeding technologies and recording of cattle.
A testimony by Mr. William Odidi of Migori County, Kenya, on improved pasture and fodder production

Introduction
Rongo Sub-County is one of the 8 Sub-Counties in Migori County covering an area of 201 Km² with a population of 100,809 persons and a population density of 501 persons per square kilometer with an average of 5 persons per Km. It has four wards which act as extension units for the provision of extension services to the farming community. The sub county has good soils and favourable climatic conditions which greatly support agricultural activities especially dairy farming.

Dairy Sub-Sector in Rongo
Dairy sub-sector supports livelihood of over 25,000 farm families in Rongo Sub-County. It is evident that growth in dairy sub-sector can greatly improve the living standards as it creates employment, reduces poverty and promotes food security. However inadequate feed resource was limiting the productivity of dairy animals in the sub-county. The EAAPP supported dairy farmers to exploit the existing potential for dairy production through dissemination of dairy technologies especially improved feeding of the dairy cow.

Key achievements of the project in the sub-county;
- About 1,500 targeted farmers adopted the technologies
- Over 3,500 non-targeted farmers also adopted the technology to the extent of doing away with sugarcane which is the main cash crop and replacing it with improved pasture and fodder production.
- Increased acreage under improved pasture and fodder production from less than 25 ha initially to 55 ha currently.
- Commercialization of feeds by selling over 5000 bales of hay from improved grass (Boma Rhodes) and around 2000 bales of Desmodium legume hay to other dairy farmers within the County and neighbouring Counties like Homabay, Kisii and Nyamira generating about Ksh. 2.1M (US $ 20,000).
- Availability of quality dairy feeds to dairy farmers in the sub-County.
- Increased crop residue utilization through the use of pulverizer machine to improve dry matter intake. The surplus is sold to generate income.
- Enhanced feeds storage capacity through construction of feeds stores/barns by farmers
- Increased number of farmers commercializing dairy farming

Outcomes
- Doubling of milk productivity from 5 – 10 litres per cow per day.
- Increased number of farmers with dairy cattle in the area due to the availability of feeds.
- Revival of Rongo dairy farmers’ cooperative society which is now receiving more than 1,000 litres of milk daily up from 50 litres before EAAPP intervention in 2013.
- Improved income, enabling farmers to educate their children with no external assistance.
Examples of EAAPP activities in the sub-county

As a result of success stories in dairy in the sub-county, other development partners have come on board and are involved as follows;

- Heifer Project International - send cow project (150 Dairy Animals issued to farmers)
- ICIPE - promotion of fodder production
- Brookside Dairies - Rongo dairy farmers’ cooperative society - for milk collection, bulking and cooling.
- Migori County - 19 Dairy animals issued to farmers
- USAID Project - promotion of AI

Conclusion

The EAAPP has enhanced the potential of dairy farming in Rongo Sub-County, a sub-sector which had been ignored for a long time. The success in dairy farming in Rongo due to EAAPP intervention has triggered interest from other development partners especially in the area of improved pasture and fodder production, which contributes to improved performance of the sub-sector for better livelihood and food security.
A Success story on Agribusiness model farm by Nicholas Mbijiwe of Imenti sub-County, Kenya

Introduction
Imenti South Sub-county was created from the former greater Meru Central District in 2007. The Sub-county lies along the Eastern slopes of Mt. Kenya bordering Mara Sub County to the South, Meru central to the North, Tharaka to the East and Mt. Kenya to the West. The sub county has 6 wards and covers an area of 661 Km². Human population is 179,604 with 47,197 households (HH) are according to the 2009 census. Population density is 272 per km². The population of dairy cattle is about 40,000 with milk production of about 4 million liters annually worth Ksh.8.7 Billion (US$ 87M). Assuming 50% fertility rate, the number of animals in milk at any one year in the county is 20,000, and with an annual milk production of 4 million litres, this works out to be 200 litres per animal per year. This kind of production is much lower than the national dairy lactation yield. EAAPP introduced an approach into the County through which to capacity build farmers to better their production. The Model Farm concept is based on the approach of establishing Centers of Excellence to serve as learning Centers for neighboring farmers, from within and outside the County. The EAAPP established 11 Agribusiness Model Farms in the Sub County, for this purpose.

Mr. Mbijiwe’s Agribusiness Model Farm
Mbijiwe’s agribusiness model farm is located in Imenti South Sub-county in Meru County. It is in Mikubune location of Nkuene Ward. The Vision of the farm is to be the leading producer of milk and milk products in the Eastern Region of Kenya while its Mission is to breed a highly productive dairy herd through selection and good animal husbandry practice. The main objectives are as follows;
- To increase the farm's dairy herd size
- To increase fodder/pasture production and quality of livestock feeds.
- To improve nutrition and general animal husbandry
- To increase average milk production from 22 to 40 kg of milk per cow per day

The farm is approximately 4 acres with a mixed farm enterprises comprising of dairy, horticulture, food crops, poultry, rabbits, pigs, and fish farming. However, the predominant enterprise is dairy which is under intensive management system. In 2012 before EAAPP intervention the farm had 10 dairy cattle (5 lactating cows, 2 heifers and 3 calves).

Challenges addressed through EAAPP Intervention;
- Low milk production per cow
- Inadequate quality and quantity of fodder
- Low level of commercialization
- Poor methods of disposal of agricultural waste generated on the farm

EAAPP Interventions
EAAPP assisted in development of a 5-year Farm Business Plan Capacity building on;
- dairy cattle breeding (proper heat detection and breed selection)
- animal nutrition and on-farm feed formulation
- fodder/pasture establishment and conservation
- hygienic milk production, udder health management & milk testing techniques
- dairy cattle recording and registration.
- environmental safeguards and effective use of acaricide and tick control
The farmer is involved in the following activities after EAAPP intervention:
- Conducts on-farm trainings – Over 1500 farmers trained at the farm. (on dairy feeding and general dairy management).
- Participates in exhibitions and shows (Nairobi International trade fair, District agricultural stakeholders shows etc); thousands of stakeholders reached.
- Participates in Radio Programs (FM radios - Inooro, Mugaa and, KBC) training farmers and other stakeholders
- Holds talk shows on local TV stations (QTV, KBC, KTN)
- Has hosted 793 visitors from within and outside the country in the last two years.

Key Achievements
- Improved farm profitability due to proper record keeping
- Reduced calving interval at the farm from 18 months to 12 months
- Currently the herd is at 19 (10 lactating cows, 5 heifers and 4 calves)
- Registered all his animals
- Established 2.5 acres of fodder (sourced from KALRO) thus improving quantity and quality of feed produced on the farm.
- Increased milk productivity per cow from 22 to 39 litres per cow per day.
- On-farm feed formulation at the farm and for neighbours.
- Dry season feeding strategy by out-sourcing and storing hay
- Improved crop residue utilization
- Construction of spraying/vaccination crush & proper waste disposal.
- Acquired a high capacity vehicle
- Acquired an additional 20 acres of land to expand dairy enterprise
- Installed water for irrigation and domestic use
- Establishment of additional enterprises; fish and poultry.

Impact
- Has been able to educate two of his children up to the university
- Proper family nutrition and welfare

Conclusion
In conclusion, Mr. Mbijiwe stressed that growing his own feeds and ration formulation (using locally available ingredients) had greatly reduced the cost of producing a litre of milk which should be every farmer’s aim. He also added that feed conservation during times of plenty was very important if one was to sustain milk production.

Discussion Session
Question: Do you charge farmers who come for trainings at your farm? How much do you charge them?
Answer: Mr. Mbijiwe informed the meeting that he charges kshs. 200 per farmer per session and each session takes 3 ½ hours each.
A success story on Artificial Insemination by Patrick Njoroge from Murang’a County, Kenya

Introduction

Geographical scope

Kangema sub-county is one of the eight sub-counties in Murang’a County. It borders Mathioca sub-county to the north, Kahuro to the South, Kiharu to the East and the Aberdare forest to the west.

The Sub county covers an area of 172.7Km² with an estimated population of 92,680 (2009 census figures) with 21,814 households. The arable land is 120.5 km² with an average land holding of 0.2-2.0 acres. The sub-county lies in an altitude of 1350-2400m meters above sea level. It is in AEZ LH1-UM1 (tea zone to marginal coffee) and receives bimodal rainfall with annual average of between 1350-2700mm. The long rains are received in March to May while the short rains fall in October – December.

Livestock status

The district has the following livestock enterprises in order of economic importance: Dairy cattle, dairy goats, Poultry, rabbit production, sheep, beekeeping and pig production. Livestock population is estimated to be; cattle 42,622, Poultry 51,807, local goats 14,805, dairy goats 6,259, sheep 11,216, pigs 531, bee hives 2,137 and rabbits 6,296 in the Sub county.

Artificial insemination services

Before EAAPP;

■ The private AI service providers had dominated the area to the extent of forming cartels.
■ They had hiked charges to a level where many dairy farmers could no longer afford.
■ The average charges for local semen and imported semen was kshs 1,500 and 3,000 respectively. Repeat services would still be charged the same amount and hence farmers felt exploited. As a result some farmers resorted to using natural service.

EAAPP Interventions

In April 2012 EAAPP supported Kangema sub-county with an Artificial Insemination (AI) kit which comprised of the following:

■ A field semen tank
■ 300 doses of semen
■ A liquid nitrogen tank full of liquid nitrogen
■ Protective clothing

The kit was assigned to KIKAMA co-operative with an agreement that they provide AI services to their members on credit. The cost of AI was deducted at the end of the month as they pay the farmers. The other farmers who were not members of the cooperative would also be served but would pay cash. KIKAMA brought on board a private AI service provider with whom they had an MOU on the service provision terms.
Achievements

At the end of June 2015 the number of services provided had reached 256 out of which 146 female calves and 35 bull calves had been realized. This is approximately 80% Female calves and 20% male calves. The inseminator attributes this high percentage of female calves to good timing and collaboration with the farmer.

The following are some of the calves /heifers:

- Mr. James Ndegwa from Karuri Village with his three heifers and one bull calf
- Mr. Samuel Gathuku with his Ayrshire calf
- Mr. Titus Kagwanga from Ichichi village with his two heifers
- Ms. Wanjiru with her female calf
Has achieved 256 pregnancies out of which 146 female calves and 35 bull calves had been realized, (about 80% of the calves were females).

- The group has expanded their business by refilling the semen tank with both local and imported semen.
- They also serve farmers with sexed semen.

**Outcome**

- Farmers have been able to sell the registered heifers which are earning them money to educate their children and reduce the demand gap for heifers in the sub-county.
- Many farmers were able to expand their dairy herd from the female calves realized.

**Conclusion**

The AI kit has assisted dairy farmers in the Sub-county since they do not have to wait for long before the technician serves the cows. They are able to time the cows’ heat period better after the training received from the experienced AI technician, and hence realizing more female calves.

With EAAPP Intervention;

- The charges for arm-service has come down to an average of kshs 900 and services are done on credit deducted from the milk delivery payments.
- Many Heifer calves have been born due to the close working relationship with the AI service provider.

**Recommendation (way forward)**

There is need to determine factors that lead to sex of offspring during A.I using conventional (unsexed) semen.
Cassava research and development
Cassava Research and Development in the eastern and central Africa: Past, Present and Future Outlook

Kanju, E.1*, Legg, J.1, Kulakow, P.2, Ferguson, M.3, Ntawuruhunga, P.4, Abass, A.1, Uzokwe, V.1, Tumwegamire, S.1, and Asiedu, R.2.

*Correspondence: ekanju@cgiar.org

Abstract

Cassava is the fourth most important source of dietary energy in the developing world after the cereal crops wheat, maize, and rice, feeding an estimated 800 million people worldwide. It is also an important source of income, especially for women in sub-Saharan Africa. Cassava has several desirable attributes that make it an excellent food security crop. Recently, it has been identified as the least sensitive crop to the climatic conditions predicted to occur. Since 2000, the world’s cassava production has sharply increased driven by demand for dried cassava and starch for use in livestock feed and industrial applications in Asia, and in Africa by expanding urban markets for cassava food products. In several African countries, cassava is being more and more perceived, not only as a food security crop, but also as a raw material for various types of industries. However, cassava is affected by a diverse set of constraints including pests and diseases, use of poor agronomic practices, the use of cultivars with poor genetic potential and the use of poor quality planting materials which adversely affect production. Through partnerships between the International Institute of Tropical Agriculture and national research programs, new varieties have been developed that combine high resistance or tolerance to the major viral diseases namely Cassava Mosaic Disease and Cassava Brown Streak Disease. Efforts are been put in place to ensure these varieties reach farmers.

There are several on-going initiatives to address the major challenges in cassava research for development, processing, value addition and marketing. With the increasing interest for commercial production of cassava, breeders will face the challenge of developing new varieties with dual resistance to cassava mosaic and cassava brown streak diseases suitable for each value chain. In order to transform the subsector, in a way that ensures food security, income generation and economic diversification, the identification of profitable value chains and market preferences, strategies for reducing price variability on the demand side, and options for enhancing the quality, volume and reliability of production on the supply side will be required.

Finally in order to realize the huge potential that cassava has, to help alleviate poverty both through food security and commercialization, there will be a need to: create awareness and put in place control strategies of diseases and pests; establish clean seed systems; develop and release of varieties with high dry matter productivity and high nutrient use efficiency; promote improved agronomic practices; develop and introduce appropriate labor saving technologies; develop and promote efficient and appropriate processing and post-harvest technologies; develop value chains and markets in order to boost demand and increase returns to producers and put in place enabling policies to promote production and consumption of cassava.
Introduction

Cassava (*Manihot esculenta* Crantz) originally from South America, is the fourth most important source of dietary energy in the developing world after the cereal crops wheat, maize, and rice, feeding an estimated 800 million people worldwide (FAO, 2013a). Both the roots and leaves are consumed. The protein content in cooked cassava leaves is high, but of poor quality, with sulphur amino acids as the most limiting amino acids (Ngudi et al., 2003). Its ability to stay in the ground for up to three years makes it an excellent food security crop. Its other desirable attributes include: drought tolerance, ability to give reasonable yields under poor soil conditions and its ability to suppress weeds when its canopy is fully developed. Cassava responds extremely well to high CO₂ concentrations, making it a very important crop for the 21st century (Legg et al., 2014). Africa alone accounts for more than 55% of the world’s production, and cassava is the first food crop in fresh tonnage before maize and plantain in sub-Saharan Africa. Cassava is also an important source of income, especially for women in sub-Saharan Africa (SSA). High quality cassava flour is used in bakeries, biscuits and pharmaceuticals. Apart from direct human food, cassava is used for animal feed. Furthermore, cassava is the second most important source of starch in the world (Legg et al., 2014). Its high starch content (20-40%) makes cassava a desirable energy source for both human consumption and industrial biofuel applications. All the countries in the region import starch. For these reasons it has been recognized as a powerful poverty fighter with the potential to help alleviate poverty both through food security and commercialization (Nweke et al., 2001; FAO, 2013a). For the same reasons the African Union’s Pan-Africa Cassava Initiative has identified it as a key agricultural commodity, food security crop and “poverty fighter”. In summary, cassava which was known as the “food for the poor” has become a multipurpose crop that responds to the priorities of developing countries, to trends in the global economy, and to the challenge of climate change (FAO, 2013a). Total cassava production in Africa exceeded 146 million tons in 2012 (FAO, 2013b), more than any other crop in Africa. Its productivity is on average nearly 12t/ha (8t/ha in Democratic Republic of Congo (DRC), 14.2t/ha in Kenya and 12.7t/ha in Uganda). However yields in some South Asian countries are much higher: China (18t/ha), Indonesia (23.5t/ha), Thailand (19.8t/ha) and India (40.2t/ha) (FAO, 2013b). The low average yields in eastern Africa are caused by many factors including susceptibility of commonly grown varieties to major diseases and pests, including cassava mosaic disease (CMD) and cassava brown streak disease (CBSD). Due mainly to CMD and CBSD pandemics, Tanzania which was the fourth largest producer of cassava in Africa in 1996, slipped to 7th position in 2011.

Major challenges affecting the subsector

Biotic constraints

Cassava is affected by a diverse set of constraints. Some of the most important of these are pests and diseases. Arguably, the greatest deleterious global impacts on cassava production have resulted from the inadvertent introduction of insect pests or disease-causing pathogens to regions in which they did not previously occur. The most important examples of this have been the introductions of the arthropod pests—cassava mealybug [*Phenacoccus manihoti* Mat.-Ferr.] (CM), cassava green mite [*Mononychellus tanajoa* (Bondar)] (CGM), and cassava bacterial blight (CBB) caused by *Xanthomonas axonopodis* v. *manihotis* to Africa in the 1970s (Legg et al., 2015). Cassava mosaic and CGM infestation outbreaks became so devastating that biological control measures were implemented by International Institute of Tropical of Agriculture (IITA). Variegated grasshoppers, termites and white scales can be of concern in some specific places and seasons.

Following the introduction of cassava to Africa in the 16th century, it became infected by a unique set of viruses, none of which are recorded from the crop’s centre of origin in South America. About 15 virus species and several
strains have been identified infecting cassava in Africa and its offshore islands. Eleven of these are responsible for the two most devastating diseases, namely: CMD and CBSD. The large and increasing economic impact of CMD and CBSD in Africa is such that they are currently considered to be the greatest global threat to cassava production (Legg, Somado, et al., 2014). Several strains of these viruses have been identified. The most notable of these is East African cassava mosaic virus-Uganda (EACMV-UG) also known as the “Uganda variant” a recombinant between two distinct begomovirus species (EACMV and ACMV) (Zhou et al., 1997 cited by Legg et al., 2015).

Prior to the twenty-first century, CBSD remained restricted to coastal East Africa - from northeastern Kenya in the north to Mozambique in the south, and inland to the shores of Lake Malawi (Hillocks & Jennings, 2003; Nichols, 1950 cited by Legg et al. 2015). This situation changed abruptly in the early 2000s, however, as new outbreaks were reported from mid-altitude (>1000 m above sea level) areas of south-central Uganda (Alicai et al., 2007 cited by Legg et al., 2015), western Kenya, and northwestern Tanzania, precipitated by massive increases in populations of the whitefly, Bemisia tabaci. CBSD has subsequently been shown to be spreading as a pandemic through the major cassava-growing regions of East and Central Africa and threatens to spread further westwards into Central and West Africa (Legg, Somado, et al., 2014).

Abiotic constraints
Its ability to produce on low-fertility soils has given rise to the misconception that cassava does not require, nor even respond to, the application of mineral fertilizer (FAO, 2013a). No wonder yields are low especially in Africa where soils are generally poor in fertility. Cassava’s need for fertilizer is increasing as traditional means of maintaining soil fertility (such as intercropping and the mulching of plant residues) are abandoned under more intensive production systems. Poor agronomic practices, the use of cultivars with poor genetic potential and the use of poor quality planting materials are also important constraints to production. Although cassava can withstand relatively prolonged periods of drought, however, the crop is very sensitive to soil water deficit during the first three months after planting. Water stress at any time in that early period reduces significantly the growth of roots and shoots, which impairs subsequent development of the storage roots, even if the drought stress is alleviated later. Once established, cassava can grow in very dry areas that receive just 400 mm of average annual rainfall. But higher yields have been obtained with much higher levels of water supply. Cassava also responds well to irrigation. However, cassava is also susceptible to excess water – if the soil becomes water-logged, sprouting and early growth is affected and yields fall (FAO, 2013a).

History of cassava improvement in eastern and central Africa
Breeding for CMD and CBSD resistance was initiated in Tanzania (at Amani, near Tanga) in 1930s by British colonial scientists and was sustained through to 1958. The resistance of cultivated cassava to CMD was low in that part of Tanzania, as it was elsewhere in Africa. This encouraged researchers to exploit resistance sources from wild cassava relatives through interspecific hybridization. Moderately resistant clones with reasonable yield were selected from among the progeny of third backcrosses to cassava of ceara rubber (M. glaziovii) by cultivated cassava hybrids. Higher CMD resistance was subsequently obtained by intercrossing among resistant selections probably because it concentrated recessive genes (Jennings & Iglesias, 2002). These clones were consequently referred to as the “Amani hybrids.” One of the most resistant products of this program was the variety 46106/27. Its resistance to CBSD has persisted up to the present in farmers’ fields in coastal East Africa, where it is known locally as “Kaleso” in Kenya and “Namikonga” in Tanzania (Hillocks & Jennings, 2003).

The IITA’s Roots and Tubers Improvement Program, established in 1971 at Ibadan, Nigeria, gave priority to cassava, and its breeding strategy was to incorporate disease resistance into susceptible but well-adapted local cultivars.
Crosses between clone 58308 (selected from seed families from the Amani hybrids), local cultivars, and *M. glaziovii* were made. The improved families from these crosses showed superior resistance to CMD. During the 1990s, breeding work was extended to many of the major cassava-producing countries of Africa, through partnerships between IITA and national research programs. CMD gene pyramiding generated varieties with increasingly high levels of resistance, and many of these were selected for local environmental suitability in target countries and made available to farmers (Dixon *et al*., 2008, 2010; Ntawuruhunga *et al*., 2006).

The IITA established its East and Southern Africa Regional Research Centre (ESARC) in Uganda at the former Namulonge Agricultural and Animal Research Institute (NAARI), presently National Crops Resources Research Institute (NaCRRI), to address issues of cassava, banana, and plantain development; coordinate all related activities, and work closely with the national agricultural research sys (NARS). IITA-ESARC began extensive cassava germplasm development to counter the pandemic of African cassava mosaic disease (ACMD) in the region in 1995 through the Eastern Africa Root Crops Research Network (EARRNET). More than 100,000 seeds were evaluated through the conventional plant breeding scheme. Selected genotypes were kept in *in-situ* conservation from where the regional cassava national programs selected clones for further evaluation in their own countries. Burundi, DRC, Kenya, Rwanda, Tanzania, and Uganda benefited immensely. Through EARRNET, the region gained significantly from the large germplasm base to mitigate the scourge of ACMD and the production of cassava was restored. Almost all the officially released varieties from these countries (accessions with the MM, MH and LM prefixes) were sourced from the EARRNET breeding program.

Following the outbreak of CBSD in the Great Lakes region in 2004, screening for CBSD resistance was initiated in Uganda using a large set of CMD-resistant families (Ntawuruhunga, *et al*., 2012) and half-sib seed families from CBSD tolerant parents from Tanzania. Historically, much of the breeding work to combat CBSD has focused on tolerance, since resistance to infection is rare even in introgressed interspecific hybrids, and the expression of foliar symptoms has been considered as acceptable if root symptoms are absent, infrequent, or very mild. Recent studies have suggested an overlap in the resistance status of “tolerant” and “resistant” varieties, however, as concentrations of CBSVs in CBSD-tolerant varieties, expressing only mild foliar symptoms, have been shown to be significantly lower than concentrations of CBSVs in susceptible varieties (Maruthi, *et al*., 2014). This suggests that “tolerant” varieties possess molecular resistance mechanisms that impair the replication of CBSVs. Yield loss experiments have indicated that the reduction in growth resulting from foliar symptoms can lead to larger reductions in yield than spoilage of roots due to CBSD-associated root damage (Hillocks *et al*., 2001). This suggests that future breeding work needs to place greater emphasis on identifying sources of resistance to infection, which will prevent expression of symptoms in both foliage and roots.

**Recent advances in research and development**

The IITA breeders in collaboration with NARS’ breeders have developed genotypes that combine high resistance to CMD (including EACMV-UG) along with tolerance to CBSD. Several of them have been officially released in their respective countries and dozens are on the pipeline. In a regional project implemented by IITA in five CBSD endemic countries (Malawi, Mozambique, Kenya, Tanzania and Uganda), breeders have exchanged five of their best five elite varieties/breeding lines for regional evaluation. The project titled: “New Cassava Varieties and Clean Seed to Combat CMD and CBSD” (5CP) is funded by the Bill and Melinda Gates Foundation from June 2012 to December 2016. The project aims to ensure that farmers have access to diverse disease-free improved varieties with combined resistance to CBSD and CMD, as well as preferred end-user characteristics. The varieties will also be used extensively in breeding programs as sources of resistance to generate new improved clones. Inter-crossing among
these will concentrate resistance genes and allow recessive genes to be expressed (Hillocks and Jennings, 2003).

Both additive and non-additive genetic effects have been reported to be important in the expression of CBSD resistance, and in studies of these effects, Kaleso (Namikonga) had the highest general combining ability for resistance to CBSD (Kulembeka et al., 2012; Mtunda, 2009; Munga, 2008). This cultivar is now widely used by national breeding programs in the region to generate CBSD-resistant genotypes. Since it is very dangerous to rely on only one source of resistance, efforts are in place to identify other sources of resistance to both CMD and CBSD. The following clones have shown promising performance against both diseases and will therefore be used as sources of resistance: 1. AR 40 – 6 (introduced from CIAT in the form of Tissue Culture - TC; has M. flabellifolia background) 2. KBH 2002/135 (selected from half-sib seeds from TME 130 introduced from IITA, Nigeria) 3. KBH 2002/066 (selected from half-sib seeds from I96/1613 introduced from IITA, Nigeria) 4. KBH 2002/363 (selected from half-sib seeds from I96/1632 introduced from IITA, Nigeria) 5. KBH 2006/026 (selected from half-sib seeds from LM 2002/2174 introduced to KARI Mtwapa, Kenya from IITA, Nigeria) 6. LM 2002/1833 (selected from half-sib seeds from I91/01730 introduced to from KARI Mtwapa, Kenya from IITA, Nigeria) and 7. I92B/00073 (introduced to Tanzania as TC material from IITA, Nigeria).

There are several other on-going projects that are implemented by IITA (in collaboration with partners) or by other institutions. These include among others: “Doubled Haploid Project” that is implemented by CIAT; “Next Generation Cassava Breeding” (NextGen) implemented by Cornell University; “African Cassava Whitefly: Outbreak, Causes and Sustainable Solutions” implemented by NRI; “Community Action in Cassava Brown Streak Disease Control Through Clean Seed in Tanzania” implemented by Department of Research and Development, Tanzania (ARI Kibaha); “Developing Tools for Describing, Quantifying and Managing Diseases Causing Degeneration of Planting Material in RTB” implemented by the International Sweet potato centre (CIP); “Biotechnology Applications to Combat CBSD” implemented by IITA; “Support to Agricultural Research for Development of Strategic Crops in Africa” (SARD-SC) implemented by IITA; Virus Resistant Cassava for Africa (VIRCA) implemented by the Donald Danforth Plant Science Centre and “Disease Diagnostics for Sustainable Cassava Productivity in Africa” implemented by the Department of Research; Development, Tanzania (ARI Mikocheni). In efforts to control the white fly using biological control, IITA in collaboration with the Biological Control Unit of the Ministry of Agriculture in Tanzania has introduced the parasitoid, Eretmocerus hayati from Australia to screen them for adaptability to local conditions and their for their effectiveness to control the pest.

In efforts to make cassava also to contribute to nutritional security, breeders have developed varieties with high pro-vitamin A (PVA) to fight micronutrient deficiency. In 2014, three such varieties (IITA-TMS-IBA070593, IITA-TMS-IBA070539 and NR070220) were officially released in Nigeria. They have a pro-vitamin A content that averages 10 parts per million (ppm) based on fresh roots. These varieties have been introduced to Tanzania for use in breeding high pro-vitamin A varieties for the region. Seed families from these varieties have also been introduced and some 247 promising clones have been selected for further evaluation. Among them is KBH 2015B/0021, the first promising PVA clone in Tanzania that is sweet, mealy (boiling) and deep yellow flesh color.

The major findings in cassava biotechnological applications include the following:

a. A major locus underlying carotenoid accumulation in cassava roots has been identified
b. A major locus underlying resistance to cassava green mite has been identified
c. Molecular markers for CBSD tolerance in three mapping populations indicate that there are three different ‘sources’ of field resistance to CBSD. Combining these sources of resistance by tracking the quantitative trait
loci (QTL) should enhance levels of field resistance
d. A possible CMD2 mutation has been found in Tanzanian landrace (Albert) which previously was only recognized in West African germplasm. This might be a new QTL for CMD2
e. Using genomic selection, a dramatic reduction in cassava breeding cycle length from 5 to 1 year is possible
f. Genetic transformation of seven African farmer preferred cultivars – this is the first report of the genetic transformation of African farmer preferred cassava cultivars. The aim is to improve them for resistance to CBSD, CBB and Post-harvest Physiological Deterioration (PPD).

**Major challenges in cassava research for development**

a. Improving starch yield: With the increasing interest for commercial production of cassava, breeders will need to develop varieties suitable for each value chain. The most important trait will be high starch yield. Currently, TMEB419 with starch yield of nearly 23% is the standard for high starch production in Nigeria and many countries. Few varieties have exceptionally high starch yield. Breaking the dry matter content barrier to reliably produce starch of 23 to 29% will be a major challenge. Thailand has varieties with 30% starch content. Early introductions of cassava from Latin America to Africa and Asia represented a narrow genetic base, which limited the diversity available to farmers for selection of new varieties (FAO, 2013a). There is a need to introduce new germplasm to broaden the genetic base.
b. Meeting end user preferences: Over 80% of cassava is consumed as food. While income can purchase nutrition security, adoption of cassava varieties in many situations will depend on providing desired end user characteristics such as functional properties of cassava starches, leaf harvest, bio-fortification and time of harvest/in ground storage. Industrial traits will have specific target niches and will address specific markets. One variety cannot meet all needs.
c. Addressing the challenge of dual resistance to CMD and CBSD: New varieties must have dual resistance to the two devastating diseases. It will entail using different modes of resistance and tolerance to ensure new varieties are resilient. Breeding for virus resistance (CBSVs) rather than tolerance should be pursued. Truly resistant cultivars are not readily infected, even when exposed to large amounts of vector-borne inoculum; when infected develop inconspicuous symptoms and not associated with obvious deleterious effects on growth and yield and support low virus content and thus to be poor source of inoculum (Thresh et al., 1998). The major challenge with this approach is the high cost of using RT-PCR for quantifying virus titre.

**Future outlook**

i. **Cassava: The Rambo crop?**

Studies which have quantified the impacts or responses of cassava to climate change, have found cassava to be highly resilient to future climatic changes compared to other major staples such as maize, sorghum and millets and could provide Africa with options for adaptation (Jarvis et al., 2012). As climates are changing worldwide at rates not seen before, this affects food production itself and the growth and reproduction of plant pathogens which reduce crop yield and quality (Dixon, 2012). Future projections indicate that cassava pest and disease pressure is likely to continue in many regions of Africa, moving into some new regions, as well as reducing pressure in other
regions (Jarvais et al., 2012). To ensure cassava adapts to climate change key priorities for research lie in increasing resistance to these key pests and diseases, as well as further developing management practices to address greater pest or disease pressure (Herrera Campo et al., 2011, cited by Jarvais et al., 2012). Furthermore, there is need for functional and efficient pest and disease surveillance mechanisms to keep an eye on new outbreaks.

**ii. Growing interest by private investors on commercial production**

In several African countries, cassava is being more and more perceived, not only as a food security crop, but also as a raw material for various types of industries. In some countries, there is strong political support at the highest level to make cassava an engine of economic growth. As mentioned above, cassava can be converted into a large number of products ranging from traditional and novel food products, livestock feeds, ethanol, and starch and its numerous derivatives. For cassava to be a contributor to development, the demand for cassava must grow more rapidly than population. This can only be made possible if new uses for cassava are introduced and promoted.

Although cassava is reputed to be a very rustic crop that grows well under marginal conditions where few other crops could survive, for it to achieve its full potential, its productivity must be improved (Ceballos et al., 2004; Dixon and Ssemakula, 2008; FAO, 2013a). This is more urgent today when the whole sub-Saharan Africa is confronted with a rapidly growing population and urbanization associated with demands for food, feed and industrial raw materials. Furthermore, projections indicate that future food production will need to double to meet the global demand by 2050 (Rosenthal et al., 2012).

To realize high cassava production and productivity, the following will be necessary:

a. use of farm machinery – the number of tractors per 100 km² of arable land has been used as an indicator of agricultural development e.g. for Kenya and Tanzania, the number of tractors is about 25 whereas for India and Japan the number is 128 and 4,542 respectively (World Bank 2014),
b. investment in clean seed systems to increase and sustain cassava productivity and

**c. improved agronomic practices.**

**iii. Value addition and marketing**

In order to transform the subsector, in a way that ensures food security, income generation and economic diversification, the identification of profitable value chains and market preferences, strategies for reducing price variability on the demand side, and options for enhancing the quality, volume and reliability of production on the supply side will be required (FAO, 2013a).

The identified value chains and markets should boost demand and increase returns to producers. An increased supply of raw materials will provide an incentive to processors to expand capacity and modernize their factories, which will stimulate further production increase, driving an upward spiral of rural development (FAO, 2013a). Governments should promote private investment in cassava processing plants, and foster associations that link cassava growers and processors, such as the Thai Tapioca Starch Association and Nigeria’s Cassava Market and Trade Development Corporation. An active industry association can foster cooperation among value chain participants, promote grading standards, share market information, and lobby governments to support cassava subsector development (FAO, 2013a).

Improving market access and competitiveness will require vertical and horizontal coordination, strategic market-led research, and mechanisms for stimulating innovation and sharing knowledge, including farmers’ practical know-
how. As policymakers encourage higher levels of value addition, a major effort will be needed to integrate small-scale growers into the cassava marketing chain. Each country should identify the key features of enabling policies and institutions for sustainable intensification of smallholder cassava production.

For people whose livelihood depends mainly on agriculture, volatility in output prices means fluctuations in income and greater risk. Guaranteeing farmers a reasonable price for their crops will encourage them to invest in production. Approaches to reduce farmers’ exposure to price volatility include use of subsidies. However, more sustainable approaches include contract farming, and greater availability of crop insurance which, while it does not eliminate risk, does mitigate losses caused by adverse weather and similar events, thus improving risk-bearing capacity and encouraging investment in production. While common in industrialized countries, crop insurance is very limited in the developing world and particularly so for smallholder crops such as cassava (FAO, 2013a).

**Conclusion**

Cassava has been recognized as a powerful poverty fighter with the potential to help alleviate poverty both through food security and commercialization. However, to realize this potential the following will need to be done: i) Create awareness and put in place control strategies of diseases (war on cassava viruses in Africa – including the vector, *Bemisia tabaci*) ii) establish clean seed systems iii) develop and release varieties with high dry matter yield and high nutrient use efficiency iv) promote improved agronomic practices and the widespread adoption of conservation tillage, mulching and other soil improvement practices, the reversal of land degradation, and adding an irrigation component to rain-fed cultivation through rainwater harvesting and supplemental irrigation v) develop and introduce appropriate labor saving technologies especially for planting, weeding (weeds can reduce yields by 50% and account 20 – 40% of the production costs), harvesting and peeling vi) develop and promote efficient and appropriate processing and post-harvest technologies vii) develop value chains and markets in order to boost demand and increase returns to producers and viii) implement enabling policies to promote production and consumption of cassava – examples include substituting imported cereals with domestically produced cassava flour (Brazil has mandated the blending of 10% cassava flour with wheat flour in bread and Nigeria recently raised its levy on wheat flour to 100%, and will use revenue for a cassava bread development fund; it has also announced plans to substitute 10% of the maize in poultry feed with cassava grits).

**References**


I. Genetic Resource Management and Improvement

Cassava (Manihot esculenta Crantz) germplasm collection and in vitro conservation in Uganda: A progress report

Samukoya, C.*, Nakabonge, G. and Baguma, Y.

National Crops Resources Research Institute (NaCRRI), P.O. Box 7084, Kampala, Uganda.

*Correspondence: samukoyaclara@yahoo.com

Abstract

Viral diseases notably cassava mosaic disease (CMD) and cassava brown streak (CBSD) are the major factor limiting cassava productivity including causing of significant genetic erosion. Thus, there is need for cassava germplasm conservation. This study, therefore, was conducted to contribute to establishment of an in-vitro collection of cassava genotypes including landraces, wild relatives and the breeding populations. To achieve this objective a survey tool was developed for collection of both cassava germplasm and farmers’ knowledge. A total of 205 farmer-preferred varieties (accessions) were collected from Midwestern (Kiryandongo, Masindi, Buliisa and Hoima districts), west Nile (Arua, Nebbi, Koboko districts) and Eastern (Soroti, Serere, Amuria and Kaberamaido districts) Uganda. Of these, 139 have been initiated into tissue culture via the meristem tip technique and the rest are being sprouted in the screen house for initiation. Of the collected accessions, 67 samples were indexed for cassava mosaic virus using PCR specific primers for African cassava mosaic virus (ACMV) (AL1/F and ARO/R) and East African cassava mosaic virus Uganda variant (EACMV-UG) (AL1/F1 and ACMV-CP/R3). Of the 67 samples indexed, 40% were virus-free and 60% were positive to African cassava mosaic virus (ACMV) and East African cassava mosaic virus Ugandan variant (EACMV-Ug). This initiative is the first of its kind to collect cassava germplasm, and has got immediate plans for in vitro conservation and document farmer’s knowledge on cassava genetic resources in Uganda. The germplasm will be exploited by the breeding community as well as research and education. Farmers will also be assured of a backup collection that can be reverted to when need arises, and modalities for this can be done through community conservation initiatives.

Key words: cassava, in vitro, conservation, germplasm, Uganda

Introduction

Availability of genetic diversity is a prerequisite for genetic improvement of any crop. Germplasm conservation worldwide is, therefore, increasingly becoming an essential activity due to the high rate of disappearance of plant species resulting from intensive cultural practices associated with progressive agriculture as well as ravages of diseases and insect pests (Filho et al., 2005).

Indigenous knowledge is important in germplasm collection, conservation and genetic improvement (Elias et al., 2001) because ignoring it has led to wrong sampling of germplasm during explorations, and recommendation of varieties against farmer preferences. As a result, most of the technologies which have
been developed are on the shelf, since farmers are not ready to adopt them as they do not address their preferences and needs (Chiwona-Karlton et al., 1998).

Cassava, once regarded as “food for the poor”, has become a multipurpose crop that responds to: the priorities of developing countries, trends in the global economy and challenges of climate change (FAO, 2013). In tropical Africa, cassava serves both as a food security crop and a source of income generation (FAO, 2008).

Vegetative propagated plant species like cassava can best be conserved in vitro, at relatively low cost and reduced space (Tyagi et al., 2007). The cassava conservation initiative was, therefore, designed with an ultimate goal of establishing an in vitro collection of cassava germplasm and associated farmer’s knowledge at the National Crops Resources Research Institute (NACRRI) in Uganda.

Materials and methods
This work is carried out in the tissue culture and transformation platform of bioscience unit at the Cassava Regional Centre of Excellence (CRCoE) based at NaCRRI in Uganda.

Collection of cassava germplasm
The primary objective was to collect all diversity of cassava that is available in Uganda as a whole. Randomly selected district from different regions were visited. This was to enable the team to use the limited resources but have an idea of what is available in the country. Field excursions were carried out in mid-northern (Arua, Nebbi, Koboko districts), mid-Western (Buliisa, Hoima and Kiryandongo districts) and Eastern (Soroti, Kaeramaido and Katakiw districts) regions of Uganda. The teams always had a breeder to distinguish the landraces and the released improved lines which were not of interest as they are already available at NaCRRI. Questionnaires were also administered to farmers in possession of the collected germplasm. Farmers were requested to give information on characteristics of varieties in question. For example they were expected to know much about the uses, yield, taste, storability, resistance to diseases and drought resistance. It is important to note that sample collection is still in progress to raise enough diversity as well as related data for analysis.

Rejuvenation of plants
Stakes (15-20 cm long) of cassava (Manihot esculenta Crantz) were surface sterilised with 5% commercial Clorox solution (3.85% Sodium hypochlorite) for thirty minutes, washed three times and planted in three litre buckets prefilled with top soil and maintained in the screen house to sprout into shoots. The buckets of soil containing the cuttings were watered regularly to maintain adequate water regime for spouting and growth of plants. The screen house average temperature was 28°C and 52% relative humidity respectively.

In vitro establishment
Culture of cassava meristematic tips:
Apical shoot explants (3-5 cm long) from shoots established in the screen house were excised using scalpel into magenta vessel containing distilled water. The surgical blade was dipped in 70% ethanol before use on the next sample. The collected explants were pre-washed three times with tap water and liquid soap and transferred to the inoculation room in the tissue culture laboratory where they were transferred to sterile jars.
The washed samples were surface sterilised under a running lamina flow cabinet as follows: Samples were immersed in 70% ethanol for 1 minute taking care not to lose the label; washed twice with sterile distilled water; further immersed in 0.5% commercial Clorox solution (contains 3.85% sodium hypochlorite) for five minutes. The containers were agitated vigorously to ensure complete surface contact of disinfectant with the shoot tips, and then they were washed four times with sterile distilled water. After the last wash, some water was left in the samples to avoid dehydration of the explants during initiation process.

Meristem tips measuring 0.1-1 mm in length and with one or two leaf primordia were excised from the sterilised shoot tips with forceps and scalpel blades under a stereo-microscope as described by Kartha et al. (1974).

**Media and growth conditions:**

The isolated tips, were inoculated on initiation medium which was composed of solidified MS basal medium (full strength) (Murashige and Skoog, 1962) supplemented with 0.5 mg/l Benzyl Amino Purine (BAP) (Sigma Chemical Company St Louis, USA), 2% (w/v) sucrose and 0.7% agar. Its pH was adjusted to 5.8 with 1N KOH or HCl. The media was sterilized by autoclaving for 15 min at 121 °C and 1.2 kg cm-2. After inoculation, cultures were sealed with parafilm and transferred to the incubation room, programmed to provide a 16/8 hours photoperiod, a temperature of 24±2 °C and 70% relative humidity (RH). Responding explants (one to two months after initiation) were transferred to elongation medium (in jars) that composed of MS basal medium supplemented with 1 mg/l Naphthalene Acetic Acid (NAA) (Sigma Chemical Company St Louis, USA). The established plants (one month on elongation medium) were transferred to plain MS Medium (full strength) as described by Murashige and Skoog (1962) for multiplication to raise sufficient numbers for conservation as well as downstream analyses of genotyping and virus indexing.

**Virus indexing**

Leaf tissues were taken from all the sprouted samples in screen house and used for isolation of DNA/RNA for virus indexing to determine the status of the collected samples before introduction to the laboratory. After establishment in the lab, leaf samples were again sampled to confirm viral status as well as establish the effectiveness of meristematic tip culture in virus elimination from the collected infected samples. In this case, given the available requirements, cassava mosaic virus (CMV) was considered.

**Results**

**Cassava germplasm collection**

Generally, different collections according to farmers’ naming were realised in all the regions visited. However, mid-northern and mid-western regions had higher collections compared to eastern region (Table 1). There was also variation in availability of land races among districts within the same region (Figure 1).

Most names given to the collected varieties were descriptive and unique to tribes cultivating them. However, it is important to note that there is a high likelihood that some of the collections from different regions could be the same with varying names according to ethnic groups. This will be confirmed when the accessions are genotyped. The accompanying indigenous knowledge and phenotypic data will be analysed.
Table 1: Cassava germplasm collected by agro-ecological zones

<table>
<thead>
<tr>
<th>Region</th>
<th>Landraces collected</th>
<th>Wild relatives</th>
<th>Total collections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-Western</td>
<td>110</td>
<td>05</td>
<td>115</td>
</tr>
<tr>
<td>Mid Northern</td>
<td>60</td>
<td>05</td>
<td>65</td>
</tr>
<tr>
<td>Eastern</td>
<td>24</td>
<td>01</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>194</td>
<td>11</td>
<td>205</td>
</tr>
</tbody>
</table>

Figure 1: Cassava collections by District

Screen house and laboratory establishment of cassava germplasm

Collected cassava cuttings sprouted in one week after planting (Figure 2). Cassava cuttings from different regions responded differently when potted in screen house (Table 2). The highest response was observed in samples from eastern region followed by those from mid-western region. The mid-northern region had the least response both in screen house and in vitro.

In vitro response was observed to be relative to the response in screen house as collections from mid-western and eastern responded better that those from mid-Northern region (Table 2 and Figure 2). Among those that failed to respond in screen house were some few wild relatives regardless of the region they were collected from. However, those that sprouted in the screen house also responded well in tissue culture. Responding samples which were initiated by meristem tip technique were sub-cultured and maintained on MS media.
Table 2: Cassava germplasm response to screen house and tissue culture conditions

<table>
<thead>
<tr>
<th>Region</th>
<th>Total collection</th>
<th>Screen house response</th>
<th>In vitro response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-Western</td>
<td>115</td>
<td>113</td>
<td>100</td>
</tr>
<tr>
<td>Mid Northern</td>
<td>65</td>
<td>45</td>
<td>25</td>
</tr>
<tr>
<td>Eastern</td>
<td>25</td>
<td>25</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>205</td>
<td>183</td>
<td>139</td>
</tr>
</tbody>
</table>

Figure 2: Cassava collections established in the screen house and in vitro

Virus indexing

PCR analysis using cassava mosaic specific primers on screen house samples showed that the collected germplasm indicated a high prevalence of CMD. Specifically, African cassava mosaic virus (ACMV) was detected in most samples followed by mixed infection of ACMV and East African cassava mosaic virus Ugandan variant (EACMV-UG). Infection by EACMV-UG alone was minimal. A good percentage of the collections were free from CMD. These may possess some resistance traits as they have been exposed in the field but not infected (Table 2). It was, however, noted that there was no significant difference in the prevalence of CMD at screen house and that after initiation in the lab by meristem tip technique.

Table 3: Virus indexing by PCR of some Ugandan collections

<table>
<thead>
<tr>
<th>Analysed samples</th>
<th>African cassava mosaic virus (ACMV) (%)</th>
<th>East African cassava mosaic virus -Ugandan variant (EACMV-ug) (%)</th>
<th>ACMV+EACMV-ug (%)</th>
<th>Non-reactive samples (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-Western</td>
<td>36.8</td>
<td>3.5</td>
<td>4</td>
<td>56</td>
</tr>
<tr>
<td>Mid- Northern</td>
<td>48.3</td>
<td>3.4</td>
<td>41.4</td>
<td>6.8</td>
</tr>
<tr>
<td>Eastern</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>40.7</td>
<td>3.5</td>
<td>16.3</td>
<td>39.5</td>
</tr>
</tbody>
</table>
Discussion

The decision and practice of conserving the available Ugandan cassava germplasm is timely and worth as there is a high probability of losing this important diversity to various biotic and abiotic factors.

The preliminary results obtained from the surveys undertaken indicated the presence of many varieties in the regions visited based on farmers' perception. This could be due to the fact that different ethnic groups have different names for the same varieties. This occurrence was also observed by Salick et al. (1997) as one genotype was given eight names by different families of the Amueshan tribe. To confirm that the collected varieties represent different genotypes NEXTGEN Cassava project and Cornell University have supported genotyping activities to prove this postulation.

The results further indicate some regions have more varieties than others. This could be due to the fact that some ethnic groups prefer cassava as their staple food crop different from others who prefer food crops such as banana and sweet potato. It could also be possible that areas which have adopted improved cassava varieties have abandoned the traditional ones. It was noted in mid-western Uganda that farmers germinate cassava seeds, evaluate and make selections based on taste and yield. The selected varieties are assigned local names thus contributing to the high diversity in that region.

Cassava, being a vegetative propagated crop, could be best conserved in vitro, and this conservation is relatively low cost and requires reduced space usage (Tyagi et al., 2007). However it has been observed that there is variation in response of varieties collected from different regions at screen house and in vitro. The variation could be genotype specific as earlier reported in other studies that showed differential responses of genotypes (Mapayi et al., 2013). Optimizations of protocols is still ongoing to ensure that all collected genotypes are successfully initiated.

The results obtained indicated that 40% of indexed germplasm tested positive to CMV. The higher prevalence of ACMV than EACMV could be because of limited resistance in most indigenous varieties as documented by other researchers (Otim-Nape et al., 2000; Gibson, 1996). Lack of significant difference in incidence of CMV by PCR analysis of samples before and after meristem culture could be due to the fact that meristem technique was used alone and not supplemented with other techniques like cryotherapy and thermotherapy. Several studies have proved that meristem tip culture worked best for virus elimination in combination with thermotherapy (Panattoni et al., 2014; Hillocks, 1997; Li et al., 2002, Manganaris et al., 2003).

Conclusions and recommendations

The preliminary results obtained during this study indicated that cassava landraces can be successfully initiated and conserved in vitro to ensure easy accessibility to the research community and farmers. The results further confirm that virus elimination through meristem tip culture alone may not be effective in cassava germplasm viral disease cleaning. The study demonstrated a promising beginning towards in vitro conservation of cassava germplasm in Uganda.

Overall, conservation initiatives in Uganda need more support in terms of personnel and equipment for better in vitro management including cassava virus elimination from conserved germplasm.
Acknowledgement

This work was supported by East African Agricultural Productivity Project, EAAPP and the NEXTGEN cassava project.

References


Discussion session

**Question:** What was the role of gender in genetic conservation and the relationships between the germplasm collections from the male / female headed households?
**Answer:** The germplasm tool (questionnaire) captured all the social related information including gender, though not presented in this paper.

**Question:** Could effective extension contribute to erosion of traditional varieties?
**Answer:** Yes. Extension workers convince farmers on how cultivars are better than landraces. As a result farmers uproot landraces and replace with improved ones.

**Question:** How long are germplasm going to be preserved and has indexing for CBSD and CBD been done?
**Answer:** For as long as are required and even forever. Medium term conservation has been initiated; long term conservation condition (Cryopreservation) optimization is in progress.

**Question:** How many households were sampled and how come varieties promoted by EAAPP are not found in all districts by now?
**Answer:** About 3-5 sub-counties per district; 5-12 households per sub-county were randomly selected especially with the history of availability of landraces using the sub-county NAADS coordinators and Agricultural officers helped in identifying owners of landraces. EAAPP distributed only improved varieties like NASE 14. Our interest was the land races and their wild relatives only. Improved varieties are already with NARO and therefore no need to collect them.

**Question:** You focused on large diversity. How did you analyze the diversity?
**Answer:** Farmer knowledge was captured in descriptive statistics in percentages as per the farmer’s own description. Genotyping and phenotyping is yet to be done.

**Question:** Reports from the Uganda cassava programme indicates that as the CMD epidemic was moving, the sweet varieties like the “Bwana taraka” were reappearing. Is it fair to conclude that farmers were adopting only the bitter varieties? What is the diversity of the wild relatives in Uganda and in the region?
**Answer:** The bitter varieties were already there. Farmers prefer bitter but also grow sweet ones. The diversity of bitter is about 3% of collection as per farmer knowledge. Molecular confirmation is yet to be done.
Optimization of a somatic embryogenesis and transformation protocol for a farmer-preferred Kenyan cassava cultivar


1Plant Transformation Laboratory, Department of Biochemistry and Biotechnology, Kenyatta University, P.O. Box 43844-00100, Nairobi, Kenya; 2Institute for Biotechnology Research, Jomo Kenyatta University of Agriculture and Technology, P.O. Box 62000-00200, Nairobi, Kenya; 3Kenya Agricultural and Livestock Research Organization, P.O. Box 57811, Nairobi, Kenya; 4Department of Agricultural Science and Technology, Kenyatta University, P.O. Box 43844-00100, Nairobi, Kenya; 5Department of Plant Science and Crop Protection, University of Nairobi, P.O. Box 29053-00625, Nairobi
*Correspondence; oduor.richard@ku.ac.ke

Abstract

Cassava (Manihot esculenta Crantz) is a vital source of food in developing countries and also holds potential for industrial use. It is, however, affected by various biotic and abiotic stresses that greatly affect its production. Genetic engineering may allow rapid development of cassava mosaic disease (CMD) and cassava brown streak disease (CBSD) resistance in this crop. Since the existing regeneration and transformation protocols are not compatible with all the cassava cultivars, efficient and robust transformation and regeneration protocols for farmer-preferred cultivars need to be optimized for ease of transfer of novel genes. In this study, we optimized an efficient transformation and regeneration protocol for a farmer-preferred Kenyan cassava cultivar Kibanda meno mkubwa and compared it with model cultivar TMS 60444. We cultured two types of explants (immature leaf lobes and stems) on Murashige and Skoog (MS) medium supplemented with varying concentrations of auxins; 2,4-dichlorophenoxyacetic acid (2,4-D), Picloram and -naphthalene acetic acid (NAA), a cytokinin; 6-Benzylaminopurine (BAP) and a gibberellin (GA3) under a 16 hour light/8 hour darkness photoperiod regime. Results showed high regeneration and transformation frequencies for both cultivars. High frequencies of callus induction (>98%) for both cultivars were obtained when 2,4-D and Picloram were used. Similarly, both auxins initiated somatic embryogenesis with Picloram producing the highest frequency of somatic embryos (>92%) in TMS 60444 using stem explants. Gus assays revealed high frequencies of transformation of >77% (TMS 60444) and 60% (Kibanda meno mkubwa). This protocol offers promising perspectives for rapid improvement of this cultivar and therefore sets up a platform for cleaning planting materials as well as cassava genetic improvement programs such as control of viral diseases.

Key words: Immature leaf lobes, kibanda meno mkubwa, regeneration, somatic embryogenesis, stems, transformability.

Introduction

Cassava (Manihot esculenta Crantz); a woody perennial shrub, is a vital source of food for over a billion people in developing countries and also holds potential for production of industrial starch and bioethanol (Chetty et al., 2013). Despite these uses, the production and productivity of the crop is constrained by
many factors including low protein content, presence of cyanogenic glycosides, post-harvest deterioration, and prevalence of pests and diseases (Legg and Raya, 1998; Fan et al., 2011). It is estimated that over 77,502 ha of land in Kenya are currently under cassava cultivation (FAOSTAT, 2011). In East Africa, cassava production faces constraints from two major diseases: cassava mosaic disease (caused by single stranded DNA geminiviruses); and the cassava brown streak disease (caused by a single stranded RNA ipomivirus) (Chetty et al., 2013). Strategies to control these diseases, while of great importance to the cassava industry, have greatly relied upon conventional improvement programs. Such programs, however, have encountered massive limitations inherent to the conventional breeding programs (Ceballos et al., 2004).

Cassava improvement through conventional breeding further remains a challenge due to poor seed set, inconsistent flowering and heterozygosity that hinder backcrossing (Opabode et al., 2013). Biotechnology, through genetic engineering, holds great potential for long term improvement of crops for enhanced production towards food security. Recent reports of success in generation of disease-free plants such as transgenic papaya against ringspot virus (Gonsalves 1998) and CMD-free cassava (Vanderschuren et al., 2007) offer great promise towards other stresses not tried out so far. Cassava genetic engineering could allow rapid development of CMD and CBSD resistance, provided that efficient and robust transformation and regeneration technology for farmer-preferred cultivars is available. This requires optimization of such protocols for ease of transfer of novel genes since existing regeneration and transformation protocols would not be compatible with all the cultivars (Hankoua et al., 2006; Saelim et al., 2006; Elibariki et al., 2014). Success in transformation and regeneration of cassava has been previously reported with protocols employing different phytohormones and explants including apical meristems, zygotic embryos, immature leaf lobes and stems (Atehnkeng et al., 2006; Hankoua et al., 2006; Medina et al., 2007; Fletcher et al., 2011; Rossin and Rey, 2011). While the majority of studies are biased towards the use of immature leaf lobes as explants, their occurrence per parent stock is limited; hence, necessitating the possibility of exploring other plant parts such as stems.

This study, therefore, was aimed at regenerating Kenyan cassava cultivars collected from the coastal region using two types of explants (stems and leaf lobes) under varying concentrations of auxins (2, 4-D, Picloram and NAA), a cytokinin (BAP), and gibberellin (GA$_3$). It was also aimed at determining the transformability of this cultivar using Agrobacterium tumefaciens with the GUS reporter gene with a view to further genetically improving it for resistance against CMD and CBSD.

**Materials and methods**

**Plant materials**

The cultivar, *Kibanda meno mkubwa*, from the coastal province of Kenya was selected for the study since it is preferred by farmers because of its high starch levels that enables it fetch high prices in the market (Mwango’mbe et al., 2013). For comparison, the model variety TMS 60444 was used.
In vitro cultures

Parent stocks of the cultivar were obtained from Kenya Agricultural and Livestock Research Organization (KARLO), Mtwapa. Parent plants were propagated in the glasshouse at the Plant transformation laboratory, Kenyatta University. In vitro plantlets were then established on cassava micro-propagation medium comprising 4.4 g/l Murashige and Skoog (MS) salts with vitamins (Murashige and Skoog, 1962), 30 g/l of sucrose and 8 g/l phyto agar. Explants were then prepared by poking of immature leaf lobes (ILL) and longitudinal dissection for stems, and cultured on callus induction media comprising of MS salts with Gamborg B5 vitamins supplemented with varying concentrations of Picloram and 2,4-D, 100 mg/l myoinositol, 0.5 mg/l CuSO₄, 50 mg/l casein hydrolysate and 30 g/l sucrose. Auxin concentrations were 4, 6, 8 and 10 mg/l and were added individually to the media prior to sterilization by autoclaving at 121ºC for 15 minutes. To induce calli, ten (10) explants were cultured per petri plate across the four treatments and the cultures incubated at 28ºC in a growth chamber under a 16 hour light/ 8 hour darkness photoperiod regime.

For somatic embryogenesis, 30 calli (replicated 3 times) were transferred on a similar media (as in callus induction experiments) and the cultures maintained there for 28 days. Emerging somatic embryos were matured on media comprising MS salts with Gamborg vitamins, 30 g/l sucrose, 8 g/l agar and varying combination ratios of BAP, NAA and GA₃ (Table 1). Germination and plantlet recovery was achieved on maturation media supplemented with 0.8% w/v activated charcoal. Recovered plantlets were then rooted on hormone free MS media with 30 g/l of sucrose and 8 g/l phyto agar. These plantlets were later acclimatized on peat moss and hardened in the glasshouse in potted soil.

Transformation

Transformability of the cassava cultivar under this study was assessed by co-cultivating immature leaf lobes with A. tumefaciens strain EHA 101, harboring binary vector PTF 102 (Figure 1). The vector contains a Gus reporter gene driven by 35S promoter and terminator. It also has the bar gene that confers resistance to the herbicide basta and therefore is used as the plant selectable marker for positively transformed tissues (Figure 1). A total of ninety (90) immature leaf lobe explants were co-cultivated with EHA 101 for generation of putative transformants according to Chetty et al. (2013). Histochemical Gus assays were performed on ten putatively transformed calli (replicated 3 times) as described by Jefferson (1987).
Figure 1: Binary vector pTF102 with the Gus reporter gene used for cassava transformation

Data collection and statistical analyses

All callus induction experiments were performed using ten explants per plate and five plates per treatment for both cultivars under study. Callus induction, somatic embryo and transformation frequencies were recorded. Data were analyzed by Multivariate analysis of variance (MANOVA) with statistically significant variables computed according to Tukey’s HSD test at a confidence level of 95% (P<0.05) using statistical analysis software (SAS) version 9.1 (SAS, 2004).
Table 1: Phyto-hormone combination ratios used for somatic embryo maturation and germination of cotyledonary embryos

<table>
<thead>
<tr>
<th>Media</th>
<th>Combination ratios (mg/l)</th>
<th>BAP</th>
<th>NAA</th>
<th>GA3</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>3</td>
<td></td>
<td>0.02</td>
<td>0.5</td>
</tr>
<tr>
<td>M1</td>
<td>3</td>
<td></td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>M2</td>
<td>2</td>
<td></td>
<td>0.03</td>
<td>0.5</td>
</tr>
<tr>
<td>M3</td>
<td>2</td>
<td></td>
<td>0.01</td>
<td>1.5</td>
</tr>
<tr>
<td>M4</td>
<td>1</td>
<td></td>
<td>0.02</td>
<td>1.5</td>
</tr>
<tr>
<td>M5</td>
<td>1</td>
<td></td>
<td>0.03</td>
<td>1</td>
</tr>
</tbody>
</table>

Results

Following the transfer of immature leaf lobes (ILL) and stem explants to callus induction medium (CIM) containing varying concentrations of 2,4-D and Picloram, the two cultivars showed callus formation within 14 days (Figure 2A and B). The highest frequency of callus induction using 2,4-D (98.59%) for KMM was achieved following culture of stem explants on media supplemented with 4mg/l of the auxin while the lowest was recorded using ILL on media with 10mg/l 2,4-D (Table 2). The model cultivar recorded a callus induction frequency of (98.37%) under this auxin. When explants were cultured on media with Picloram, the highest frequency of callus induction was observed in ILL (88.97%). Relatively higher frequencies of callus induction were recorded in the model cultivar TMS 60444 under similar conditions (Table 3). The calli developed into somatic embryos (SE) as soon in KMM as that for TMS 60444, with primary somatic embryos (SE) observed after five weeks for TMS 60444 while it took KMM explants a further two weeks to obtain high quality primary SE (Figure 1C and D). The frequencies of somatic embryo formation are outlined in Figure 3. Somatic embryos (SE) resulted in green cotyledons (Figure 2E and F) for both cultivars albeit at varying frequencies. Cotyledons were observed in both cultivars cultured on maturation media under all maturation media formulations. The frequencies of maturing somatic embryos across the media formulations are shown in Figure 4. The matured somatic embryos (cotyledonary embryos) later germinated on media with activated charcoal. Interestingly, KMM produced a slightly higher frequency of cotyledons than the model cultivar (Table 4).

Shoots from obtained cotyledons were successfully recovered on media supplemented with activated charcoal (Figure 2G). The efficiencies of shoot formation for KMM and TMS 60444 are shown in Table 4: For TMS 60444, 11 out of the 39 cotyledons (28%) formed shoots. A slightly lower frequency of shooting (19%) was achieved in KMM. Relatively high frequencies of transformation were recorded for both cultivars according to the Gus assay result (Figure 2 J and K). Here, the highest frequency of transformation (75.3%) was produced by the model cultivar TMS 60444 while KMM produced the lowest frequency (60.5%) (Table 4). The regenerated cassava plants grew normally in soil with regular watering (Figure 2 L).
Figure 2. Callus induction, somatic embryogenesis and transformation profiles.

A. Callus development in cultivar KMM. B. Appearance of callus from model cultivar TMS 60444 after 3 weeks of culture on callus induction media. C. Immature somatic embryos from cultivar KMM (indicated by the arrow) D. Cultivar TMS 60444 on immature somatic embryos CIM media. E and F Green cotyledons in KMM and TMS 60444 respectively on callus maturation media. G. Germination of mature somatic embryos on media supplemented with activated charcoal. Shoot elongation and rooting in TMS 60444 (H) and KMM (I). J. GUS assay staining of KMM and K for TMS 60444. L. Fully developed regenerants in the glasshouse Scale bar represents 0.1mm.
Table 2: Callus induction frequency (%) of two types of explants of two cassava varieties cultured on MS basal medium supplemented with different concentrations of 2,4-D

<table>
<thead>
<tr>
<th>2,4-D conc. (mg/l)</th>
<th>Kibanda meno mkubwa</th>
<th>TMS 60444</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Immature leaf lobes</td>
<td>Stem</td>
</tr>
<tr>
<td>4</td>
<td>82.26±0.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>98.59±1.15&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
<td>92.11±0.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td>92.06±1.15&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>85.32±1.15&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>94.17±2.88&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>74.00±1.15&lt;sup&gt;c&lt;/sup&gt;</td>
<td>80.38±1.15&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Values in the same column followed by the same letter are not significantly different (P<0.05, n=50).

Table 3: Callus induction frequency (%) of two types of explants of two cassava varieties cultured on MS basal medium supplemented with different concentrations of Picloram

<table>
<thead>
<tr>
<th>Picloram conc. (mg/l)</th>
<th>Kibanda meno mkubwa</th>
<th>TMS 60444</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Immature leaf lobes</td>
<td>Stem</td>
</tr>
<tr>
<td>4</td>
<td>65.33±1.16&lt;sup&gt;d&lt;/sup&gt;</td>
<td>80.20±1.16&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>6</td>
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<td>84.33±1.73&lt;sup&gt;ad&lt;/sup&gt;</td>
</tr>
<tr>
<td>8</td>
<td>44.14±1.73&lt;sup&gt;d&lt;/sup&gt;</td>
<td>68.19±1.73&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>88.97±1.73&lt;sup&gt;a&lt;/sup&gt;</td>
<td>82.02±1.73&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

*Values in the same column followed by the same letter are not significantly different (P<0.05, n=50).

Figure 3: Effect of varying concentrations of 2,4-D/Picloram and explant types on frequency of somatic embryogenesis in a Kenyan cassava cultivar under a 16 hour light/8 hour darkness photoperiod regime. Error bars represent standard errors of the mean (P≤0.05).
Figure 4: Effect of phyto-hormone combination ratios on frequency of maturation of somatic embryos from immature leaf lobes of Kibanda meno mkubwa alongside TMS 60444. Error bars represent standard errors of the mean at (P<0.05).

Table 4: Somatic embryo germination, shooting and transformation frequencies of Kibanda meno mkubwa alongside TMS 60444

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>No. of germinating cotyledons</th>
<th>Shooting frequency (%)</th>
<th>Transient transformation frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kibanda meno Mkubwa</td>
<td>42</td>
<td>19.23±3.12</td>
<td>60.15±2.33</td>
</tr>
<tr>
<td>TMS 60444</td>
<td>39</td>
<td>28.13±2.33</td>
<td>75.33±3.45</td>
</tr>
</tbody>
</table>

Discussion

Recalcitrance of cassava to transformation and regeneration is one of the greatest challenges facing genetic modification of this crop (Li et al., 1998). It is therefore imperative that protocols for each cultivar be optimized so as to allow for a more reliable system of cassava improvement. In this study, success was achieved in transformation and regeneration of a farmer-preferred Kenyan cassava cultivar Kibanda meno mkubwa (KMM) and compared with model cultivar TMS 60444. Results on callus induction and somatic embryogenesis indicate that formation of callus in cultivar KMM varied with the type and concentration of auxins used, which is in line with other studies. For instance, Rossin and Rey (2011) reported similar findings in a range of cassava cultivars where Picloram was more superior than 2,4-D in generation of somatic embryos. Similarly, Saelim et al. (2006) found 2,4-D to be a superior auxin to Picloram while comparing somatic embryogenesis using different explants in cultivar KU50.

Primary somatic embryos (SE) were observed after five weeks for TMS 60444 while it took KMM explants a further two weeks to obtain high quality SE. The effect of combining auxins and cytokinins during somatic embryo maturation is essential during cassava regeneration as these mediate whole plant recovery and have been extensively reported in previous studies (Hankoua et al., 2005; 2006; Medina et al., 2007).
For instance, Fan et al. (2011) demonstrated that NAA regulated organ growth while BA facilitated cell division and elongation in cassava tuberization. A key factor in the use of these phyto-hormones, is their synergistic interaction in culture media at appropriate concentrations which ensures optimal efficiencies of regeneration. In the present study, BAP in combination with NAA and GA₃ were successfully used in maturation of somatic embryos.

The varying trend in findings observed using ILL and stem explants is as a result of genotype-explant-phytohormone interactions. In general, it was observed that somatic embryo cultures from both cultivars, induced using ILL and transferred onto maturation medium comprising 1mg/L BAP, 0.03mg/L NAA and 1mg/L GA₃ matured and formed cotyledons albeit with varying frequencies. Despite the high number of somatic embryos obtained from stem explants, none of these matured into cotyledonary embryos and hence no plants were recovered from them. This could be as a result of differences in the pathways of somatic embryogenesis and organogenesis as revealed by Hankoua et al. (2006). Activated charcoal was vital in plant recovery in this study, just like in other plant tissue culture programs where it has been used to improve cell growth and development (Liu, 1993; Teixeria et al., 1994; Pan and Van Staden, 1998). The use of activated charcoal is based on its ability to adsorb inhibitory chemical compounds, key among them being phenols (Liu, 1993; Teixeria et al., 1994). Cassava has been shown to produce these compounds, which are toxic, and therefore eliminating them from culture media is imperative for somatic embryogenesis and regeneration (Taylor et al., 2001).

Furthermore, activated charcoal provides a dark environment in medium thus promoting soil-like conditions. Thomas (2008) suggested the gradual release of adsorbed products such as nutrients and PGRs in addition to substances naturally present in activated charcoal that promote plant growth. Transformed calli showed a moderate blue coloration which is an indication that these tissues had picked up the construct during transformation. Data on transient expression of GUS reporter gene revealed differences in frequencies of transformation between KMM and the model cultivar TMS 60444. This shows that cassava transformation remains genotype dependent and variability in transformation efficiencies between independent procedures cannot be totally eliminated as previously reported (Koehorst-van Putten et al., 2012).

**Conclusion and recommendations**

A reproducible in vitro protocol for regeneration of a Kenyan cassava cultivar Kibanda meno mkubwa was successfully achieved using immature leaf lobe and stem explants. This sets up a platform for further studies on this cultivar aimed at countering the various production constraints that the crop suffers. Of the two explants evaluated, immature leaf lobes show better response to callus induction, somatic embryogenesis and regeneration and therefore are the best explants for regeneration of these cultivars via somatic embryogenesis. This study also demonstrated that the cassava cultivar is transformable through Agrobacterium-mediated gene transfer. The protocol for callus induction, somatic embryogenesis and whole plant recovery optimized in this study is suitable and therefore recommended for regenerating KMM. Using the best performing plant growth regulators and their combinations, it will be easy to regenerate this cultivar during any improvement program. Further molecular work is needed to ascertain stability of the transgene in transgenic plants. Studies such as southern blot and reverse transcriptase polymerase chain reaction are recommended.
Acknowledgement
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References


II. Integrated Pest and Disease Management

Phylogenetic diversity of cassava green mite, *Mononychellus progresivus* (Acari: Tetranychidae) from different geographical sites in East Africa

*D. L. Mutisya1, R. Molo2, E. M. El-Banhawy2, D. Miano3, C. W. Kariuki1, A. Owiti2, W. Aool2*

1Kenya Agricultural & Livestock Research Organization-Katumani, P. O. Box 340-90100, Machakos, Kenya; 2National Agricultural Research Organization-NACRRI, Namulonge, Uganda
3Department of Plant Science and Crop Protection, University of Nairobi, P. O. Box 29053-00625, Nairobi, Kenya.
*Corresponding author: dlmutisya@gmail.com

Abstract

Cassava green mite (CGM) of the *Mononychellus* genus is an invasive species in Africa introduced from South America. Its phylogenetic diversity over geographical localities has never been assessed in East Africa where mite density dynamics oscillate from few individuals to a peak of hundreds. DNA was extracted on internal transcribed spacer 2 (ITS2) and cytochrome oxidase subunit I (COI) and compared for phylogenetic variations of CGM from different locations of East African region. A comparative search from the NCBI Gene bank resulted into identical species nucleotides from Congo and Benin. Sequences from the three sites in Kenya were 99-100% similar to CGM nucleotide from the Congo-Benin accessions (X79902.1) on ITS2 gene region. On COI, a 98-99% site sequences similarity was observed on *M. progresivus* accession X79901.1. A closely related divergence was determined of specimens collected from Tanzania and Uganda. The CGM sequence from coastal Kenya was found to have the highest phylogenetic divergence from the Congo-Benin sequences. A small biogeographic phylogenetic divergence (0-1%) was evident from the analyses among the collection sites. While the results confirm *M. progresivus* identity in East Africa it also indicates intra-species phylogenetic variations on the COI gene region of interest

Key words: cytochrome oxidase subunit I, internal transcribed spacer 2, *Mononychellus* species, cassava, altitude

Introduction

Cassava, *Manihot esculenta* Crantz is an important staple food for over 800 million people (Nweke, 1996; FAO, 2007). The cassava green mite (CGM) pest of *Mononychellus* species constrains the production of this important crop due to direct leaf damage leading to reduction of photosynthetic leaf area (Yaninek et al., 1987). Early reports indicate that the CGM was accidentally introduced in Africa when cassava was imported from South America. It was first reported in Uganda during the 1970s, from there it spread everywhere in Africa including East Africa (Nyigia, 1972; Malindagabo and Birandano1984; Megevand et al., 1987; Yaninek and Herren, 1988). Most workers have reported that success of biological control of *Mononychellus tanajoa* Bondar (= *M. progresivus* Doreste) in warm-humid regions in Africa was after release of the predatory mite *Typhlodromalus aripo* De Leon of family Phytoseiidae from South America (Yaninek and Hanna; Kariuki et al., 2005). Pest mite density threshold has been determined at ≥27 mites/
leaf on various varieties (Mutisya et al., 2014). Mutisya et al. (2015) has explored effective management of CGM in different agro-ecological zones of Kenya and found that only in the dry low midlands there was need to judicially spray abamectin acaricide to safe crop from leaf drop during 3-5 months of drought. In the coastal and cool upper midland zones predacious mites suppressed the pest mite density to below injury levels (Mutisya et al., 2014).

As reported earlier, Gutiérrez (1987) had reviewed Mononychellus species complex citing eight species found on cassava in South America; Mononychellus tanajoa Bondar, M. progresivus Doreste, M. manihoti Doreste, M. bondari Paschoal, M. caribbeanae McGregor, M. mcgregori Fletchman & Baker and M. estradai Baker & Pritchard. Navajas et al. (1994) showed complete identical similarity of the genomic characteristics of different African populations of CGM to those of Colombia, whereas the populations from Brazil (South America) were found to be different. Tetranychid species diversity has been reported since the last century (Boudreaux, 1963; Navajas et al., 1994). Memarizadeh et al. (2013) reported acaricide abamectin resistance by the red tomato mite, Tetranychus evansi Pritchard & Baker in Asian countries where species intra-geographical variations were evident among the populations on ITS and COI regions. The possible effect of geographical localities to genetic diversity of CGM aroused our interest to determine how the species M. progresivus differ from one country to another in East Africa on the ribosomal and mitochondrial gene regions. The information is important in pest control especially where use of acaricide is advocated for in advance drought conditions of the marginal lands as Mutisya et al. (2015) determined from Kenya’s varied agro-ecological zones. The present study was therefore carried out to determine CGM species comparative phylogenetic diversity from seven distinct geographical sites in East Africa.

Materials and methods

Mite sample sites

Samples of cassava green mite Mononychellus species specimens were recovered from cassava plants in six different geographical zones of East Africa (Table 1). These were low midlands at Kisumu (LM3) and Katumani (LM4) of Kenya; upper midlands at Namanga (UM3) and Sirare (UM2) of Tanzania sites while in Uganda sites were Kawanda and Namulonge of Lake Basin Mbale Farm Lands. In each field, three leaves from different plants were sampled at random and hundreds of CGM actives mixed in a vial. The GPS points were taken for positional recording. The phytophagous specimens were brushed with a 4-inch paint brush from the underside of the leaves onto A4-paper and further picked with a camel hair (size 000) and inserted in 99-100% alcohol vial.
Table 1: Sample sites of cassava green mite (CGM) in East Africa where cassava is grown at specific agro-ecological zones (AEZs)

<table>
<thead>
<tr>
<th>Country</th>
<th>Locality</th>
<th>AEZ</th>
<th>Coordinates</th>
<th>Altitude (m)</th>
<th>AEZ description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>Kiboko</td>
<td>Low midlands (LM3)</td>
<td>02°5’ 52&quot; S 37°25 57&quot; E</td>
<td>1186</td>
<td>Hot-wet</td>
</tr>
<tr>
<td></td>
<td>Katumani</td>
<td>Low midlands (LM4)</td>
<td>01 20’ 51&quot; S 37 08’ 24” E</td>
<td>1609</td>
<td>Warm-dry</td>
</tr>
<tr>
<td>Uganda</td>
<td>Kawanda</td>
<td>Upper midlands (LV-MF)</td>
<td>0° 24’25”N 32° 32’07”E</td>
<td>1147</td>
<td>Warm-wet</td>
</tr>
<tr>
<td></td>
<td>Namulonge</td>
<td>Upper midlands (LV-MF)</td>
<td>02° 38’ 88” N 36° 47’ 02” E</td>
<td>1139</td>
<td>Warm-wet</td>
</tr>
<tr>
<td>Tanzania</td>
<td>Namanga</td>
<td>Upper midlands (UM3)</td>
<td>02° 3’ 00” S 36° 46’ 00” E</td>
<td>1311</td>
<td>Warm-dry</td>
</tr>
<tr>
<td></td>
<td>Sirare</td>
<td>Upper midlands (UM2)</td>
<td>01° 38’ 00” S 34° 10’ 00” E</td>
<td>1658</td>
<td>Cool-wet</td>
</tr>
</tbody>
</table>

Mean mite density dynamics during dry and wet periods were scored for each country site to predict times of peak (Figure 1). Kenya had the highest population fluctuations of <10 to > 300 mites /leaf while Tanzania followed with <10 to < 200 mites, respectively. The least range of mite density was Uganda where the wetter season had <5 to < 70 mites / leaf.

Figure 1. Distribution range (minimum and maximum peaks) of the cassava green mite *Mononychellus* species in different sampled sites of East Africa
DNA extraction

Genomic deoxyribonucleic acid (DNA) was extracted from individual mite specimens of collected green mite specimens using tissue kit (Qiagen, GHBB, Germany) according to the manufacturer’s instructions. The DNA samples of four specimens were first eluted in 30μl of buffer AE and stored at 4 °C. Polymerase chain reaction (PCR) was performed in a total volume of 20μl containing 1X PCR buffer, 1.5 mM MgCl2, 10mM of dNTP mix, 10 pM of each primer, 1.5 units Taq Expand TM high fidelity PCR reagents (Roche Diagnostics, Mannheim, Germany) and 2 μl (approx 5ng) and the mixture was incubated in thermal cycler (Applied Biosystems 9700). The PCR products were amplified by an initial denaturing at 95 °C for 4 min, followed by 35 cycles of 92 °C for 1min, 51 0C for 2 min, 72 °C for 1min, and a final extension at 72 °C for 9 minutes. The ITS2 regions were amplified using the primers 5’AGAGGAAGTAAAGTCGTAACAAGAG-3’ for the 3’ end of the 18SrDNA and 5’-ATATGCTTAAAATTCAGGGGG-3’ for the 5’ end of the 28S. The mitochondrial COI primers used were 5’-TGATTTTTTGTCACCAGAAGG-3’ and 5’-ACAGCTCTTATAGATAAACG-3’ (Navajas et al., 1994). The amplified PCR products of 20μl were stained with ethidium bromide and visualized by using 1% agar rose gel electrophoresis at 80 voltage for 50 minutes, then later purified using the QIAquick® PCR purification kit (QIAGEN, Germany) according to the manufacturer’s instructions. The purified products (4-5μl) were directly sequenced by using an ABI 3100 series automated sequencer (Applied Bio-systems Inc).

Mite nucleotide analyses

The nucleotide sequences of mites from the three sites were Blast on NCBI database to determine phylogeny match (%) with other species of similar gene regions. The nucleotide sequences were aligned using BioEdit 5.0. ClustalX was used for the multiple alignments before construction of Neighbour-Joining phylogeny trees by use of MEGA 5.2.2 on COI and ITS2 gene regions of CGM sequences from the three sites. The Juke-Cantor Model of Maximum Composite Likelihood was used for analysis, where Bootstraps replications of 1000 were applied for significant measure of nucleotide divergence.

Results

Species nucleotide identity match (%)

The Kiboko CGM nucleotide had 100% similarity to NCBI Gene bank accession X79902.1 of species Mononychellus progresivus Doresteon ITS2 region (Table 2). Further, a 99% similarity to the same NCBI accession was observed of all the other CGM nucleotides from the sites. This was 0-1% intra-divergence range of CGM races from the different sites. No other species taxa from NCBI were found related to M. progresivus from the sites at Kenya, Uganda and Tanzania.
Table 2: Comparative internal transcribed spacer 2 (ITS2) BLAST genetic match results of *Mononychellus progressivus* from different sites in Kenya to species nucleotides from NCB data base

<table>
<thead>
<tr>
<th>Country</th>
<th>Site</th>
<th>Base pairs (letters)</th>
<th>% Match</th>
<th>NCBI Accession</th>
<th>Gene Region</th>
<th>Species identity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>Kiboko</td>
<td>796</td>
<td>100</td>
<td>emb/X79902.1</td>
<td>18SrRNA</td>
<td><em>Mononychellus progressivus</em> Doreste</td>
</tr>
<tr>
<td></td>
<td>Katumani</td>
<td>838</td>
<td>99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uganda</td>
<td>Kawanda</td>
<td>919</td>
<td>99</td>
<td>emb/X79902.1</td>
<td>18SrRNA</td>
<td><em>Mononychellus progressivus</em> Doreste</td>
</tr>
<tr>
<td></td>
<td>Namulonge</td>
<td>801</td>
<td>99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanzania</td>
<td>Namanga</td>
<td>863</td>
<td>99</td>
<td>emb/X79902.1</td>
<td>18SrRNA</td>
<td><em>Mononychellus progressivus</em> Doreste</td>
</tr>
<tr>
<td></td>
<td>Sirare</td>
<td>823</td>
<td>99</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

On the COI the sequences blast (NCBI) resulted into 99% similarity to *M. progressivus* (X79901.1) from Congo-Benin races while a 90- 91% similarity to *Tetranychus urticae* (Koch) accessions DQ017588.1 and KF544952.1, respectively were noted (Table 3). The sequences from Katumani (Kenya) were 99 and 91% similar to the same accessions of *M. progressivus* and *T. urticae*, respectively. The nucleotide blast from Tanzanian sites of Namanga and Sirare were 99% similar to accession X79901.1 (*M. progressivus*) and 91% to accession KF544952.1 (*T. urticae*). On the other the Uganda nucleotide sequence from Kawanda and Namulonge were 99% similar to X79901.1 (*M. progressivus*) and 90% to accessions CUC02469.1 and KFDQ017588.1, respectively.

Table 3: Comparative cytochrome oxidase subunit I (mtCOI) of two closest genetic match (%) results of cassava green mite species from different sites in East Africa to species nucleotides from NCBI data base

<table>
<thead>
<tr>
<th>Country</th>
<th>Site</th>
<th>Base pairs (letters)</th>
<th>% Match</th>
<th>NCBI Accession</th>
<th>Gene region</th>
<th>Species identity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>Kiboko</td>
<td>371</td>
<td>99</td>
<td>X79901.1</td>
<td>mtCOI</td>
<td><em>Mononychellus progressivus</em> Doreste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>91</td>
<td></td>
<td>DQ017588.1</td>
<td>mtCOI</td>
<td><em>Tetranychus urticae</em> Koch</td>
</tr>
<tr>
<td></td>
<td>Katumani</td>
<td>371</td>
<td>99</td>
<td>X79901.1</td>
<td>mtCOI</td>
<td><em>Mononychellus progressivus</em> Doreste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td></td>
<td>DQ017588.1</td>
<td>mtCOI</td>
<td><em>Tetranychus urticae</em> Koch</td>
</tr>
<tr>
<td>Uganda</td>
<td>Kawanda</td>
<td>441</td>
<td>99</td>
<td>X79901.1</td>
<td>mtCOI</td>
<td><em>Mononychellus progressivus</em> Doreste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td></td>
<td>CUC02469.1</td>
<td>mtCOI</td>
<td><em>Tetranychus urticae</em> Koch</td>
</tr>
<tr>
<td></td>
<td>Namulonge</td>
<td>481</td>
<td>99</td>
<td>X79901.1</td>
<td>mtCOI</td>
<td><em>Mononychellus progressivus</em> Doreste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td></td>
<td>DQ017588.1</td>
<td>mtCOI</td>
<td><em>Tetranychus urticae</em> Koch</td>
</tr>
<tr>
<td>Tanzania</td>
<td>Namanga</td>
<td>450</td>
<td>99</td>
<td>X79901.1</td>
<td>mtCOI</td>
<td><em>Mononychellus progressivus</em> Doreste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>91</td>
<td></td>
<td>KF544952.1</td>
<td>mtCOI</td>
<td><em>Tetranychus urticae</em> Koch</td>
</tr>
<tr>
<td></td>
<td>Sirare</td>
<td>483</td>
<td>99</td>
<td>X79901.1</td>
<td>mtCOI</td>
<td><em>Mononychellus progressivus</em> Doreste</td>
</tr>
<tr>
<td></td>
<td></td>
<td>91</td>
<td></td>
<td>KF544952.1</td>
<td>mtCOI</td>
<td><em>Tetranychus urticae</em> Koch</td>
</tr>
</tbody>
</table>
Mite phylogeny diversity

The ITS2 phylogeny tree showed that the highest sequence divergence was from Katumani and Kiboko in relation to NCBI similar species accession emb/X79902.1 of *M. progresivus* (Figure1). The sequence from Mtwapa was the closest to the *M. progresivus* (emb/X79902.1). The out-groups of *T. urticae* (PM408046.1), *T. evansi* (AJ419833.1) and *E. orientalis* (HQ688670.1) were clearly different genera.

The COI phylogeny tree showed that Kiboko and Mtwapa had the highest genetic divergence from NCBI accession X79901.1 (Figure 2). Katumani sequence was genetically closest to the NCBI accession (X79901.1). The out-groups, *T. evansi* (GU565322.1), *T. urticae* (GQ141909.1) and *E. orientalis* (HQ688670.1) were clearly different taxa from *M. progresivus*.

![Neighbour-Joining phylogenetic tree based on internal transcribed spacer 2 (ITS2) nucleotide divergences of *Mononychellus progresivus* showing phylogeny positions among related taxa from NCBI. Bootstrap values (>50%) based on 1000 replications are shown at branch nodes.](image)

**Figure 1:** Neighbour-Joining phylogenetic tree based on internal transcribed spacer 2 (ITS2) nucleotide divergences of *Mononychellus progresivus* showing phylogeny positions among related taxa from NCBI. Bootstrap values (>50%) based on 1000 replications are shown at branch nodes.
Figure 2: Neighbor-Joining phylogenetic tree based on cytochrome oxidase subunit I (COI) nucleotide divergence of *Mononychellus progressivus* showing phylogeny positions of related taxa from NCBI. Bootstrap values (>50%) based on 1000 replicates are shown at branch nodes.

Removing the outlier taxa of genera *Tetranychus* and *Eutetranychus* and basing nucleotide divergence on the Congo-Benin accessions enabled closer examination of CGM nucleotide at geographical intra-divergence level. Figure 3 shows that Kiboko, Namanga and Sirare had highest intra-divergence from NCBI accession X79902.1 on ITS2 region.

Figure 3: Neighbor-Joining phylogenetic tree based on internal transcribed spacer 2 (ITS2) nucleotide divergences of *Mononychellus progressivus* from different sites of East Africa in comparison to Cong-Benin accession X79902.1). Bootstrap values (>50%) based on 1000 replications are shown at branch nodes.
On the other hand, Mtwapa CGM nucleotide indicated the highest intra-geographical difference both from the rest of site nucleotides on COI region (Figure 4).

**Figure 4:** Neighbour-Joining phylogenetic tree based on cytochrome oxidase subunit I (COI) nucleotide divergence of *Mononychellus progresivus* showing species nucleotide from different sites from East Africa in comparison to Cong-Benin accession X79901.1). Bootstrap values (>50%) based on 1000 replicates are shown at branch nodes.

**Discussion**

The NCBI Blast search showed that the cassava species in Kenya and the East African region was *M. progresivus*, similar to the Congo-Benin CGM sequences carried out by Navajas *et al.* (1994). A close look of the percentage match of the three site sequences to the NCBI Gene bank showed that there was no nucleotide variation between Kenya *M. progresivus* and Congo-Benin (X79902.1) race on the ITS2 region where 0-1% intra-divergence was observed while on the COI a divergence of 1% was observed. Similar intra-geographical divergence was reported between sequences of Benin and Congo by Navajas *et al.* (1994) where 0-2.1 and 0-0.4% intra-specific divergence on COI and ITS2, respectively. This indicates that some bio-geographical genetic variations are inherent on *M. progresivus* species in Africa.

The ITS2 phylogeny tree showed the *M. progresivus* sequences from Kiboko and Katumani were the most distant to Congo-Benin sequences from NCBI Gene bank. On the other hand the COI phylogeny tree showed that both Kiboko and Mtwapa sequences were the most distant from the same accession. Mtwapa site was both the warmest and humid, in comparison to the hot dry Kiboko and the cooler Katumani sites of Kenya.

Some workers allude that the ITS(2) is the most stable for molecular systematics at the species level, a fact confirmed on *M. progresivus* sequences in Kenya being more similar to the species in central and west Africa (Morrison, 2006; Knowles and Carstens, 2007). The results contrast the results of the pioneer work by Navajas *et al.* (1994) where ITS2 region had 0-4% while COI showed 0-2.1% nucleotide intra-divergence. The current study showed a 0-1% divergence on the ITS2 while COI region had 1%. Murega *et al.* (1989) demonstrated that Kenya and Uganda
CGM populations were compatible after a crossing experimental study where successful progeny was achieved in 100% of the test mature cohorts. The Kenya M. progresivus sequence variations on the COI region showed geographical race genetic divergence manifestation. While the COI region is acclaimed as the DNA region for species bar coding within the range of 600 codon base pairs, its utility continue to be tested both in phylogeny and genetic studies in arthropods and vertebrates (Navajas et al., 1996; Morrison, 2006). Kanouh et al. (2010) has reported some intra-species biogeographic variation of the predator genus Phytoseiulus showing intra-geographic nucleotide divergence. Spider mite acaricide toxicity on red tomato spotted mite Tetranychus urticae Koch in Iran has shown reduced efficacious control of as populations develop more chemical resistance (Memarizadeh et al., 2013). Mutisya et al. (2015) have recommended abamectin spray of CGM in the hot-dry marginal lands where cassava is threatened by high densities of the pest mite. How such diverse intra-specific CGM races would respond to seasonal spray regimes of abamectin is worth a study at different regions in East Africa where cassava suffers long drought period.

Conclusion
The study showed that the COI gene region could be reliably analysed for bio-geographical race variation and nucleotide substitution difference. This work can be a baseline for further evaluations on geographical site mite resistance to acaricide use.

Recommendations
Where possible, a future study on how different M. progresivus races responds to different cassava cultivars will lead to more information on suitable cassava variety development and enhanced phytoseiid T. aripo presence on the plant. Such a study would lead to enhanced information on predator-plant relationship leading to non-economic injury level density-models of CGM on cassava in Africa.

Acknowledgement
The authors would like to acknowledge the East African Productivity Project (EAAPP) for providing funds for the varieties evaluation at KALRO-Katumani. The input of the anonymous reviewers is appreciated, resulting to the content of the present paper.

References


Discussion session

Question: Wanted to know whether cassava green mite is mononychellus or polyphagous? And if it is polyphagous, then why were samples not taken from other hosts?

Answer: Cassava green mite is purely monophagous on cassava plant and hence samples were taken from cassava only.
Status of cassava bacterial blight in Uganda and Kenya

Opio, S.M.1,2*, Odongo, H.M.3, Alicai, T.1, Miano, D.W.3, Tusiime, G.2, Kimenju, J.W.3, Muiru, W.M.3 and Munga, T.L.4

1National Crops Resources Research Institute, P.O. Box 7084 Kampala, Uganda; 2Department of Crop Science, Faculty of Agriculture, Makerere University, P.O. Box 7062, Kampala; 3Department of Plant Science and Crop Protection, University of Nairobi, P.O. Box 29053-00625, Nairobi; 4Kenya Agricultural and Livestock Research Organization, Mtwapa P.O. Box 1680108, Mtwapa.
*Correspondence: talicai@hotmail.com

Abstract
Xanthomonas axonopodis pv manihotis, the causal agent of Cassava bacterial blight (CBB) is among the top ten pathogenic bacteria worldwide. In addition to yield reduction, the disease affects the quality of planting materials rendering them unavailable for the successive seasons. In Kenya, CBB was considered a quarantine disease confined in the western part of the country. However, symptoms of the disease have been observed on cassava plants indicating its presence in the coastal region of Kenya and throughout Uganda. In order to develop CBB management strategy, the distribution of the disease and the diversity of the pathogen genetically had to be determined. Therefore, surveys were conducted and symptomatic leaf samples were collected in both Uganda and Kenya from farmer’s fields. Bacteria were later cultured and observed morphologically and tested biochemically in Kenya while in Uganda, DNA was extracted and amplified using PCR. These were later purified and sent to Macrogene for sequencing. Field observations confirmed the existence of CBB in both countries. In Uganda, the highest average CBB incidence (66.9%) and severity (2) scores were noted on farmers’ preferred variety, TME14. The bacterial cultures were characterized by hyaline and yellow colonies with butter like consistency, smooth surfaces and margins in both countries. The colony colours observed morphologically suggest genetic diversity in the strains in both countries. This study therefore confirms the presence of CBB in the two countries and recommends varietal screening to develop cassava varieties that are resistant to the disease.

Key words: Cassava bacterial blight, Xanthomonas axonopodis diversity, cassava

Introduction
Cassava is an important tropical root crop in Africa (Nassar and Ortiz, 2007). In 2011, the total area under cassava production in the sub Saharan Africa was about 13.05 million hectares (FAOSTAT, 2013). The crop is, however, constrained by a number of factors. In addition to socioeconomic factors, insect pests and diseases have been sighted as responsible for causing increasing yield gaps in countries where cassava is grown (Olsen and Schaal, 1999). Given the growing importance of cassava in the region, cassava bacterial blight (CBB) becomes a threat to cassava production; under favourable conditions, it could cause complete yield loss (Lozano, 1986; Boher et al., 1995). The disease is caused by X.axonopodis pv.manihotis (Vauterin et al., 1995). It is a systemic and epiphytic pathogen (Lozano and Sequeira 1974; Boher and Verdier 1994) transmitted through infected vegetative materials (Boher and Verdier, 1994). Insects have also been observed to be involved in transmission of the disease (Zandjanakou-Tachinet al., 2007). Infected plant symptoms are usually diverse and include blight, wilt, and angular lesions, stem exudates, cankers and die back (Maraite, 1993). Unfortunately, little effort has been put in understanding this disease in the region, since it has been
eclipsed by viral diseases that were assumed to be more important. Consequently, this study was designed to determine the current status of CBB in Uganda and Kenya.

**Materials and Methods**

A survey was conducted and symptomatic leaf samples were collected in 21 counties of Kenya and in 56 districts of Uganda. In Uganda, four districts were randomly taken per region and from each district, three farmer's field were surveyed while in Kenya, farms were selected within a radius of 10km. Symptomatic leaf samples were collected, placed in sample bags and parameters like collection site, variety, symptom description and date of collection were taken per field. The severity was scored on a scale of 1 - 5 where 1- no symptom, 2 - angular leaf spotting only, 3 - wilting, enlarged angular leaf spot, leaf blight, defoliation, gum exudation, shoot tip die-back, 4-Wilting, blighting, defoliation, gum exudation, shoot tip die-back, 5-wilting and blighting, defoliation and gum exudation, abortive lateral shoot formation, stunting, complete die-back. A total of 230 and 120 samples were collected from Kenya and Uganda, respectively.

**Isolation of bacteria**

Leaf samples were surface sterilized with liquid soap, 70% alcohol and 30% sodium hypochlorite and rinsed several times with sterile de-ionised water to remove the disinfectants. The leaves were later chopped into small pieces and put in 700µl of sterile de-ionised water in eppendorf tubes and allowed to stand for 30 minutes. A loopful of the suspension was spread on media (5g of yeast extract, 5g of glucose and 5g of Bacto peptone and 15g of agar per litre). The plates were later incubated at 28˚C for 48 hours. Single colonies were selected for characterization and the rest stored at 4˚C for routine use and in 60% glycerol at -80˚C for long term storage.

**Gram stain reaction**

The gram stain technique described by Bradbury (1978) modified by Ongujobiet al. (2010) was used. A loopful of each isolate was obtained from a 24-hour old culture and smeared on a glass slide with a drop of sterile distilled water. The smear was later covered with crystal violet solution for a minute, washed off gently under running water and covered with Lugol’s iodine for a minute. This was rinsed with 70% ethanol and immediately washed with water. Subsequently, it was counter-stained with safranin for four minutes, rinsed thoroughly with water and air-dried before microscopic examination (Ongujobiet al., 2010).

**Motility test**

The method described by Olutiolaet al. (1991) modified by Ongujobiet al. (2010) was used. A loop full of bacterial cells was obtained from a 48-hour old culture of each of the isolates. These were suspended in a drop of sterile distilled water on a hanging drop slide, and the glass slide was observed under a microscope (Ongujobiet al., 2010).

**Gelatin hydrolysis test**

The procedure described by Leiliott and Hayward. (1996) was adopted. The test media (13 g NA powder, 4 g gelatin, 0.5 g glucose, 0.5 g KHO₄ and 15 g K₂HPO₄) was used. The plates were stab- inoculated with the isolates and incubated for 2 days at room temperature, after which a mercuric chloride solution [15 g HgCl₂ salt, 20 ml concentrated hydrochloric acid (HCl) and 100 ml of distilled water] was used to flood the plates. Control plates were stab-inoculated with sterile distilled water (Leiliott and Hayward, 1996).
Starch hydrolysis test
The method described by Dye (1962) modified by Ongujobi et al. (2010) was followed. The media (3 g yeast extract, 2 g soluble starch and 15 g of agar per litre) was inoculated with each isolate and incubated for 4 days then flooded with Lugol's iodine solution. Control plates were not inoculated (Ongujobi et al., 2010).

Fluorescent pigment production test
Plates of King’s B media (1.5g K2HPO4, 10g of glycerol, 20 g of proteose peptone, 5g MgS04·7H2O, 15g of agar per litre) were prepared (King et al., 1954) modified by Bradbury (1978). The plates were streaked with isolates incubated at room temperature for 3 days and examined under ultraviolet lamp (light at 253.7 nm and 375 nm) for diffusible fluorescent yellowish green pigment. Un-inoculated plates served as controls (Bradbury, 1978).

Reaction to triphenyl-tetrazolium chloride (TTC)
The method described by Louverkovich and Klement (1966) was used to prepare 1% aqueous solution of TTC. NA plates without TTC served as control. Forty eight hour bacterial suspensions were streaked onto separate plates and incubated for seven days and observed for presence of bacterial growth (Louverkovich and Klement, 1966).

Genomic DNA isolation
A single colony was picked and inoculated in 10ml of LB broth in 50ml falcon tubes and incubated overnight at 28°C while shaking at 250rpm in a rotary incubator. Genomic DNA was extracted and re-suspended in 100ul of sterile di-water and stored at -20°C.

Molecular characterization
Samples collected from Kenya were analysed using morphological and biochemical approaches while in Uganda, molecular approaches using PCR with xam specific primers that amplified the target sequence of 500bp was performed. Briefly, a 25µl PCR reaction mix containing 25mM MgCl2, 5x Green Gotaq reaction buffer, 10mM dNTPmix, 10µM of each primer RB25 (TTGCAGGTTGAAGATGATGC) and RB26 (TTTCGAGGTCATCATGCGTA), 5U of TaqDNA polymerase and 2 µl of the template DNA. The PCR was performed using the cycling conditions as follows: denaturation at 95°C for 5mins, 30 cycles of 95°C for 30s, 58°C for 30s, 72°C for 1 min 30s, and a final extension at 72°C for 5 min and a holding temperature of 4°C. Electrophoresis was done with 5ul of the amplicons using a 1% Agarose gel stained with ethidium bromide. The balances were purified using the Wizard SV gel PCR purification kit following the manufacturer’s instructions. These were eluted in 50ul of sterile di-water and sent for sequencing at Amstelveen, Macrogen Netherlands.

Results
Distribution of cassava bacterial blight
A survey throughout the 7 AEZ in Uganda (Figures 1 and 2) indicated presence of CBB with varied incidence. A total of 1068 farmers’ fields were surveyed from 56 districts. The disease was observed in 68% of the fields. Cassava bacterial blight incidence was greatest in the eastern AEZ with an average incidence of between 50-100% and lowest in Karamoja region with the mean incidence ranging from 0-10% (Fig 2). The disease was noted with the highest frequency on TME14 which was the most commonly grown variety. In Kenya, a total of 21 counties were surveyed with 301 farmers’ fields visited. CBB was present in 17 of the 22 counties surveyed (Fig 2). Kilifi and Kwale counties recorded the highest mean incidences of 64% and 55%, respectively.
Figure 1. The incidence (%) of cassava bacterial blight in different AEZ’s of Uganda

Figure 2. The incidences (%) of cassava bacterial blight in Kenya and Uganda in 2013
Isolation of *Xanthomonas axonopodis* pv. *manihotis* strains

In Kenya, 230 samples collected, 180 samples exhibited bacterial growth. They were cream and yellow in colour. Yellow colonies first appeared cream then slowly turned yellow in the second and third day after isolation. They had butter like consistency with smooth surfaces and margins. Furthermore, they had a gram negative reaction and appeared motile. They also hydrolysed starch and gelatine and were negative for fluorescent pigment production test. In Uganda, of the 120 samples collected and cultured, 98 bacterial colonies grew on YPGA media (Figures 3b and c) from which DNA was extracted. Two colony colours (Fig 3 b and c) were observed with 97 of them being hyaline and 1 yellow from Wakiso and Hoima districts respectively. Of the 98 samples only 39 were confirmed as positive with the primers (Fig 4).

Figure 3. Cassava Bacterial Blight (a) stem infected by Cassava Bacterial Blight. (b), (c) are the different colony colours of *X. axonopodis* cultured on YPGA media.

Figure 4. A gel electrophoresis of amplicons of DNA from *X. axonopodis*. The expected 500 bp amplicon for different samples is shown. Lane 1 is the 1kb DNA ladder.
CBB sequence data

From the NCBI website, the sequence similarities were examined by means of a blast search of nucleotides of published sequences in the Gene bank. A number of sequences were generated that showed similarity to the sequenced gene. The sequences were reanalysed using MegAlign under DNA star navigator Version 12.1.0.145 software. A multiple sequence alignment was done using pairwise alignment method to compare the different sequences. This was used to generate a phylogenetic tree (Figure 5).

Figure 5. A phylogenetic tree of sequences performed using MegAlign from DNA star navigator Version 12.1.0.145 software. The analysis includes two matches from the NCBI blast site (Col 95 and Bra 2010) and the sequences from farmers’ fields. Similar strains of bacteria cluster together.
Discussion

In Uganda, CBB occurrence was highest in the eastern, followed by the northern regions which are relatively hotter environments. A similar observation was made in Nigeria as was reported by Onyeka et al. (2008) where they observed a high prevalence of the disease in the eco-zones of Nigeria with high temperatures, a condition typical in the tropics. This observation may stem from the fact that the initial source of planting material were already contaminated and boosted the source of inoculum during the rainy season. Among the major means of pathogen dispersal is the use of already infected cuttings (Lozano and Sequeria, 1974). The fields observed were mainly habited by several weed species which might have acted as reservoirs for the disease. This pathogen is known to be able to survive epiphytically on many weeds. Some of the species known to act as alternate hosts include Amaranthus sp, Panicum fasciculatum, Sorghum halepense and other species that belong to the Euphorbiaceae (Marcano and Trujillo, 1982). The disease was further observed with moderate incidence in the central and mid-western regions because of the farming practices. Here, fields were of small field sizes that might have resulted in improper spacing observed that could have enhanced movement of the pathogen from plant to plant through means such as rain splash. Also, being on a high altitude would offer cooler environments appropriate for multiplication of the pathogen. However, Karamoja region had the lowest incidence possibly due to extremely high temperatures that could not support CBB establishment. Generally, there was low incidence in the seven regions probably because the sample collections were made during the hot seasons.

TME14 was the most widely grown variety by the farmers and yet very susceptible to the pathogen. As observed from the farmers’ fields, varieties with wide leaves were more severely hit than their slender leaved counterparts. This is perhaps because the pathogen had more chances of landing on the wide leaves than the slender shaped leaves because of the large surface area.

The pathogen isolated from Kenya, was gram negative, tested positive for motility, hydrolysed starch and gelatine. These further showed positive growth in media containing triphenyl-tetrazolium chloride and did not produce any fluorescent yellowish pigment when observed under an ultra violet lamp. These findings were the same as those identified by Lozano (1986), Appah et al. (2004) and Ongujobi et al. (2010). In Uganda, the isolates were seen with a complex of colonies isolated from each single leaf. This shows that CBB infection did not occur in isolation. Other opportunistic pathogens could have taken advantage of the compromised state of the host’s defences and colonized the plant.

The sequence data from the two colony colours reveal several strains in Uganda suggesting diversity in levels of virulence. As observed (Figure 5), there were two major clusters. These represent two evolutionary ancestries that have changed over time from their ancestors. This diversity may be due to a number of evolutionary forces acting on the pathogen populations for example mutations that could bring about numerous Insertions and genetic drift. Several zones are widely cultivated with a broad range of highly susceptible cassava varieties that may perhaps influence the existence of the broad range of the pathogen strains observed. The ability of the pathogen to stay fit in a heavily populated environment would mean developing better survival mechanisms. Hence the more diverse they are, the better their chances of survival. This would also imply development of more virulent strains of the pathogen. A high level of virulence exhibited by the pathogen would mean heavy infection and therefore propagation in the susceptible varieties. This will consequently lead to an even heavier impact on the cassava yields.
Conclusion

This study confirms the presence of CBB in the two countries. The findings are a reflection of the various shortcomings in the CBB control measures. It also points to the need for appropriate disease management strategies to prevent the disease from becoming an epidemic. It is therefore necessary that movement of cassava cuttings between zones be limited to only certified cassava seed producers. A wide screening of the cassava germplasm for resistance to CBB is therefore necessary to develop varieties that are able to resist this devastating pathogen.

Acknowledgement

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References


**Discussion session**

*Question:* How was the conclusion reached since the Kenyan team used morphological and biochemical methods to analyse CBB while the Ugandan team used molecular?

*Answer:* In Kenya, the team only confirmed the disease distribution while the Ugandans went further by including disease diversity. However, the conclusion for diversity was only for Uganda.

*Question:* What are the favourable climatic conditions for high multiplication of CBB?

*Answer:* Hot and humid
Potential for integration of parasitoids and soil pathogenic fungi to control white fly on cassava

Aool Winnifred1*, R. Molo1, E. Arengo1 and C. Omongo2

1National Agricultural Research Laboratories (NARL), P. O. Box 7065, Kampala, Uganda.
2National Crops Resource Research Institute, (NaCRRI) P. O. Box 7084 Kampala, Uganda
*Corresponding author: agwinnie1f@gmail.com

Abstract

Cassava is an important staple for more than 800 million people, mostly in sub-Saharan Africa. The cassava whitefly is a vector of African cassava mosaic (ACM) and cassava brown streak (CBS) viruses currently threatening cassava production. Several methods have been deployed for control of whiteflies over the years including use of a suite of biological agents. Species diversity and abundance of indigenous whitefly parasitoids were assessed on cassava in country-wide surveys and laboratory analysis of field-collected whitefly pupae in Uganda carried out. Eratmocerus hayati, an exotic parasitoid species, was introduced to complement indigenous whitefly parasitoids in Uganda. Soil samples from both Kenya and Uganda were also analyzed for occurrence of pathogenic fungi for integration in white fly control. Two indigenous parasitoids were recovered from the six agro-ecological zones surveyed. Cassava varieties I92/0067, TME 14 and NASE 14 supported the highest parasitoid population with parasitism ranging between 4.7-13.8% and the highest parasitism rate was recorded on TME 14 for E. mundus. The current parasitism levels by the indigenous white fly parasitoid species alone or in combination were low thus the introduction of exotic parasitoids. Based on high parasitism rates (over 57%) in USA, the exotic E. hayati parasitoid was introduced for deployment in Uganda. Fifteen fungal isolates have been purified for identification and will be evaluated as entomopathogens against whiteflies.

Introduction

Whiteflies (Homoptera: Aleyrodidae) are considered one of the world’s major agricultural pest groups injuring a wide range of valuable agricultural commodities through mechanical feeding and virus transmission thus causing considerable crop loss (Legg, 1994). Cassava, Manihot esculenta Crantz, is no exception to this rule, acting as a host of several species of whiteflies (i.e., Bemisia tuberculata Bondar, Trialeurodes variabilis Quantaine, Aleurotrachelus socialis Bondar, Tetraleurodes sp., and Aleuroglandulus malangae Russell (Castillo 1996)) in Colombia and of Bemisia tabaci (Gennadius) in Africa and Asia (Bellotti and Vargas 1986) where it vectors cassava brown streak virus (CBSD) and the African cassava mosaic virus (ACMD) (Owor et al., 2004).

Cassava yield losses due to CMD and CBSD have spurred a worldwide search for cost-effective management strategies. Biological control practices can play a significant role in integrated pest management (IPM) systems targeting whiteflies because of their preventative and sustainable nature. Gold (1987) reported that cassava whiteflies are attacked by a complex group of natural enemies, including parasitoids, predators, and fungi and reported that among the natural enemies, parasitoids were more important mortality factors of cassava whiteflies than predators. Castillo (1996) reported several cassava whitefly parasitoids in the northern cassava growing areas of Colombia. The parasitoids belong to the genera Encarsia, Eretmocerus (Hymenoptera: Aphelinidae) and Amitus (Hymenoptera: Platygastridae).
Entomopathogens contribute to the natural regulation of many populations of arthropods. Much of the research in this area concerns the causal agents of insect diseases and their exploitation for biological pest control. Many entomopathogens can be mass produced, formulated and applied to pest populations in a manner analogous to chemical pesticides, i.e. as non-persistent remedial treatments that are released inundatively. Entomopathogenic fungi that parasitize insects are valuable weapons for biocontrol and play an important role in promoting integrated pest management. To date, various strains of entomopathogenic fungi such as *Lecanicillium* (previous name, *Verticillium*) sp. (Jackson *et al*., 1985; Steenberg and Humber, 1999; Junger *et al*., 2006), *Beauveria bassiana* (Quesada *et al*., 2006), and *Paecilomyces* (Shia and Feng, 2004), have been used to control aphids, lepidopteran larva and other pests. The objective of the present study was to evaluate various control options for integration in management of whiteflies.

**Materials and methods**

**Whitefly parasitoid diversity and abundance**

The diversity and abundance of whitefly parasitoid were assessed in countrywide surveys conducted in 15 cassava growing districts representing 4 agro ecological zones in Uganda during 2013. Cassava crops, 3-7 months old were sampled and in each field, 20 cassava plants were examined on a field diagonal. Variety, age of crop and cropping patterns were also recorded. On each plant, the eleventh to fifteenth leaves were harvested in paper bags stored in cool boxes. In the laboratory counts of parasitized and unparasitized pupae of whiteflies were made under a dissecting microscope. The parasitized pupae were then reared for emergence of parasitoids. Parasitism was calculated as percentage of parasitized pupae to the total parasitizable pupa instars (both parasitized and un parasitized). Parasitoids were identified based on colour as *Encarsia sophia* appeared as black pupal cases while *Eretmocerus mundus* appeared orange with a shiny pupal skin with the pupa having red eyes. The emerging adult parasitoids were collected and identified using a binocular microscope and identification guides (Polaszek *et al*., 1992; Schauf *et al*., 1996; Rose and Zolnerowich, 1997).

**Introduction of Exotic whitefly Parasitoid Species: hayati**

A survey to determine the alternative host of whiteflies and parasitism was conducted in Quinta mazatlan, Monte Alto, McAllen Community Garden, Terra Preta, Hidalgo, La Villa, Brownsville and South Padre Island in Mc Allen Texas. Several plant hosts of *B. tabaci* were examined for presence of larvae and pupae. In the field, infested lower leaves were manually collected from the hosts, placed in plastic bags which were labeled and stored in cool boxes at 10°C. The leaves were then transported to biological control laboratory at Airfield Moore. In the laboratory insect pins were used to remove parasitized forth instar pupae from the underside of each leaf under a dissecting microscope. These were then stored in vials and kept in a refrigerator at 10°C to avoid emergence. The vials containing *Eretmocerus hayati* parasitized pupae were then store in an insulated box containing ice and transported to Uganda.

**Isolating entomopathogenic fungi using the Galleria bait method**

Soil samples from which entomopathogenic fungi were isolated were picked from 64 sites in Uganda and 3 sites in Kenya (Table 1). Approximately 1kg of soil was taken from the top 10cm and placed in plastic bags. These samples were then transferred into 250 ml plastic cups with a lid and maintained at 4°C for 4 weeks until they were used in this assay (Sookar *et al*., 2008). Entomopathogenic fungi were isolated from soil using *Galleria mellonella* L. (greater wax moth) larvae (Zimmermann, 1986). Honey combs infected with the wax worm larvae were also collected from beekeepers and brought to the laboratory to set up a culture. Eggs laid on dry honey combs were removed every 4–5 days and kept in a separate cage. Larvae were fed with dry honey comb and larval stages used as the bait insects.
Several larvae in the third and fourth instars were placed in sterilized petri dishes on a humid filter paper that were sealed with parafilm prior to the baiting experiments to ensure that they are not contaminated. The collected soil samples were moistened with sterile distilled water and then baited with the wax moth larvae. Five larvae

### Table 1: Some soil sample collection sites

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<td>2.40170</td>
</tr>
<tr>
<td>Yumbe</td>
<td>Y12</td>
<td>942</td>
<td>31.23918</td>
<td>3.37362</td>
</tr>
<tr>
<td>Yumbe</td>
<td>Y20</td>
<td>940</td>
<td>31.22263</td>
<td>3.33704</td>
</tr>
<tr>
<td>Yumbe</td>
<td>Y5</td>
<td>750</td>
<td>31.42318</td>
<td>3.48864</td>
</tr>
</tbody>
</table>
were placed into the soil with sterile forceps, incubated in the dark at 25°C and checked after 7, 14 and 21 days (Sookar and Khayrattee, 2000). In the course of the 21 days, dead larvae were continuously removed from the soil with sterile forceps and placed in a 1% sodium hypochlorite solution for 3 minutes to surface sterilize the larvae, followed by washing in sterile distilled water for 3 minutes, and excess water removed by dabbing with a piece of sterilized filter paper. Dead larvae were individually placed in sterilized 9 cm glass Petri dishes on humid filter paper, sealed with Parafilm and incubated at 25°C. Fungal outgrowth was checked every 2 days for 14 days. Conidia and mycelia were then removed from the insect surface with a sterile loop and streaked onto potato dextrose agar plates containing 0.05 g/l chloramphenicol previously dissolved in 10 ml absolute alcohol. The fungi and fungi-like organisms recovered were identified microscopically according to Humber (2005). Each fungus recovered from an infected wax moth larva was considered an isolate.

**Results and discussion**

**Indigenous parasitoid species**

Two whitefly parasitoid species, *Eretmocerus mundus* and *Encarsia sophia*, were commonly recovered from whitefly pupae in various agro ecological zones (Figure 1). The highest combined parasitism rate by the parasitoid species was 16.2% in northwestern farmlands-wooded savannah and the lowest (14.0%) in west Nile farmlands. Highest parasitism level was 14.8% for *E. mundus* in the northwestern farmlands-wooded savannah and 8.7% for *E. sophia* in the Lake Victoria Crescent and Mbale farmlands.

![Figure 1: The percentage parasitism rates of indigenous parasitoids in six agro-ecological zones of Uganda](image)

(Key: WNF – West Nile Farmlands; NWF – North Western Farmlands; MF – Mbale Farmlands; SELB – Southeastern and Lake Kyoga Basin)

Cassava varieties 192/0067, TME 14 and NASE 14 supported parasitism rates ranging between 4.7-13.8% with the highest rate 14.8% recorded on TME 14 for *E. mundus* (Figure 2). All sampled varieties sustained low population of *E. sophia* parasitoids with parasitism rates ranging from 0.4- 2.8%.
Figure 2: Parasitism percentages of two indigenous parasitoid species on different cassava varieties in Uganda

The results are consistent with the findings of Legg and Braima (1999) and reports of Otim (2004) who reported *Eratmoceras* and *Encasia* species are the indigenous parasitoid species and the occurrence and parasitism levels were higher for *E. mundus* than *E. Sophia* in Uganda. There was however a lower parasitism rate of each species compared to findings of Otim et al., (2004) who found an overall parasitism level of 57%. This difference in parasitism level could be due to the sampling areas covered and the cassava varieties occurring in the areas surveyed.

**Entomopathogens**

Isolation of entomopathogenic fungi from 67 sites yielded a range of isolates from the *Metarhizium, Beauveria* and *Paecilomyces* genera. *Metarhizium sp* were the most commonly occurring (56.7%) while *Paecilomyces* were the least common (5%) isolates recovered from the areas surveyed. Soil samples collected from all sites in Kenya yielded *Metarhizium sp* only. Soil samples collected from Yumbe, Kamuli, Nebbi, Busia and Kenya yielded no fungal isolates of the *Paecilomyces* genus. The highest percentage (61.3) of fungal isolates of genus *Beauveria* was recorded from Kamuli district. Soil samples collected from Nebbi district yielded equal percentages of *Metarhizium* and *Beauveria sp* (Table 2).
Table 2: Some fungal isolates recovered from various soil samples

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Mycelia color</th>
<th>Colony shape</th>
<th>Fungal genera</th>
</tr>
</thead>
<tbody>
<tr>
<td>A12</td>
<td>White</td>
<td>Cotton-like mass</td>
<td>Beauveria spp</td>
</tr>
<tr>
<td>A15</td>
<td>Light green</td>
<td>Flat powdery</td>
<td>Metarhizium spp</td>
</tr>
<tr>
<td>A3</td>
<td>Dark green</td>
<td>Flat powdery</td>
<td>Metarhizium spp</td>
</tr>
<tr>
<td>A3</td>
<td>Greenish brown</td>
<td>Flat powdery</td>
<td>Paecilomyces spp</td>
</tr>
<tr>
<td>A5</td>
<td>Dark green</td>
<td>Cotton-like mass</td>
<td>Metarhizium spp</td>
</tr>
<tr>
<td>A8</td>
<td>Cream</td>
<td>Cotton-like mass</td>
<td>Beauveria spp</td>
</tr>
<tr>
<td>Bus15</td>
<td>Light yellow</td>
<td>Cotton-like mass</td>
<td>Metarhizium spp</td>
</tr>
<tr>
<td>Bus17</td>
<td>Whitish pink</td>
<td>Cotton-like mass</td>
<td>Beauveria spp</td>
</tr>
<tr>
<td>Bus18</td>
<td>Dark yellow</td>
<td>Flat powdery</td>
<td>Metarhizium spp</td>
</tr>
<tr>
<td>K10</td>
<td>Olive green</td>
<td>Flat powdery</td>
<td>Metarhizium spp</td>
</tr>
<tr>
<td>K16</td>
<td>Creamish white</td>
<td>Flat powdery</td>
<td>Metarhizium spp</td>
</tr>
<tr>
<td>K2</td>
<td>Yellowish green</td>
<td>Cotton-like mass</td>
<td>Metarhizium spp</td>
</tr>
<tr>
<td>K20</td>
<td>Cream</td>
<td>Cotton-like mass</td>
<td>Beauveria spp</td>
</tr>
<tr>
<td>K6</td>
<td>White</td>
<td>Cotton-like mass</td>
<td>Beauveria spp</td>
</tr>
<tr>
<td>K7</td>
<td>Greyish pink</td>
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</tr>
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<td>Metarhizium spp</td>
</tr>
<tr>
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<td>White</td>
<td>Cotton-like mass</td>
<td>Beauveria spp</td>
</tr>
<tr>
<td>Kam13</td>
<td>Light yellow</td>
<td>Cotton-like mass</td>
<td>Beauveria spp</td>
</tr>
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<td>Kam18</td>
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<td>Cotton-like mass</td>
<td>Metarhizium spp</td>
</tr>
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<td>Kam6</td>
<td>Olive green</td>
<td>Cotton-like mass</td>
<td>Metarhizium spp</td>
</tr>
<tr>
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<td>Cream</td>
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<td>Creamish grey</td>
<td>Flat powdery</td>
<td>Metarhizium spp</td>
</tr>
<tr>
<td>Ke3</td>
<td>Grey</td>
<td>Flat powdery</td>
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<td>M11</td>
<td>Grayish brown</td>
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<td>Paecilomyces spp</td>
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<td>Creamy brown</td>
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<td>Greyish green</td>
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<td>Greyish</td>
<td>Flat powdery</td>
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<td>White</td>
<td>Cotton-like mass</td>
<td>Beauveria spp</td>
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<td>Metarhizium spp</td>
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<td>Y12</td>
<td>Brown</td>
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<td>Metarhizium spp</td>
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<td>Y20</td>
<td>Brown</td>
<td>Cotton-like mass</td>
<td>Metarhizium spp</td>
</tr>
<tr>
<td>Y5</td>
<td>Light green</td>
<td>Flat powdery</td>
<td>Metarhizium spp</td>
</tr>
</tbody>
</table>
There is need to identify the various species of the naturally occurring entomopathogenic fungi and determining their efficacy on whiteflies through pathogenicity tests for integration in management of this pest. *Metarhizium anisopliae* and *Paecilomyces fumosoroseus* have been used in the control of whiteflies (*Bemisia tabaci*), thrips (*Ceratothripoides claratris*) and mealy bug (*Pseudococcus cryptus*) on tomatoes in Thailand. Panyasiri *et al.* (2007) reported that *Paecilomyces fumosoroseus* showed up to 76.7% against *Bemisia tabaci*. A similar study was conducted in Mexico against thrips and whiteflies (Sanchez-Pena *et al.*, 2011). In Brazil, Mascarin *et al.* (2013) investigated the virulence of entomopathogenic fungi on whiteflies. Their findings revealed that adults of *Bemisia tabaci* were highly susceptible to *Paecilomyces fumosoroseus* (with >93% mortality) while *Beauveria bassiana* showed mortality of >50%. In addition, Sookar *et al.* (2008) studied the effect of *Metarhizium anisopliae* and *Beauveria bassiana* on *Bactrocera zonata* and *Bactrocera cucurbitae* in Kenya. Highest mortality rates (98%) were recorded in *Bactrocera zonata* while *Bactrocera cucurbitae* was 94%.

**Recommendations**

Fifteen fungal isolates were purified for identification and will be evaluated as entomopathogens against whiteflies. There is now need to mass produce, release and monitor the establishment of *E. hayati* in Uganda before evaluating its parasitism rate. The team also needs to conduct efficacy tests of the fungal isolates on whiteflies. Integrating these available biological options will go a long way in the management of cassava mosaic and cassava brown streak diseases if used alongside other options such as resistant/tolerant suitable cassava varieties.

**References**


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**Discussion Session**

**Question:** Which varieties have low cyanide levels?

**Answer:** There are many like MM96/9308 – cassava variety grown in Kenya

**Question:** Issues of safe guards (both environmental and social) in using biological control?

**Answer:** Prior testing is done before introduction and with classical biological control specificity tests are done before introductions therefore safety is guaranteed.

**Question:** Does whitefly sting people?

**Answer:** No, it does not, the people in the picture were going to collect galleria (wax moth) from bee hives for isolation of entomopathogenic fungi.
Occurrence and distribution of cassava infecting viral pathogens and identification of their alternative hosts in Uganda

Adero, J.1, 2, Alicai, T.1,* and Byarugaba, D.2

1National Crops Resources Research Institute (NaCRRI), P.O. Box 7084, Kampala, Uganda; 2College of Veterinary Medicine and Biosecurity, Makerere University Kampala, P.O Box 7062, Kampala, Uganda.

*Correspondence: talicai@hotmail.com

Abstract
Cassava mosaic disease caused by cassava mosaic geminiviruses and cassava brown streak disease caused by cassava brown streak ipomoviruses are the major constraint to cassava production in Uganda. In sub-Saharan Africa, B. tabaci is a major vector of cassava mosaic geminiviruses and cassava brown streak ipomoviruses. Partial sequences of the DNA-A component of African cassava mosaic virus and full length sequences of the DNA-A component East African cassava mosaic virus-Ugandan variant viruses detected from Ageratum conzyzoides, Asystasia gangetica, Solanum incanum, Leonotis nepetifolia, Hewettia sublobata, Erythrina abyssinica and Manihot glaziovii were determined and sequences showed 91–99% nucleotide sequence identity with cassava mosaic geminiviruses. Cassava brown streak virus was also detected in Manihot glaziovii and partial sequence of these isolates showed 99% identity with cassava isolates from East Africa. Partial sequences of the mitochondria cytochrome oxidase I (mtCOI) DNA of whiteflies collected from non-cassava plants were obtained and pair wise comparison revealed 99% nucleotide sequence identity with cassava whitefly sequences. These results provide definitive evidence for the occurrence of alternative host plants for cassava viruses and whiteflies.

Introduction
Cassava (Manihot esculenta Crantz) is a staple food crop grown by subsistence farmers in Sub-Saharan Africa and contributes significantly to the household food security in the region. Currently there are major viral diseases such as cassava brown streak disease (CBSD) and cassava mosaic disease (CMD) which affect the crop causing devastating yield losses (Legg et al. 2011). Cassava mosaic disease caused by eight distinct cassava mosaic geminiviruses (CMGs) has undoubtedly been the most widespread constraint to cassava production in Africa and in the region (Sserubombwe et al., 2008). The CBSD in East Africa is caused by two ipomoviruses (genus Ipomovirus; family Potyviridae) namely, cassava brown streak virus (CBSV), and Ugandan cassava brown streak virus (UCBSV) (Mbanzibwa et al., 2011).

Cultivated cassava is believed to be the principal reservoir for CMGs, while this is not well known for CBSD, although it is speculated that viruses causing the disease jumped to cassava from its natural host(s) (Monger et al., 2001). Studies have indicated that both CBSD and CMD can affect plants other than cassava. ACMV and EACMV-UG have been detected in Uganda in M. glaziovii (Sserubombwe et al., 2008), in two weed species from the Democratic Republic of Congo (Monde et al., 2010) and in leguminous plant species, weeds and M. glaziovii in Nigeria (Alabi et al., 2008). CBSV has been detected in Manihot glaziovii in Tanzania (Mbanzibwa et al., 2011).
Bemisia tabaci (Genn.) is the vector of CMGs and CBSVs, which are the main production constraint to cassava, both in Uganda and elsewhere in Africa (Legg et al., 2011). Anecdotal reports have indicated that many of the non-cassava CMG infected plant species support high whitefly populations. A study conducted in Uganda showed that the whitefly vector could colonize Manihot glaziovii, Jatropha gossypifolia, Euphorbia heterophylla, Aspilia africana, and Abelmoschus esculentus, suggesting that cassava B. tabaci (Ug1 genotypes) are not restricted to cassava in Uganda (Sseruwagi et al., 2006). Studies have also indicated that cassava whiteflies colonize crop families ranging from the Solanaceae, Cucurbitaceae, and Fabaceae plant families to various ornamental species (Acarvajal, 2013).

The CMD and CBSD continue to devastate cassava crops in East and Central Africa. As a consequence, a number of programs have been instituted by African governments through the national agricultural research systems (NARS) and, local and international stakeholders to monitor the spread and enforce mitigation measures. However, limited research has been conducted to establish occurrence of these viruses in alternative host plants; therefore, potential risk being posed to cassava cultivation remains underestimated. A clear understanding of the role of alternative host plants associated with diseases epidemiology would be invaluable to assist the development of integrated pest (vector, disease and weeds) management strategies.

The aim of the project was to undertake an epidemiological study of CMD and CBSD in cassava cultivating areas in Uganda and to establish the genetic diversity of viruses detected in the wild plants in Uganda.
**Materials and methods**

A field survey was conducted in twenty four (24) districts in five (5) agro-ecological zones in Uganda where cassava and associated virus diseases (CMD and CBSD) are important. Symptomatic cassava leaves and leaves from non-cassava plants with virus like symptoms growing in or around the cassava fields were picked and preserved in 70% ethanol for CMGs analysis and in botanical press for CBSVs analysis. Details of location, GPS coordinates, cassava varieties, plant names (English or local) and photographs for plants sampled were taken. From each field surveyed, cassava disease parameters were measured. Adult whiteflies found on non-cassava were collected using an aspirator and stored in 90% ethanol and sent to School of Molecular and Cell Biology, University of the Witwatersrand, South Africa for analysis of the mitochondria cytochrome oxidase I (mtCOI) DNA using the MT10/C1-J-2195 and MT12/L2-N-3014 primers. These were used to establish the colonization and/or host range of cassava *B. tabaci* in nature.

RNA and DNA was extracted from cassava leaves by CTAB protocol described by Lodhi *et al.* (1994) and by Dellaporta *et al.* (1983), respectively. Nucleic acids from non- cassava plants were extracted by and FosterAmp method.

The cDNA was synthesized using SuperScriptTM III first strand synthesis kit (Invitrogen, USA) and CBSV were detected by PCR using primers CBSVDF2 (5’-GCT MGA AAT GCY GGR TAY ACA A-3’) and CBSVDR (5’-GGA TAT GGA GAA AGR KCT CC-3’) as described by Mwanzibwe *et al.* (2011). The expected band size generated was 344-bp product for CBSV and 440 bp for UCBSV. CMGs were detected using primers UV-ALI/F (5’-TGT CTT CTG GGA CTT GTG TG-3’) and ACMV-CP/R3 (5’-TGC CTC CTG ATG ATT ATA TGT C-3’) specific to EACMV-UG, ACMV-AL1/F (5’-GCC GGA ATC CCT AAC ATT ATC-3’) and 3’ACMV-ARO/R (5’-GCT CGT ATG TAT CCT CTA AGG CCT G3’) specific to ACMV as described by Alicai *et al.* (2007) and Uni/F (5’-GGG GGT CGA CGT CAT CAA TGC GTG TGT AC-3’) and Uni/R (5’-AAG GAA TTC ATG GGG GCC CAA AGA GAC TGG C-3’) as described by Briddon and Markham (1994). Expected band generated ~1000bp, 1600bp and 2800 bp for ACMV, EACMV-UG and near full length virus DNA-A’s, respectively. The PCR products were purified using Wizard SV gel purification Kit, quantified and shipped to GENEWIZ Inc, USA for sequencing.

Sequences obtained in the study were analysed by pairwise comparison with published CMG and CBSV sequences in gene bank using the NCBI basic local alignment search tool (BLAST). Multiple sequence alignments with reference sequences from the gene bank was performed using Cluster W (weighted), phylogenetic trees were inferred using molecular evolutionary genetics analysis (MEGA) software version 6.0 (Tamura *et al.*, 2013). A map was generated using the Quantum GIS (QGIS) software version 2.2 to show the distribution of identified alternative in Uganda. Plants confirmed to be alternative host cassava viruses and cassava whitefly were identified at Makerere University, Department of botany.

**Results**

Out of the 240 alternative hosts samples analysed, one (1) was positive for CBSV while ten (10) tested positive for UCBSV, nine (9) tested positive for ACMV and three (3) plants tested positive for EACMV-UG by PCR. Pairwise comparison all nine ACMV and three EACMV sequences had significant similarities >90% with sequences CMGs from the gene bank. As shown in figure 1, the phylogenetic analysis of sequences clearly indicated two clusters. Three viruses formed a different cluster from known cassava viruses despite the high similarities, while the rest of the virus sequences clustered closely with ACMV and EACMV-UG reference sequences from the gene bank.
Figure 1. Phylogenetic tree inferred from the maximum likelihood method using MEGA6 for CMB sequences

ACMV and EACMV-UG isolates in bold and isolates and alternate host species are indicated with asterisk. Sweet potato feather virus- (SPFV: SC12KC771331.1) was used as the out-group.

Abbreviations: Wak: 7.3- Wakiso District site 7, weed 3; Wak: 9.1- Wakiso District site 9, weed 1; Nam: 12 –Namulonge weed 12, Amol: 2- 3 -Amolatar District site 2 weed 3, Iga: 14: 2 -Iganga District site 14: 2, Kay: 3: 4-Kayunga District site 3, weed 4; Nam: WC1-Namulonge wild cassava 1, Nam: WC2 - Namulonge wild cassava 2; Nam: WC3 - Namulonge Wild Cassava 3; Nak: 9: 3-Nakasongola district site 19 weed 3; Mub: 28.1- Mubende district site 28 weed 1; Nam: 11- Namulonge: weed 11.

Pairwise comparison of the partial CP genome sequences of CBSV virus obtained from Nam: WC: 1, had a Significant similarity of 99% to CBSV sequence (Mbanzibwa et al., 2011). All 10 UCBSV sequences had no significant similarity with cassava virus sequences in the gene bank, so they were disregarded. As shown in the Figure 2, the phylogenetic analysis of Nam: WC: 1 sequence showed that virus detected did not cluster with any reference CBSV sequences from cassava.
Figure 2. Phylogenetic tree inferred from the maximum likelihood method using MEGA6 for CBSV sequences

Isolates from cassava are indicated in bold and virus sequences from alternate host plants whose sequences with an asterisk. Bean golden mosaic virus- (BGMV-NC_004042) was used as the out-group.


Pairwise comparison of partial MTCO1 gene sequences from whiteflies sequences obtained from non-cassava hosts had 99% similarity with sequences of cassava whiteflies in the gene bank. As shown in Figure 3, the phylogenetic analysis of sequences showed that MTCO1 partial sequences from whiteflies clustered well with reference genebank sequences of cassava whiteflies in East and West Africa, showing close relationship.
Figure 3. Phylogenetic tree inferred from the maximum likelihood method using MEGA6 for MTCO1 gene sequences from white flies

Sequences of cassava whiteflies are indicated in bold font and white fly sequences from non-cassava plants are indicated with an asterisk; B. afer and B. subdecipens were used as the out-groups.

A total of 12 plants that were confirmed as susceptible to cassava viral diseases and these plants were identified as: *Manihot glaziovii* (Euphorbiaceae), *Solanum incanum* (Solanaceae), *Hewettia sublobata* (Convolvulaceae), *Erythrina abyssinica* (Fabaceae), *Asystasia gangetica* (Acanthaceae), *Ageratum conyzoides* (Asteraceae) and *Leonotis nepetifolia* (Lamiaceae).

Plants identified as alternative hosts for cassava whiteflies were: *Vernonia amygdalina* (Asteraceae), *Solanum incanum* (Solanaceae), *Ageratum conyzoides* (Asteraceae), *Ficus asperifolia* (Moraceae), *Ocimum suave wild* (Lamiaceae) and Epalakolong (Ateso).

Central Uganda had the highest distribution of alternative host for cassava viruses (10 plants), with the highest occurrence in NaCRRRI (5 plants) in this study. This area has been documented as a hot spot for cassava viral diseases (CMD and CBSD) with high whitefly population in Uganda.

The distribution of whiteflies on non-cassava plants was also highest in central region and around the Lake Victoria crescent (with an occurrence on 21 out of 26 plants countrywide).
Discussion

Significant similarities of >90% with sequences CMGs from the gene bank indicates that sequences obtained from viruses detected from non-cassava hosts are strains of ACMV and EACMV-UG viruses infecting cassava. Three viruses formed a different cluster from known cassava viruses despite the high similarities, while the rest of the virus sequences clustered closely with ACMV and EACMV-UG reference sequences from the gene bank. This clearly indicates that these cassava viruses could be undergoing evolution when they are transmitted and infect other plant species, or these viruses could be originally from weeds. Therefore there is a possibility that these viruses can be transmitted from cassava to weeds or vice versa.

Pairwise comparison of the partial CP genome sequences of CBSV virus had a similarity of 99% to CBSV sequence (Mbanzibwa et al., 2011) in the gene bank, indicating that virus detected is a strain of CBSV. Therefore, there is a possibility that these viruses can be transmitted from cassava to other plant species. The phylogenetic analysis of Nam: WC: 1 sequence showed that virus detected did not cluster with any reference CBSV sequences from cassava, clearly indicating that the strain detected is different from known CBSV in cassava. This could lead us to draw a conclusion that cassava viruses could be undergoing evolution while transmission and infection of other plant species.

Pairwise comparison of partial MTCO1 gene sequences from whiteflies sequences obtained from non-cassava hosts had 99% similarity with sequences of cassava whiteflies in the gene bank, showing that non cassava plants were supporting cassava whiteflies, thus alternative hosts from the vector. The identification of additional hosts for the vector, previously thought to be restricted to cassava may have important epidemiological significance for the spread of cassava diseases in Uganda.

In this study, Solanum incanum (Solanaceae) and Ageratum conyzoides (Asteraceae) have been identified to be susceptible to both CMGs and its vector. It is therefore likely that these viruses can be transmitted between cassava and non-cassava hosts by the whitefly vector. The study also found that M. glaziovii had dual infection of ACMV and CBSV, indicating that this plant is a very good reservoir for cassava viruses. And due to its perennial nature, it can therefore provide continuous inocula all year round, given that it’s also very much loved by many farmers for its shed.

A wide host range for cassava viruses and whitefly vectors can facilitate survival during periods when cassava is not available, so when cassava with clean planting is re-introduced, these alternative host plants will serve as a source of inoculum for the viruses.

Central region and specifically around the Lake Victoria crescent plays a big role in population dynamics of the whitefly vector because unlike other regions, it has a constant weather pattern (moist) throughout the year, such that whitefly populations, cassava and even weeds are maintained year round and therefore the is constant transmission of disease within and out of cassava to weeds by whiteflies.

There was a positive correlation between the distribution of the alternative host plants for both cassava viruses and the whitefly vector in this study. It is an indication that at high vector pressure, cassava viruses are likely to get transmitted to non-cassava plant species as the inhabit these different plants making them alternative host plants for cassava viruses, and this clearly explains the findings in this study.
Conclusion
The non-cassava plants could be contributing to virus evolution and disease epidemics of cassava viruses by serving as inoculums and vector sources. This study identified new alternative host plants for CMD, CBSD and whiteflies, all of which co-interact to play a role in the epidemiology of cassava viral diseases. Studies should continue to identify other un-known alternative hosts plants, studies on the ability of B. tabaci to transmit cassava viruses to non-cassava hosts and vice versa would complement these findings to provide a foundation for a detailed understanding of epidemiology and help to develop sustainable strategies for the management of the disease in Uganda and in the wider Sub-Saharan Africa region.

References
Discussion session

Question: Which are these plants that cause the diseases?
Answer: CMD is caused by cassava mosaic and CBSD is caused by cassava brown streak. And these viruses have been known to affect cassava. The study has only identified other plant species that these viruses also infecting, making them alternative host plants for the viruses.

Question: What happens to the virus in terms of virulence when it gets into the alternative hosts?
Answer: This study was a foundation/beginning in this area but during multi sequence alignment we identified several mutations in these virus genomes forming different clusters.
Integrating cassava varieties and *Typhlodromulus aripo* to sustain biological control of cassava green mite

Richard Molo¹,*, W. Aool¹; S. Adumo¹; D. L. Mutisya²

¹National Agricultural Research Laboratories, P.O. Box 7065. Kampala. Uganda
²KARI-Katumani. P. O. Box 340-90100. Machakos, Kenya

*Corresponding Author: richardmolo7@gmail.com; Mobile phone: +256 772697622

Abstract

The cassava green mite (CGM), *Mononychellus tanajoa* is a key pest which reduces root yield of cassava by 30-80%. Nine cassava varieties were evaluated in Kenya based on CGM abundance and HCN of leaves for their ability to sustain low CGM population to enhance biocontrol of *T. aripo*. In Uganda, cassava fields were surveyed in five agro ecological zones and samples of cassava apices were analysed in the laboratory to determine the ability of cassava varieties to sustain high population of *T. aripo*. In the screening trial, lowest cumulative CGM population densities (<1200 mites /leaf) were recorded on MM97/3567, Tajirika and MM96/9308 in correspondence with lowest cyanide content of leaves, 8.5 ± 4.9, 12.5 ± 3.2 and 12.3 ± 2.5 mg/kg respectively. These varieties have been recommended to reduce the multiplication rate of CGM and enhance control by *T. aripo*. In field surveys, cassava varieties with hairy and non hairy tips sustained *T. aripo* with highest densities 0.96 actives /tip on hairy TME14. High *T. aripo* population densities corresponded with high densities of hairs on cassava tips. There were significant inverse linear relationships between CGM densities and *T. aripo* on NASE3 and TME14 cassava varieties at high CGM population densities (high CGM damage level 3). The MM97/3567, Tajirika and MM96/9308 in Kenya and NASE3, TME14 in Uganda have been identified to be the most promising candidate cassava varieties for CGM biological control involving *T. aripo*, particularly during the dry season when high CGM densities occur.

Key words: *Mononychellus tanajoa*, *Typhlodromulus aripo*, biological control, cassava apices, cassava varieties

Introduction

Cassava is attacked by cassava green mite (CGM), *Mononychellus tanajoa* (Acari: Tetranychidae) an introduced pest in the 1970s in Africa (Nyiira 1972). Since first appearance in East Africa, the pest has expanded its distribution to the entire cassava growing belts where it causes estimated yield losses ranging between 30-80 % (Yanninek et al., 1989). Climatic and soil factors are considered to influence the population dynamics of CGM with positive or negative effects. To date, control of CGM in Africa has relied mainly on predatory mite species of the family Phytoseiidae. Initial biological control efforts involved evaluation of over 11 phytoseiid mite species of Colombian and Brazilian origin during 1986-1993. But none of these species became successfully established in Africa. However, in the later years of evaluation, one predatory mite species *Typhlodromulus aripo* was introduced from Brazil. Through field releases, the species was identified as the most successful biological control agent and since then, it has been considered as the key predator of CGM in the cassava belts of Africa (Yaninek et al. 1991; Yaninek et al. 1993; Hanna and Toko, 2003).

*Typhlodromulus aripo* was imported and released in East Africa in 1994. Following establishment, subsequent studies demonstrated the potential of *T. aripo* in increasing cassava production in both local and improved cassava (Karuki et al., 2004; Molo unpublished). This predator has unique ecological requirements that improve its efficiency in
controlling CGM. It inhabits the apex of cassava which is an adaptation to climatic extremes (Onzo et al. 2003; Yaninek and Hanna 2003) and all its reproduction occurs in the apex (Onzo et al., 2003). Studies by Zundel (2006) indicate that drought causes *T. aripo* to migrate from cassava apices to wild plants leading to reduction in predation of CGM prey on cassava. The East African region suffers frequent drought that facilitates proliferation of CGM population (Skovgard et al. (1993) Gnanvossou et al. (2001) and Magalhaes et al., (2002) also found that *T. aripo* has a high searching ability for CGM at very low prey densities which increases its efficiency as a biocontrol agent. Cassava varieties that sustain relatively low CGM population will facilitate biological by *T. aripo* at a faster rate. Appropriate cassava varieties that support low CGM populations and increase persistence of *T. aripo* on cassava are needed to facilitate biological control of CGM. The objective of this study was to identify cassava varieties to aid abundance and persistence of *T. aripo* on cassava and increase its efficiency in controlling CGM.

**Materials and Methods**

**Identification of cassava varieties for enhancing the efficiency of *T. aripo***

Nine cassava varieties including MM99005, MM990183, X-Mariakani from the eastern, Kaleso, Karibuni, Tajirika from coastal and MM97/3567, MM96/2480 and MM96/9308 from western Kenya were planted in screen houses in eastern lowlands, western midlands and the humid coastal lowlands regions of Kenya and maintained at 20.0 ± 2 °C and 63 ± 4% RH. Cassava green mites were collected from coastal Kenya lowlands and 10 individuals of CGM adult motiles were released on each cassava variety. On day five, after mite introduction, the numbers of CGM /leaf on each cassava variety were counted (Yaninek et al., 1989) every three days for up to 55 days. Leaf samples representing CGM damage scores on a scale 1-5 where 1 = no damage and 5 severe damage were picked in paper bags. They were brittle oven dried at 60 °C and weighed. The loss in leaf biomass was determined as weight difference between damaged and undamaged leaves. Cassava leaf cyanide (HCN mg/kg) content of CGM damage leaves at damage score 1-5 was determined by Picric Acid method.

**Assessing persistence and impact of *T. aripo* on cassava**

A follow up of previous field releases of *T. aripo* made in Uganda (1994-98) was conducted in April and December 2013 during the rainy and dry season respectively. Cassava fields were sampled every 5-10 km along major roads and in each field, 20 cassava plants were examined. CGM population was counted on the first fully opened leaf of each cassava plant. CGM leaf damage was assessed on a damage scale 1-5 where 1 = clean plants, 2= less than 75% of leaves showing chlorosis, and 3= over 75 % of leaves showing chlorosis. One cassava tip on each of the 20 plants was examined and *T. aripo* was recorded as present or absent. Five cassava tips were randomly decapitated from each field and put in vials containing 70 % alcohol. They were dissected in the laboratory under a binocular microscope and *T. aripo* actives were counted. One outer bract on each cassava tip was removed and placed under a dissecting microscope and the total number of hairs on it was counted. A total of 22 districts in five agro ecological zones were surveyed.

**Results**

**Cassava varieties for enhancing the efficiency of *T. aripo***

The CGM population increased with time and cassava varieties MM97/3567 sustained the lowest cumulative CGM population (300 mites /leaf) over a period of 55 days (Figure 1). The variety Tajirika (1146 mites /leaf) and MM96/9308 (1186 mites /leaf) sustained intermediate CGM population densities. The highest cumulative CGM population (1665.7 actives /tip) was on Mariakani.
Figure 1. Cumulative numbers of CGM on cassava varieties in Kenya

Cassava varieties, Kaleso, Karibuni and MM96/2480 showed the highest level of HCN in correspondence with high CGM densities. Meanwhile, the varieties MM97/3567, Tajirika and MM99005 showed the lowest cyanogenic potential of 8.5 ± 4.9, 12.5 ± 3.2 and 12.3 ± 2.5 mg/kg respectively (Figure 2). High leaf cyanide (HCN) content corresponded with higher leaf biomass loss (%).

Figure 2. Cyanide content (HCN mg/kg) and leaf biomass loss (%) for cassava varieties

Case letters denote significance (P< 0.05) levels
Persistence of *T. aripo* on cassava varieties and impact on CGM

The abundance of *T. aripo* on field collected tips of cassava varieties is shown in Figure 3. The cassava varieties with hairy and non hairy tips sustained *T. aripo* with population densities ranging between 0.08-1.0 actives /tip. The hairy cassava varieties included TME2961, NASE3, Akena, NASE12, NASE14 and TME14. Hair densities ranged from 1.02-1.67 hairs /bract) with the highest on TME14 and the lowest on TME2961. There were no hairs on the tips of Bao, NASE4 and TME204.

![Figure 3. Relationship between tip hairiness and abundance of *T. aripo* on cassava varieties](image)

**Vertical bars indicate standard errors**

Table 1 shows variability of CGM and *T. aripo* infestation on cassava varieties in various agro ecological zones. Highest CGM population densities were on NASE3 (1.89 mites /leaf) in Northern Moist Farmlands and NASE14 (2.07 mites /leaf) in the Southern and Eastern Lake Kyoga basin. Meanwhile the lowest CGM population densities were on TME2961 and Bao (0 mites leaf) and Akena (0.23 mites /leaf) in the Northern Moist Farmlands. There were no significant differences between varieties in CGM population at high and low densities. The population densities of *T. aripo* ranged from 0-0.33 actives /tip, but there were no significant differences in *T. aripo* population on cassava varieties in various agro ecological zones. There were variations among cassava varieties in the proportion of *T. aripo* infested plants with the highest percentage (50.77%) on NASE14 in the Western Medium High Farmlands and the lowest (0-11.25%) on TME2961, Bao, NASE12, TME14, TME204 and Akena in the Northern Moist Farmlands, TME204 in Northwestern Farmlands and NASE12, TME2961 and Akena in Western Medium High Farmlands.
### Table 1: Population densities of *T. aripo* on cassava varieties in various agro ecological zones during the beginning of first rains in April and end of second rains in December 2013

<table>
<thead>
<tr>
<th>Agro ecological zone</th>
<th>Variety</th>
<th>CGM density / leaf</th>
<th><em>T. aripo</em> density / tip</th>
<th>% <em>T. aripo</em> infested plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Moist Farmlands</td>
<td>TME2961</td>
<td>0° (0)</td>
<td>0.06° (0.15)</td>
<td>0° (0)</td>
</tr>
<tr>
<td>Bao</td>
<td>0° (0)</td>
<td>0.03° (0.08)</td>
<td></td>
<td>0° (0)</td>
</tr>
<tr>
<td>NASE12</td>
<td>0.58° (42.0)</td>
<td>0.07° (0.20)</td>
<td>10.37° (8.90)</td>
<td></td>
</tr>
<tr>
<td>NASE3</td>
<td>1.89° (66.88)</td>
<td>0.11° (0.33)</td>
<td>30.62° (33.32)</td>
<td></td>
</tr>
<tr>
<td>TME14</td>
<td>0.69° (8.77)</td>
<td>0.11° (0.41)</td>
<td>10.70° (11.17)</td>
<td></td>
</tr>
<tr>
<td>TME204</td>
<td>0.84° (60.03)</td>
<td>0.13° (0.6)</td>
<td>6.98° (2.93)</td>
<td></td>
</tr>
<tr>
<td>Akena</td>
<td>0.23° (25.3)</td>
<td>0° (0)</td>
<td></td>
<td>15.00° (6.7)</td>
</tr>
<tr>
<td>Northwestern Farmlands</td>
<td>TME204</td>
<td>0.52° (4.0)</td>
<td>0.02° (0.05)</td>
<td>11.25° (12.5)</td>
</tr>
<tr>
<td>Southern and eastern Lake Kyoga basin</td>
<td>NASE3</td>
<td>1.28° (31.07)</td>
<td>0.16° (0.65)</td>
<td>21.06° (17.12)</td>
</tr>
<tr>
<td>TME14</td>
<td>0.92° (14.64)</td>
<td>0.33° (1.70)</td>
<td>34.73° (40.34)</td>
<td></td>
</tr>
<tr>
<td>TME204</td>
<td>0.71° (52.6)</td>
<td>0.03° (0.07)</td>
<td>12.09° (11.67)</td>
<td></td>
</tr>
<tr>
<td>NASE14</td>
<td>2.07° (264)</td>
<td>0.24° (1.0)</td>
<td>18.91° (10.65)</td>
<td></td>
</tr>
<tr>
<td>Akena</td>
<td>1.12° (158.32)</td>
<td>0.24° (0.90)</td>
<td>18.75° (23.33)</td>
<td></td>
</tr>
<tr>
<td>West Nile Farmlands</td>
<td>TME204</td>
<td>0.33° (0.63)</td>
<td>0.17° (1.0)</td>
<td>40.61° (42.5)</td>
</tr>
<tr>
<td>Western Medium High Farmlands</td>
<td>TME14</td>
<td>0.70° (10.33)</td>
<td>0.22° (1.23)</td>
<td>43.32° (50.0)</td>
</tr>
<tr>
<td>NASE12</td>
<td>0° (0)</td>
<td>0° (0)</td>
<td>0° (0)</td>
<td></td>
</tr>
<tr>
<td>TME2961</td>
<td>0.36° (20.0)</td>
<td>0° (0)</td>
<td>0° (0)</td>
<td></td>
</tr>
<tr>
<td>NASE14</td>
<td>0.36° (18.37)</td>
<td>0° (0)</td>
<td>50.77° (60.0)</td>
<td></td>
</tr>
<tr>
<td>Akena</td>
<td>1.40° (20.0)</td>
<td>0° (0)</td>
<td>0° (0)</td>
<td></td>
</tr>
</tbody>
</table>

**NB** Figures in parentheses are actual numbers of CGM and *T. aripo* for log x+1 transformed values and actual percentages for arcsine transformed values for percentage *T. aripo* infested plants; Figures with same superscript letters within a column are not significantly different.

At various CGM leaf damage levels, CGM and *T. aripo* population densities varied among cassava varieties (Table 2). At damage score 1, cassava varieties differed significantly (df 100, F= 5.32; P= < 0.0001) with the lowest CGM densities (0-0.07 mites /leaf) on Bao, TME2961 and NASE12 while the highest CGM densities (1.42 actives /leaf) were on NASE3. TME204, TME14, Akena and NASE14 sustained intermediate CGM population densities ranging from 0.59-0.70 actives /leaf with no significant variation among the population densities. The population densities of *T. aripo* ranged from 0-0.24 actives /tip but they did not differ significantly (df 100, F= 1.00; P > 0.452) among the cassava varieties. At CGM damage score 2, cassava varieties also differed significantly (df 44, F= 2.79; P<0.022) in population densities of CGM. The highest CGM densities (0.83-0.97 mites /leaf) were on NASE3 and TME14 and the lowest (0.23-0.39 mites /leaf) were on NASE12 and TME204. Intermediate CGM population densities (0.70-0.81 mites /leaf) were on Akena and NASE14 but the differences were not significant. The population densities of *T. aripo* ranged from 0-0.29 actives /tip but there was no significant difference in *T. aripo* population densities among the cassava varieties (df 44, F=1.43; P>0.225). At high CGM damage score 3, CGM population densities were
significantly highest (2.30-2.41 mites /leaf) on Akena and TME204 and lowest on NASE3, NASE12, and TME14 (1.64-1.82 mites /leaf). Population densities of CGM were intermediate on NASE4 (2.07 mites /leaf). The population densities of *T. aripo* ranged from 0-0.34 actives /tip but there were no significant differences among cassava varieties on the population densities of *T. aripo*.

**Table 2: Population densities of *T. aripo* and CGM on cassava varieties at various CGM leaf damage scores**

<table>
<thead>
<tr>
<th>Variety</th>
<th>CGM leaf damage levels</th>
<th>Score 1</th>
<th>Score 2</th>
<th>Score 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SE</td>
<td>Mean ± SE</td>
<td>Mean ± SE</td>
<td>Mean ± SE</td>
</tr>
<tr>
<td>CGM</td>
<td>T. aripo</td>
<td>CGM</td>
<td>T. aripo</td>
<td>CGM</td>
</tr>
<tr>
<td>Bao</td>
<td>0.0 ± 0.0b</td>
<td>0.03 ± 0.01a</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TME2961</td>
<td>0.07 ± 0.02b</td>
<td>0.05 ± 0.01a</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>NASE12</td>
<td>0.05 ± 0.04b</td>
<td>0.05 ± 0.04a</td>
<td>0.23 ± 0.18b</td>
<td>0.0 ± 0.0a</td>
</tr>
<tr>
<td>TME204</td>
<td>0.59 ± 0.48ab</td>
<td>0.09 ± 0.07a</td>
<td>0.39 ± 0.37b</td>
<td>0.07 ± 0.03a</td>
</tr>
<tr>
<td>NASE3</td>
<td>1.42 ± 0.47a</td>
<td>0.15 ± 0.13a</td>
<td>0.97 ± 0.35a</td>
<td>0.17 ± 0.14a</td>
</tr>
<tr>
<td>TME14</td>
<td>0.79 ± 0.46ab</td>
<td>0.29 ± 0.26a</td>
<td>0.83 ± 0.47a</td>
<td>0.29 ± 0.26a</td>
</tr>
<tr>
<td>Akena</td>
<td>1.32 ± 0.63ab</td>
<td>0.17 ± 0.13a</td>
<td>0.81 ± 0.25ab</td>
<td>0.05 ± 0.03a</td>
</tr>
<tr>
<td>NASE14</td>
<td>0.70 ± 0.63ab</td>
<td>0.24 ± 0.13a</td>
<td>0.70 ± 0.31ab</td>
<td>0.24 ± 0.12a</td>
</tr>
<tr>
<td>NASE4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.07 ± 0.21ab</td>
</tr>
</tbody>
</table>

(-) not applicable for the CGM damage score; Scores: 1= less than 25 % of leaf surface with chlorosis; 2= more than 25% but less than 75 % of leaf surface with chlorosis, and 3= over 75 % of leaf surface with chlorosis; Figures with same superscript letters within a column are not significantly different.

A linear regression of abundance of CGM and *T. aripo* was performed to assess the importance of cassava varieties in sustaining *T. aripo* (Table 3). At CGM leaf damage score 1, Bao demonstrated a significant inverse relationship of abundance of CGM and *T. aripo* (Table 3). In several other varieties, increasing CGM population densities were linked to increasing *T. aripo* population and vice versa but these were not significant. At CGM leaf damage score 2, increasing CGM population densities were linked to increasing *T. aripo* population and vice versa but these were not significant. But at CGM leaf damage score 3, NASE3 and TME14 demonstrated significant inverse relationships of abundance of CGM and *T. aripo*. In other varieties, increasing CGM population densities were linked to increasing *T. aripo* population and vice versa but these were not significant (Table 3).

**Table 3: Linear regression statistics of abundance of CGM on *T. aripo* on cassava varieties at various CGM leaf damage scores**

<table>
<thead>
<tr>
<th>Variety</th>
<th>Regression coefficients</th>
<th>t-value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Akena</td>
<td>0.03</td>
<td>0.27</td>
<td>0.789</td>
</tr>
<tr>
<td>Bao</td>
<td>-0.30</td>
<td>-2.06</td>
<td>0.042*</td>
</tr>
<tr>
<td>NASE12</td>
<td>-0.25</td>
<td>-1.90</td>
<td>0.060</td>
</tr>
</tbody>
</table>
## Discussion

In the cassava varietal screening trial, cassava varieties showed high tolerance levels to CGM as indicated by the low cumulative pest density on MM97/3567 and Tajirika. Resistance level of cassava varieties also increased with low cyanide levels on cassava leaves and the most susceptible varieties showed the highest cyanide levels. Chemical plant attributes have been shown to influence the abundance, fecundity and survival rate of insect herbivores in various crops (Cortesero et al., 2000). In other studies elsewhere (Riis et al., 2003), high cyanide levels have been shown to predispose plants to insect attack through increased feeding but reduces multiplication rate of insect herbivores. Basing on the results from this study, the cassava varieties with low cyanide levels have been found to harbour low CGM population densities. Therefore one way to improve the effectiveness of *T. aripo* is to use cassava varieties with low cyanide levels such as MM97/3567 to reduce the multiplication rate of CGM and under low CGM population densities, *T. aripo* can adequately bring CGM population under control.

As shown in Figure 3, several hairy cassava varieties sustained high population of *T. aripo*. Based on tip characteristics, it was clear that hairiness contributed immensely to abundance of *T. aripo* on the cassava varieties. Hairy cassava tips are probably preferred by *T. aripo* because they offer several advantages. Hairs on plant tips have been associated with maintaining high humidity levels (Johnson, 1975) and preference of hairy cassava tips by *T. aripo* may due higher humidity levels inside the cassava tips which shield *T. aripo* from dehydration. During encounter with prey, insect predators also use hairs on the leaves for support (MacRae and Croft, 1997) and hairy cassava tips found in the present study may provide suitable habitats for *T. aripo* to adequately exploit CGM prey. There was evidence in this study that cassava varieties with non hairy cassava tips (glabrous) also sustained high population of *T. aripo*.  

### Table 1

<table>
<thead>
<tr>
<th>Variety</th>
<th>Regression coefficients</th>
<th>t- value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASE14</td>
<td>-0.09</td>
<td>-0.77</td>
<td>0.441</td>
</tr>
<tr>
<td>NASE3</td>
<td>0.16</td>
<td>0.61</td>
<td>0.542</td>
</tr>
<tr>
<td>NASE4</td>
<td>0.16</td>
<td>1.41</td>
<td>0.162</td>
</tr>
<tr>
<td>TME14</td>
<td>-0.26</td>
<td>0.87</td>
<td>0.388</td>
</tr>
<tr>
<td>TME204</td>
<td>0.23</td>
<td>-1.10</td>
<td>0.276</td>
</tr>
<tr>
<td>TME2961</td>
<td>-0.28</td>
<td>-1.94</td>
<td>0.056</td>
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</tbody>
</table>

**Score 2**

<table>
<thead>
<tr>
<th>Variety</th>
<th>Regression coefficients</th>
<th>t- value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akena</td>
<td>0.26</td>
<td>1.03</td>
<td>0.309</td>
</tr>
<tr>
<td>NASE12</td>
<td>-0.04</td>
<td>-0.25</td>
<td>0.806</td>
</tr>
<tr>
<td>NASE14</td>
<td>0.16</td>
<td>0.74</td>
<td>0.465</td>
</tr>
<tr>
<td>NASE3</td>
<td>0.54</td>
<td>1.53</td>
<td>0.133</td>
</tr>
<tr>
<td>TME14</td>
<td>0.57</td>
<td>1.22</td>
<td>0.230</td>
</tr>
<tr>
<td>TME204</td>
<td>0.03</td>
<td>0.08</td>
<td>0.938</td>
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</table>

**Score 3**

<table>
<thead>
<tr>
<th>Variety</th>
<th>Regression coefficients</th>
<th>t- value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>AKENA</td>
<td>0.11</td>
<td>0.327</td>
<td>0.746</td>
</tr>
<tr>
<td>NASE3</td>
<td>-0.48</td>
<td>-2.360</td>
<td>0.026*</td>
</tr>
<tr>
<td>NASE4</td>
<td>-0.23</td>
<td>-0.856</td>
<td>0.400</td>
</tr>
<tr>
<td>NASE12</td>
<td>-0.56</td>
<td>-1.687</td>
<td>0.104</td>
</tr>
<tr>
<td>TME14</td>
<td>-0.66</td>
<td>-3.130</td>
<td>0.004*</td>
</tr>
</tbody>
</table>

*indicates values were significant for the cassava varieties at P<0.05
Naturally, some cassava varieties produce exudates and this substance has been found to be an important food for *T. aripo* (Onzo *et al.*, 2003) that could provide a resource for survival on the cassava plants. Similarly, it been reported that *T. aripo* survives, develops and oviposits on pollen diet (Gnanvossou *et al.*, 2005) and probably the hairy apices of some cassava varieties contribute to better trapping of pollen grains (Roda *et al.*, 2003) from wild plants which provide alternative food sources with commensurate effects on survival, longevity and fecundity of *T. aripo*. The influence of hairs on phytoseiids has also been reported in other plant species apart from cassava (Romero and Benson, 2005).

This study showed that *T. aripo* released in Uganda from 1994-98 could still be recovered on cassava in 2013. At leaf damage score 1, there was an inverse significant linear relationship between CGM and *T. aripo* population densities on Bao. This relationship indicated that the CGM densities at leaf damage score 1 were sufficiently low for *T. aripo* to deplete CGM, demonstrating the impact of *T. aripo*. But as stated by Hopper and King (1986) and Wiedenmann and Smith (1993), this linear relationship is applicable only under a range of low host densities as occur for CGM on cassava during the rainy season (Yanninek *et al.* (1989). However, at CGM leaf damage score 3, which was an indicator of very high CGM population densities, there were significant inverse linear relationships between CGM and *T. aripo* on NASE3 and TME14. Because of the higher CGM population densities that occur during the dry season, the two cassava varieties have been identified to be the most promising candidates for CGM biological control involving *T. aripo*.

**Conclusion and recommendations**

From these studies, it is evident that cassava varieties will be deployed extensively in the East African region to sustain biological control of *T. aripo*. Cassava varieties that are tolerant to CGM have been identified based on cyanogenic levels. Releasing *T. aripo* on tolerant cassava varieties will accelerate control of CGM with *T. aripo*. Two cassava varieties in Uganda, NASE3 and TME14 were found to have high densities of hairs on cassava tips which corresponded with high *T. aripo* population densities. The significant inverse linear relationships observed in this study between CGM and *T. aripo* at high CGM population densities, suggest that *T. aripo* can drastically reduce CGM population at high CGM densities. These cassava varieties have been selected particularly for use during the dry season when high densities of CGM occur on cassava. Also based on other findings that cassava varieties possess hairy tips that conserve *T. aripo* on cassava and that MM97/3567, Tajirika and MM96/9308 possess low cyanide levels that confer tolerance to CGM, the cassava varieties identified in Kenya together with NASE3 and TME14 in Uganda have been recommended to enhance biological control of CGM with *T. aripo*, provided that farmers are satisfied with their agronomic performance. These varieties can be planted as sole crops or as mixtures with other susceptible cassava varieties where they can provide refuge for *T. aripo* in cassava fields.

**Acknowledgement**

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**References**


Weed flora of cassava in northern, mid western and west Nile zones of Uganda

Kawooya, R.1*, Wamani, S.2, Magambo S.3 and Nalugo R.4

1 National Crops Resources Research Institute (NaCRRI), P.O. Box 7084, Kampala, Uganda; 2 Ngetta Zonal Agricultural Research and Development Institute, P.O. Box 52 Lira, Uganda; 3 Bulindi Zonal Agricultural Research and Development Institute, P.O. Box 101 Hoima, Uganda; 4 Abi Zonal Agricultural Research and Development Institute, P.O. Box 219 Arua, Uganda.

*Correspondence: kawoox@yahoo.co.uk

Abstract

Information on the effect of weeds on cassava is limited. Most lists of weeds that are available were not crop based. This study was conducted during the second season of 2013 at three Zonal Agricultural Research Development Institutes (ZARDIs) namely; AbiZARDI in Arua, NgeZARDI in Lira and Bulindi ZARDI in Hoima. Weed densities were estimated from quadrant of (1m × 1m) with 5 samples taken systematically along diagonal transects in each cassava field. Total number of weed species were counted and recorded. Broad leaved weeds were counted per quadrant, identified and recorded. Grasses were also counted, identified and recorded. Common names of different broad leaved or grass weeds got per quadrant were recorded with their respective numbers per quadrant. 5 quadrant samples were taken per acre. Results indicate that grass weed species were the most frequent averaging 55.01% of the entire weed species. Five weed species namely Couch grass, Spear grass, Wandering jew, Guinea grass and Goat weed commonly occurred in the area surveyed. Importantly, this study has formed the basis for selection of feasible and safe options for control of cassava weeds in Uganda. The information will help both smallholder and commercial cassava growers achieve sustainable increases in their productivity and incomes through the development and adoption of improved weed control methods.

Key words: Agro ecological zones, cassava, weed

Introduction

Weeds in Uganda like the rest of Africa are a key recalcitrant of all crop pests, proliferating each year on every farm (Obuo et al., 1998). Weed problems are more severe in African tropical regions than in temperate Europe and North America because the tropical environment favors their fecundity. Weeds grow more vigorously and regenerate more quickly because of the heat and high light intensity. Higher humidity and high temperature that are, conditions characteristic of sub-Saharan Africa, favor rapid and excessive weed growth (Akobundu, 1980). African soils contain 100 to 300 million buried weed seeds per hectare of which a fraction germinate and emerge each year. Indeed, a review of crop pests in sub-Saharan Africa indicated that weeds are the most important pest to effectively control in all zones studied (Sibuga, 1997). Over 286 species of common weeds have been identified in crop fields in some West African countries (Njoku, 1996). In Uganda and the rest of East Africa, limited information exists on the weed flora of cassava and yet they are a major obstacle to cassava productivity (http://www.fao.org/docrep/009/a0154e/a0154e10.htm). In response to this challenge, a study was initiated to document the status of weed flora in selected cassava growing regions of Uganda, information of which can be used to design interventions for sustainable weed control in cassava growing communities.
**Materials and methods**

The study was conducted at three Zonal Agricultural Research Development Institutes (ZARDIs) namely; AbiZARDI in Arua, NgeZARDI in Lira and Bulindi ZARDI in Hoima, during the second season of 2013. Weed densities were estimated from quadrant of (1m × 1m) with 5 samples taken systematically along diagonal transects in each cassava field. Total number of weed species were counted and recorded. Broad leaved and grasses weeds were counted per quadrant, identified and recorded. Common names of different broad leaved or grass weeds got per quadrant were recorded with their respective numbers per quadrant. Five quadrant samples were taken per acre. The area surveyed was 10 acres from each of the surveyed ZARDI respectively. Data showing the relative frequencies of weeds was analyzed using GenStat 14th Edition statistical package.

**Results and discussion**

Preliminary findings indicate that grass weed species were the most frequent weeds in all the surveyed areas at Lira, Arua and Hoima, averaging 55% of the entire weed species recorded and the rest (45%) were broad-leaved species (Figure 1). On the contrary similar studies conducted in South Western Nigeria, Onochie (1975) observed that annual weeds especially broad leaved ones were the most common in cassava fields.

**Figure 1:** Overall frequency of weeds number per acre prevalent in cassava fields in northern, mid-western and west Nile regions of Uganda

Five weed species namely *Digitaria abyssinica* (African couch grass), *Imperata cylindrica* (Spear grass), *Commelina benghalensis* (Wandering Jew), *Panicum maximum* (Guinea grass) and *Ageratum conyzoides* (Goat weed or White weed or Chick weed) occurred in the entire area surveyed at the three ZARDIs (Figure 2). The other weed species varied from one ZARDI to the other. Most of the weeds recorded were among those regarded as “the world’s worst” (Melifonwu, 1994).
Conclusion
This study identified that both broad-leafed and grasses are prevalent in cassava fields in northern, mid-western and west Nile regions of Uganda. This should form the basis for selection of feasible and safe options for control of cassava weeds in Uganda. The information will help both smallholder and commercial cassava growers achieve sustainable increases in their productivity and incomes through the development and adoption of improved weed control methods.

Acknowledgement
This study was supported with funding from the Eastern Africa Agricultural Productivity Project (EAAPP).

References


IV. Value Addition and Socio-Economics

Quality and safety characteristics of cassava crisps sold in Mombasa and Nairobi, Kenya

Abong’ G.O.¹, Shibairo, S.I.¹, Okoth, M.W.¹, Lamuka, P.O.¹, Katama C.K.² and Ouma J.¹

¹University of Nairobi, P. O. Box 29053-00625, Nairobi; ²Kenya Agricultural and Livestock Research Organization, Mwapa, P.O. Box 16-80109 Mwapa.
*Correspondence: georkoyo@yahoo.com

Abstract

Cassava crisps are increasingly becoming popular in Kenya’s coastal city of Mombasa and selected areas of Nairobi. Crisps are popularly consumed as snacks out of homes and in-between meals. However, little research on the quality and safety of the crisps has been undertaken on the new snack. The current study sought to characterise the quality and safety in terms of cyanide levels of cassava crisps commercially traded in Mombasa and Nairobi. Samples of six commercially traded crisps brands were collected in duplicate from vendors and supermarkets and evaluated for moisture, oil, cyanide and sodium chloride contents. Product colour and texture were also evaluated objectively using colour meter (CIALAB, L*, a*, b* parameters) and texture analyser (Newton Force). The results indicate that there were significant differences among brands in moisture content (P=0.0001), oil content (P<0.0001) and cyanide content (P=0.026). Variation of sodium chloride was, however, insignificant (P=0.07). Moisture content ranged from 4.3 to 6.77%, oil content ranged from 19.17 to 30.68% while cyanide and salt contents ranged 13.5ppb to 32.24 ppb and 2.3% to 2.7%, respectively. There were no significant differences (P=0.57) in the texture of the crisps samples as well as in the yellowness (b*) parameter (P=0.137). On the other hand, significant differences were observed on colour lightness (L*) parameter (p=0.0016) and the redness (a*) parameter (P=0.021). Moisture and cyanide levels exceeded the statutory limits and hence may constitute potential health risk to the consumer. Processing methods that render cassava crisps safer should be developed and processors trained on the same.

Key words: cassava crisps, cyanide, oil content

Introduction

The contribution of cassava to food security and incomes for rural communities in sub-Saharan Africa cannot be overemphasized (Ferris et al., 2001). However, due to its short post-harvest shelf life, cassava roots need to be processed within 24 hours of harvest to reduce losses. More stable products such as fermented and non-fermented flours, sun dried chips, starches and culinary products have been made from cassava (Achacha, 2001; Makokha, 2001). Highly stable fried crisps have for instance become important snacks especially in major urban cities of Mombasa and Nairobi consumed by people of diverse backgrounds. The quality of crisps depends on a number of factors such as frying temperature, slice thickness and oil used (Abong’ et al., 2011). It is however, not known to what extent there are quality and food safety variations in cassava crisps currently sold in urban centres of Kenya.
Depending on the variety, cassava contains varying amounts of cyanogenic glucosides that may pose serious health risks when consumed in high quantities (Wangari, 2013). Deep oil frying, just like other modes of processing, is known to reduce cyanogenic compounds (Brimer et al., 2013). As to whether the crisps currently in the market have safe cyanide levels as set by World Health Organization (WHO) at <10 mg/kg (FAO/WHO, 1991) is not known. The current study was designed to assess quality characteristics as well as safety in terms of cyanide levels of cassava crisps commercially traded in Mombasa and Nairobi in Kenya.

**Materials and methods**

**Study area and sampling**

A cross-sectional survey was undertaken in Mombasa and Nairobi Counties of Kenya between February and April 2014. Mombasa and Nairobi were purposively selected due to the existence of relatively large number of cassava farmers and notable processing activities. Due to the limited number of cassava crisps processors known to exist, exhaustive sampling of the different brands of crisps was carried out within the two counties, including purchases from retail outlets and street processors. About six samples were purchased in duplicates of 100 g and analysed for cyanide content, moisture content, salt content, oil content, colour and texture variations. Three brands of cassava crisps were purchased from Nairobi and Mombasa in each case.

**Laboratory analyses**

Moisture content was determined by drying in forced air oven at 105 °C as described by Abong’ et al. (2011). The oil content was determined by extraction of about 2.5 g of finely ground samples in Soxhlet apparatus for 8 hours using analytical grade petroleum ether (boiling point 40-60 °C) as described by Abong’ et al. (2011). Salt (NaCl) content was determined using the modified FAO/WHO method No. 16.209 (AOAC, 1980) as described by Abong’ et al. (2010). Cyanide (HCN) levels in cassava crisps samples were determined by distillation followed by alkaline titration as described by AOAC (1980), official method 915.03B. Cassava crisps colour was determined as described by Abong’ et al. (2011) using the CIE Lab L*, a* and b* scale, with L* indicating lightness, a* indicating redness and b* indicating yellowness degree. Cassava crisps texture was measured using a texture analyser (Sun Rheometer Compac 100, Sun Scientific, Japan) as described by Abong’ et al. (2011).

**Data analysis**

Data were subjected to analysis of variance (ANOVA) and means separated by Duncan Multiple Range Test using Statistical Analysis System (SAS version 9). Pearson correlation was performed between moisture content and texture.

**Results and discussion**

**Physical quality of cassava crisps**

Moisture content ranged from 4.3 to 6.77% on a wet weight basis, with only two samples having the recommended moisture levels of less than 5 % (EAS, 2010) as indicated in Figure 1. There were significant differences in moisture content (P=0.0001) among crisps brands. On the other hand, there were no significant
differences (P=0.57) in texture. Moisture content as essential when considering shelf-life of any food or feed. Most high moisture foods are highly perishable given the fact that abundant water supports microbial growth and other chemical reactions (Sewald, 2014). Low moisture foods such as crisps are therefore long lasting and hence the lower limit of moisture set for similar products. High moisture contents in the current samples may be a pointer to poor handling after processing or inadequate dehydration during frying. Choice of packaging material may also contribute to high moisture content. Highly permeable material or improper sealing may contribute to higher moisture and hence lower shelf-life than anticipated (Tungsangprateep, 2003; Amadi and Adebola, 2008). Crisps texture is determined by dry matter content, moisture content and processing parameters such as time and temperature (Kulchan, 2010). Low temperature exposes slices to longer frying time and hence affect texture - being soft if variety is of low dry matter content and hence soggy product or hard if variety has high dry matter content. In the current study, moisture content had insignificant correlation (r=-0.22, P>0.05) with texture. Texture values were generally higher than potato crisps values reported by Abong’ et al. (2010).

Figure 1: Moisture content (%) and texture (Newton force) of crisps samples from Nairobi and Mombasa Kenya. The bars indicate standard errors. Cassavanbi=samples from Nairobi, Cassavamsa=samples from mombasa

Crisps samples differed significantly in colour lightness (L*) (P=0.0016) and the redness (a*) (P=0.021). There was, however no significant difference (P=0.137) in the yellowness (b*) (Table 1). The lightness parameter >70 indicate most of the crisps are white-cream meaning the raw cassava colour changed to a small extent under the frying conditions. On the other hand, the negative redness values indicate lack of browning or redness and hence crisps can be considered to have nil or minimal acrylamide formation. At the same time, the yellowness parameter (b*) values obtained indicate yellowing to a certain degree. These results differ significantly with those of most potato crisps that usually display higher redness and yellowness values (Abong’ et al., 2010; Abong’ et al., 2011). This difference can be attributed to the differences in raw materials which have profound differences in chemical composition. Response to cassava crisps by the consumers may therefore not be considered similar as colour gives the first external expression of food product and determines its likability.
Table 1: Colour characteristics of cassava crisps in Nairobi (N=3) and Mombasa (N=3) Kenya

<table>
<thead>
<tr>
<th>Sample</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cassavanbi1</td>
<td>71.45 ± 0.08</td>
<td>-0.53 ± 0.08</td>
<td>17.47 ± 0.08</td>
</tr>
<tr>
<td>Cassavanbi2</td>
<td>69.60 ± 1.96</td>
<td>-0.35 ± 0.12</td>
<td>17.68 ± 1.76</td>
</tr>
<tr>
<td>Cassavanbi3</td>
<td>71.13 ± 0.41</td>
<td>-0.52 ± 0.20</td>
<td>16.92 ± 1.27</td>
</tr>
<tr>
<td>Cassavamsa1</td>
<td>72.48 ± 1.05</td>
<td>-0.60 ± 0.40</td>
<td>14.78 ± 1.75</td>
</tr>
<tr>
<td>Cassavamsa2</td>
<td>74.70 ± 1.90</td>
<td>-0.87 ± 0.29</td>
<td>16.32 ± 1.95</td>
</tr>
<tr>
<td>Cassavamsa3</td>
<td>72.92 ± 3.53</td>
<td>-0.87 ± 0.43</td>
<td>15.97 ± 3.34</td>
</tr>
</tbody>
</table>

Values are means of duplicate measurements.

Cassavanbi=samples from Nairobi, Cassavamsa=samples from Mombasa

Chemical properties

Significant differences were observed in oil content (p<0.0001) and cyanide content (p=0.026) (Figure 2). Variation of sodium chloride was, however, insignificant (p=0.07). Oil contents ranged from 19.17% to 30.68% and were mostly within the East African Standards requirement of not >30% and are relatively low compared to those of potatoes (Abong’ *et al.*, 2010), while all the tested samples had levels of cyanide (13.5 to 32.24 mg/kg) above the recommended maximum value of 10 mg/kg and the salt content ranged from 2.3% to 2.7%, all samples being above the recommended maximum level of 2% (EAS, 2010).

Figure 2: Residual Cyanide (mg/kg), oil (% wwb) and sodium chloride (% wwb) contents of cassava crisps from Nairobi and Mombasa Kenya. The bars indicate standard errors. Cassavanbi=samples from Nairobi, Cassavamsa=samples from Mombasa.

Oil content is an important processing parameter and its level in a food product has a number of implications. Higher oil content means more oil is used as an ingredient, which is quite expensive in most cases (Abong’ *et al.*, 2010). Due to consumption trends and nutrition knowledge, high oil products are also likely to be shunned by health conscious consumers given the link between fat type and coronary diseases (Hu *et al.*, 2010).
High amount of oil in food products also has a negative impact on the shelf life - reducing shelf life due to possible rancidity. On the other hand, quite low oil content may lead to very hard and not appealing crisps just as much as very high oil content leads to sogginess and hence product rejection. Processing parameters must therefore be chosen to optimize the oil content of an individual product.

Cyanide in cassava is one of the key toxicants that hinder its utilization and it occurs in both sweet and bitter varieties in varying amounts (Wangari, 2013). Acute cyanide intoxication can lead to death if not treated, while chronic intoxication has been linked to goitre and nervous diseases (Rosling, 1994). Due to its lethal effect in human beings, the World Health Organization and many food standard setting organizations such as the East African Community (East African Standards) stipulate that cassava products ready for consumption should have less than 10 mg/kg cyanide. None of the crisps sampled could therefore be considered safe for consumption as far as cyanide is concerned. However, this has to be determined based on the level of consumption of cassava crisps. The current processing parameters that are mainly uncontrolled temperatures are therefore insufficient to eliminate cyanide to safe levels despite the fact that sweet varieties are used.

High salt content consumption that is mainly through food has been linked to high blood pressure and hence stroke and other cardiovascular diseases (He, 2001). The practice therefore worldwide is to reduce salt intake (Campbell et al., 2012). Higher than the regulated salt levels indicated in the current study means processors do not observe or are not aware of the required limits. Awareness creation among the processors may therefore be important towards safe and quality cassava crisps.

**Conclusion**

Current cassava crisps in Nairobi and Mombasa generally have higher moisture, cyanide and sodium chloride contents than the values stipulated by the existing standards and may raise safety concerns. The quality of the cassava crisps in terms of colour and texture is not uniform. The requisite quality and safety of the products may be achieved through proper training of the processors on methods that reduce cyanide to acceptable levels.

**Acknowledgement**

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Discussion Session

Question: What is the desired colour of cassava? Are there are different varieties with different colours?
Answer: Colour is consumer determined, only need to be acceptable.

Question: Cyanide content is a big concern. Have you involved KEBS and engaged the public media?
Answer: Yes, but we have to get solutions first rather than being alarmists.

Question: A sample size of 6 is too small. Why this small number?
Answer: I indicated that we did exhaustive sampling. This is all we could find.

Question: You indicated that cassava crisps had high levels of cyanide than the statutory limits then you recommended that the processors should be trained. Are those crops safe to eat?
Answer: Certainly, not at the high levels of consumption. This will be concluded in the fourth study on intake in 2-3 months.

Question: What cassava varieties were used for crisps for better understanding of the high cyanide levels recorded?
Answer: Varieties varied with area and some processors did not know the variety name; but all sampled were the sweet types.

Question: What are the strategies that you have developed to reduce cyanide content?
Answer: These strategies are discussed in another paper and include variations in slice thickness and frying temperature. Introduction of blanching and fermentation is also helpful. The technology is at an advanced stage of refining.

References


Microbiological safety and quality of dried cassava chips and flour sold in Mombasa and Nairobi in Kenya


1 University of Nairobi, P. O. Box 29053-00625, Nairobi; 2 Kenya Agricultural and Livestock Research Organization, P. O. Box 16-80109 Mtwapa.

*Correspondence: gacherupatrick@gmail.com

Abstract
Cassava is rich in carbohydrates and is the third most important source of calories, in the tropics. The handling and processing practices expose it to microbial contamination. Samples from Nairobi and Coastal region of Kenya were evaluated for: Total count, Staphylococcus aureus, total coliforms, mould and E. coli to establish their safety and quality for human consumption. Results for dried cassava chips showed; TVC 5.16-8.04 log cfu/g; 4.81-7.21 log cfu/g, mould 1.00-3.86 log cfu/g; 1.00-3.28 log cfu/g and Staphylococcus aureus 2.69-4.36 log cfu/g; 2.90-4.71 log cfu/g for Nairobi and Coastal region respectively. Cassava flour was; TVC 5.66-7.67 log cfu/g; 5.92-8.12 log cfu/g, mould 1.00-6.73 log cfu/g; 2.65-5.08 log cfu/g, Staphylococcus aureus 3.77-5.79 log cfu/g; 1.00-5.73 log cfu/g, and coliforms 0-6.34; 2.00-6.27 log cfu/g for Nairobi and Coastal regions respectively. One sample tested positive for presence of Staphylococcus coli. Eighty seven percent (87%) of cassava flour and 77% of dried cassava chips samples were confirmed for presence of Staphylococcus aureus. There was a significant (P≤0.05) difference in the microbial counts. Results indicate excessive manual handling and poor post-harvest handling practices of products hence they are of poor quality and unsafe for consumption. Proper training on good practices should be given to processors. Alternative hygienic drying methods for cassava are also recommended.

Key words: cassava flour, cassava chips, contamination

Introduction
Cassava (Manihot esculenta Crantz) contributes a lot to increasing food security and generating incomes and employment opportunities in the rural areas. Most of the cassava is produced by small scale farmers using traditional farming systems (Githunguri et al., 2007). About 38% of the cassava produced in the coastal lowlands of Kenya is consumed at household level and 51% of the farmers make dried chips for domestic use, sale to starch and feed factories or as an intermediate for production of flour (Kiura et al., 2005). Physiological reactions and activities of microorganisms that enter bruises caused during harvesting promote unfavourable biochemical changes and microbial deterioration in cassava. Traditional processing of cassava chips and flour is often done under unhygienic conditions. The chips are sun dried in the open surfaces such as flat rocks, roads, flat rooftops, flat baskets, or bare ground (FAO, 2005). Storage conditions after drying may also be of high humidity thus reversing the gains acquired during drying. Unhygienic conditions during production, storage and slow sun drying especially during the rainy season, often results in bacteria and mould contamination (Chiona et al., 2014) like Aspergillus species that produce
aflatoxins which are a major health concern to humans and livestock (Manjula et al., 2009). The presence of *Staphylococcus aureus* and *Escherichia coli* indicates unhygienic standards, excessive personnel handling and use of poor quality water during processing, post-processing handling and marketing (Obadina *et al*., 2008). The objective of the current study was to analyse the level of contamination of cassava products that are in the market and available to consumers so as to assess the quality and safety of these products for human consumption.

**Materials and Methods**

**Sampling**

Markets were identified in Coastal (Mombasa) and Nairobi regions for their large consumer population. Sampling was purposive and the number of samples collected was according to availability, thus ensuring exhaustive sampling. Thirteen (13) dried cassava chips and 23 cassava flour samples were purchased from the selected markets in the study sites.

**Microbial determination**

Total viable counts (TVC), yeast and moulds, *S. aureus*, total coliforms and confirmatory tests were done according to Harrigan and McCance (1976).

**Results and discussion**

The standards Codex 176-1989 (CAC, 2013); EAS 739: 2010; cassava chips specification and EAS 740: 2010; on cassava flour specification set acceptable microbiological limits to be met that is; total viable count of 5.00 log cfu/g, mould maximum limit of 3.00log cfu/g, *S. aureus* limits 2.00log cfu/g. coliforms should be absent from the foods.

Table 1 shows results of microbial counts of dried cassava chips sampled from different traders in the two study sites; Nairobi and Mombasa. The dried cassava chips samples from Nairobi were from Gikomba market and Kawangware markets while in Mombasa they were from Kongowea and Majengo markets.

**Table 1: Microbial Count (log cfu/g) in Dried Cassava Chips Sourced from Nairobi and Coastal Region**

<table>
<thead>
<tr>
<th>Sample/Market</th>
<th>Region</th>
<th>TVC (log cfu/g)</th>
<th>Mould (log cfu/g)</th>
<th><em>Staphylococcus aureus</em> (log cfu/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIK 1</td>
<td>Nairobi</td>
<td>7.19 ± 0.00f</td>
<td>1.00 ± 0.00a</td>
<td>3.93 ± 0.01c</td>
</tr>
<tr>
<td>GIK 2</td>
<td>Nairobi</td>
<td>5.92 ± 0.11e</td>
<td>2.15 ± 0.21b</td>
<td>2.69 ± 0.12e</td>
</tr>
<tr>
<td>GIK 3</td>
<td>Nairobi</td>
<td>5.61 ± 0.02b</td>
<td>2.00 ± 0.00a</td>
<td>3.03 ± 0.11b</td>
</tr>
<tr>
<td>GIK 4</td>
<td>Nairobi</td>
<td>5.16 ± 0.06e</td>
<td>1.00 ± 0.00a</td>
<td>2.69 ± 0.12e</td>
</tr>
<tr>
<td>GIK 5</td>
<td>Nairobi</td>
<td>8.04 ± 0.01h</td>
<td>1.00 ± 0.00a</td>
<td>4.36 ± 0.03e</td>
</tr>
<tr>
<td>GIK 6</td>
<td>Nairobi</td>
<td>6.17 ± 0.08a</td>
<td>2.15 ± 0.21b</td>
<td>3.92 ± 0.11e</td>
</tr>
<tr>
<td>KAW 1</td>
<td>Nairobi</td>
<td>6.95 ± 0.01*</td>
<td>2.00 ± 0.00a</td>
<td>4.27 ± 0.02e</td>
</tr>
<tr>
<td>KAW 2</td>
<td>Nairobi</td>
<td>7.54 ± 0.07*</td>
<td>3.86 ± 0.02*</td>
<td>4.31 ± 0.05a</td>
</tr>
<tr>
<td>KON 1</td>
<td>Mombasa</td>
<td>6.14 ± 0.04e</td>
<td>3.28 ± 0.03a</td>
<td>4.58 ± 0.18e</td>
</tr>
<tr>
<td>KON 2</td>
<td>Mombasa</td>
<td>6.53 ± 0.05a</td>
<td>3.10 ± 0.02a</td>
<td>4.71 ± 0.07e</td>
</tr>
</tbody>
</table>
There was a significant (P≤ 0.05) difference in the microbial counts in the dried cassava chips samples from markets in Nairobi and Mombasa. The Total viable count of samples of dried cassava chips from Nairobi and Mombasa markets ranged from 5.16-8.04 log cfu/g and 4.81-7.21 log cfu/g with mean counts of 6.57 log cfu/g and 6.12 log cfu/g in respectively.

Mould counts in dried cassava chips
Yeast and mould count of dried cassava chips samples collected in Nairobi and Mombasa from ranged 1.00-3.86 log cfu/g and 1.00-3.28 log cfu/g with a mean count of 1.90 log cfu/g and 2.29 log cfu/g respectively. The yeast and mould counts reported in 87.5% of dried cassava chips from Nairobi were below the set limit. This is attributed to drying of the cassava chips to the optimum level as the samples had moisture content that was below 10%. One sample from Kawangware market (KAW 2) was found to have a count that was above the set limit representing 12.5% of the dried chip samples from Nairobi markets. These results agree with a report by Ogori and Gana (2013), the low counts are attributed to bio load proliferation and low moisture of ≤12% as observed in a study by Aryee et al. (2006) that limit microbial growth. 60% of the samples of dried cassava chips collected in the Coastal city of Mombasa had yeast and mould counts that were above the set limit in the standard and may be attributed to the moisture content in the chips that ranged between 10.15%-11.57%. The results of this study do not agree with a report by Kaaya and Eboku (2010) in Uganda that showed a mean mould count of 4.69 log cfu/g. The significance of low moisture contents in foods cannot be overemphasized as they help to enhance the shelf life of food samples and prevent rapid spoilage by microorganisms (Uriah and Izuagbe, 1990). It is important to note the high perishable nature of the cassava roots means that they are easily contaminated by fungi (Wareing et al., 2001). In a study by Kaaya and Eboku (2010) samples collected were found to be contaminated with Penicillium (22.2%), Aspergillus (20.4%), and Fusarium species (5.6%). Fungal contamination can lead to discoloration of the chips, give rise to mouldy taste and produce off odours (Gwinner et al., 1996).

Staphylococcal counts in dried cassava chips
Staphylococcal count of dried cassava chips samples collected in Nairobi and Mombasa ranged from 2.69-4.36 log cfu/g and 2.90-4.71 log cfu/g with a mean count of 3.65 log cfu/g and 3.79 log cfu/g respectively.

The staphylococcal species reported in dried cassava chips were high and 77% of samples were confirmed for presence of *Staphylococcus aureus* whose isolation is attributed to post processing handling and exposure both at the processing sites and in the markets (Obadina et al., 2008). This is because the drying is usually done in open air where animals are reared. Guthrie (1983) intimated that large numbers of *Staphylococcus* cells range (5.69-6.69 log cfu/g) are necessary for disease symptoms to be manifested.
There were significant (P≤0.05) difference in the microbial counts in the cassava flour samples amongst the traders in the markets in Nairobi and Mombasa (Table 2).

**Table 2: Microbial Count (log cfu/g) in cassava flour sourced from Nairobi and Mombasa**

<table>
<thead>
<tr>
<th>Sample/Market</th>
<th>Region</th>
<th>TVC (log cfu/g)</th>
<th>Mould (log cfu/g)</th>
<th>Staphylococcus aureus (log cfu/g)</th>
<th>Total Coliforms (log cfu/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIK 1</td>
<td>Nairobi</td>
<td>5.66 ± 0.03</td>
<td>1.00 ± 0.00</td>
<td>5.08 ± 0.07</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>GIK 2</td>
<td>Nairobi</td>
<td>6.81 ± 0.04</td>
<td>3.90 ± 0.07</td>
<td>3.77 ± 0.10</td>
<td>5.76 ± 0.03</td>
</tr>
<tr>
<td>GIK 3</td>
<td>Nairobi</td>
<td>7.06 ±0.01</td>
<td>4.26 ± 0.21</td>
<td>3.87 ± 0.04</td>
<td>6.27 ± 0.08</td>
</tr>
<tr>
<td>GIK 4</td>
<td>Nairobi</td>
<td>6.67 ± 0.07</td>
<td>3.66 ± 0.11</td>
<td>4.56 ± 0.06</td>
<td>6.06 ± 0.08</td>
</tr>
<tr>
<td>GIK 5</td>
<td>Nairobi</td>
<td>7.62 ± 0.00</td>
<td>2.97 ± 0.10</td>
<td>5.38 ± 0.03</td>
<td>5.00 ± 0.01</td>
</tr>
<tr>
<td>GIK 6</td>
<td>Nairobi</td>
<td>7.06 ± 0.03</td>
<td>3.96 ± 0.02</td>
<td>4.45 ± 0.07</td>
<td>6.34 ± 0.02</td>
</tr>
<tr>
<td>GIT 1</td>
<td>Nairobi</td>
<td>7.31 ± 0.00</td>
<td>4.53 ± 0.03</td>
<td>5.79 ± 0.02</td>
<td>5.42 ± 0.00</td>
</tr>
<tr>
<td>KAW 1</td>
<td>Nairobi</td>
<td>7.22 ± 0.04</td>
<td>5.91 ± 0.03</td>
<td>5.44 ± 0.08</td>
<td>6.15 ± 0.00</td>
</tr>
<tr>
<td>KAW 3</td>
<td>Nairobi</td>
<td>6.98 ± 0.04</td>
<td>6.71 ± 0.04</td>
<td>5.48 ± 0.00</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>KAW 4</td>
<td>Nairobi</td>
<td>6.85 ± 0.03</td>
<td>6.73 ± 0.00</td>
<td>4.37 ± 0.24</td>
<td>5.68 ± 0.03</td>
</tr>
<tr>
<td>KAW 5</td>
<td>Nairobi</td>
<td>7.49 ± 0.03</td>
<td>3.24 ± 0.09</td>
<td>5.83 ± 0.04</td>
<td>5.94 ± 0.00</td>
</tr>
<tr>
<td>KAW 6</td>
<td>Nairobi</td>
<td>7.67 ± 0.08</td>
<td>5.55 ± 0.03</td>
<td>4.80 ± 0.10</td>
<td>5.81 ± 0.00</td>
</tr>
<tr>
<td>MUT 1</td>
<td>Nairobi</td>
<td>7.10 ± 0.00</td>
<td>4.69 ± 0.07</td>
<td>5.65 ± 0.00</td>
<td>4.78 ± 0.00</td>
</tr>
<tr>
<td>UTH 1</td>
<td>Nairobi</td>
<td>7.04±0.08</td>
<td>3.52 ± 0.00</td>
<td>5.11 ± 0.12</td>
<td>5.58 ± 0.00</td>
</tr>
<tr>
<td>UTH 2</td>
<td>Nairobi</td>
<td>7.61 ± 0.05</td>
<td>5.46 ± 0.11</td>
<td>5.01 ± 0.16</td>
<td>4.60 ± 0.00</td>
</tr>
<tr>
<td>UTH 3</td>
<td>Nairobi</td>
<td>7.00 ± 0.06</td>
<td>4.26 ± 0.12</td>
<td>5.00 ± 0.13</td>
<td>5.33 ± 0.00</td>
</tr>
<tr>
<td>UTH 4</td>
<td>Nairobi</td>
<td>6.96 ± 0.02</td>
<td>3.45 ± 0.05</td>
<td>4.86 ± 0.11</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>MAR 1</td>
<td>Mombasa</td>
<td>6.40 ± 0.01</td>
<td>4.08 ± 0.02</td>
<td>3.02 ± 0.09</td>
<td>3.30 ± 0.00</td>
</tr>
<tr>
<td>MAJ 1</td>
<td>Mombasa</td>
<td>5.92 ± 0.01</td>
<td>2.65 ± 0.07</td>
<td>4.34 ± 0.03</td>
<td>2.00 ± 0.00</td>
</tr>
<tr>
<td>MAJ 2</td>
<td>Mombasa</td>
<td>7.32 ± 0.04</td>
<td>3.68 ± 0.09</td>
<td>5.28 ± 0.03</td>
<td>6.20 ± 0.07</td>
</tr>
<tr>
<td>MAJ 3</td>
<td>Mombasa</td>
<td>8.12 ± 0.03</td>
<td>3.64 ± 0.01</td>
<td>5.28 ± 0.01</td>
<td>6.27 ± 0.02</td>
</tr>
<tr>
<td>MAJ 4</td>
<td>Mombasa</td>
<td>5.94 ± 0.10</td>
<td>2.69 ± 0.12</td>
<td>1.00 ± 0.00</td>
<td>4.00 ± 0.00</td>
</tr>
<tr>
<td>MAJ 5</td>
<td>Mombasa</td>
<td>7.18 ± 0.12</td>
<td>5.08 ± 0.09</td>
<td>5.73 ± 0.10</td>
<td>6.23 ± 0.01</td>
</tr>
</tbody>
</table>

Means ± Standard deviation; Means in the same column with different superscripts are significantly different (P≤ 0.05).

**Nairobi:** Gikomba (GIK), Githurai (GIT), Kawangware (KAW), Muthurwa (MUT) and Uthiru (UT); **Mombasa:** Marikiti (MAR) and Majengo (MAJ).

**Total viable counts in dried cassava chips and cassava flour**

Total viable count ranged from 5.66-7.67 log cfu/g and 5.92–8.12 log cfu/g with mean count of 7.07 log cfu/g and 6.82 log cfu/g for Nairobi and Mombasa respectively.

The high TVC reported in sampled dried cassava chips (Table 1) and all the cassava flour (Table 2) sampled from markets of both the study sites were above the set limits. These results agree with a study by Ogori and Gana (2013) but are in disagreement with a report by Olaoye et al. (2006). The significant high bacteria load...
reported may be due to poor drying and processing methods.

**Mould counts in cassava flour**
The yeast and mould count ranged from 1.00-6.73 log cfu/g and 2.65–5.08 log cfu/g with a mean count of 4.34 log cfu/g and 3.64 log cfu/g for Nairobi and Mombasa respectively. About 88% and 67% of the flour samples from Nairobi and Mombasa respectively had counts that were above what is set as the allowed maximum limit in flour standard.

This high mould counts may be attributed to the fact that flour is sold in open air markets and are displayed in jute bags lined with nylons thus prone to drizzling or droplets of water and spores of various species of moulds which are heavily suspended in air especially in an untidy and unhygienic environment. According to Odetunde *et al.* (2014) sporulating moulds easily get in contact with foods that are openly displayed. The results in this study agree with a report by Adebayo-Oyetoro *et al.* (2013); Odetunde *et al.* (2014) that suggested high fungal growth in the samples of flour that were in markets in Nigeria. Kuku *et al.* (1984); Abba – Kareem *et al.* (1991), isolated fungi *Aspergillus fumigatus* and *Aspergillus niger* from cassava flour. Moulds are potential spoilage agents (Uriah and Izuagbe, 1990) and cause off flavors in foods as well as changes in appearance of food (Elmer, 1990). The high mould counts reported in this study are an indication of potential spoilage agent and mycotoxins food poisoning (Reiss, 1978).

**Staphylococcal counts in cassava flour**
The range for Staphylococcus counts of flour samples collected from markets in Nairobi Mombasa ranged from 3.77–5.79log cfu/g and 1.00– 5.73 log cfu/g with the mean being 4.97log and 4.11log cfu/g respectively. About 87% of cassava flour confirmed for presence of *S. aureus*. Ogori and Gana (2013) reported presence of Staphylococcus species in flour made from dried cassava “chunks” (chips) in a study site in Nigeria that could produce toxins, that are a cause of external skin infection and potent infections, agreeing with results in this study. The reports of Liston and Matches (1976); Guthrie (1983) confirmed that the most important sources of this organism in foods and beverages are the nasal canals and infected hands and they constitute health hazards. Staphylococcal spores have ability to withstand high temperature and they produce enterotoxins which are not easily destroyed and may cause food poisoning.

**Coliform counts in flour**
Total coliform count in cassava flour samples ranged from 0.00 -6.34 log cfu/g and 2.00-6.27 log cfu/g with a mean count of 4.63 log cfu/g and 4.67log cfu/g in Nairobi and Mombasa markets respectively. These values indicated that 82.4% of the samples collected in the markets within the Nairobi had at least a presence of coliforms. One sample of flour collected from a market in Nairobi (GIK 4) confirmed positive for presence of *E. coli*. According to EAS 740: 2010 should no coliform should be present in cassava flour. Flour samples from Nairobi and Mombasa were found to be heavily contaminated with coliforms.

Presence of coliforms in foods may indicate that foods were exposed to conditions favorable for the introduction and growth of pathogenic organisms (Odetunde *et al.*, 2014). These results correspond to what was reported by Odetunde *et al.* (2014) in Nigeria. High counts in cassava flours may be due to coliform proliferation from the atmosphere (Okpokeri *et al.*, 1985). The occurrence of lactose fermenters such as *Escherichia coli* suggests a degree of contamination with faecal discharges of human and animal...
The presence of these pathogenic microorganisms is thus an indication of microbial contamination with an incessant possibility of hazards to the health of man (Odetunde et al., 2014). Coliforms were absent from the dried cassava chips.

Conclusion and recommendations

High load of bacterial, Staphylococcus spp. and coliforms present in dried chips and cassava flour samples indicate excessive personnel handling and poor hygiene during post-harvest processing, handling and marketing. High mould counts in flour indicate poor storage practices in materials. Therefore, cassava chips and flours in the sampled markets were of low quality and may be unsafe for consumption. Since the presence of pathogenic microorganisms as well as other microbial contaminations is almost impossible to get rid of, it is paramount that basic hygiene and sanitary rules should be observed in the whole of cassava production value chain. Proper training on good practices especially good hygiene; as well as equipping farmers and processors with more hygienic sun drying equipment and methods will lead to improved quality and safety of the cassava products available in the market. Traders should also be trained on Good Hygiene Practices (GHP) and Good Storage Practices (GSP) to make sure they maintain the safety and quality of the products.

Acknowledgment

This study was funded by Eastern Africa Agricultural Productivity Project (EAAPP). Field research facilitation by the District Agricultural Officers in the respective districts and KALRO-Mtwapa is highly appreciated.

References


IV Success Stories in Cassava research and development

A testimony by Mrs Molly Akwir, a farmer from Uganda on how cassava transformed farmers lives

*Mrs and Chairperson of AFOSEN*

Agency for Food Security Network (AFOSEN) was formed in 2008 to address food security and farmers’ income. It was registered at Apach District and Sub-county levels as a farmers’ body. It covers 2 Sub-counties and 2 Town Councils in Apac District in Uganda. Farmer join by paying a fee of UGX 3,000 (US$ 1) and membership of UGX 30,000 (US$ 10) annually. Membership to date is 359 farmers organized in 13 Clusters (303 adults, 52 youth and four people with disability (PWD)).

**How AFOSEN became the leader in cassava production in Uganda**

In 2012, AFOSEN was identified as one of the farmer groups to promote cassava production under EAAPP. Members were trained on multiplying improved cassava varieties by the National Agricultural Research Organization (NARO). They were provided with improved cassava variety (Nase 14) by EAAPP through NAADS for multiplication and promotion while members provided land and labour. Regular inspection of the cassava multiplication fields was ensured by EAAPP for quality assurance through NARO and MAAIF. Mature cassava stems were thereafter bought through NAADS and NGOs while farmers redistributed 70% of stems originally received to other farmers. The farmers were encouraged by the earnings and which attracted more members to start growing cassava on a large scale basis. There were more markets locally through NAADS and outside.
Uganda (South Sudan and Rwanda) and this increased cassava production further making Apac to be the leading cassava producing District in Uganda. The group has established 2,500 acres of cassava since the project started.

Achievements
AFosen members spent the money earned from sale of cassava stems, tubers, chips and flour to a number of uses as listed below:

- Constructing permanent residential houses
- Purchase of land for more farming
- Purchase of oxen and ox-ploughs for animal traction
- Purchase of grinding mills
- Purchase of motorcycles and bicycles
- One farmer bought a truck
- Establishing various businesses e.g. Agro-input shop and retail shops
- Educating children
Grinding mill for Mr. Jasper Opwonya which earn him 150,000 UGX (US$40) daily

Agro-input Shop for Mr. Fred Akena which earns him about 170,000 UGX (US$50) daily

- Improved family nutrition
- Improved health care
- Acquiring solar power for lighting, charging phones and running TV and Videos as businesses

Collaborators

The Success of AFOSEN has attracted more collaborators as follows;
- Cassava mechanization and agro-processing project (CAMAP) is promoting mechanization
- Africa Innovations Institute (AfrII) is promoting value addition of cassava and business skills
- Integrated Seed sector Development (ISSD) built a store and trained members on agribusiness

Future Plans

- Acquire flash dryer to produce large quantity of HQCF
- Build Solar dryers in each of the 13 Clusters to improve processing
- Buy one Chipper for each of the 13 Cluster
- Put at least one grinding Mill in each of the 13 Clusters
- Construct a good store in every Cluster for better product storage
- Acquire a Truck for ferrying cassava tubers to processing unit
- Acquire one farmer Van for mobilization
- Build Bore holes to improve water availability for processing
- Increase cassava production from current 2,500 to 35,900 acres
- Acquire a Tractor to enable large scale commercial production
- Special needs skill for youth and PWD
- Increase member income from UGX 10 to 50 million per year.
Rice research and development
I. Genetic Resource Management and Improvement

The magnitude of genotype X environment interaction for bacterial leaf blight resistance in rice growing areas of Uganda

Lussewa, R.K.¹, Edema, R.² and Lamo J.³

1ARI-Ukiriguru, Mwanza, Tanzania; 2 Makerere University, P.O. Box 7098, Kampala, Uganda; 3Namulonge National Crop Resource Research Institute, Kampala, Uganda.

*Correspondence: rkilloh@yahoo.com

Abstract

Bacterial leaf blight (BLB) of rice caused by Xanthomonas oryzae pv oryzae is a major constraint in most lowland rice production areas of Uganda. The disease is widely distributed in all irrigated and rain-fed lowland rice ecosystems in the country. The pathogen (Xoo) is highly variable and its control is difficult. Development and deployment of host resistance is the only effective means of BLB management. A study, composed of two sets of germplasms a total of 30 rice genotypes comprised of 13 lines with varying levels of BLB resistance and 17 F₄ lines that had been previous generated through crossing 7 parental lines, and then advanced in bulk from F₁, was conducted in Namulonge-Wakiso, Olweny-Lira and Kibimba- Bugiri districts of Uganda. The study also included the 7 parental lines and 6 popular varieties used in most farmers’ fields. Variety IR 24 had been used as a universal check against BLB in Asian rice populations. Results of the study done in Uganda revealed differential reactions on a set of near isogenic lines in the background of IR24 and some national and regional cultivars. IRBB1 (Xa1), IRBB2 (Xa2) and IRBB14 (Xa14) showed moderately susceptible to susceptible toward the field pathogen populations in all three locations. Whereas genotype IRBB4 with gene Xa4 differentiated pathotypes of Kibimba and Lira from that of Namulonge, IRBB10 (Xa10) and IRBB11 (Xa11) differentiated pathotypes of Lira from the rest. Genotypes that had been pyramided with BLB genes of resistance showed similar reaction to all three field populations. Generally, the near isogenic lines IRBB1, IRBB2, IRBB11 and IRBB14 had the highest percentages of leaf area damaged by disease attack. The highest was shown by IRBB11 with the Kibimba pathotypes for which disease attack was 43%. Low attack was observed on pyramided genotypes in all locations and two with single gene i.e. IRBB8 and IRBB21, respectively. Interestingly IR24 was as resistant as any of the pyramided combinations. Results also revealed different reactions on the tested genotypes in the three locations. The analysis of variance by AMMI partitioned the main effects of treatments into genotype, environment, and genotype x environment (GxE) interactions. Results also revealed that, the mean sum of squares due to treatments, genotypes, environments and genotype x environment interaction were significant, and contributed 48.2%, 15.3%, 19.3% and 13.3% respectively. PCA1 accounted for 73.02% of the total GxE sum of squares.

Key words: Magnitude, bacterial leaf blight (BLB), rice, genetic by environment ineraction (GxE), Uganda
Introduction

Bacterial leaf blight (BLB) of rice caused by *Xanthomonas oryzae* pv. *oryzae* (Swings et al. 1990) is widespread in several rice growing areas of Asia, Australia, the United States, Latin America and Africa, covering both tropical and temperate countries (Mew, 1987, 1989; Mew et al., 1993; Gnanamanickam et al. 1999; Séré et al.2005). The disease has been observed in fields in several West African countries with high a incidence of 70% to 80% (Séré et al.2005). Yield losses due to BLB generally vary 20-30% but a range from 50 to 90% have been reported in some areas (Ou, 1985; Séré et al.,2005). The presence of *X.oryzae* pv.*oryzae* has now been confirmed in Uganda (Onasanya et al. 2010). However, little is known about the variability of local *Xanthomonas oryzae* pv.*oryzae* pathogen populations (Lamo, 2009). A recent survey reported the occurrence of bacterial leaf blight in some parts of rice growing areas of Eastern Uganda with high incidence and severity (Lamo, 2009 and Habarurema et al., 2012).

However, investigation of the resistance to bacterial leaf blight of rice varieties has never been initiated. Chemical control of BLB is impractical, and no truly effective bactericide is commercially available for its control (Ou, 1985). Some bacterial antagonists of *Xoo* tried as biological agents could not be used commercially (Vasudevan et al.,2002). On the other hand controlling the disease using cultural practices by improving or changes in cultural practices are only partially effective in restricting the pathogen from spread (Niño-Liu et al., 2006). Practicing field sanitation such as removing weed hosts, rice straws and debris, ratoons, and volunteer seedlings is important to avoid infection caused by this disease. Likewise, maintaining shallow water in nursery beds, providing good drainage during severe flooding, plowing under rice stubble and straw following harvest are also management practices that can be followed (Mizukami and Wakimoto, 1969). Proper seed dressing, application of judicious nitrogen fertilizer rate, proper plant spacing and crop rotation are also recommended for the management of BLB (IRRI, 2003). However, the usefulness of cultural practices for BLB control varies depending on the location and disease incidence records (Niño-Liu et al., 2006).

The use of varietal resistance or breeding for BLB resistance is the main control measure presently available since no other control method is economically effective (Niño-Liu et al., 2006). Several resistance genes are available for deployment against this disease. The utilization of resistant varieties carrying R genes is one of the most effective, economical and environmentally friendly approach to control the bacterial blight (Keyu et al., 2008; Lore et al., 2011). Globally, BLB-resistant rice cultivars were identified/developed and as many as 31 Xa genes conferring resistance against *Xoo* have been identified so far (Nino Liu et al.,2009). However, the durability of resistance depends upon the prevalence of pathogen races in time and space (Jagjeet et al., 2010). This is due to the fact that the pathogen *Xoo* is highly variable and more than 30 races/pathotypes of the bacterium have been reported worldwide (Adhikari et al., 1999; Noda et al., 2001).

This research report is based on results obtained from recently findings. It deals with an in depth and up to date analysis undertaken to assess the variation in the Xoo population in terms of number and frequency of the pathogens prevalent and their likely impact on the development and stability of donors of resistance against BLB. Therefore, the genetic relationship among different Xoo pathotype in three locations in Uganda representing the rain-fed/irrigated rice bowl was analysed using near isogenic lines with known genes for resistance and selected genotypes selected from past breeding work for BLB resistance in Uganda rice population. The overall objective of this study was to determine the nature of genetic variability for resistance to bacterial leaf blight (*Xanthomonas oryzae* pv *oryzae*) in selected Ugandan rice landraces and introduced...
varieties derived from intraspecific and interspecific genotypes through determining the magnitude of GxE interaction of the selected genotypes.

Materials and methods

Experimental location

The research was conducted at three locations: Namulonge (Central-Uganda); Kibimba (Eastern-Uganda) and Olweny (Northern-Uganda). Namulonge, is located at 0° 31’ 47” N and 32° 36’ 9” E at an elevation of 1,133 meters above sea level. It has a bimodal type of rainfall with an annual mean rainfall of 1,300 mm, with the first rain season from April to July and the second season in September to December. The site has a tropical wet and a mild dry climate with slightly humid conditions averaging 65% humidity. Temperatures rarely rise beyond 28°C, with the minimum about 15°C, and typically less than 70% relative humidity (Lugojja et al. 2002;., NARO, 2005)

Kibimba Irrigation Scheme is located in the eastern region of Uganda, at a latitude 0°32’ 14” N and longitude 33°51’ 9”E, in Bugiri district. It is an irrigation scheme started as a joint venture between the Ugandan government and the Peoples Republic of China. It has approximately 1,400 acres. This scheme was privatized in 1995 and it is currently under Tilda Ltd, a UK based -Indian company.

The Olweny rice scheme is located in Lira district in northern Uganda, at 2° 11’ 49.3”N and 33° 1’ 33.3”E. The Olweny wetland system about 10,000 hectares in size, includes 600 hectares that has been developed into the Itek (350 ha) and Okile (250 ha) Rice Projects, located in Amach and Barr sub-counties. This region also has a bimodal type of rainfall.

Germplasm used

Two sets of germplasms were used in this study. The first set included a total of 30 rice genotypes comprised of 13 lines with varying levels of BLB resistance and 17 F4 lines that had been previous generated through crossing 7 parental lines, and then advanced in bulk from F1. The 7 parents were included in the 13 lines used in the study (Table 1), while the remaining 6 were among the popular varieties used in most farmers’ fields. These six varieties include K85 (local Ugandan landrace), NERICA1 (upland), IR54 (IRRI -Tanzania), IR 24, CT 12, WITA 9 (AfricaRice) and K5 (Ugandan landrace). Variety IR 24 had been used as a universal check against BLB in Asian rice populations. Meanwhile, K5 and K85 are the varieties most preferred in Uganda, though they are susceptible to BLB. CT12 is a newly released rice variety that has been successful in Uganda and also resistant to BLB (Lamo, 2010).

Table 1: List of rice genotypes used

<table>
<thead>
<tr>
<th>No.</th>
<th>Genotype name</th>
<th>Pedigree</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IR54</td>
<td>Unknown</td>
<td><strong>IRRI -Tanzania</strong></td>
</tr>
<tr>
<td>2</td>
<td>NERICA4</td>
<td>WAB450-I-B-P-91-HB</td>
<td>Africa Rice/WARDA</td>
</tr>
<tr>
<td>3</td>
<td>CT145</td>
<td>Unknown</td>
<td><strong>CIAT</strong></td>
</tr>
<tr>
<td>4</td>
<td>CT12</td>
<td>CT16344-CA-9-M</td>
<td>CIAT</td>
</tr>
<tr>
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<td>NERICA1</td>
<td>WAB450-I-B-P-38-HB</td>
<td>Africa Rice/WARDA</td>
</tr>
<tr>
<td>6</td>
<td>WITA9</td>
<td>Unknown</td>
<td>Africa Rice/WARDA</td>
</tr>
<tr>
<td>7</td>
<td>K5</td>
<td>Cross</td>
<td>Uganda (Local)</td>
</tr>
</tbody>
</table>
The second set of germplasm consisted of differential lines comprised 17 near-isogenic rice lines (NILs) based on IR24, with each NIL carrying one to four specific genes for resistance to BLB (Lore et al. 2011). The objective was to identify the existing BLB pathotypes in Uganda. The differentials were planted beside the genotypes tested at each trial site for the GxE. These differential lines and their respective genes of resistance are listed in Table 2:

<table>
<thead>
<tr>
<th>No.</th>
<th>Genotype name</th>
<th>Pedigree</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>CT147 x WITA132</td>
<td>Cross</td>
<td>***NACRRI-Namulonge</td>
</tr>
<tr>
<td>9</td>
<td>NERICA14 x WITA132</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>10</td>
<td>NERICA10 x NERICA14</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>11</td>
<td>NERICA4 x NERICA10</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>12</td>
<td>CT23</td>
<td>CT16333(20)-CA-18-M</td>
<td>CIAT</td>
</tr>
<tr>
<td>13</td>
<td>WITA132 x NERICA14</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>14</td>
<td>WITA132</td>
<td>Unknown</td>
<td>Africa Rice/WARDA</td>
</tr>
<tr>
<td>15</td>
<td>NERICA14 x CT145</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>16</td>
<td>NERICA14</td>
<td>WAB8801-32-1-2-P1-HB</td>
<td>Africa Rice/WARDA</td>
</tr>
<tr>
<td>17</td>
<td>K85</td>
<td>Unknown</td>
<td>Uganda (Local)</td>
</tr>
<tr>
<td>18</td>
<td>NERICA10</td>
<td>WAB45011-1-1-P41-HB</td>
<td>Africa Rice/WARDA</td>
</tr>
<tr>
<td>19</td>
<td>NERICA10 x WITA132</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>20</td>
<td>WITA132 x CT147</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>21</td>
<td>NERICA14 x CT23</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>22</td>
<td>CT147</td>
<td>Unknown</td>
<td>CIAT</td>
</tr>
<tr>
<td>23</td>
<td>WITA132 x CT145</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>24</td>
<td>NERICA4 x CT145</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>25</td>
<td>NERICA10 x CT147</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>26</td>
<td>WITA132 x CT147</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>27</td>
<td>CT145 x NERICA14</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>28</td>
<td>WITA132 x NERICA14</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>29</td>
<td>CT147 x NERICA4</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
<tr>
<td>30</td>
<td>NERICA14 x NERICA4</td>
<td>Cross</td>
<td>NACRRI-Namulonge</td>
</tr>
</tbody>
</table>

*IRRI: International Rice Research Institute **CIAT: International Centre for Tropical Agriculture, ***NACRRI: National Crop Resource Research Institute
Table 2: Bacterial blight NILs and their genes of resistance to bacterial leaf blight (BLB)

<table>
<thead>
<tr>
<th>No</th>
<th>NIL</th>
<th>Xa-gene</th>
<th>No</th>
<th>NIL</th>
<th>Xa-gene</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IRBB1</td>
<td>Xa1</td>
<td>10</td>
<td>IRBB50</td>
<td>Xa4+xa5</td>
</tr>
<tr>
<td>2</td>
<td>IRBB2</td>
<td>Xa2</td>
<td>11</td>
<td>IRBB51</td>
<td>Xa4+xa13</td>
</tr>
<tr>
<td>3</td>
<td>IRBB4</td>
<td>Xa4</td>
<td>12</td>
<td>IRBB52</td>
<td>Xa4+Xa21</td>
</tr>
<tr>
<td>4</td>
<td>IRBB7</td>
<td>Xa7</td>
<td>13</td>
<td>IRBB54</td>
<td>xa5+Xa21</td>
</tr>
<tr>
<td>5</td>
<td>IRBB8</td>
<td>xa8</td>
<td>14</td>
<td>IRBB55</td>
<td>xa13+Xa21</td>
</tr>
<tr>
<td>6</td>
<td>IRBB10</td>
<td>Xa10</td>
<td>15</td>
<td>IRBB56</td>
<td>Xa4+xa5+xa13</td>
</tr>
<tr>
<td>7</td>
<td>IRBB11</td>
<td>Xa11</td>
<td>16</td>
<td>IRBB57</td>
<td>Xa4+xa5+xa21</td>
</tr>
<tr>
<td>8</td>
<td>IRBB14</td>
<td>Xa14</td>
<td>17</td>
<td>IRBB60</td>
<td>Xa4+xa5+xa13+xa21</td>
</tr>
<tr>
<td>9</td>
<td>IRBB21</td>
<td>Xa21</td>
<td>18</td>
<td>IR24</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Liu et al., 2007

Experimental design

The 30 test genotypes were planted in three locations of Namulonge, Lira, and Kibimba. Seedlings were transplanted into a 10 x 3 alpha lattice design with three replications and a plant spacing of 20cm x 20cm with 2 seedlings per hill. In addition, the 17 NILs and IR24 were also planted along side the experimental plots in 4 lines of 6.0m.long.

Data collection and management

BLB assessment on the NILs: Disease reaction on the NILs was recorded based on length of leaf showing symptoms of BLB at crop maturity period. The length of the BLB lesion (cm) was then classified in accordance with Cottyn and Mew’s system (2004) as follows:

<table>
<thead>
<tr>
<th>Lesion length</th>
<th>&lt; 5 cm</th>
<th>5-10 cm</th>
<th>10-15 cm</th>
<th>&gt; 15cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction</td>
<td>Resistant (R)</td>
<td>Moderately resistant (MR)</td>
<td>Moderately susceptible (MS)</td>
<td>Susceptible (S)</td>
</tr>
</tbody>
</table>

BLB assessment on the 30 test genotypes: Data were collected on the 30 genotypes by recording their disease score 42 days after transplanting, using IRRI standard scoring scale (IRRI, 1996), shown in Table 3: This scale was used because estimated average percentages of disease attack on leaves for replicated plots were used during disease assessment in field.

Table 3: Scale used for scoring bacterial leaf blight disease severity in rice in the field

<table>
<thead>
<tr>
<th>Scale</th>
<th>Percentage of Diseased leaf area</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-5</td>
<td>Resistant (R)</td>
</tr>
<tr>
<td>3</td>
<td>6-12</td>
<td>Medium resistant (MR)</td>
</tr>
<tr>
<td>5</td>
<td>13-25</td>
<td>Medium susceptible (MS)</td>
</tr>
<tr>
<td>7</td>
<td>26-50</td>
<td>Susceptible (S)</td>
</tr>
<tr>
<td>9</td>
<td>&gt;50</td>
<td>Highly susceptible (HS)</td>
</tr>
</tbody>
</table>

Source: International Rice Research Institute (IRRI), Manila, Philippines, 1996
Data analysis

Pathotype diversity:

The pathogenic variability of the Xoo was assessed on the basis of the extent of damage of Xoo on the differential lines, according to differences in their disease scores in the different locations. The mean disease scores for genotypes were then grouped according to Cottyn and Mew’s (2004) classification.

Genotype by environment interaction analysis:

Analysis of variance (ANOVA) for each location was done separately, followed by combined ANOVA across locations for the BLB resistance trait. Locations and replications were treated as random effects, while genotypes were treated as fixed effects. The ANOVA was performed using Genstat statistical package (Lawes Agricultural Trust, 2012). The linear model used for the single location ANOVA was:

\[ Y_{ij} = \mu + r_i + g_j + e_{ij} \]

Where: \( Y_{ij} \) = observed effect for ith replication and jth genotype,
\( \mu \) = grand mean of the experiment,
\( r_i \) = effect of the ith replication,
\( g_j \) = effect of the jth genotype (F1 hybrid or inbred line),
\( e_{ij} \) = residual effect or random error of the experiment.

The linear model for the across-location ANOVA was:

\[ Y_{ijk} = \mu + l_i + r(l)_{j(i)} + g_k + (g_l)_{i(k)} + e_{jk(i)} \]

Where: \( Y_{ijk} \) = observed effect for the ith location, jth replication within the ith location, and kth genotype,
\( \mu \) = grand mean of the experiment,
\( l_i \) = effect of the ith location,
\( r(l)_{j(i)} \) = effect of the jth replication within the ith location,
\( g_k \) = effect of the kth genotype (F1 hybrid),
\( (g_l)_{i(k)} \) = interaction of the kth genotype with the ith location, and
\( e_{jk(i)} \) = residual effect or random error of the experiment. (Habururemaet al. 2012)

Genotype stability for resistance to BLB disease:

Genotype stability for resistance to BLB disease was determined using the additive main effects and multiplicative interaction (AMMI) analysis in Genstat 14th edition statistical software (Lawes Agricultural Trust, 2012). The AMMI model used was:

\[ Y_{ger} = \mu + \hat{a}_g + \hat{a}_e + y_{gen} + \hat{a}_g + \hat{a}_e + E_{ger} \]

Where: \( Y_{ger} \) is the BLB disease lesion of genotype g in environment e for replicate r,
\( \mu \) is the grand mean,
\( \hat{a}_g \) is the genotype g mean deviation,
\( \hat{a}_e \) is the environment e mean deviation,
\( y_{gen} \) is the number of PCA axes retained in the model,
\( n \) is the singular value for PCA axis n,
\(y_{gn}\) is the genotype eigenvector value for PCA axis n,
\(a_{an}^{env}\) is the environment eigenvector values for PCA axis n,
\(e_{gn}^{res}\) is the residual, and
\(E_{gen}^{err}\) is the error (Ntawuruhunga et al. 2001).

An AMMI1 biplot was generated to provide visualization of the main effects of the treatment and the environments, in addition to the most important treatment x environment interactions. Another analysis was conducted using a biplot of genotype main effects plus genotype x environment interaction (GGE) to further visualize the genotype x environment two-way interaction. The GGE biplot allows visualization of the crossover treatment x environment interactions, relationships among treatments, and relationships among environments.

### Results

**Pathotype diversity of Xanthomonas oryzae pv oryzae (Xoo):**

Results of the near isogenic lines (NILs) evaluated in three locations has revealed differences in their reaction patterns to BLB isolates on the NILs as shown in Table 4:

<table>
<thead>
<tr>
<th>Genotype/NIL</th>
<th>Xa gene</th>
<th>Reaction against pathotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>NamXoo (Namulonge)</td>
</tr>
<tr>
<td>IRBB 1</td>
<td>Xa1</td>
<td>S</td>
</tr>
<tr>
<td>IRBB 2</td>
<td>Xa2</td>
<td>S</td>
</tr>
<tr>
<td>IRBB 4</td>
<td>Xa4</td>
<td>MS</td>
</tr>
<tr>
<td>IRBB 7</td>
<td>Xa7</td>
<td>MR</td>
</tr>
<tr>
<td>IRBB 8</td>
<td>Xa8</td>
<td>MR</td>
</tr>
<tr>
<td>IRBB 10</td>
<td>Xa10</td>
<td>MS</td>
</tr>
<tr>
<td>IRBB 11</td>
<td>Xa11</td>
<td>S</td>
</tr>
<tr>
<td>IRBB 14</td>
<td>Xa14</td>
<td>S</td>
</tr>
<tr>
<td>IRBB 21</td>
<td>Xa21</td>
<td>R</td>
</tr>
<tr>
<td>IRBB 50</td>
<td>Xa4 + Xa5</td>
<td>MR</td>
</tr>
<tr>
<td>IRBB 51</td>
<td>Xa4 + Xa13</td>
<td>MR</td>
</tr>
<tr>
<td>IRBB 52</td>
<td>Xa4 + Xa21</td>
<td>MR</td>
</tr>
<tr>
<td>IRBB 54</td>
<td>Xa5 + Xa21</td>
<td>R</td>
</tr>
<tr>
<td>IRBB 55</td>
<td>Xa13 + Xa21</td>
<td>R</td>
</tr>
<tr>
<td>IRBB 56</td>
<td>Xa4 + Xa5 + Xa13</td>
<td>R</td>
</tr>
<tr>
<td>IRBB 57</td>
<td>Xa4 + Xa5 + Xa21</td>
<td>R</td>
</tr>
<tr>
<td>IRBB 60</td>
<td>Xa4 + Xa5 + Xa13 + Xa21</td>
<td>R</td>
</tr>
<tr>
<td>IR24</td>
<td>-</td>
<td>R</td>
</tr>
</tbody>
</table>
IRBB1 (Xa1), IRBB2 (Xa2) and IRBB14 (Xa14) showed moderately susceptible to susceptible toward the field pathogen populations in all three locations. These three genotypes each contain a single gene of resistance to BLB. Whereas genotype IRBB4 with gene Xa4 differentiated pathotypes of Kibimba and Lira from that of Namulonge, IRBB10 (Xa10) and IRBB11 (Xa11) differentiated pathotypes of Lira from the rest.

IRBB1 (Xa1), IRBB2 (Xa2) and IRBB14 (Xa14) showed moderately susceptible to susceptible toward the field pathogen populations in all three locations. These three genotypes each contain a single gene of resistance to BLB. Whereas genotype IRBB4 with gene Xa4 differentiated pathotypes of Kibimba and Lira from that of Namulonge, IRBB10 (Xa10) and IRBB11 (Xa11) differentiated pathotypes of Lira from the rest. Genotypes that had been pyramided with BLB genes of resistance showed similar reaction to all three field populations. Generally, the near isogenic lines IRBB1, IRBB2, IRBB11 and IRBB14 had the highest percentages of leaf area damaged by disease attack. The highest was shown by IRBB11 with the Kibimba pathotype (KibXoo) for which disease attack was 43% (Figure 1).

Low attack was observed on pyramided genotypes in all locations and two with single gene i.e IRBB8 and IRBB21, respectively. Interestingly IR24 was as resistant as any of the pyramided combinations.

**Figure 1:** Virulence percentage of *Xanthomonas oryzae* pv. *oryzae* on NILs at locations

**Genotype by environment interaction analysis of variance**

Analysis of variance (ANOVA) across environments detected significant variation among genotypes and for the GxE interaction on the BLB resistance trait. This phenomenon indicated differences in response to the
environments of the genotypes used in the study.

** Levels 100.0 90.0 80.0 70.0 60.0 50.0
CT 12 1. .......
WITA 132/NER14 27. .......)........
CT 145/NER14 3. ..)
WITA 132 25. ..)
CT 147/Ner10 6. ....))
NER14/WITA 132 20. .......)
CT 147 4. ))
NER 10/WITA 132 13. ..))
WITA132/ NER10 29. ..))
NER14/CT 145 18. ....)))
IR54 9. ....)...)
NER 10/NER14 12. ))
NERICA14 24. ..))
NER10 16. ......))
NER 4/NER10 15. .......)......)
CT 147 /WITA 132 5. ....)))
CT 147/NER4 7. ....)...))
NER 14/NER4 14. ......))
NERICA 1 22. ..))
WITA 132/CT 147 26. ..)))
NERICA 4 23. ..))
WITA 9 28. ..))
WITA132/CT 145 30. ..)).....)
CT 23 8. ............).....)
NER14/CT 23 19. ..................)
CT 145 2. ..)
NER10/CT 147 17. ..))
NER4/CT145 21. ..))
K 85 10. ......))
K5 11. ......))

Figure 2: Dendrogram of the genotypes tested for BLB in three locations in Uganda 2011

Stability of BLB-resistant rice genotypes tested across 3 locations

The analysis of variance by AMMI partitioned the main effects of treatments into genotype, environment, and genotype x environment (GxE) interactions. Results also revealed that, the mean sum of squares due to treatments, genotypes, environments and genotype x environment interaction were significant, and contributed 48.2%, 15.3%, 19.3% and 13.3% respectively (Table 5). PCA1 accounted for 73.02% of the
total GxE sum of squares.

**Table 5: Analysis of stability of BLB resistance on rice genotypes tested at different locations**

<table>
<thead>
<tr>
<th>Source of Variations</th>
<th>df</th>
<th>Mean Squares</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>89</td>
<td>84.33***</td>
<td>48.2</td>
</tr>
<tr>
<td>Genotypes</td>
<td>29</td>
<td>82.36***</td>
<td>15.3</td>
</tr>
<tr>
<td>Environments</td>
<td>2</td>
<td>1522.00***</td>
<td>19.3</td>
</tr>
<tr>
<td>GxE Interaction</td>
<td>58</td>
<td>35.74***</td>
<td>13.3</td>
</tr>
<tr>
<td>PCA I</td>
<td>30</td>
<td>50.45***</td>
<td></td>
</tr>
<tr>
<td>Residual</td>
<td>28</td>
<td>19.97*</td>
<td></td>
</tr>
<tr>
<td>Pooled residual</td>
<td>174</td>
<td>12.80</td>
<td></td>
</tr>
</tbody>
</table>

df: Degrees of freedom; F: variance ratios; **, ***: significant at p ≤ 0.01 and p ≤ 0.001

NOTE: For GxE interaction the percentage of PCA1 = 73.02% and PCA 2= 26.97% (Residual)

In order to determine whether bi-plot analysis is suitable, a mean value of BLB score against PCA 1 scores was conducted (Figure 2).

Figure 2: Graph for percentage mean BLB score against IPCA 1 score

Since a high number of genotypes with PCA scores close to zero were realized, bi-plot analysis was employed. For the 30 genotypes tested, 11 genotypes about 37% had a mean score outside of the range of ± 0.5. These were NERICA4, K5, CT147 x WITA132, NERICA14 x WITA132, NERICA4 x NERICA10, NERICA14 x CT145, NERICA14, NERICA10, CT147, WITA132 x CT147 and CT145 x NERICA14 (Figure 3)
Figure 3: Biplot of IPCA 2 against IPCA1 for % BLB score of 30 genotypes at locations of Uganda

The variation of genotypes in two clear environmental clusters with environment 1 and 3 together and environment 2 separate was depicted in Figure 3. Similarly, the AMMI 2 revealed four apparent groups of the genotype in terms of their response to the environment. Each group is on both sides of the quadrants of the biplot. Several lines show low score for BLB in each of the quadrants.

The results for IPCA scores and means of 30 genotypes in 3 environments showed that many genotypes were highly interactive (Table 6).
Table 6: Mean percentage of BLB lesions on the tested genotypes from the three locations

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Mean % bacterial leaf blight lesion</th>
<th>Namulonge</th>
<th>Kibimba</th>
<th>Olweny</th>
<th>Genotype mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT 147 x NERICA 4</td>
<td>22.09</td>
<td>31.08</td>
<td>19.16</td>
<td>24.11</td>
<td></td>
</tr>
<tr>
<td>NERICA14 x CT 23</td>
<td>21.00</td>
<td>53.75</td>
<td>15.28</td>
<td>30.01</td>
<td></td>
</tr>
<tr>
<td>NERICA 4 x NERICA10</td>
<td>15.07</td>
<td>31.19</td>
<td>11.30</td>
<td>19.19</td>
<td></td>
</tr>
<tr>
<td>K85</td>
<td>33.64</td>
<td>37.21</td>
<td>31.35</td>
<td>34.07</td>
<td></td>
</tr>
<tr>
<td>NERICA10 x NERICA14</td>
<td>16.77</td>
<td>26.58</td>
<td>13.75</td>
<td>19.03</td>
<td></td>
</tr>
<tr>
<td>NERICA14 x NERICA 4</td>
<td>24.99</td>
<td>29.64</td>
<td>22.57</td>
<td>25.73</td>
<td></td>
</tr>
<tr>
<td>NERICA14 x WITA 132</td>
<td>19.79</td>
<td>37.69</td>
<td>15.81</td>
<td>24.43</td>
<td></td>
</tr>
<tr>
<td>NERICA10 x WITA 132</td>
<td>18.79</td>
<td>37.38</td>
<td>14.73</td>
<td>23.63</td>
<td></td>
</tr>
<tr>
<td>NERICA14 x CT 145</td>
<td>17.29</td>
<td>38.52</td>
<td>12.92</td>
<td>22.91</td>
<td></td>
</tr>
<tr>
<td>NERICA10</td>
<td>15.94</td>
<td>26.08</td>
<td>12.88</td>
<td>18.30</td>
<td></td>
</tr>
<tr>
<td>IR 54</td>
<td>18.77</td>
<td>42.35</td>
<td>14.12</td>
<td>25.08</td>
<td></td>
</tr>
<tr>
<td>NERICA 4 x CT 145</td>
<td>26.30</td>
<td>34.35</td>
<td>23.48</td>
<td>28.04</td>
<td></td>
</tr>
<tr>
<td>NERICA10 x CT 147</td>
<td>27.21</td>
<td>33.80</td>
<td>24.56</td>
<td>28.52</td>
<td></td>
</tr>
<tr>
<td>CT 147 x WITA 132</td>
<td>21.24</td>
<td>31.46</td>
<td>18.17</td>
<td>23.62</td>
<td></td>
</tr>
<tr>
<td>CT 147</td>
<td>17.82</td>
<td>35.39</td>
<td>13.88</td>
<td>22.37</td>
<td></td>
</tr>
<tr>
<td>WITA 132 x NERICA14</td>
<td>14.50</td>
<td>14.01</td>
<td>12.57</td>
<td>13.66</td>
<td></td>
</tr>
<tr>
<td>NERICA14</td>
<td>16.35</td>
<td>28.47</td>
<td>13.05</td>
<td>19.29</td>
<td></td>
</tr>
<tr>
<td>CT 23</td>
<td>20.20</td>
<td>19.90</td>
<td>18.36</td>
<td>19.49</td>
<td></td>
</tr>
<tr>
<td>NERICA1</td>
<td>17.34</td>
<td>23.56</td>
<td>14.74</td>
<td>18.54</td>
<td></td>
</tr>
<tr>
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<td>11.29</td>
<td>11.22</td>
<td>9.42</td>
<td>10.64</td>
<td></td>
</tr>
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<td>K 5</td>
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<td>32.36</td>
<td>34.79</td>
<td>34.46</td>
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<td>20.82</td>
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<tr>
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<td>16.22</td>
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<tr>
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<td>37.65</td>
<td>14.24</td>
<td>23.42</td>
<td></td>
</tr>
<tr>
<td>NERICA4</td>
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<td>20.75</td>
<td>16.01</td>
<td>18.31</td>
<td></td>
</tr>
<tr>
<td>CT 147 x NERICA10</td>
<td>20.31</td>
<td>37.57</td>
<td>16.41</td>
<td>24.77</td>
<td></td>
</tr>
<tr>
<td>WITA 132</td>
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<td>34.10</td>
<td>16.13</td>
<td>23.31</td>
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<td>27.01</td>
<td>35.60</td>
<td>24.13</td>
<td>28.91</td>
<td></td>
</tr>
<tr>
<td>Location mean</td>
<td>20.50</td>
<td>30.99</td>
<td>17.39</td>
<td>22.96</td>
<td></td>
</tr>
</tbody>
</table>

F-test: *** *** *** ***

The most resistant genotypes across the different locations were CT12 (10.64%), WITA132 x NERICA14 (13.66%), NERICA10 (18.3%), NERICA4 (18.31%) and NERICA1 (18.54%). The least resistant genotypes included two local checks (K5 (34.46%) and K85 (34.07%), as well as CT145 (28.91%) and NERICA14 x CT23 (30.01%). Results also indicated that most of the genotypes were affected by the disease at Kibimba with a mean of 30.99% and less so at Lira site (17.39%). It was also shown that the most interactive genotypes included NERICA14 x CT23 and K5 (-2.0) interpreted from their IPCA1 values, while the least interactive genotype was NERICA10 which recorded an IPCA1 value of -0.05 (Table 7).
Table 7: Mean percentage BLB score and interaction scores of the genotypes across locations

<table>
<thead>
<tr>
<th>Genotype</th>
<th>%BLB score</th>
<th>IPCA 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT147 x NERICA4</td>
<td>24.11</td>
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</tr>
<tr>
<td>NERICA14 x CT23</td>
<td>30.01</td>
<td>3.10</td>
</tr>
<tr>
<td>NERICA4 x NERICA10</td>
<td>19.19</td>
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</tr>
<tr>
<td>K85</td>
<td>34.07</td>
<td>-0.96</td>
</tr>
<tr>
<td>NERICA10 x NERICA14</td>
<td>19.03</td>
<td>-0.10</td>
</tr>
<tr>
<td>NERICA14 x NERICA4</td>
<td>25.73</td>
<td>-0.81</td>
</tr>
<tr>
<td>NERICA14 x WITA132</td>
<td>24.43</td>
<td>1.03</td>
</tr>
<tr>
<td>NERICA10 x WITA132</td>
<td>23.63</td>
<td>1.13</td>
</tr>
<tr>
<td>NERICA14 x CT145</td>
<td>22.91</td>
<td>1.50</td>
</tr>
<tr>
<td>NERICA10</td>
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<tr>
<td>IR 54</td>
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<td>1.82</td>
</tr>
<tr>
<td>NERICA4 x CT145</td>
<td>28.04</td>
<td>-0.34</td>
</tr>
<tr>
<td>NERICA10 x CT147</td>
<td>28.52</td>
<td>-0.54</td>
</tr>
<tr>
<td>CT147 x WITA132</td>
<td>23.62</td>
<td>-0.04</td>
</tr>
<tr>
<td>CT147</td>
<td>22.37</td>
<td>0.99</td>
</tr>
<tr>
<td>WITA132 x NERICA14</td>
<td>13.66</td>
<td>-1.51</td>
</tr>
<tr>
<td>NERICA14</td>
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<td>0.23</td>
</tr>
<tr>
<td>CT 23</td>
<td>19.49</td>
<td>-1.50</td>
</tr>
<tr>
<td>NERICA1</td>
<td>18.54</td>
<td>-0.59</td>
</tr>
<tr>
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<td>10.64</td>
<td>-1.47</td>
</tr>
<tr>
<td>K5</td>
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<td>WITA132 x CT147</td>
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<td>-0.58</td>
</tr>
<tr>
<td>WITA9</td>
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<tr>
<td>CT145 x NERICA14</td>
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<td>0.69</td>
</tr>
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</tr>
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<td>CT147 x NERICA10</td>
<td>24.77</td>
<td>0.94</td>
</tr>
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<td>0.54</td>
</tr>
<tr>
<td>CT145</td>
<td>28.91</td>
<td>-0.26</td>
</tr>
</tbody>
</table>

The GGE biplot based on the 30 genotypes at 3 environments (Namulonge, Kibimba and Lira) in a two-way table of the BLB score is illustrated in Fig 4. The environment-standardized data are used, which
assumes that all environments are equally important in genotypic evaluation. The GGE biplot explained 91.28% of the BLB score for resistance when the analysis was environment-centered. NERICA14 x CT23 had the least resistance to BLB in Kibimba while K5 and K85 scored least resistance to BLB in both Lira and Namulonge. This environment-focused singular-value partitioning allows appropriate visualization of the relationships among environments and similar overlapping clusters of environments as shown in the AMMI analysis. The biplot Figure 4 also, revealed four apparent groups of the genotype in terms of their response to the environment. Each group is on both sides of the quadrants of the biplot. Several lines show low score for BLB in each of the quadrants. The analysis further revealed that there was moderate genotype x environment interaction (13.3%) relative to the main effect (15.3%), which led to moderate crossover genotype x environment interactions, as evidenced by the fact that PC1 scores took different signs and the 3 environments fell in only two quadrants in terms of their discrimination of genotypes for BLB score.

![Figure 4: Distribution and performance of the genotypes against X.oryzae pv.oryzae in the locations](image)

**Discussion**

The reaction pattern of the 18 near isogenic lines (NILs) in the three locations ranged from moderately susceptible to susceptible for IRBB1 (Xa1), IRBB2 (Xa2) and IRBB14 (Xa14). These three genotypes have
single genes for resistance. In addition, genotype IRBB4 (Xa4) differentiated pathogen populations of Kibimba and Lira from that of Namulonge, while IRBB10 (Xa10) and IRBB11 (Xa11), being moderately resistant, differentiated pathogen populations of Lira from the rest, IRBB21 (Xa 21) showed resistance in all three locations, a findings that contradicts those of Goel et al. (1998) and Swamy et al. (2006), who reported that IRBB21 (Xa 21) was unresponsive to all pathotypes found in India. However, in another study conducted in Punjab IRBB21 is revealed to be most resistant against 17 BLB isolates (Singh et al. 2003). Similar results were also reported by Mazzola et al. (1994), who noted that IRBB21 is resistant to all pathotypes of Xoo prevalent in India and the Philippines.

This finding suggests that single genes could be used to develop BLB resistant lines through pyramiding. Lines with pyramided genes including IRBB50, IRBB52, IRBB54, IRBB55, IRBB56, IRBB57 and IRBB60, were at least moderately resistant in all three locations, in contrast to single-gene isolines, which had varying and often susceptible reactions. This further supports the view that pyramiding is an appropriate breeding approach for developing resistance to BLB. Singh et al. (2001), indicated that pyramided lines with more than one Xa gene among Xa4, Xa5, Xa13 and Xa21 had increased effectiveness against all isolates from Punjab.

Genotypes, environments, and interactions between genotypes and environments were significant, contributing 15.3%, 19.3% and 13.3% of the genetic variation, respectively. This indicated that there was adequate variability to be worth using AMMI and GGE to detect and describe the performance of the genotypes response to BLB. The significance of the differences among environments indicated a distinctness of intrinsic factors in the different environments. The AMMI 1 biplot explained 99.9% of the total variation, partitioned into PCA1 = 73.02% and PCA 2 = 26.97%.

AMMI 1 plot showed that of the 30 genotypes, a total of 11 (37%) had a mean IPCA1 score outside the range of ± 0.5. The PC1 vs PC2 plot showed that 18 of the 30 genotypes had low interactions with environments for BLB scores. The overall result indicates that there is adequate variability in the NILs to warrant the development of resistant lines. Further, two clear clusters of environments suggests that breeding for multiple target environments could be necessary.

Several genotypes were highly interactive, implying that selection for stability across locations could useful. In these results genotypes, identified as lines as having stable resistance for BLB were: CT12, WITA132 x NERICA14, NERICA10, NERICA4 and NERICA1. The resistance of these varieties may be general enough to avoid needing to develop different BLB resistant lines for separate environments.

AMMI analysis revealed that many evaluated genotypes had significant GxE interactions (P≤ 0.01). Olweny (Lira) located in eastern Uganda, showed the lowest overall BLB score for the tested genotypes with an average mean disease percentage of 17.4% followed by Namulonge with 20.5%. The variation revealed in the AMMI analysis could be due to a number of factors, such as amount of rainfall, temperature, relative humidity, pests or BLB pathotypes. Although AMMI allows visualization of the main effects of the BLB score for the different genotypes and the environments, it does not show which genotype was consistently the most resistant in all locations. The which-won-where pattern can be visualized only by the polygon view of the GGE biplot. The consistently high BLB score for K5 and K85 in both Lira and Namulonge confirms that these new lines are indeed susceptible to BLB. These are the two improved varieties along with landraces that
farmers had started abandoning them due to their susceptibility to bacterial leaf blight and other diseases.

**Conclusion and recommendations**

AMMI indicated significant interactions reflecting differences in the genotypes depending on the environment in which they are tested. These results emphasize that the environment contributes to differential genotype reactions to BLB, and hence to obtain true resistant genotypes there is a need for using multi-locations with several seasons of testing. There is a need to evaluate different isolates from each test environment to separate the effects of the physical environment from differences caused by differing pathotypes.

Our information could be applied in breeding programmes to develop rice cultivars in East Africa or Africa at large, with durable resistance to the BLB pathogen. Furthermore, as Xoo is a seedborne, regional or international monitoring of the pathogen can be utilized in the quarantine programmes.

Due to diverse agro-climatic rice-growing zones as the case shown by the three sites, and the presence of a number of genetically distinct virulent Xoo strains in Uganda, pyramiding of two or more effective *xa* genes in agronomically superior genotypes and search for new disease resistance in context of African origin from wild oryza spp seems to be the most effective disease management strategy in our region.

**Acknowledgements**

We are delighted to sincerely thank the Regional Rice Centre of Excellency Project (RRCoE)-Tanzania under the East Africa Productivity Program (EAAPP) for the full funding of this research. With high gratitude, we would like also to express our sincere appreciations to the staff of NaCRRI-Namulonge, the Department of Agricultural Production and Environmental Sciences-Makerere Univesity and Africa Rice –Tanzania office for their assistance and encouragement.

**References**


## Discussion Session

**Question:** The bacterial leaf blight is new to Uganda. Do you think it had enough time to develop physiological races?

**Answer:** Although the disease was reported in 2009, it might have been there unreported and also bacterial disease took very short period to express itself in the rice population and also due to seed exchange with our farmers from different areas. This could also be the source of introducing new races/pathotype of the disease.

**Question:** Reports from the Uganda cassava program indicate that as the CMD epidemic was moving, the sweet varieties like the “Bwana taraka” were reappearing. Is it fair to conclude that farmers were adopting only the bitter varieties? What is the diversity of the wild relatives in Uganda and in the region?

**Answer:** Diversity of the bitter varieties is about 3% of the collection as per farmer knowledge. Molecular confirmation is yet to be done.

**Question:** From the presentation, it was mentioned that the findings showed a large diversity. How was the diversity analyzed?

**Answer:** Farmer knowledge (description) percentages according to farmer naming and description. The Genotyping and phenotyping are yet to be done and data analysed by software accordingly.

**Question:** From the presentation, it was mentioned that the findings showed a large diversity. How was the diversity analyzed?

**Answer:** Farmer knowledge (description) percentages according to farmer naming and description. The Genotyping and phenotyping are yet to be done and data analysed by software accordingly.

**Question:** How many households were sampled and how come varieties promoted by EAAPP are not found in all districts by this time?

**Answer:** 3-5 sub-counties per district; 5 -12 households per sub-county randomly selected especially with the history of availability of landraces using the sub-county NAADS coordinators, Agric officers, production officers helped in identifying owners of landraces.

**Question:** How long will the germplasm be preserved? Was the indexing for CBSD and CBB done?

**Answer:** The germplasm will be preserved as long as it is required and even forever. Medium term conservation has been initiated; as well as Long term conservation condition.
Question: Could effective extension contribute to erosion of traditional varieties?
Answer: Yes, the extension workers convince farmers on how cultivars are better than landraces. As a result farmers uproot landraces and replace with the improved ones.

Question: What type of breeding strategy to recommend from your GxE of bacterial blight study?
Answer: To collect different disease isolates from different locations and test different genotypes and from this breeding should include those evaluated from different tests.

Question: Is the NERICA rice genetically Modified (GMO)?
Answer: NERICA is not in the series of GMOs

Question: The bacterial leaf blight is new to Uganda, do you think it had enough time to develop physiologically? There was significant GxE interaction – but this is not in agreement with the established fact; resistance must be stable.
Answer: Although the disease was reported in 2009 it might be there before reported and also bacterial disease took very short period to express itself in the rice population and due to seed exchange with our farmers from different places. This can also be the source of introducing new races or pathotype of the disease since it is a seed borne disease

Question: Research carried out in Namulonge Kibimba – why not Doho rice scheme?
Answer: Due to time and financial stand I had to conduct the research in few locations with the expectation of representative of the others
Performance of nine upland rice (*Oryza sativa* L.) genotypes in three locations in Kenya


Kenya Agricultural and Livestock Research Organization-Kibos, P.O. Box 1490, Kisumu, Kenya.

*Correspondence: wikore2000@yahoo.co.uk*

**Abstract**

Rice is increasingly becoming one of the most important cereals in Kenya. Its demand which is higher than the production volume has been increasing at 12% per annum. Currently, almost two-thirds of the rice being consumed in the country is imported. This is due to a number of constraints including low yielding varieties, limited area under cultivation, biotic and abiotic stresses as well as socio-economic constraints. The present experiment was, therefore, undertaken to identify superior, well adapted and acceptable rice varieties for the upland ecologies of Kenya. The performance of nine promising rice genotypes was field evaluated at three locations using randomized complete block design (RCBD) replicated four times. All agronomic recommendations were used and data were collected on yield and yield components. The analysis of variance revealed significant differences between the lines. The results indicated that despite the erratic rainfall at KARI Kibos, NERICA 14 out-yielded the check varieties indicating tolerance to moisture stress. In Muhoroni and Lichota where the rainfall pattern was more favourable, FOFIFA 3729 and FOFIFA 3782 out-performed all the genotypes including the best performing check. These results suggest that NERICA 14 can be grown in areas with less rainfall while FOFIFA 3729 and FOFIFA 3782 can be recommended for the high potential areas.

Key Words: Genotypes, Kenya, Upland rice, yield, yield components

**Introduction**

Upland rice in Kenya is increasingly gaining ground in terms of importance and area covered. The average productivity is as low as 0.8 t/ha due to many factors including lack of suitable varieties, biotic and abiotic stresses and socio-economic constraints. This is further aggravated by the challenges of climate change which includes unreliable rainfall. Crusciol *et al.* (2003) reported that the cultivation of rice under water deficit conditions during the vegetative and reproductive stages presents a reduction in dry matter production. According to Gerik *et al.* (1996), the balance between production of assimilates and demand for the development of the reproductive organs becomes severely affected by the reduction in the photosynthetically active leaf area. According to Kato (2004), the effect of drought varies with the variety, degree and duration of stress and its coincidence with different growth stages.

Grain yield depends on genotype, environment and management practices and their interactions (Messina *et al.*, 2009). Under the same management conditions, variation in grain yield can be explained by the effects of genotype and environment (Dingkuhn *et al.*, 2006). Interaction between the genotype and the environment helps in identifying genotypes that are suitable for specific environments. In the upland ecology, drought stress has been cited as the largest and most severe constraint to rice production in Asia and sub-Saharan Africa (Kumar 2010; Kamoshita *et al.*, 2008). The upland ecosystem where drought possess a big challenge are widespread in the rain-fed rice growing areas of Kenya. According to Gichere *et al.* (2013), 98% of Kenya’s crops are rain-fed and only 19% of the country’s potential area is suitable for irrigation. The high variability of rainfall coupled with climate
change markers such as floods and droughts poses a significant risk to farmers. Consequently, there is a strong need of having suitable varieties that can be grown in the moisture challenged ecologies. This trial was, therefore, conducted with an aim of identifying suitable genotypes that can withstand the diverse challenges experienced in the above mentioned ecologies.

**Materials and methods**

Nine upland breeding lines including two checks were evaluated during the 2012 long rains at KARI Kibos, Lichota, and Muhoroni. KARI Kibos is situated at (0° 03’S” and 34° 1’ 48”E) and Lower midlands (LM) 3 agro ecological zone with an altitude of 1173 meters above sea level. The soil type is grey to black cotton heavy clay soil classified as Planosols (Kibos Annual Report, 2006). The temperatures ranged between mean minimum of 17.6 °C and mean maximum of 29.4 °C while the rainfall was 773.6 mm during the growing period (KARI-Kibos Meteorological Weather Station, 2012). Lichota site, on the other hand, lies in LM agro-ecological zone with red loamy soils.

The average temperatures during the growing period was 21.5 °C while the total rainfall received during the same period was 1267 mm. Muhoroni site falls in the sugar belt area of western Kenya and received a total of 709 mm during the growing period. The experimental design used in all the sites was a randomized complete block design (RCBD) replicated four times. A basal application of 46 kg P₂O₅ ha⁻¹ was used at planting. Top dressing was done using nitrogen fertilizer at 52 kg N ha⁻¹ applied in two equal splits at 20 and 50 days after seedling.

Data was collected on yields and yield components which included days to 50% flowering, tiller number, plant height, number of panicles per hill, panicle length, number of grains per panicle, 1000-grain weight and grain yield using IRRI’s Standard Evaluation System (SES). The data were analyzed using SAS Statistical package and means separated using Student-Newman-Keul’s (SNK) test. Combined analysis of variance was done

**Results**

Climatic data during periods of conducting the experiments in 2012 are shown in figure 1 below. On the whole, Lichota received the most rainfall followed by Muhoroni. Kibos received the least rainfall.
Preliminary analysis of variance showed that genotypes were differently influenced by the environments, since the genotype x environment interaction was significant for all variables. All sites showed no significant differences between the genotypes as far as number of panicles per hill is concerned. The number of grains per panicle, however, significantly different only at Lichota. Significant differences between the genotypes were only identified as far as panicle length, 1000 grain weight and grain yield are concerned (p< 0.05) (Table 1).

**Number of panicles per hill**
The number of panicles per hill were more in Muhoroni for all the genotypes with Dourado having the highest while the least was from FOFIFA 3782. The least number of panicles were recorded at Lichota. At Kibos, the highest were from FOFIFA 3782 while the least were from FOFIFA 3729. At Lichota the highest was from NERICA 8 while the least was from FOFIFA 3730.

**Number of grains per panicle**
More grains per panicle were found at the Kibos site with NERICA 13 having the highest and NERICA 14 the least. At Muhoroni and Lichota, the highest number was from NERICA 4 while the least were from NERICA 8 and Dourado in Muhoroni and Lichota respectively.

**Panicle length**
The performance for this variable seems comparable in all the sites with longest of 22.8 cm for NERICA 13 at Kibos and the shortest of 10.6 cm for Dourado at Lichota.

**1000-grain weight**
The highest 1000 grain weight was 37 for FOFIFA 3782 at Lichota and the least of 9 from Dorado Precoce at the same site.

**Grain Yield**
The highest yield of 2.13 t/ha was recorded from NERICA 14 at Kibos while the least (0.03 t/ha) was recorded from Dourado at Lichota.

**Figure 2: Average temperatures during the growing period at Kibos and lichota**

Temperature (°C)

<table>
<thead>
<tr>
<th>Month</th>
<th>Kibos</th>
<th>Lichota</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>25.0</td>
<td>20.0</td>
</tr>
<tr>
<td>April</td>
<td>20.0</td>
<td>15.0</td>
</tr>
<tr>
<td>May</td>
<td>15.0</td>
<td>10.0</td>
</tr>
<tr>
<td>June</td>
<td>10.0</td>
<td>5.0</td>
</tr>
<tr>
<td>July</td>
<td>5.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Significant differences between yields within each site were identified at all the sites apart from Lichota where only Dourado precoce had significant differences from the other treatment while all the other treatments did not have significant differences among themselves.

NERICA 14 had the highest yields of 2.13 t/ha at KARI Kibos. At Lichota, FOFIFA 3729 and FOFIFA 3782 outperformed the best check giving yield of 2.05 t/ha and 2 t/ha respectively while in Muhoroni, the best performers above the best check were FOFIFA 3730, FOFIFA 3729 and FOFIFA 3782. The lowest yields were obtained from Dourado Precoce in all the sites with Kibos giving of 0.63 t/ha, Muhoroni 0.20 t/ha and Lichota 0.03 t/ha (Table 1).

In Muhoroni and Lichota where the rainfall pattern were more favourable, FOFIFA 3729 and FOFIFA 3782 outperformed all the genotypes including the best performing check.

Table 1: Performance of different upland rice genotypes in three environments

<table>
<thead>
<tr>
<th>Variety</th>
<th>Kibos</th>
<th>Lichota</th>
<th>Muhoroni</th>
<th>mean</th>
<th>Kibos</th>
<th>Lichota</th>
<th>Muhoroni</th>
<th>Mean</th>
<th>Kibos</th>
<th>Lichota</th>
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<th>mean</th>
</tr>
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<tbody>
<tr>
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<td>13</td>
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<td>16.57</td>
<td>18.54</td>
<td>152.06</td>
<td>103.61</td>
<td>88.8</td>
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<td>FOFIFA 3729</td>
<td>9</td>
<td>9</td>
<td>13</td>
<td>11</td>
<td>19.91</td>
<td>19.33</td>
<td>16.89</td>
<td>18.71</td>
<td>121.25</td>
<td>116.75</td>
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<td>FOFIFA 3782</td>
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<td>10</td>
<td>12</td>
<td>11</td>
<td>19.44</td>
<td>18.12</td>
<td>15.62</td>
<td>17.72</td>
<td>115.47</td>
<td>103.92</td>
<td>92.2</td>
<td>103.85</td>
</tr>
<tr>
<td>NERICA 4</td>
<td>16</td>
<td>11</td>
<td>17</td>
<td>15</td>
<td>22.67</td>
<td>20.01</td>
<td>18.91</td>
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<td>139.69</td>
<td>149.08</td>
<td>115.6</td>
<td>134.8</td>
</tr>
<tr>
<td>DOURADO PRECORE</td>
<td>14</td>
<td>23</td>
<td>18</td>
<td>18</td>
<td>21.7</td>
<td>21.23</td>
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<td>140.33</td>
<td>108.92</td>
<td>94.9</td>
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</tr>
<tr>
<td>Lsd</td>
<td>4.34</td>
<td>3.962</td>
<td>5.115</td>
<td>5</td>
<td>2.24</td>
<td>1.643</td>
<td>1.906</td>
<td>1.86</td>
<td>28.54</td>
<td>28.517</td>
<td>21.79</td>
<td>26.758</td>
</tr>
<tr>
<td>CV (%)</td>
<td>24.2</td>
<td>23</td>
<td>23.9</td>
<td>24</td>
<td>7.4</td>
<td>5.8</td>
<td>7.6</td>
<td>7</td>
<td>14.7</td>
<td>16.7</td>
<td>15.1</td>
<td>15.5</td>
</tr>
</tbody>
</table>

Figure 3: Yields of 9 genotypes in 3 environments
**Discussion**

Analysis of variance showed that genotypes were differently influenced by the environment for 1000 grain weight and yield, since the genotype x environment interaction was significant (p<0.01) for both. Site also showed significant differences for 1000-grain weight (p<0.05) and yield p<0.01. For grains per panicle and panicle length, locations showed significant (p<0.01) differences while the interaction for site and genotype was not significant. These differences can be explained by different climatic conditions, especially rainfall distribution, that occurred during the periods of conducting the experiments (Figure 1).

The number of grains panicle−1 seemed to have no influence on grain yield in these trials as had also been observed by Lafitte et al. (2004) Additionally, Pinheiro (2003) and Yue et al. (2006) found that spikelet sterility is the component of productivity more sensitive to water stress. The performance for this variable seems comparable in all the sites with longest of 22.8 cm for NERICA 13 at Kibos and the shortest of 10.6 cm for Dourado at Lichota. The heaviest grains of 37g was recorded for FOFIFA 3782 at Lichota while the lightest genotype weighing only 9 g was Dorado Precoce at the same site. Yue et al. (2006) also observed that yield loss under drought stress were associated with reduction of fertile panicle rate and grain weight.

At KARI-Kibos where the rainfall was lower than in all the other sites, NERICA 14 was the best performing genotype followed by NERICA 4 which was the best check. These results suggest the higher competitive effect of the NERICA 14 under less moisture as compared to the other genotypes. This performance could also be associated with earliness which enabled the variety to escape drought. According Taiz and Zeiger (2004), the first responses of plants to water deficit consists in decreasing the leaf area production, stomatal closure, accelerated senescence and abscission of leaves. For Correia et al. (2004), this type of response may be associated with a mechanism of tolerance to water stress, and that under conditions of low water availability in the soil, plants invest more biomass in the root system, with the objective of increasing its nutrient absorption capacity. Rice genotypes that produce a higher grain yield under drought are those able to maintain better plant water status, especially when stress occurs around flowering and grain formation (Fukai et al., 2008), since leaf and panicle water potential are very highly associated with panicle exertion and anther dehiscence.

When comparing the genotypes at Lichota and Kibos, there was a reduction in yield for FOFIFA 3729 and FOFIFA 3782 by 46 % and 39 % respectively. FOFIFA 3729 seemed more efficient in terms of growth and utilization of the resources of the soil in relation to NERICA 14 where there was more moisture like Lichota. This conforms to the observation by Lafitte et al. (2006) that there is usually a variability in the grain yield of rice genotypes when subjected to water deficit.

To meet the conditions of water stress-producing regions of upland rice like kibos, where during the growing season the rainfall distribution may have some irregularities, the drought tolerance should be an aggregated characteristic of the genotype, since most of the time the rainfall distribution is adequate. Jongdee et al. (2006) reported that genotypes can be developed showing good grain yield in water stress conditions and, at the same time, being responsive to favorable soil moisture, provided they are evaluated in both environments. According to the authors, this is feasible for moderate water stress, when the reduction in productivity is less than 50%. However, under severe stress, mechanisms for escape or tolerance to water deficit are required. Genotypes FOFIFA 3729, 3730 and 3782 were productive under places with higher rainfall, but were more sensitive to water deficit.
Conclusion

These results suggest that NERICA 14 can be grown in areas with less rainfall while FOFIFA 3729 and FOFIFA 3782 can be recommended for the higher potential areas.

Acknowledgements

The authors are grateful to EAAPP for financial support in conducting this research. The enabling environment provided by the Centre director KARI Kibos and the Director KARI are highly appreciated. All the effort of the collaborating scientists and the technical staff as well as collaborators who contributed to the success of this work are highly acknowledged.

References


Kumar A. (2010) Lecture notes. Leaders training Course for women working on rainfed rice from Asia and Africa. IRRI. Phillippines


Discussion Session

**Question:** What is the relationship between grain yield and the following parameters; panicle number, length and seed set given the surprising results

**Answer:** There is actually a positive correlation between these traits (studied) and grain yield. The results in Dourada that had more panicles but enclosing with low grain yield was because its longer growth duration so the rains stopped before it could have good grain filling.

**Question:** How does low temperature leads to sterility of rice? Any possibility for breeding cold tolerant as there are many cold (highland) areas in the region?

**Answer:** When the temperature go below 17°C for just 2 hours during flowering, the pollen will not shed and we end up with no grain setting because of no pollination.

**Question:** The assessment performance was of upland rice in 3 locations but it looks like some materials tested were low land? You also evaluated uplands in cold areas instead of testing for cold tolerance

**Answer:** All varieties we tested were upland rain-fed. I agree with you that some areas need cold tolerant varieties. Unfortunately we didn’t have cold tolerant variety among the nine that were tested; and I think it is important to include cold tolerance in future work
Incidence and spatial distribution of stem borers in rice grown in Kahama district, Tanzania

Alfonse Leonard.

Lake Zone Agricultural Research and Development Institute (LZARDI), P.O. Box 1433, Mwanza, Tanzania.
Correspondence: leonardalfonce@yahoo.com

Abstract
Species diversity, abundance, dispersion and damage incidences of Rice stem borers in framer’s fields were studied in four major rice growing areas of Kahama District in Tanzania. In each quadrat; rice tillers damaged as ‘dead heart’, panicles damaged as ‘white head’ and total number of tillers and panicles were counted. Stem borer incidences were computed for each of the studied rice varieties and with reference to the sowing dates. Stem borer larvae were extracted from the damaged tillers in 16 quadrants established in each field. Adult Moths were trapped by light traps and collected in vials for identification. Results indicated the presence of Chilo partellus, Maliarpha separatalla and Sesamia calamistis in all study areas. The most abundant species was Chilo partellus (48.6%) followed by Maliarpha separatalla (35.4%) and Sesamia calamists was least abundant (16.1%). Stem borers dispersion was aggregated along the edges of rice fields in three locations (wards) namely; Bulige, Chela and Ngaya. The dispersion in the fourth ward, Kashishi was uniform as established from two of the three dispersion indices tested. Behenge and Supa varieties were more susceptible to stem borer damage than Kalamata and Mayobhe. The best sowing date with minimum stem borer damage was from 1st to 20th December. Further studies would be required to establish the available alternative hosts, the extent of economic losses and the distribution of rice stem borers in the rest of the Lake zone of Tanzania.

Key words: Abundance, Dispersion, Moths, Varieties, dead heart, white head

Introduction
Rice is produced and consumed by almost half of global population (Dhuyo and Soomro, 2007). Rice covers about 11% of the earth's arable land and by far the most important crop worldwide (Ogah, 2013). Rice is a popular food in Africa especially in South of Sahara (Banwo, 2002). The crop is produced in east and west parts of Africa. Rice is the third most important food crop in Tanzania after maize and cassava; it is the source of employment and income for many farming households (MAFC, 2009). About 17 percent of households in Tanzania produce rice (MAFAP, 2012). Rice production in Tanzania covers approximately 681 000 ha representing 18 percent of the cultivated land. About 48 percent of rice is produced in Morogoro, Shinyanga and Tabora where there is more favourable growing condition (RLDC, 2009).

Tanzania depends on traditionally grown local varieties of rice which were imported from Arabic countries before 1960. These varieties include Behenge, Kalamata, Kula na bwana, Supa and many others (RLDC, 2009). The varieties are grown due to the ability to adapt climatic conditions and the taste preference of Tanzanians.
The average rice yield in Tanzania is 2.8 t/ha which is below world average of 3-6 t/ha (Rwezaura et al., 2011). Low rice yield in Tanzania is contributed to many factors which include diseases, weeds and insect pests. Rice stem borers are among the 13 insect species reported as major constraints of rice production in Tanzania (Banwo, 2002). These stem borers are; Maliarpha seperatella, Sesamia calamistis and Chilo partellus (Abdulla, 2007). All three species are distributed in major rice growing regions including Shinyanga.

The larvae are the destructive growth stage of stem borer pests. These larvae bore and feed on the leaf sheath where they cause whitish discoloration at the feeding site. Larvae from the sheath bore into the stem; they stay in the pith and feed in the inner surface of the walls. The feeding always separates apical parts of the plant from the base (Pathak et al., 1998). When this type of damage occurs at vegetative stage of the plant growth, the central leaf whorl does not unfold. It becomes brown, and dies out, but the lower leaves remain green and healthy. This damage is known as “dead heart” and the affected tillers die out without producing panicle. At flowering stage of the plant, the damage results in the drying of panicle. The damaged panicles become white and empty; this damage symptom is called “white head” (Pathak and Khan, 1994).

Rice varieties react differently to stem borer attack. Some rice cultivars are susceptible while others are tolerant to stem borer damage. Susceptibility of rice varieties to stem borer damage is associated with physiological characteristics such as high water and silica content in the plant. Resistant varieties contain an antibiosis factors that hinder larvae development; for example benzoic acids, salicylic acid and some fatty acids inhibit growth of stem borer larvae (Pathak et al., 1998).

Manipulating of sowing time has been used in stem borer management program. In Pakistan early sowing date has low stem borer incidences than medium and late sowing dates (Muhammad, 2012). In West Africa, late planted maize experience high stem borer damage than the early planted ones (Rami et al., 2002). Stem borer pests have for many years been blamed by farmers as the major factor contributing to high rice yield loss in Kahama District. The current study aims at investigating the existing species of the rice stem borers, their incidences, the magnitude of damages caused and spatial distribution in rice fields in Kahama District.

Materials and methods
The survey was conducted in 20 farmers’ fields from November, 2013 to May, 2015. Data was collected twice at both reproductive and vegetative growth stages. Rice fields were randomly selected at an approximate interval of 1km from each other. A plot size of about 1 acre (70m x 70m) was demarcated by using fibre tape. A guard row of approximately 15-20 meters was maintained. Sowing date and rice varieties were considered as a selection criteria of farmer’s fields. In all four wards sampled, at least three rice varieties (supa, kalamata, mayobhe and behenge) were common and sowing dates were grouped into three groups (15-30/11/2013, 1-20/12/2013 and 28/12/2013-05/01/2014). Stratified sampling method was used in all selected farms whereby the farm was divided into four strata. In every stratum four quadrats of 1m x 1m size were established for sampling, giving a total of 16 quadrats in each field.

The experimental design was a split plot. Wards were regarded as main plot/factor while farmer’s fields were regarded as sub plot/ factor. The assessments were done three (3) weeks after planting for dead heart damage and ten (10) weeks after planting for white heart damage. Number of damaged tillers as dead heart and white heads in each quadrat were counted. The total number of tillers and panicles within the quadrat were also counted to establish the value upon which the percentage incidence would be derived as described by Suresh et al. (2009).
The number of larvae of stem borers present in various tillers were counted in each quadrat. The spatial distribution pattern for stem borer was determined by three indices of dispersion, including Morista index, Iwao’s mean crowding regression and Taylor’s power law as described by Morista (1959), Iwao (1968) and Taylor (1965) respectively. These three indices were chosen so as to obtain consensus of dispersion, because the use of only one index can be misleading (Casey, 2012). These indices are described by the formula below;

\[
\text{Morista’s index (}I_d\text{)} = \frac{\sum_{i=1}^{N} n_i(n_i - 1)}{n(n - 1)} \times N
\]

Where \( I_d \) = Index or Coefficient of dispersion, \( N \) = number of samples, \( n_i \) = number of individuals in the sample, \( n \) = total number of individuals in the sample. If \( I_d < 1 \), \( I_d = 1 \), and \( I_d > 1 \) indicate uniform, random and aggregated spatial distribution patterns respectively. Iwao’s mean crowding regression was determined through solving the following equation:

\[
m' = \alpha + \beta m
\]

Where \( \alpha \) (estimated by \( a \)) = intercept of the ordinate, \( \beta \) (estimated by \( b \)) = slope of the regression line when \( m \) is regressed by mean. Mean crowding \( m' \), was derived from the equation and \( m \) was replaced with the mean and variance from the count data.

\[
m' = m + \left( \frac{S^2}{m} \right) - 1
\]

For the part of Taylor power law, the relationship between mean and variance, \( S^2 = am^b \), was used to solve the coefficient \( a \) and \( b \) with linear regression when the log transformation was used.

\[
\log(S^2) = \log(a) + (b) \log(m)
\]

Two light traps were used for moths trapping during night time in each field whereby White cloth was reinforced with ropes and tied between two stands/wooden splints. Two electrical bulbs (black and white light sources) were attached to the cloth to attract the moths. Moths gathering on the white cloth were collected into collection vials applied with Ethyl Acetate and sorted later to identify the respective species.

Identification of stem borer species was done using the identification guide by Pathak and Khan (1994). Species abundance was calculated according to Thomas (2005) as follows;

\[
\text{Abundance of species} = \frac{\text{Number of individuals of the same species}}{\text{Total number of moth}} \times 100\%
\]
The collected data was tested for normality using SPSS statistical package upon which conformity to the normal distribution suggested no need for transformation. Data for borers’ abundance were subjected to the analysis of variance (ANOVA) and mean separation tested at P<0.05 by using Genstat 15 edition statistical package (VSN international). Coefficient of dispersion data were analysed by Iwao’s crowding regression and Taylor power law indices, regression and parameters were generated by using SPSS statistical package. Significant differences among means were separated using Least Significant Difference test (LSD) at 5% probability.

Results

Species density and abundance in different wards

Three species of stem borers, *C. partellus*, *M. separatella* and *S. calamistis* were recorded from all surveyed sites (Figure 1). All three stem borer species were captured in all twenty farms assessed. Out of the four wards surveyed, *C. partellus* was highly abundant in Chela (70.7%) and Ngaya (56.8%) while *M. separatella* was highly abundant in Kashishi (58.9%) and Bulige (45.0%). *Sesamia calamistis* was observed to be less important in Bulige, Kashishi and Ngaya. In Chela, *S. calamistis* (16.7%) was the second abundant species after *C. partellus*. Overall, *C. partellus* was highly abundant (48.6%) followed by *M. separatella* (35.4%) and lastly *S. calamistis* (16.1%). Significant differences in numbers of stem borer species were observed in four wards surveyed (P <0.05) (Table 1). Abundance of *M. separatella* also varied significantly among the wards (P<0.05).

<table>
<thead>
<tr>
<th>Wards</th>
<th>Stem borer species</th>
<th>Kashishi (Mean±SE)</th>
<th>Bulige (Mean±SE)</th>
<th>Chela (Mean±SE)</th>
<th>Ngaya (Mean±SE)</th>
<th>Mean abundance (%) (Mean±SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chilo partellus</td>
<td>33.0±6.95ab</td>
<td>33.8±6.95ab</td>
<td>70.7±6.95a</td>
<td>56.8±6.95a</td>
<td>48.6±6.95a</td>
</tr>
<tr>
<td></td>
<td>Maliarpha separatella</td>
<td>58.9±8.32a</td>
<td>45.0±8.32a</td>
<td>12.6±8.32b</td>
<td>25.1±8.32b</td>
<td>35.4±8.32b</td>
</tr>
<tr>
<td></td>
<td>Sesamia calamistis</td>
<td>8.1±4.61b</td>
<td>21.5±4.61b</td>
<td>16.7±4.61b</td>
<td>18.1±4.61b</td>
<td>16.1±4.61b</td>
</tr>
<tr>
<td>CV(%)</td>
<td>64.8</td>
<td>64.8</td>
<td>64.8</td>
<td>64.8</td>
<td>64.8</td>
<td></td>
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<tr>
<td>F- value</td>
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<td>0.004</td>
<td>0.004</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>LSD at 0.05</td>
<td>32.5</td>
<td>21.02</td>
<td>36.42</td>
<td>18.21</td>
<td>32.4</td>
<td></td>
</tr>
</tbody>
</table>

Mean values with the same letter within a column are not significantly different at P < 0.05
**Stem borer distribution**

Mean stem borer larvae per quadrat in four wards studied ranged from 1.00 – 2.63 in Kashishi, 0.60 – 2.31 in Bulige, 0.00 – 6.00 in Chela and 1.00 – 6.13 in Ngaya (Table 2). In Kashishi, two indices were in agreement that stem borer population were uniformly distributed in fields while one index showed aggregated distribution. In Bulige and Ngaya all indices were in agreement that stem borer larvae were aggregated in rice fields. In Chela two indices suggested the aggregate distribution of stem borer larvae while one index showed uniform distribution.

Morisista’s index was greater than 1 in Bulige, Chela and Ngaya indicating aggregated population distribution while in Kashishi was less than one indicating uniform distribution (Table 2). The slopes of the regression lines for Iwao’s mean crowding regression were numerically greater than 1 in Bulige, Chela and Ngaya, indicating aggregated distribution while in Kashishi the slope was significantly less than one indicating uniform distribution. Slopes of the regression lines for Taylor’s power law were greater than 1 in Kashishi, Bulige and Ngaya indicating aggregate distribution of larvae, in Chela slope was less than 1 indicating uniform distribution.

In all the four wards surveyed, stem borer larvae were more aggregated along the edges of rice fields than in the middle parts (Figure 2). The aggregation of larvae along the edges of field did not differ more than the concentration in the middle of the field. Among these wards, Chela had the highest number of larvae followed by Ngaya, Kashish while Bulige had the least (Figure 2).

**Table 2: Dispersion indices of stem borer larvae in rice fields in four wards of Tanzania, 2013/2014**

<table>
<thead>
<tr>
<th>Ward</th>
<th>Range of means</th>
<th>Morisista’s index</th>
<th>Iwao’s mean crowding regression</th>
<th>Taylor power law</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Kashishi</td>
<td>1.00 – 2.63</td>
<td>0.85</td>
<td>0.741</td>
<td>0.53</td>
</tr>
<tr>
<td>Bulige</td>
<td>0.60 – 2.31</td>
<td>1.10</td>
<td>-0.14</td>
<td>1.13</td>
</tr>
<tr>
<td>Chela</td>
<td>0.00 – 6.00</td>
<td>2.95</td>
<td>0.57</td>
<td>1.02</td>
</tr>
<tr>
<td>Ngaya</td>
<td>1.00 – 6.13</td>
<td>3.87</td>
<td>1.40</td>
<td>1.10</td>
</tr>
</tbody>
</table>
Figure 2: Mean stem borers’ aggregation within rice fields at three locations in Tanzania

Effect of site (ward) on incidence of stem borer

Among the surveyed wards, Kashishi and Ngaya had more damage incidences than Bulige and Chela (Table 3). There was significant differences in both dead heart and white head incidences (P<0.05). At both vegetative and reproductive stages Kashishi and Ngaya had higher stem borer damage incidence than Bulige and Chela.

Table 3: Rice stem borer incidences (%) in different wards in Tanzania during 2013/2014

<table>
<thead>
<tr>
<th>Ward name</th>
<th>Incidences</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dead heart (%)</td>
<td>White head (%)</td>
<td></td>
</tr>
<tr>
<td>Kashishi</td>
<td>3.69a</td>
<td>2.38b</td>
<td></td>
</tr>
<tr>
<td>Bulige</td>
<td>2.21b</td>
<td>1.79c</td>
<td></td>
</tr>
<tr>
<td>Chela</td>
<td>2.54b</td>
<td>1.69c</td>
<td></td>
</tr>
<tr>
<td>Ngaya</td>
<td>3.67a</td>
<td>2.59a</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>3.03</td>
<td>2.11</td>
<td></td>
</tr>
<tr>
<td>LSD</td>
<td>1.13</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>0.18</td>
<td>0.14</td>
<td></td>
</tr>
</tbody>
</table>

Mean values with the same letter within a column are not significantly different at P <0.05

The effect of rice varieties on stem borer incidences

Rice varieties grown at Kahama District are local varieties which include Behenge, Kalamata, Mayobhe and Supa. The most susceptible variety to stem borers damage was Behenge followed by Supa having incidences of (4.30% for dead heart and 3.07% for white head) and (3.53% for dead heart and 2.81% for white head), respectively. Mayobhe and Kalamata were somehow tolerant to stem borer damage (Table 4). In all varieties the incidence of stem borer was higher at the vegetative stage than at the reproductive stage. There was
significant difference of stem borer incidences among rice varieties (P<0.05)

**Table 4: Rice stem borer incidences (%) in different varieties in Tanzania during 2013/2014**

<table>
<thead>
<tr>
<th>Variety</th>
<th>Incidence</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dead heart (%)</td>
<td>White head (%)</td>
<td></td>
</tr>
<tr>
<td>Supa</td>
<td>3.53a</td>
<td>2.81a</td>
<td></td>
</tr>
<tr>
<td>Kalamata</td>
<td>2.56b</td>
<td>1.58b</td>
<td></td>
</tr>
<tr>
<td>Mayobhe</td>
<td>2.40b</td>
<td>1.58b</td>
<td></td>
</tr>
<tr>
<td>Behenge</td>
<td>4.30a</td>
<td>3.07a</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>3.03</td>
<td>2.11</td>
<td></td>
</tr>
<tr>
<td>LSD</td>
<td>0.97</td>
<td>1.23</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>0.18</td>
<td>0.14</td>
<td></td>
</tr>
</tbody>
</table>

Mean values with the same letter within a column are not significantly different at P<0.05

**The effect of sowing date on the stem borer incidences**

Sowing date had an effect on the incidences of stem borer damage. The results showed differences in the incidences of stem borers within rice varieties sown in different dates (Table 5). Early sown rice (15/11/2013 – 30/11/2013) had high incidences of Dead Heart (DH) due to stem borer at vegetative stage (2.853%) than medium (1/12 - 20/12/2013) and late sown rice (28/12/2013 - 05/01/2014) having 2.3125% and 2.6% DH, respectively. In contrast to reproductive stage, late sown rice had higher incidences of White Head (WH) (2.6% than medium (1.4%) and early sown ones (2.3%). There was significant difference in white head incidences while no significant difference was observed in dead heart incidences at P<0.05 level (Table 5). According to these results, the best planting date with minimum stem borer damage is from 1st December to 20th December, 2013.

**Table 5: Rice stem borer incidences (%) in different sowing date in Tanzania during 2013/2014**

<table>
<thead>
<tr>
<th>Sowing date</th>
<th>Incidences</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dead heart (DH) (%)</td>
<td>White head (WH) (%)</td>
<td></td>
</tr>
<tr>
<td>15-30/11/2013</td>
<td>2.85a</td>
<td>2.30ab</td>
<td></td>
</tr>
<tr>
<td>1-20/12/2013</td>
<td>2.31a</td>
<td>1.40b</td>
<td></td>
</tr>
<tr>
<td>28/12-05/01/2014</td>
<td>2.60a</td>
<td>2.62a</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.59</td>
<td>2.11</td>
<td></td>
</tr>
<tr>
<td>LSD</td>
<td>1.03</td>
<td>1.22</td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>0.16</td>
<td>0.19</td>
<td></td>
</tr>
</tbody>
</table>

Mean values with the same letter within a column are not significantly different at P < 0.05
Discussion

In general *C. partellus* was more dominant throughout Kahama District than *M. separatella* and *S. calamistis*. This could be the reason that *C. partellus* completes its life cycle faster than other species found in Kahama District. Nsami *et al.* (2001) reported that *C. partellus* was highly abundant in Eastern Zone of Tanzania where it constituted 80% while *S. calamistis* constituted only 4%. Abdulla (2007) reported that *C. partellus* completes life cycle faster than other stem borer species hence high population growth than other species. *C. partellus* colonizes suitable feeding niches much earlier than the indigenous stem borers and hence it reduces the number of other stem borer species that colonize the habitat (Ofohata *et al.*, 2000). The significant differences in stem borer abundance observed among wards might be due to difference in available host plants around rice fields. Govender *et al.* (2013) reported that in South Africa stem borer species abundance differed depending on available host plants. Also Moolman *et al.* (2013) reported the difference in species density among different host plant surveyed.

In all the four wards surveyed, at least one of the three indices showed that stem borer larvae were aggregated ($b>1$) (Table 2). In Bulige, Chela and Ngaya results indicated that stem borers were aggregated along the field edges while in Kashishi three indices of dispersion showed that stem borer larvae were uniformly distributed throughout the fields although they were more concentrated at the edges of field (Figure 2). These larvae were aggregated along the edges of rice fields in all the four wards surveyed (Figure 2). This study confirms the previous findings by Gounou and Schulthess (2004) who reported the aggregate distribution of stem borer in various host plants assessed. Concentration of stem borer larvae along the field might have caused by migration of stem borers from other host plants around rice fields. Aggregation of stem borer larvae along the edges of rice fields is an indication that stem borer larvae came from other host plants around the rice fields.

In East Africa, 39 wild host plants of stem borers have been identified. Most common wild host plants in the region are belonging to the families Poaceae, Cyperaceae and Typhaceae (Le Ru *et al.*, 2006). Mailafiya *et al.* (2011) reported numerous wild host plants like *Cperus spp*, *Panicum spp*, *Pennisetum spp*, *Sorghum spp*. These host plants are all found in the surveyed wards and they could have been the source of stem borer larvae that infected rice fields.

Knowing spatial dispersion is useful for the development of sampling plan since one should concentrate where the larvae are dispersed. For these stem borers, sampling plan should concentrate on the edges of rice fields. Casey and Trumble (2012) reported that for the development of sampling plan, spatial dispersion can help in choosing sampling unit; one should concentrate on examining the edge of the field since stem borers are aggregated. Dispersion data agree to a better understanding of the relationship between an insect and its environment and give basic knowledge for interpreting spatial dynamics and come out with efficient sampling programs (Casey and Trumble, 2012). Stem borer sampling error is caused by aggregate spatial distribution behaviour of lepidopteran rice stem borers (Ndemah *et al.*, 2001; Gounou and Schulthess, 2004).

There were significant differences in stem borer damage among the wards surveyed. The difference in stem borer damage could be attributed to the various rice varieties grown in particular areas since Behenge variety which is more susceptible is grown at Ngaya and Chela which have also high incidences of stem borer damage (Table 3). Touhidur *et al.* (2004) reported that population density, the timing injury and rice growing conditions are factors that favour stem borer attack. These factors might have caused the differences in incidences of stem borers among farms and wards.
Damage incidences in rice varieties varied significantly at reproductive stage (White head) (Table 4). Kalamata and Mayobhe varieties are naturally tolerant to stem borer due to their low damage incidence. Resistance characteristic possessed by these varieties may be caused by having repellent structures or lack of feeding stimulus in the plant. It could also be due to the presence of materials or deficiency of nutrients which are important for the insect pest (Muhammad, 2012). Mechanism of resistance to stem borer may be contributed by two physical characteristics caused by direct mortality and sub-lethal effect to young stem borer larvae. Tightness of leaf sheaths around the silk prevents larval movement. Premature hardness of the internodes also reduces penetration and feeding of the larvae (Zhu et al., 2002).

The results from this study confirm the previous findings by Ogah (2013) that the differences in stem borer infestation observed among the rice genotypes suggest that the genotypes respond differently to stem borer attack. Similar observation was reported by Muhammad (2012) whereby the rice cultivars studied contained variable resistant gene to yellow stem borers. Farmers in Kahama District grow local varieties due to their aroma characteristic but they are susceptible to stem borer attack. This concurs with findings by Muhammad (2012) that aromatic germplasm are more sensitive to stem borer attack than non-aromatic varieties. Pathak and Khan (1994) reported that rice varieties differ in the level of stem borer susceptibility. However, varieties resistant to one stem borer species are not necessarily resistant to another species. They further reported that rice varieties which are highly resistant to stem borer have not been investigated, but the scores vary from high susceptibility to moderate resistant varieties.

There were significant differences in the effect of sowing time on pest incidence at reproductive stage (Table 5). In general, early and late planting had the highest stem borer incidences than medium planting time. Manipulation of sowing time ensures that crops are grown when the pest is least abundant so that the crop does not interfere with peak period of moth activity (Rami et al., 2002).

This study confirms the previous finding by Muhammad (2012) who reported that stem borer incidences differ in different rice sowing dates. He reported that in Pakistan early sown crop was most resistant to stem borer attack having the lowest incidence among other plants. The differences in the findings might be due to the stem borer species causing the damage, since they reach the peak at different times. Manipulation of sowing date ensures that the most susceptible crop growth stage does not coincide with the period of peak moth activity (Rami et al., 2002). Hendarsih and Usyati (2005) reported that in Indonesia stem borer infestation increased with delay in planting time; early planted rice cultivars had low stem borer infestation compared to late planted varieties. Historically shifting in planting time has been reported in Java Indonesia since 1920s and 1930s and was observed to be effective way of controlling both yellow and white stem borers (Rami et al., 2002).

Sowing date has been reported to reduce the stem borer infestation in different crops in Africa (Lucius and Oniemayin, 2011). Studies in Ethiopia, using different planting times under natural infestation in maize crop showed a positive correlation between crop loss and late planting time.

**Conclusion**

This study indicates that three stem borer species i.e. C. partellus, M. separatella and S. calamistis are distributed wherever rice is grown in Kahama District. Out of the three species, C. partellus is the most
abundant followed by *M. separatella* while *S. calamistis* was observed to be of less significance. *C. partellus* are dominant in Chela and Ngaya while *M. separatella* are dominant in Bulige and Kashishi wards. Generally, rice stem borers exhibits aggregated dispersion along rice fields in Bulige, Chela and Ngaya while in Kashishi they were more uniformly distributed. Damage incidence of the pests is higher in Kashishi and Ngaya than in Bulige and Chela. Among four rice varieties grown by farmers; Behenge and Supa are more susceptible to stem borer damage than Mayobhe and Kalamata. Farmers who sow rice in early and late time experience high incidence of stem borer damage than in medium time.

**Recommendations**

Future studies should target to establish the extensiveness of rice stem borer problem in the Lake Zone, since stem borer abundance and damage may vary with respect to ecological conditions. The need to undertake assessment of stem borer incidence in other crops and wild host plants cannot be overemphasized due to the recorded aggregation along the edges of rice field. Screening of farmer preferred varieties to tolerance against rice stem borer is of great importance and should be coupled with yield loss estimates to guide rational management options. The manipulation of sowing date as stem borer management option in Kahama should target planting from 1st -20th December of the respective year. However, due to variation in planting time because of the onset of rains, further studies may be required to re-affirm the dates.

**Acknowledgement**

This study was undertaken with financial support from the East Africa Agricultural Productivity Program (EAAPP). The farmers and agricultural extension officers in all the wards where the study was undertaken are acknowledged for the invaluable support they offered.

**References**


Discussion Session

**Question:** What were the sex ratios of the different moth species caught in the light trap?
**Answer:** The sex ratio was not determined.

**Question:** Although there are differences in the spatial distribution of the stalkborers, what are their economic threshold levels in rice?
**Answer:** Literature says that the economic threshold depend on cost of control and price of the commodity for that case 10% yield loss can be its economic threshold in Tanzania.

**Question:** Did you look at the presence of alternative hosts and parasitoids around rice and how they contributed to incidence and spatial distribution?
**Answer:** No, that is why I recommend assessing the incidences in other host plants. There was limitation of funds in this study.
Assessment of grain yield losses caused by rice blast disease in major rice growing areas in Tanzania

Charles, Joseph*, Chuwa, Mnyuku, S.O.W. and Mabagala, R.B.

Department of Crop Science and Production, Sokoine University of Agriculture
*Correspondence: chuwacj@yahoo.co.uk

Abstract
Grain yield losses in rice (Oryza sativa L.) caused by Pyricularia oryzae Cavara, [synonym P. grisea Sacc (teleomorph: Magnaporthe grisea (Hebert) Barr)] causal agent of rice blast disease, is a major problem facing rice growers worldwide. In Tanzania, rice blast is considered as the most serious disease, resulting in severe yield losses especially, when susceptible rice varieties are grown. In order to assess yield losses caused by P. oryzae, studies were conducted in the screen-house using ten rice varieties viz; Jaribu 220, Supa, Kalamata, Shingo ya Mwali, Mwarabu, Mbawambili, Kihogo, IR 64, TXD 306 and TXD 85. Results showed that rice blast disease affected rice plant at all stages of growth and resulted in reduction in number of tillers per plant, grain weight, number of seeds per panicle and grain yield. Most of the rice varieties were susceptible to P. oryzae at seedling, early tillering and heading stages (reproductive stages). During early growth stages, symptoms were mainly found on leaves. Leaf blast disease severity reached maximum at tillering stage, then the disease symptoms disappeared gradually. Leaf blast development progressed significantly differently between rice varieties. The varieties Mwarabu and Jaribu 220 were the most susceptible at 45 and 55 days after inoculation (DAI). The area under disease progress curve (AUDPC) increased with leaf age. The relationship between rice blast disease severity and grain yield loss indicated that each increase in the disease severity resulted in a simultaneous reduction in grain yield. Both leaf and panicle rice blast disease severities were positive and highly significantly correlated with grain yield losses (r = 0.96, P < 0.001 and r = 0.91, P < 0.001, respectively). The number of tillers and seeds per panicle were negatively correlated with disease severity and grain yield weight (r = -0.912 and -0.958 respectively). The varieties Jaribu 220, Mwarabu, Supa, Mbawambili and Kalamata were susceptible to blast disease. Grain yield losses of between 11.85 to 37.76 % per hectare were recorded for such rice varieties.

Key words: AUDPC, Pyricularia oryzae, rice blast disease, yield losses

Introduction
Rice blast disease is one of the most devastating diseases that can cause high grain yield losses in farmers’ fields (Mohapatra et al., 2008; Koide et al., 2009; Ashtiani et al., 2012). It is a fungal disease caused by Pyricularia oryzae which belongs to the class Ascomyceta and the genus Magnaporthe (Gandalera et al., 2013). The asexual state is called Magnaporthe oryzae (Couch and Kohn, 2002; Noguchi et al., 2007a; Gandalera et al., 2013). The disease occurs worldwide where rice is grown, but its occurrence and severity vary yearly, based on location and environmental conditions (Devi and Chhetry, 2014). The disease infects all parts of the rice plant except roots, but leaves and panicles are the most seriously affected parts (Pinheiro et al., 2012). Leaf blast lesions reduce the net photosynthetic rate of individual leaves (Koutrubas et al., 2009). Neck blast is considered the most destructive phase of the disease and can occur without being preceded by severe leaf blast (Zhu et al., 2005). The necrotic lesions on mature rice plants particularly in the panicle can cause major yield losses (Gandalera et al., 2013). Several studies have reported that leaf, panicle and neck blast disease incidences caused similar yield losses. In
Japan the yield losses of 20 to 100% were reported by Khush and Jena (2009) and Pinheiro et al. (2012). In Brazil, yield losses as high as 100% (Prabhu et al., 2009a) have been reported in upland rice varieties. In India, losses of 5 – 10%, were recorded (Padmanabhan, 1965), while 8% yield losses in Korea and 14% losses in China and 50 to 85% in the Philippines have been reported (Shafaullah et al., 2011). Hai et al. (2007) reported grain yield losses of susceptible rice varieties of 38.21 to 64.57% due to neck blast in Vietnam.

About 5-70% grain yield losses were reported in Kashmir depending upon the stage of the crop infected and severity of the disease (Bhat et al., 2013). Inoculation reduced grain yield from 22 to 26% in Italy (Koutroubas et al., 2009). Grain yield losses of 25.21 to 45.52% were recorded in Rajasthan (Maheshwari and Sharma, 2013). In Iran, low yield losses of 0.99 - 1.22% were reported by Mousanejad et al. (2010). Other studies in Iran reported yield reduction of 10-20% in susceptible rice varieties, but in severe cases the yield loss caused by rice blast may reach up to 80% (Pasha et al., 2013). Panicle blast disease severity affects grain filling (Castejon-Munoz et al., 2007). Infected panicles caused 20 to 100% yield losses in Japan (Pinheiro et al., 2012) and 100% yield losses in Brazil (Prabhu et al., 2002). Yield losses due to blast disease have a direct impact on the welfare of farm households as well as on the national economy.

The symptoms of rice blast disease on leaves, nodes and panicles may vary according to the environmental conditions, the age of the plant and the level of resistance of the host genotypes (De-xi et al., 2010). Climatic conditions affect greatly the disease establishment, development and severity, resulting in large genotype-by-environment interactions. The yield variability among both different rice varieties and rice growing areas, explain the effects of climate and crop management on rice yields. However, yield constraints are related to disease incidence and severity in relation to crop management and environmental conditions (Naing et al., 2008). Mousanejad et al. (2010) demonstrated that rice blast disease incidence and severity during the reproductive stage (75 days after seeding) was most closely related to yield losses with an infected area of 1% corresponding to 3% yield loss. However, these studies reported also that most of the resistant rice varieties were severely diseased, although lower than that of susceptible varieties (Bonman et al., 1991). In Tanzania, information on rice grain yield losses in relation to rice blast disease level is limited. Therefore, the objective of this study was to investigate the effect of rice blast disease on grain yield in major rice growing areas of Tanzania.

**Materials and methods**

Ten rice varieties preferred by farmers in Tanzania (Kalamata, Mbwambili, Supa, TXD 306, TXD 85, Kihogo, Mwarabu, IR64, Shingo ya Mwali and Jaribu 220) were evaluated to determine the effect of rice blast disease on yield losses. The experiment was conducted in the screen-house at the Chinese Agricultural Technology Demonstration Centre in Dakawa, Mvomero district, Morogoro region. The seeds of each variety were sown in one square meter plot (experimental unit) at a spacing of 20 cm x 20 cm arranged in a completely randomized design, with three replications. Each replication consisted of a plot with five rows and each plot contained 25 seeds of each variety. The plots were flooded with water and such conditions were maintained until the grains reached physiological maturity. The non-inoculated plots were sprayed with Tricyclazole fungicide to prevent occurrence of rice blast disease.

**Inoculum preparation and inoculation**

*Pyricularia oryzae* was cultured in Petri dishes on oatmeal agar, incubated at 25 ± 1°C to induce sporulation as described by Rathour et al. (2006). After sporulation, spore suspension at a concentration of about 10⁴ spores/ml was prepared in sterilized distilled water with 0.1% Tween 20 to increase spore dispersion (Prasad et al., 2009).
The conidial concentration of 2 x 10^5 spores/ml was prepared (Namai and Ehara, 1986). Spore counts were done using a haemocytometer. When the plants reached the 4-5 leaf stage (21 days after seeding), they were inoculated with P. oryzae following the procedures described by Zhang et al. (2009). Inoculation was done in the evening using a low-pressure spray bottle on each individual rice plant. All agronomic practices including fertilizer (UREA 120 kgN/ha) were applied as recommended.

**Disease assessment**

Rice blast disease evaluation was conducted throughout the growing season, starting with observation of the first disease symptoms after inoculation. Observation of blast disease symptoms was done at 14 days after inoculation based on blast disease assessment given by the standard evaluation system of IRRI (1996), using a 9 scale basis where; 0 = no lesions; 1 = small, brown, specks of pinhead size; 3 = small, roundish to slightly elongated, necrotic, gray spots about 1-2 mm in diameter; 5 = typical blast lesions infecting < 10 % of the leaf area; 7 = typical blast lesions infecting 26-50 % of the leaf area; 9 = typical blast lesions infecting >51 % leaf area and many dead leaves. Rice blast disease severity was then calculated using the formula described by Hajano et al (2011):

\[
\text{Disease severity} = \sum \frac{n \times v \times 100}{N \times V}
\]

where, \( n \) = number of leaves infected by blast, \( v \) = value score of each category attack, \( N \) = number of leaves observed and \( V \) = value of the highest score.

Rice blast disease development on plants was observed six times at 15, 25, 35, 45, 55, and 65 days after inoculation (DAI). Diseased leaf area was calculated by multiplying length and width of lesion. The area under disease progress curve (AUDPC) was calculated from single ratings as described by Shaner and Finney (1977), Pasha et al. (2013) and Mohapatra et al. (2008) with modification as follows:

\[
\text{AUDPC} = \sum [(0.5)(Y_{i+1} + Y_i)(T_{i+1} - T_i)]
\]

Where, \( Y \) = disease severity at time \( i \) and \( T \) = time (days) of the assessment.

The percentages of panicle blast disease severity (PBS) were obtained by rating individual panicles using the formula described by IRRI (2002) and Pasha et al. (2013) with modifications as shown below:

\[
\text{PBS} = \frac{A}{B} \times 100
\]

Where, \( A \) = the number of infected panicles, and \( B \) = the number of panicles observed for each variety per plot. Based on both the leaf and panicle severities, rice varieties were classified as resistant (R) with 0-15 %; moderately resistant (MR) with 15.1-30 %; moderately susceptible (MS) with 30.1-50 %; or susceptible (S) with 50.1-100 % disease severities (Puri et al., 2006).

At physiological maturity, three middle rows of each plot were harvested and kept separately. The panicles of each variety were threshed manually and grain weight was recorded. Rice grain yield was determined at 13 % grain moisture content as recommended by Mousanejad et al. (2010). Percent grain yield losses caused by rice blast disease for each variety were also determined using the formula described by Mousanejad et al. (2010):

\[
\text{Yield loss} = \frac{\text{Yield of non-inoculated} - \text{Yield of inoculated} \times 100}{\text{Yield of non-inoculated}}
\]
Weather data for the months of March to July 2013 were collected from the Meteorological station at Dakawa and from Tanzania Meteorological Agency websites.

Before analysis, data were transformed using arcsine transformation formula as described by Mousanejad et al. (2010) as shown:

\[ Y = \text{Arcsin} \sqrt{P} \]

Where, \( Y \) is transformed data, \( p \) is the observed proportion.

Data analysis

Data were analyzed using GENSTAT computer statistical package for ANOVA to determine significant differences between ten rice varieties. Comparison between means was done using Duncan’s Multiple Range Test (DMRT). A regression analysis was done to find out the correlation between the disease levels and percent loss in yield. Charts/graphs were drawn using the Microsoft Excel program (Bonman et al., 1991).

**Results and discussion**

Rice blast disease symptoms on leaves, neck, and panicles are shown in Figure 1. Depending upon the genetic makeup, each of ten rice varieties reacted differently to rice blast disease. Rice blast disease symptoms were observed on leaves of all rice varieties between 14 and 20 days after inoculation. The symptoms began on the lower leaves 15 days after inoculation and progressed to the upper leaves. After heading, *P. oryzae* infected the panicles. Panicle blast caused direct yield losses, since filling of the grain on infected panicles was poor (Table 1). Leaf lesions began as small whitish, grayish spots and enlarged progressively. The shape, colour and size of the leaf lesions varied with plant age.

![Figure 1: Rice blast disease symptoms on leaves (A) and panicles (B) (photos: C. J. Chuwa, Dakawa, Morogoro)](image_url)

Generally, most of the rice varieties tested were susceptible to *P. oryzae* in the seedling, early tillering and heading stages of the crop. It was noted that, the symptoms of rice blast disease on leaves were observed in the early growth stages of the rice crop. This is because rice plants are more susceptible to blast disease at young than at mature stages of development (Babu et al., March 2014). The trend of rice blast disease development revealed that when
the plants were at maximum tillering, the disease symptoms on the leaves tended to disappear gradually. Such a situation had been attributed to adult plant resistance (Babu et al., March 2014).

**Leaf blast disease progress in rice varieties grown at Dakawa, Morogoro**

Leaf blast disease progress curves for ten rice varieties under screen-house conditions are shown in Figure 2. Leaf blast development progressed differently with different rice varieties. However for all varieties, disease started at a low level, gradually increasing in severity over time.

![Figure 2: Leaf blast disease progress curves for ten rice varieties grown by farmers in Tanzania](image)

**Figure 2: Leaf blast disease progress curves for ten rice varieties grown by farmers in Tanzania**

Rice blast disease severity increased significantly (P≤ 0.05) from 15 to 45 days after inoculation (DAI) (Figure 2). Results have shown that all varieties had low diseased leaf area (< 150 mm²/leaf) at 15 DAI and 25 DAI. After 25 DAI, diseased leaf area increased drastically. Results also indicate that the highest diseased leaf area was recorded on Jaribu 220 followed by Mwarabu, whereas, the lowest diseased leaf area was obtained on TXD 85 and IR 64 followed by Kihogo. Varieties TXD 85, IR 64 and Kihogo are therefore promising for rice blast disease resistance in Tanzania.

The lowest and the highest diseased leaf area could have been caused by genetic diversity of the varieties, age of the plant and weather conditions. This means that high relative humidity, rainfall but moderate temperatures, were associated with higher rice blast disease severities for Jaribu 220 and Mwarabu (Table 2). Similar results regarding epidemiological factors has been reported by Castejón-Muñoz, (2008), Ahmad et al. (2011) and Nasruddin and Amin (2013). Average rainfall of 42.4 mm has been noted to influence development of rice blast disease severity on both leaves and panicles (Table 2). Such findings have also been reported by Koutroubas et al., (2009) and Shafaullah et al., (2011).

The results revealed that as the plants approached maturity, they gained resistance to rice blast disease (Nasruddin and Amin, 2013). This finding is also supported by the study of Bonman et al. (1991) on the assessment of blast
disease and yield loss in susceptible and partially resistant rice cultivars in two irrigated lowland environments. The results indicated that the disease progressed and reached maximum at 45 and 55 DAI and then gradually declined. This decline in disease was attributed to adult disease resistance, leaf senescence and formation of new leaves. In quantitative resistance, where differences in level of resistance are usually less distinct, measuring disease progress is important for understanding plant–pathogen interaction (Simko and Piepho, 2012).

**Effect of rice blast disease on grain formation**

The AUDPC in screen-house conditions was significantly (P≤ 0.05) different between the ten rice varieties tested (Table 1). The highest AUDPC values were obtained from Jaribu 220 (889.0) followed by Mwarabu (652.5), Kalamata (590.2) and Shingo ya mwali (564.4). On the other hand, the lowest AUDPC values were recorded from TXD 85 (184.5) and IR 64 (179.1) followed by TXD 306 (276.1), Kihogo (391.1) and Mbawambili (456.6). However, TXD85 and IR64 had similar trends of rice blast disease progress (Table 1). The AUDPC is considered as the best parameter to declare a variety resistant or susceptible (Kumar et al., 2013). It provides more precise and practical classification of resistant and susceptible varieties than that based on the percentage disease score of each variety (Jeger, 2004; Kumar et al., 2010).

**Table 1:** The percentage of unfilled grains on different rice varieties inoculated by rice blast disease in the screen-house at Dakawa, Morogoro

<table>
<thead>
<tr>
<th>Variety</th>
<th>AUDPC</th>
<th>Inoculated (%)</th>
<th>Non-inoculated (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mbawambili</td>
<td>456.60a</td>
<td>52.67bc</td>
<td>8.67a</td>
</tr>
<tr>
<td>TXD 306</td>
<td>276.10ab</td>
<td>14.00a</td>
<td>6.33a</td>
</tr>
<tr>
<td>Kihogo</td>
<td>391.10abc</td>
<td>25.67ab</td>
<td>13.33a</td>
</tr>
<tr>
<td>TXD 85</td>
<td>184.50a</td>
<td>19.67a</td>
<td>8.67a</td>
</tr>
<tr>
<td>Jaribu 220</td>
<td>889.00d</td>
<td>74.33c</td>
<td>10.00a</td>
</tr>
<tr>
<td>Supa</td>
<td>496.70bc</td>
<td>26.33ab</td>
<td>12.33a</td>
</tr>
<tr>
<td>Kalamata</td>
<td>590.20c</td>
<td>41.00ab</td>
<td>12.67a</td>
</tr>
<tr>
<td>Shingo ya mwali</td>
<td>564.40c</td>
<td>12.33a</td>
<td>12.00a</td>
</tr>
<tr>
<td>IR 64</td>
<td>179.10a</td>
<td>18.67a</td>
<td>8.00a</td>
</tr>
<tr>
<td>Mwarabu</td>
<td>652.50cd</td>
<td>13.00a</td>
<td>5.67a</td>
</tr>
<tr>
<td>CV %</td>
<td>32.4</td>
<td>56.5</td>
<td>51.0</td>
</tr>
</tbody>
</table>

Means in the same column followed by the same letter are not significantly different by at P < 0.05. CV% = Coefficient of variation; AUDPC = area under disease progress curve

Early occurrence of rice blast disease at young stage of rice plant growth caused high damage on the leaves and finally disturb all physiological processes in the plant (Hwang et al., 1987; Mousanejad et al., 2010). The level of rice blast disease severity increased with age of rice plants during the season. The highest AUDPC values on Jaribu 220, Mwarabu, and Kalamata rice varieties showed that these varieties have high levels of susceptibility to leaf blast. The lowest AUDPC values on TXD 85 and IR 64 showed that these varieties had higher resistance to rice blast disease. Similar results were reported by Riungu et al., (2007) and Pasha et al.,(2013). Therefore, rice varieties TXD 85 and IR 64 can be used as donor parents for breeding moderate resistant rice varieties to blast disease in Tanzania.
The percentages of unfilled rice grains significantly differed (P≤ 0.05) between varieties (Table 1). Inoculated plants had higher percentages of unfilled grains than non-inoculated plants. The average of unfilled rice grains on Jaribu 220 was significantly higher (74.33 %), followed by Mbawamibi (52.67 %). The lowest percentages of unfilled rice grains were on TXD 306 (14 %), TXD 85 (19.67 %), Shingo ya Mwali (12.33 %), IR 64 (18.67 %) and Mwarabu (13 %), followed by Kihogo (25.67 %), Supa (26.33 %) and Kalamata (41 %) rice varieties. Results revealed that the highest AUDPC corresponded with high percentage of unfilled grain. Similar findings were reported by Chaudhary et al.(2005) and Pasha et al., (2013).

Regression and correlations between leaf and panicle blast parameters and grain yield losses in rice

In Figure 3, the coefficient of determination (R²) for both leaf and panicle blast disease were highly significant (R² = 0.930, P < 0.001 and R² = 0.837, P < 0.001, respectively). These results indicate that 93 % of grain yield losses per ha due to leaf blast disease severity and 83.7 % of grain yield losses was caused by panicle severity. The significance of the linear regression implies that some portion of the variability (93 % and 83.7 %) in grain yield losses were indeed explained by the linear function of leaf and panicle rice blast disease severities, respectively. However, both leaf and panicle blast disease severities were highly significantly correlated with grain yield losses (r = 0.963, P < 0.001 and r = 0.915, P < 0.001, respectively) in inoculated rice varieties (Figure 3).

Figure 3: Relationship between a) leaf blast disease severity and grain yield loss, and b) panicle blast disease severity and grain yield loss in selected rice varieties grown in Tanzania, and 2 years experimentation (n = 30).

These results indicate that leaf and panicle blast disease severities were directly related to grain yield losses. The findings that an increase in leaf or panicle blast disease severity corresponded to an increase in grain yield losses have also been reported by Shim et al. (2005).
Based on linear regression equations related to leaf \((Y = 3.20 + 0.5158X)\) and panicle
\((Y = 12.57 + 0.5010X)\) blast disease severities, it can be estimated that each unit increase of leaf blast
severity corresponded to an increased grain yield loss of 0.5158 % per ha (Figure 4). The corresponding
reduction in grain yield for each unit increase of panicle blast was 0.501 % yield loss. These models
show that differences in yield losses between rice varieties were due to both leaf and panicle blast disease
development. The regression model obtained can be used to estimate rice grain yield losses due to blast
disease. These findings are in agreement with the findings of Bonman et al. (1991) and Mousanejad et
al.,(2010) that the regression model with high coefficient of determination is useful for forecasting yield
losses.

In this study, weather factors including temperature, rainfall and relative humidity (RH) played an important
role on the development of rice blast disease severity. The different levels of rice blast disease severity on
rice varieties were most likely due to the corresponding differences in the weather parameters recorded
during the growing period and genetic diversity of the varieties studied. The average minimum (18. 9oC)
and maximum (30oC), temperature and RH of 74.1% (Table 2) were important epidemiological factors to
rice blast disease development.

**Table 2: Monthly temperatures, precipitation and relative humidity at Dakawa, Morogoro region
from March to July 2013**

<table>
<thead>
<tr>
<th>Month</th>
<th>Temperature (oC)</th>
<th>Precipitation (mm)</th>
<th>Relative humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
<td>Mean</td>
</tr>
<tr>
<td>March</td>
<td>22.0</td>
<td>32.1</td>
<td>27.1</td>
</tr>
<tr>
<td>April</td>
<td>21.3</td>
<td>30.1</td>
<td>25.7</td>
</tr>
<tr>
<td>May</td>
<td>19.5</td>
<td>29.6</td>
<td>24.6</td>
</tr>
<tr>
<td>June</td>
<td>16.1</td>
<td>29.1</td>
<td>22.6</td>
</tr>
<tr>
<td>July</td>
<td>15.4</td>
<td>29.3</td>
<td>22.4</td>
</tr>
</tbody>
</table>

Average 18.9 30.0 24.5 42.4 74.1

Source: Meteorological Department, Mvomero district, Morogoro region and

High severity level of rice blast disease was due to the environmental conditions being favourable for the
development of *Pyricularia oryzae*. Similar findings have been reported by Shafaullah et al. (2011) when they
were studying the effect of epidemiological factors on the incidence of paddy blast (*Pyricularia oryzae*) disease
in Pakistan. It is well known that the environmental conditions, especially moderate temperatures (25 – 30 °C)
and high relative humidity, are important factors inducing and facilitating sporulation and growth of *P. Oryzae*
(Castejon-Munoz et al., 2007; Castejón-Muñoz, 2008; Koutroubas et al., 2009; Babu et al., March 2014). The
presence of high rice blast disease severity on leaves and panicles affected the rate of photosynthesis in the
rice plants resulting into reduced grain filling and high percentages of unfilled grains (Koutroubas et al., 2009).
Similar results have also been reported by Gandalera et al. (2013) when working with inhibitory activity of
*Chaetomium globosum Kunze* extract against Philippine strain of *Pyricularia oryzae*. 
Effect of rice blast disease on tillering, seeds and grain yield

The results in Table 3 indicate that, rice blast disease had a substantial impact on reduction of the number of tillers per hill, seeds per panicle and grain yield. There was significant reduction (P<0.05) of the number of tillers, panicle number and grain yield between rice varieties used. The tillers per hill between inoculated and non-inoculated rice plants were significantly different ($t$-value = 3.55, P < 0.001) except on TXD 85 and IR 64 varieties (Table 3).

Table 3: The number of tillers/hill, seeds/panicle, grain yield and yield loss from rice blast on varieties preferred by farmers at Dakawa, Morogoro

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Tillers/hill</th>
<th>Tiller</th>
<th>Seeds/panicle</th>
<th>Seeds/</th>
<th>Grain Yield (kg/ha)</th>
<th>Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inoculated</td>
<td>loss/hill (%)</td>
<td>Inoculated</td>
<td>loss</td>
<td>Inoculated</td>
<td>loss (%)</td>
</tr>
<tr>
<td>Shingo ya Mwali</td>
<td>4.66a</td>
<td>53.33</td>
<td>203.7bc</td>
<td>16.76</td>
<td>8267bc</td>
<td>17.7ab</td>
</tr>
<tr>
<td>Kihogo</td>
<td>5.667a</td>
<td>46.86</td>
<td>214.3bc</td>
<td>27.77</td>
<td>9633cd</td>
<td>15.5a</td>
</tr>
<tr>
<td>Kalamata</td>
<td>5.000a</td>
<td>72.22</td>
<td>137.7ab</td>
<td>58.27</td>
<td>7800b</td>
<td>29.6bcd</td>
</tr>
<tr>
<td>TXD 85</td>
<td>13.000c</td>
<td>13.33</td>
<td>215.3bc</td>
<td>29.94</td>
<td>7567b</td>
<td>17.0ab</td>
</tr>
<tr>
<td>Mbawambili</td>
<td>6.333a</td>
<td>76.84</td>
<td>143.3ab</td>
<td>50.24</td>
<td>6167a</td>
<td>31.0cd</td>
</tr>
<tr>
<td>Jaribu 220</td>
<td>5.667a</td>
<td>78.84</td>
<td>109.7a</td>
<td>64.48</td>
<td>6130a</td>
<td>37.8d</td>
</tr>
<tr>
<td>Mwarabu</td>
<td>10.000b</td>
<td>45.45</td>
<td>189.7abc</td>
<td>27.87</td>
<td>7867b</td>
<td>13.0a</td>
</tr>
<tr>
<td>Supa</td>
<td>7.333ab</td>
<td>74.72</td>
<td>162.7ab</td>
<td>30.97</td>
<td>8550bc</td>
<td>22.3abc</td>
</tr>
<tr>
<td>TXD 306</td>
<td>14.667c</td>
<td>59.99</td>
<td>253.3c</td>
<td>28.10</td>
<td>10283d</td>
<td>11.9a</td>
</tr>
<tr>
<td>IR 64</td>
<td>8.000b</td>
<td>20.00</td>
<td>158.3ab</td>
<td>07.97</td>
<td>5967a</td>
<td>16.0a</td>
</tr>
<tr>
<td>Mean</td>
<td>8.033</td>
<td>23.4</td>
<td>11.2</td>
<td>10.9</td>
<td>7097ab</td>
<td>21.4</td>
</tr>
<tr>
<td>CV%</td>
<td>21.9</td>
<td>19.5</td>
<td>11.0</td>
<td>10.4</td>
<td>35.1</td>
<td></td>
</tr>
</tbody>
</table>

Means in the same column followed by the same letter are not significantly different at P<0.05; CV% = Coefficient of variation

However, the number of tillers/hill was not significantly different (P < 0.05) between the varieties Shingo ya Mwali, Kihogo, Kalamata, Jaribu 220, Mbawambili, Supa and IR 64 for inoculated plots. The highest tillers per hill were recorded on TXD 306 and TXD 85 varieties in diseased (inoculated) plants, while in healthy (non-inoculated) plants, TXD 306, followed by Supa, Jaribu 220 and Mbawambili were recorded with the highest number of tillers per hill (Table 3). This study revealed that rice blast disease reduces number of tillers from 20 to 78.19 %. This range is significant to justify high reduction in grain yield per plant. The highest percentage of tiller loss was recorded on Jaribu 220, followed by Mbawambili, Supa and Kalamata.

The number of seeds per panicle between inoculated and non-inoculated plants were significantly different ($t$-value = 6.50, P<0.001) (Table 4) except on Shingo ya Mwali, TXD 85, Mwarabu and IR 64 varieties. The highest number of seeds per panicle was recorded on TXD 306 in both inoculated and non-inoculated plants, followed by TXD 85, Kihogo and Shingo ya Mwali, varieties. The lowest seeds per panicle were recorded on Jaribu 220 (109.7) on inoculated plants followed by Kalamata (137.7), Mbawambili (143.3), Mwarabu (189.7), Supa (162.7) and IR64 (158.3). Rice blast disease caused seed loss/panicle ranging from 7.97 to 64.48 %. These results corresponded to high grain yield losses (Table 3).
The rice grain yields between inoculated and non-inoculated plants were highly significantly different at t-value 8.04 and \( P < 0.05 \) on Mbawambili, Jaribu 220 and Kalamata varieties (Table 3). The highest grain yield was recorded on TXD 306 (10283 kg/ha and 11067 kg/ha for inoculated and non-inoculated plants, respectively) while the lowest grain yield was recorded on IR 64 in both inoculated and non-inoculated plants, followed by Jaribu 220 and Mbawambili.

Percentage rice grain yield losses due to rice blast disease were significantly different (\( P < 0.05 \)) between the ten rice varieties (Table 3). Yield losses from Shingo ya Mwali, Kihogo, TXD 85, Supa, TXD 306, Mwarabu and IR 64 varieties did not differ significantly at the 5 % level. Yield losses from variety Jaribu 220 differed significantly from Kihogo, Mwarabu, TXD 85, Supa, TXD 306 and IR 64 at the 5 % level (Table 3). However, the highest percentage of yield losses was recorded on Jaribu 220 (37.8 %) followed by Mbawambili (31.0 %) and Kalamata (29.6 %) and the lowest yield losses were recorded on TXD 306 (11.9 %) IR64 (16.0 %), and Kihogo (15.5 %) followed by TXD 85 (17.0 %).

These results indicate that yield losses due to rice blast disease caused by \( P. \) oryzae ranged between 11.9 and 37.8 %. Similar yield losses have been reported in Egypt by Haggag and Tawfik, (2014), Iran (Mousanejad et al., 2010), Korea (Bonman et al., 1991; Shim et al., 2005). Early occurrence of rice blast disease at young stages of rice plant growth can cause considerable leaf and panicle damage and reduce tillering ability. Reduced tillering may result in a simultaneous reduction in grain yield.

The number of tillers and seeds per panicle were negatively correlated with grain yield losses (\( r = -0.857 \) and -0.958, respectively) at 5 % (Figure 4). These results revealed a direct relationship between number of tillers and seeds per panicle with grain yield. Similar coefficient of correlations (\( r \)) have been reported by Shim et al.(2005) in the study of damage analysis of rice panicle blast on disease occurrence time and severity. It was noted that at tillering stage, rice seedlings were more susceptible to blast disease than mature plants (Zhu et al., 2005) and the number of tillers and seeds were reduced substantially (Koutroubas et al., 2009). Whereas, late rice blast infection of plants at tillering stage had only small effect on both tillers and grain seed reduction (Shim et al., 2005).

![Figure 4: Regression and correlation coefficient between a) number of tillers/hill and grain yield loss b) seeds/panicle and grain yield loss on selected rice varieties grown in Tanzania.](image_url)
The regression equations of number of tillers and seeds/panicle with grain yield losses \(Y = 27.02 - 0.291X, R^2 = 0.734\) and \(Y = 37.50 - 0.745X, R^2 = 0.917\), respectively) were the most appropriate models for predicting yield losses due to rice blast disease (Figure 4). High coefficients of determination have been reported in the analysis showing the percentage of yield losses due to the effect of rice blast disease on tillers and seeds (Mousanejad et al., 2010).

**Conclusion**

Results of the current study revealed that rice blast disease significantly reduced tillering ability and grain yield. Yield reduction was influenced by varieties grown. Both the number of tillers and seeds per panicle were reduced by blast disease, contributing to the differences in grain yield recorded between rice varieties. Losses in grain yield due to panicle and leaf rice blast disease ranged from 11.9 % to 37.8 %. Tillers loss/hill and seeds loss/panicle due to rice blast disease ranged from 20 to 78.19 % and 7.97 to 64.48 %, respectively, and grain yield weight ranged from 7,776.4 kg/ha to 10,046.1 kg/ha and was influenced by both leaf and panicle rice blast disease. These results demonstrate that IR 64, TXD 85, TXD 306 and Kihogo were promising rice varieties resistant to rice blast disease, while Jaribu 220, Kalamata and Mbawambili varieties were susceptible to rice blast. Management measures to reduce the impact of rice blast on yield are thus, needed. Such management measures should include breeding for rice blast disease resistance.

**References**


Effect of African rice gall midge infestation on yield of major lowland rice cultivars in Uganda

Ekobu Moses

College of Agricultural and Environmental Sciences Makerere University, Kampala
P.O Box 7062 Kampala, Uganda.
Correspondence: ekobum@yahoo.com/ekobum@caes.mak.ac.ug

Abstract
The African rice gall midge (AfrGM) Orseolia oryzivora Harris and Gagné (Diptera: Cecidomyiidae) is increasingly emerging as an important pest of rain-fed and irrigated lowland rice in sub-Saharan Africa, including Uganda. Yield losses associated with this pest have not been estimated, but in Uganda, farmers are reported to have abandoned some varieties due to the pest. The objective of this study was to assess the yield loss caused by the AfrGM on major varieties grown in Uganda. The studies were conducted at Olweny and Serere where the pest has been consistently reported in the past five years. Three most farmer preferred varieties; Super, Kaiso and Lukindu were evaluated during, 2014 and 2015. Yield losses of 38%, 32% and 28% were observed on Super, Kaiso and Lupindu cultivars, respectively.

Key words: Orseolia oryzivora, yield, rice varieties, lowland

Introduction
The African Rice Gall Midge (AfrGM), Orseolia oryzivora Harris and Gagne (Diptera: Cecidomyiidae), is an important pest of rice, Oryza sativa in Uganda as well as other countries in West and East Africa (Nwilene et al., 2008; Williams et al., 2010 or 1999). Though infestations have been reported on Upland rice, AfrGM is primarily a pest of lowland rain-fed and irrigated rice (Nwilene et al., 2008; Ogah et al., 2010). The pest attacks rice at the vegetative growth stage during tillering whereby the larvae induce formation of tubular silver shoot galls. A galled tiller is unable to initiate growth of more leaves or a panicle. Several pest management practices including adjustment in spacing, planting time, destruction of alternative host plants, application of insecticides have not been successful in controlling the pest (Nwilene et al., 2008; Ogah et al., 2010).

However two natural enemies; endo-parasitoid; Platygaster. diplosias Risbec (Hymenoptera; Plastygasteridae) and Ecto-Parasitoid, Aprostocetus procerae Risbec (Hymenoptera: Eulopidae (William et al., 1999) have been known to attack the AfrGM. Inspite of its importance, little information is known regarding the relationship between gall midge populations and grain yield losses in Uganda and East Africa in general. Nevertheless, in West Africa yield losses of ranging from 20 to 80% have been recorded on farmers’ fields and also in research managed fields (Dakouo et al., 1988, Narco et al., 1996., Williams et al., 1999; Nwilene et al., 2006). The main objective of this study was, therefore, to determine yield losses caused by the AfrGM on three of the most farmer-preferred rice varieties in Uganda.

Materials and Methods

Study areas
The study was carried out at Olweny swamp; 02°14.56 N, 32°54.00 E in northern Uganda with grassland dominating, but emergents like Typha, papyrus, Echinochloa and wild rice and floating communities of water
lilies are common. Submerged algae and ceratophyllum are present. Scattered palms, Ficus, Albizia and acacia are occasional. Isolated cases of water hyacinth have been registered and at Serere; 01°30.00’N; 33°33.00’E in Eastern Uganda with a vegetation which is predominantly; wooded savannah, grass savannah, forests and riparian vegetation. The wooded savannah mainly comprises moist Acacia savanna and combrum savanna both associated with Hyparrhenia spp.

Three most preferred farmer varieties; Supa, Kaiso and Lukindu were planted in a randomized complete block design (RCBD) in the major AfRGM hot spots of Olweny and Serere. Each variety was replicated thrice in the experimental site measuring 17m x 15m from which smaller plots measuring 5m x5m were measured each separated by 1m alley. The AfRGM allowed to naturally infesting the rice planted during the second season of 2014 and first season of 2015. The controls consisted of each variety planted in buckets and placed inside insect proof cages and planted on the same day and managed together with those planted in the open. The numbers of infested tillers were counted at 40, 60 and 80 days after the emergence of the rice using IRRI (2002) standard evaluation system for rice (Table 1: ) and the percentage number of infested tillers was used to estimate yield loss. On each sampling occasion, galls and total number of tillers were counted on 30 hills per plot selected randomly. Yield (kg/ha) on each plot was determined by harvested square metre and corrected to 13% grain moisture content. Data collected was subjected to analysis of variance using SAS (2003) and means were separated using Student-Newman-Keuls (SNK) method. The relationship between yields, AfRGM infestation was analyzed using regression analysis. Percentage tiller infestation was calculated as below:

\[
\text{\% Tiller infestation} = \frac{\text{No. of tillers with galls} \times 100}{\text{Total number of tiller}}
\]

**Table 1: Standard evaluation system for rice (source: IRRI, 2002).**

<table>
<thead>
<tr>
<th>Scores</th>
<th>% Tiller damage</th>
<th>Rating (reaction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No damage</td>
<td>Highly resistance or immune</td>
</tr>
<tr>
<td>1</td>
<td>Less than 1%</td>
<td>Resistance</td>
</tr>
<tr>
<td>3</td>
<td>1-5%</td>
<td>Moderately resistance</td>
</tr>
<tr>
<td>5</td>
<td>6-10%</td>
<td>Moderately susceptible</td>
</tr>
<tr>
<td>7</td>
<td>11-25%</td>
<td>Susceptible</td>
</tr>
<tr>
<td>9</td>
<td>Above 25%</td>
<td>Highly susceptible</td>
</tr>
</tbody>
</table>

**Results**

All the three varieties tested were highly susceptible to AfRGM based on Standard evaluation system for rice (Table 1); the observed percentage tiller infestation was more than 25% in all the varieties. The AfRGM infestations levels (% of tillers with galls) were low at 40 days after planting but rapidly increased thereafter. Mean infestation level on all the three varieties reached 25% at 80 days after planting, by which time all the varieties were either at booting or flowering stage. Lukindu showed slightly lower AfRGM infestation than Kaiso and Supa on all the three sampling occasions, but the paired t-tests indicated no significant difference among the varieties at P≥0.05. However, due to lack of normal distribution, the observed differences were re-tested using a non-parametric Wilcoxon’s signed rank test and significant differences (p≤0.05) were observed at 40 and 60 after planting. The infestation levels on all the three varieties were quite similar across the experimental sites and the mean difference overall was not more than 2.5% (Table 2: )

The agronomic and yield parameters showed significant differences among the test varieties at (p≤0.05)
with Supa having 120 days to 50% flowering as compared to Kaiso that had 102, whereas Lukindo had 88.5 days. Similar to 50% Flowering date, significant difference were observed on the plant heights at harvest with Supa being the tallest at 180cm, while Kaiso and Lukindo had heights of 140.5cm and 120cm, respectively (Table.4). In the case of grain yield, significant difference was seen in Lukindo whereas yields in Kaiso and Supa were not significantly different at $P\geq0.05$.

**Table 2:** Variation in yield and AfRGM infestation on three rice varieties

<table>
<thead>
<tr>
<th>Variables</th>
<th>Distribution (Mean SE)</th>
<th>Paired t-test</th>
<th>Wilcoxon’s signed rank test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Supa</td>
<td>Kaiso</td>
<td>Lukindo</td>
</tr>
<tr>
<td>Yield (kg/ha)$^a$</td>
<td>1568±201.5</td>
<td>1664±178.3</td>
<td>1720±1025.1</td>
</tr>
<tr>
<td>% Infestation at 40 days$^b$</td>
<td>1.26±0.251</td>
<td>1.12±0.645</td>
<td>1.023±0.364</td>
</tr>
<tr>
<td>% Infestation at 60 days$^b$</td>
<td>18.23±1.487</td>
<td>16.98±1.784</td>
<td>16.25±3.011</td>
</tr>
<tr>
<td>% Infestation at 80 days$^b$</td>
<td>38.6±3.542</td>
<td>32.4±2.129</td>
<td>28.6±1.984</td>
</tr>
</tbody>
</table>

$^aN=18; ^bn=3$

The sampling interval at which between site infestations was greatest was at 60 days after planting. Stepwise regression analysis was carried out on variables to determine which one best predict yield loss. The variables used were percentage of tillers with galls at 40, 60 and 80 days after planting. These were angular transformed (arcsine X $\%$ tillers with galls /100) and similarly log transformed (log$_e$ (% tillers with galls +1) in order to cater for the curvature in the relationship. Analysis was run for all the varieties combined and separately.

**Table 3:** Yields of the three rice varieties based on percentage tiller infestation

<table>
<thead>
<tr>
<th>Infestation level</th>
<th>n</th>
<th>Mean Yield (kg/ha) SE</th>
<th>Yield Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Supa</td>
<td>Kaiso</td>
</tr>
<tr>
<td>0-10%</td>
<td>3</td>
<td>2960±601</td>
<td>2875±445</td>
</tr>
<tr>
<td>10-20%</td>
<td>2</td>
<td>2359±379</td>
<td>2430±445</td>
</tr>
<tr>
<td>20-30%</td>
<td>3</td>
<td>1980±598</td>
<td>1985±518</td>
</tr>
<tr>
<td>30-40%</td>
<td>2</td>
<td>1382±245</td>
<td>1467±442</td>
</tr>
<tr>
<td>40-50%</td>
<td>3</td>
<td>1137±417</td>
<td>1025±390</td>
</tr>
<tr>
<td>&gt;50%</td>
<td>5</td>
<td>720±482</td>
<td>635±421</td>
</tr>
<tr>
<td>All plots</td>
<td>18</td>
<td>1568±201.5</td>
<td>1664±178.3</td>
</tr>
<tr>
<td>Plots &gt;10%</td>
<td>15</td>
<td>1282±187</td>
<td>1324±165</td>
</tr>
</tbody>
</table>
Table 4: Mean grain yield and other agronomic parameters of the three varieties infested with AfRGM in 2014 and 2015

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Days to 50% flowering</th>
<th>Plant heights at harvest (cm)</th>
<th>Panicles per m²</th>
<th>Grain Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaiso</td>
<td>100b</td>
<td>120.2c</td>
<td>289.5b</td>
<td>2875b</td>
</tr>
<tr>
<td>Supa</td>
<td>120a</td>
<td>180.8a</td>
<td>299.7b</td>
<td>2960b</td>
</tr>
<tr>
<td>Lukindu</td>
<td>88.5c</td>
<td>140.5b</td>
<td>305a</td>
<td>3030a</td>
</tr>
<tr>
<td>Mean</td>
<td>102.8333</td>
<td>147.1667</td>
<td>298.0667</td>
<td>2955</td>
</tr>
<tr>
<td>S.E (±)</td>
<td>6.5</td>
<td>3.4</td>
<td>10.6</td>
<td>73.5</td>
</tr>
<tr>
<td>C.V (%)</td>
<td>4.8</td>
<td>5.7</td>
<td>12.1</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Mean values within a column with the same letter are not significantly different at P≤0.05

Discussion

The overall results showed that there were differences in the level of AfRGM infestations on the three varieties tested and the differences could be attributed to Antixenosis, antibiosis and tolerance. Williams et al., 1999 reported small differences of AfRGM infestation among rice varieties attributed to antixenotic or antibiosis as opposed to tolerance and this particular study revealed a similar trend.

Sixty (60) DAP was shown to be the most appropriate period to evaluate for AfRGM infestation on all the varieties as compared to 40 and 80 DAP; this is because the rice plants are at maximum tillering phase which is conducive for the pest infestation. At 40 DAP, most of the infestations was observed in border rows of the plots nearby the bushes which in most cases had alternative host of the pests like the wild rice plants and Koda Millet (*Paspalum scobiculatum*). Whereas at 80 DAP the populations of the natural enemies; *Platygaster.diplosisae* and *Aprocerus procerae* increased greatly to level sufficient enough to effectively control the AfRGM.

The significant differences in agronomic parameters like 50% flowering, plant heights and number of panicles per square meter could be attributed to genetic differences among the rice varieties. Each trait could be contributing differently to the relationship between infestation and grain yield thereby accounting for the observed differences.

Conclusion

Understanding yield loss caused by the AfRGM on rice varieties is a fundamental step in a bid to find appropriate IPM strategy. As the breeders are searching for resistant varieties against the AfRGM, the potential use of parasitoids through maintenance of refugia in and around the rice fields and the level of tolerance shown by the test varieties could be used to keep the population of the AfRGM down to levels where it can not cause economic injury in the areas where the pest is endemic.

Acknowledgements

This work was funded by the Eastern Africa Agricultural Productivity Project, supported by the World Bank. We wish to thank the farmers and extension staff from Olweny and Serere for providing the trials sites, in particular Mr.Otile and Mr. Ageet Dan. Statistical advice from Mr. Oloka working with IFPRI is highly acknowledged.

References


**Discussion Session**

**Question:** Wanted to know if growing rice under green house condition can control the pest

**Answer:** Yes but very expensive. Also other parasites will invade the green house.

**Question:** What is the natural enemy of the African rice gall midge and how effective is it to control the pest biologically?

**Answer:** There are two natural enemies; _Marilygradpr diphrosea_ and _Aprotoculus procerov_ able to bring down the population of the African Rice gall midge to low economic injury
Evaluation of moisture levels at which striga asiatica cannot cause damage in rice

Msangi, S.H*. and Sibuga, K.P.
Sokoine University of Agriculture, Morogoro, Tanzania.
*Correspondence: msangisaidi@yahoo.com

Abstract
Pot experiments were conducted in a screen house to determine the optimum moisture levels required for the parasitic weeds, singly and in combination, to establish a relationship with rice. Studies were conducted in Morogoro, Tanzania, (525 m.a.s.L., 6o45" S and 37o40" E) September, 2012-February, 2013. Ten-litre plastic pots capacity filled with dry 5:1 (sand: clay) soil mixture up to 2cm below the rim were used. Treatments were arranged in split-plot with plant combinations (Striga+ rice, rice alone) as the main plot and moisture levels (saturation, field capacity, field capacity/saturation and field capacity/wilting point; the latter two were half way in between) as subplots. Rice variety ‘Supa India’ was used and treatments were arranged in a randomized complete block design with five replicates including a duplicate that was used for destructive sampling. Emergence of Striga was significantly (P=0.05) affected by moisture level and climaxed at field capacity and 120 DAS (9 shoots/pot). Rice plants were significantly (P=0.05) tallest when under saturation moisture level both when planted alone or together with Striga. At 60 DAS and saturation moisture level, rice biomass was reduced from 5.2g to 1.2g and at 120 DAS it was reduced from 57g to 8g at field capacity moisture level. Based on the results, it is concluded that, Striga weeds prefers well drained soils and cannot tolerate flooded condition. Also damage caused to rice plant depends on the severity and the number of the Striga weeds attached to rice plant.

Key words: Moisture, rice, striga

Introduction
Rice (Oryza sativa) is the second most important food and commercial crop in Tanzania after maize. The cultivated area is 681,000 ha equivalent to 18 % of Tanzania’s cultivated land. About 71 % of the rice grown in Tanzania is produced under rain-fed condition. The average yield is very low, 1-1.5 t ha⁻¹ compared to the estimated potential yields of 4-5 t ha⁻¹ (MAFC, 1998). The most common rice pests are weeds. Yield decreases by weeds vary greatly, depending partly on the adequacy of light, water and nutrient supplies, but mainly on the competitive ability of the crop relative to that of the weed population (Fryer and Evans, 1970).

A particular pernicious group of weeds is formed by parasitic plants. Among them one can distinguish obligate and facultative parasites. Obligate parasites are those parasites that cannot complete their life cycle without a host, while facultative parasites are parasites grow independently from a host or parasitize the host. Although Striga asiatica is the most common and well known parasitic weed, recently Rhamphicarpa fistulosa has been reported as a considerable problem in East and West Africa (Rodenburg et al., 2010).

In the case of S. asiatica, it was reported that the weed grows in areas with annual rainfall ranging from 25-150 cm per year with decrease in severity of infestation in areas of high rainfall (Mohamed et al., 1998).
However, other species have been found to occur in wet areas and even in water logged conditions in Cote d’Ivore and Tanzania (Mohamed et al., 2001). All these reports suggest that parasitic weed species have specific or variable ecological niches where they can establish a relationship with their hosts. It is therefore pertinent to determine the germination requirements of *S. asiatica* so as to provide pointers for effective control practices.

The main objective of this study was to quantify soil moisture requirements for effective control of *S. asiatica*. The specific objectives were to: 1) determine moisture requirement for germination and establishment of *S. asiatica* in rice 2) quantify the extent of host damage caused by the infestation of the parasitic weed in rice

**Materials and methods**

**Pot experiment**

A pot experiment was conducted in a screen house at Sokoine University of Agriculture located at 06° 50 S and 37 39 E and an altitude of 526 meters above sea level The day temperature in a screen house during the experiment ranged between 27° to 35°C. Ten-litre plastic pots capacity filled with dry 5: 1 (sand: clay) soil mixture up to 2 cm below the rim were used. Treatments were arranged in split-plot with two plant combinations (*Striga* + rice, rice alone) as the main plot and four moisture levels (saturation (4.4l), field capacity (2.2l), field capacity/saturation (3.2l) and field capacity/wilting point (1.1l); (the latter two were half way between the indicated levels) as subplots. Rice variety ‘Supa India’ was used and treatments were arranged in a randomized complete block design with five replicates including a duplicate that was used for destructive sampling.

**Soil origin and composition**

Pots were filled with sand and clay soils mixed at a ratio of 5: 1 Sand: Clay. Clay soil was collected from Kauzeni village, 12km from Morogoro town while sand soil was collected from Mindu area, 8.2km from Morogoro town. After mixing up the soil in 5: 1 sand: clay, the texture of the soil became sand: silt: clay with the composition of 88.5: 3.3: 8.2 (%) respectively. The chemical properties of the soil were 0.07% Nitrogen, 55.28ppm Phosphorus, 88.3ppm Potassium and pH of 5.92.

**Planting**

*Striga asiatica* seeds (0.04g) were planted in the pots (10 litres capacity) by emptying each vial containing the seeds and mixing them through the upper 10 cm of soil of each pot. Three rice seeds of Supa India variety were planted at the centre of the pot at 1cm depth. After emergence rice seedlings were thinned to one plant per pot. Fertilizer was applied at the rate of 50kg N per ha.

**Experimental observations and measurements**

Data collection was done in two sections, the first was from sowing to 60 days after sowing (DAS) and the second was from 60 to 120 DAS. The experiment was ended when the rice plants attained early maturity stage therefore data collected were of vegetative growth.

Emergence of *S. asiatica* was recorded from 28 DAS and then every three days through the entire period. *Striga* plants from each individual pots were measured their heights at 60 and 120 DAS and dried for 48 h at 70°C to assess their biomass dry weight including the reproductive variables. Tallest plant from each
pot was selected for height measurement. Flowering dates were also recorded from each pot through daily observation. The capsule number and dry weights were recorded at 120 DAS. Weed capsules in khaki bags were kept in the oven at 70°C for 48 hours then weighed. Weed seeds were weighed and recorded as g pot⁻¹.

The height of rice plants was recorded after every 10 days up to 70 DAS, measured from the base of the plant to the tip of the tallest leaf. Rice tiller numbers were recorded also from 10 to 70 DAS. The dry weights of shoots and roots were combined to give total biomass dry weight. At 60 DAS, rice leaf area (cm² pot⁻¹) was measured whereby a young full developed leaf was selected for measurement. The area obtained was used to calculate the specific leaf area by dividing the area by the dry weight of the leaf (cm² g⁻¹).

Data analysis
Data analysis was carried out with Genstat 14th Edition. Data derived from the pot experiments were subjected to ANOVA. F-test was used to determine significant differences between treatments and significantly difference means were separated using Fisher’s Least Significant Difference (LSD).

Results
Emergence and number of Striga seedlings
Data for *S. asiatica* collected 60 DAS in different plant combinations showed that the highest number (three) of weeds was obtained for field capacity/wilting point whereas field capacity/saturation and field capacity had only one *Striga* weed each. At 120 DAS, in different plant combinations the maximum number (9) of *S. asiatica* was obtained at field capacity and the lowest (three) at field capacity/saturation but field capacity/wilting point had eight *Striga* plants whereas saturation had no *Striga* plant. On the other hand, *S. asiatica* counts in different moisture levels differed significantly (P < 0.05) whereby their peak was at field capacity and at field capacity/wilting point moisture levels (Figure 1).
**Figure 1**: Number of striga weeds at different moisture levels.

Key: FCWP-field capacity/wilting point, FC-field capacity, FCSAT-field capacity/saturation, SAT-saturation

**Heights of Striga (cm) weeds**

*Striga asiatica* heights differed significantly at 60 and 120 DAS in different moisture levels whereby at 60 DAS, the tallest *S. asiatica* plants were in field capacity/wilting point and field capacity followed by field capacity/saturation while at 120 DAS the tallest plant appeared in field capacity/wilting point (Figure 2).

**Figure 2**: Striga heights(cm) at different moisture levels

Key: FCWP-field capacity/wilting point, FC-field capacity, FCSAT-field capacity/saturation, SAT-saturation
Flowering and capsule counts

In different moisture levels, the results showed that flowering days of Striga weeds did not differ significantly (P > 0.05) whereby at field capacity, flowering started at 83 days; at field capacity/saturation (83.3 days) and field capacity/wilting point (83.4 days). Number of weeds’ capsules taken were significantly (P = 0.05) different in different moisture levels. Various Striga capsules were produced at field capacity/wilting point (105 capsules) and field capacity moisture levels (104 capsules). However, largest total dry weights of Striga capsules were obtained at field capacity (0.5 g) and at field capacity/wilting point (0.5 g) moisture levels. Similarly amount of seeds produced were significantly different with moisture levels. Total weed dry biomass 60 DAS, Total dry biomass of Striga weeds sown in different moisture levels differed such as: field capacity/wilting point (0.19g), field capacity (0.1g) and field capacity/saturation (0.04g). Furthermore, at 120 DAS the total dry biomass of Striga weeds in different moisture levels also increased compared with that obtained at 60 DAS. The biomass differed with moisture levels such as: field capacity (1.78g), field capacity/wilting point (1.74g) and field capacity/saturation (0.65g).

Total weed dry biomass

60 DAS, total dry biomass of Striga weeds sown in different moisture levels differed such as: field capacity/wilting point (0.19g), field capacity (0.1g) and field capacity/saturation (0.04g). At 120 DAS the total dry biomass of Striga weeds in different moisture levels also increased compared with that obtained at 60 DAS. The biomass differed with moisture levels such as: field capacity (1.78g), field capacity/wilting point (1.74g) and field capacity/saturation (0.65g).

Rice Plant height (cm)

Data for rice height was collected at 10 DAS and after every 10 day up to 60 days. There was significant (P < 0.05) difference in rice height at different moisture levels from 10 to 120 DAS. Tallest (119.5 cm) rice plants were observed at saturation moisture levels in all stages of growth (Figure 3). Significant differences was observed at 60 and 120 DAS in different plant combinations whereby tallest rice plants were at rice alone and Striga/rice plant combinations (Figure 3).
Figure 3: Rice heights (cm) at different moisture levels and plant combinations

Key: FCWP-field capacity/wilting point, FC-field capacity, FCSAT-field capacity/saturation, SAT-saturation, STRI-Striga/rice, RI-rice alone

Total rice biomass

There were significant differences in rice biomass at different moisture levels and plant combinations. At 60 DAS, the highest weight value (5.2g) was obtained at saturation moisture level and this was recorded at rice planted alone, followed by 5.1g (Striga/rice) as shown in Figure 4). On the other hand, at 120 DAS (Figure 5), the highest value (56.6g) was obtained at saturation moisture level and this was at Striga/rice followed by rice alone (45.5g).

Figure 4: Rice average total biomass (g pot-1) 60 DAS at different moisture levels and plant combinations.

Key: FCWP-field capacity/wilting point, FC-field capacity, FCSAT-field capacity/saturation, SAT-saturation, STRI-Striga/rice, RI-rice alone
Figure 5: Rice total biomass (g pot⁻¹) 120 DAS at different moisture levels and plant combinations.

**Key:** FCWP-field capacity/wilting point, FC-field capacity, FCSAT-field capacity/saturation, SAT-saturation, STRI-Striga/rice, RI-rice alone

**Rice tillers counts**
Up to 120 DAS, the number of rice tillers were significantly (P < 0.05) different in different moisture levels whereby large number of tillers (3 pot⁻¹) was recorded at field capacity/wilting point moisture level.

**Rice leaf area (cm²) and specific leaf area (cm².g⁻¹)**
In different moisture levels and plant combinations, there were significant (P<0.05) differences in rice leaf area whereby 60 DAS the higher value (36.1cm²) was recorded at field capacity/saturation where rice was planted without the parasite and the lowest (17cm²) at saturation when planted with Striga. However, the results for specific leaf area showed no significant differences (P > 0.05) in different moisture levels and plant combinations 60 DAS.

**Discussion**

**Response of S. asiatica to moisture levels**

*S. asiatica* exhibited an increase in number (Fig 1) and height (Figure2) at field capacity and field capacity/wilting point than in other moisture levels. There was an increase of number of Striga with time. The results from this study were in agreement with the results reported by Ogborn (1972) that *Striga* appears to thrive well on intermittent dry conditions. This situation was also reported by Johnson *et al.*, (1997) that *S. hemonithica* is found in the free draining areas. Furthermore, it was observed that heavy continuous rainfall can suppress *Striga* (Radosevich *et al.*, 1997). This implies that, at low soil moisture levels *S. asiatica* thrive better than in moist soils.

The earliest *Striga* produced flowers were at field capacity/wilting point moisture level and this was 83 DAS. Flowering was accompanied with the production of the capsules and the seeds whereby at field capacity/wilting point there were maximum number of Striga capsules compared to other moisture levels. The California Department
of Food and Agriculture (CFDA, 2006) reported that *Striga* flowers develop about 3 weeks after emergence. This differs from what was observed in this study which was about two months.

On the other hand, total dry biomass of *Striga* weeds significantly different whereby 60 DAS at field capacity/wilting point there was 0.19g and the numbers were increasing with days. However, at 120 DAS total dry biomass of *Striga* weeds increased compared with that obtained at 60 DAS in different moisture levels. These results on *Striga* response at different moisture levels suggest that *Striga* preferred moisture level between field capacity/wilting point moisture levels where the soil moisture was low.

**Influence of parasitic weeds on rice growth at different moisture levels**

The study revealed that there were significant (P<0.05) effects of weeds on rice in different moisture levels (Figure 3). The tallest plant was recorded at saturation moisture level when rice was alone or with *Striga*. This means that presence of weed infestations causes much stress to rice plant which also affects the physiology of the plant such as cell division, growth and development. Reduction in rice height in other moisture levels agrees with the reported information that growth involves both cell growth and development which is a process consisting of cell division, enlargement and differentiation (Jones and Lazenby, 1988) and these processes are sensitive to moisture stress because of their dependence upon turgor. Salisbury and Ross, (1992) reported that the inhibition of cell expansion is usually followed by a reduction in cell wall synthesis. Moisture levels affected tillering whereby at field capacity/wilting point there was an increase of number of tillers compared to other moisture levels. However, Ali *et al.*, (2005) reported that rice tillering was affected by water depth and the maximum tiller number was recorded at moderately low moisture level.

The observed decrease in rice biomass was influenced by *Striga* weeds. At 60 DAS, (Figure 4) the highest weight value (5.2g) was obtained at saturation moisture level when the rice was alone. On the other hand, at 120 DAS highest value (56.6g) was also obtained at saturation moisture level when rice was planted with *Striga* which meant it was rice alone as there was no emergence of *Striga* in this moisture level (Figure 5). This implies that, at saturation moisture level rice crop performs better due to absence of the parasite.

**Conclusions**

*Striga* prefers low soil moisture levels as it performed well at field capacity and field capacity/wilting point moisture levels. At saturation moisture level in presence of *Striga* seeds, rice crop performed better than in other moisture levels means there was no harm caused to the plant during its vegetative growth.

It can be concluded that under flooded condition, *Striga* cannot germinate. According to the results obtained it is recommend that to reduce the severity of *Striga asiatica*, soil moisture should be maintained at saturation throughout the growing season.

**Acknowledgement**

The authors first and foremost wish to express their profound gratitude and sincere appreciation to Prof. K. P. Sibuga, Dr. J. Rodenburg and Dr. J. Kayeke for their tireless guidance, suggestions and comments throughout to the completion of this study. We also would like to acknowledge Mzinga Corporation for their support in conducting this research.
References


Discussion Session

**Question:** Most of our low land rice growing ecology is highly affected by striga nowadays and the moisture levels are a major challenge, are there other means to help farmers so that they can combat such a challenge?

Answer: There are none

**Question:** How do you describe relationship between Striga and rice? How can saturation conditions be maintained in upland rice culture?

Answer: Relationship between striga and rice is that striga is a parasite while rice is a host. Striga depend completely on rice. In upland rice culture you cannot maintain saturation state or it will be very expensive. Better use other measures.
Improved Labour Productivity in Rice Production through Mechanization Strategies in Kenya and Tanzania

Ndabhemeye Mlengera, *Nasirembe Wanjala, Winifrida Tegambwage, Thomas Kakema, Juma Kayeke, Agness Ndunguru,

Uyole Agricultural Research Institute, P.O. Box 400, Mbeya, Tanzania; Mikocheni Agricultural Research Institute, P.O. Box 6226 Dar es Salaam, Tanzania; Chollima Agricultural Research Institute, P.O. Box 1892, Dakawa, Morogoro, Tanzania; Kenya Agricultural and Livestock Research Organization, P.O. Box 18107, Nakuru, Kenya

Corresponding Author: mundaa1@yahoo.com

Abstract

Rice farming has been conducted in both Kenya and Tanzania mostly under manual operations and has resulted in low outputs due to inefficient production methods. This has resulted into reduced acreage, low yields and labour drudgery. To increase efficiency in agricultural production among small scale farmers, mechanization was found to be the main driving tool. Research on mechanizing rice production activities from land preparation to threshing was conducted in irrigated and rain fed ecologies of Mbarali and Kyela respectively while in irrigated system of Mvomero Morogoro only herbicide effectiveness in weeds control was assessed. Seed treatment was assessed in irrigated ecology of Mwea, Kenya. Randomized Complete Block Design (RCBD) was employed in demonstration plots to assess different rice mechanization technologies. Ploughing and puddling using power tiller, oxen and hand hoe were determined in terms of man-days required. Direct rice seeding and transplanting using a walk behind motorized planter and transplanter were also compared against hand seeding and transplanting respectively. Research results indicated that there was significant difference (P < 0.05) for most mechanized operations along the rice production value chain. In order for rice growing farmers to realize the benefits accrued from mechanizing rice production, all levels of production should be mechanized. However for rice mechanization to be successful local manufacturers Implement for rice mechanization should be subsidized to enable majority of smallholder farmers to access them. Farmers should be mobilized into groups for ease of acquisition and capacity building.

Introduction

Lack of mechanization seriously limits productivity and competitiveness of rice-based systems in SSA (AfricaRice, 2011). At the same time, the continent is littered with wrecks of imported agricultural machinery, abandoned because of inappropriate designs, lack of spare parts or costly maintenance. Mechanization is crucial but its introduction requires careful analysis of successes and failures and discussion of lessons learned. Machines do not only hasten field operations but also provides a high quality product, making it more attractive to local traders and consumers.

Mechanization is essential for rice production and processing. For farmers to intensify their cropping, they
need to mechanize the manual labour-intensive operations. When NERICA production was doubled in The Gambia between 2007 and 2010, farmers found it difficult to harvest and thresh the extra rice, which resulted in reduced quality because of delayed harvesting (Africa Rice, 2011a). In Senegal, high rice prices in 2009 prompted many farmers to grow a second crop, but they then discovered that the harvesting of that crop overran into the period when they should have been preparing the land for the main-season. A recent ex-ante impact assessment conducted by the Africa Rice policy team (Africa Rice, 2011b) gave a conservative estimate of 0.9 million tons of milled rice saved by halving on-farm post-harvest losses through the use of appropriate technologies. This would save almost 17% of current rice imports, with a value of US$ 410 million in 2011 prices. This in turn could raise about 2.8 million people in rice farming households out of poverty.

Rice stakeholders from sub-Saharan Africa have recently emphasized the value of small-scale, locally adapted machinery specifically targeting labour-intensive activities, such as land preparation, weeding, harvesting and processing (Alene et al., 2006). They have also recommended that governments consult research when importing machinery to ensure their efficacy and durability under African farming conditions, and that capacity be built to provide after-sales support for farm machinery (e.g. servicing and repair) and gradually enter into farm machinery production industry.

Africa Rice has a long history of adapting and promoting appropriate-scale machinery in West Africa. The best-known example is the ‘ASI’ thresher cleaner, which is now used by the majority of farmers on the Senegal side of the Senegal River valley (Africa Rice, 2011). The latest import-and-adapt machine is a mini combine-harvester from the Philippines. Inadequate local rice supply, slow harvest and poor quality hamper production and marketing.

According to KARI (2010), rice agricultural production value chain analysis that was conducted in Kenya, a number of production constraints were identified. They include the lack of information on the economics of rice production, limited water supply, high cost of farm inputs, problematic soils, poor agronomic practices, and low soil fertility due to depletion of soil nutrients occasioned by grain and straw harvesting and more importantly, lack of mechanization strategies in rice production. Others are storage pests and poor post-harvest handling practices that have contributed to losses in quality and quantity of the rice grain yields (Kimani et al., 2011).

Agricultural mechanization in Sub-Saharan Africa (SSA) has stagnated for several decades. Some countries have formulated national strategies for agricultural mechanization but have not implemented (Tokida et al., 2012). Famine and high food prices in many African countries have led to accelerated mechanization interest in agriculture for increased crop productivity. There is need to identify specific constraints in rice production to be addressed through mechanization in order to reduce drudgery along the rice production value chain and improve efficiency in production and quality of the produce.

Rice is one of the important crops in developing countries. Rice supplies more than 30% of total calorie intake and it is a source of employment in the rural areas. Nevertheless, primary land preparation in SSA relies on human muscle power for about 80% of the cultivated land, with draught animals and small tractors being used by 15% and 5%, respectively (Rickman et al., 2013). This contrasts strongly with Asia, where land preparation on over 60% of the cultivated land is done by tractors (Mrema et al., 2008). These figures are comparable for farm power use in SSA and rice based systems are not an exception (Rickman et al., 2013).
In Tanzania rice is now the second most important food and commercial crop after maize. The rice sector is among the major sources of employment, income and food security for Tanzania farming households. Tanzania is the second largest producer of rice in Southern Africa after Madagascar but with very low average yield of 1.8 tons per hectare (RSDEA, 2012). In Tanzania rice is mostly produced in Mbeya, Morogoro and Mwanza covering more than 48% of national production (Rowhani et al., 2011).

In both Tanzania and Kenya, rice production is dominated by smallholder farmers characterized by low acreage and low yields due to most farm operations being labour intensive and time consuming, lack of both machinery and mechanization knowledge. In Kenya the government recognized rice as a strategic crop for food security and poverty alleviation. This led to the transfer of the research mandate from the Irrigation Board to the then Kenya Agricultural Research Institute (KARI) now KALRO. In the past more efforts have been directed to biological research with little effort being directed to mechanization.

In rice producing areas, the availability of labour at critical times is a major constraint to production. For a full cropping cycle more than 250 man-days/ha are required. Manual land preparation requires more than 140man days/ha, planting and weeding 70-80 man-days/ha while harvesting and transporting require an additional 60-80man-days/ha (Africa Rice, 2011).

In the southern highlands of Tanzania, Mbarali District in particular where adoption of power tiller is higher compared to other parts of the country, only land preparation and transportation are effectively mechanized while puddling, sowing, transplanting, weed control and threshing are manually undertaken, leading to increased labour and time demand hence reduced rice productivity. Paddy rice producing farmers fail to exploit rice mechanization technologies mainly due to low awareness on the existence and benefits to be reaped, and the physical access to affordable but functional machinery. Experience from Southeast Asia show that mechanization combined with improved crop management resulted in increased yields and labor requirements decreased by 60%, and the time required for all of the main rice-farming activities by 70% (Upreti, 2010).

This Research work was geared at fabricating, testing and promotion of appropriate rice machines and mechanization technologies for medium and smallholder farmers along the rice production value chain for enhanced productivity.

**Materials and Methods**

Participatory testing and promotion methods of rice mechanization technologies were implemented in Mbarali and Kyela districts in - Mbeya region and Morogoro rural in Morogoro region. Such approaches were used to create awareness and improve farmers’ skills in the use of new implements. However implement requirements vary with variation in rice growing ecologies where Mbarali and Kyela are under irrigated and rain-fed rice ecologies respectively. In Kenya design and fabrication was given priority. Experiments were conducted in demonstration trials and research centres. Treatments involved were: Power Tiller technologies (ploughing, harrowing, puddling rice and direct seeding), motorized transplanting, animal drawn implements (ox-puddlers and ox-furrow openers), and farmer practices (hand hoeing, harrowing, hand transplanting and broadcasting as the control).
Ploughing was done using the disc and ox-plough tapping power from the power tiller and oxen for the respective treatments while hand hoe was used for control treatment. Puddling was achieved using ox-puddler, power tiller harrow and hand hoe for the control. The motorised transplanter handling four rows at a time, adjusted to place 2 to 3 seedlings per hill at 25 X 15 cm spacing. Weeding for power tiller and oxen treatments was done using 2,4-D selective herbicide. Harvesting was done on 5 m x 10 m plot size at two different locations for each treatment to determine yield at 13 to 14 grain moisture and time of threshing for the different treatments. Rice crop was cut using a sickle for all treatments. Rate of threshing was assessed using motorized thresher when compared to hand. A seed dresser was evaluated for efficiency. At each level of field operation, three treatments were employed for both irrigated and rain-fed ecologies. The experiments were laid out in Randomized Complete Block Design. Man-days used in different mechanization operations were determined through number of people involved in an activity multiplied by time taken divided by six hours set as standard working hours per day in the area. Data collected through demonstration trials were analyzed using GenStat software and means separated using Duncan Multiple Range Test.

Two models, gasoline and motor powered dressers were tested. To determine capacity, rice grains were weighed in batches of 5kg. The drum door was slid open and loaded and switched on with an additional 5kg batch at a time in each model until the machine was unable to rotate the loaded drum in each case. This was done without adding the liquid insecticide; it was rotated by switching on the engine/motor. In each case when the drum could not rotate, offloading in steps of 1kg was done until the respective drums could just rotate. Overhung load was calculated as follows;

To calculate overhung load, gear drive manufacturers use the formula:
Overhung Load = 126,000 x HP x FC x LF x P.D. x RPM
where:
HP = Horsepower
FC = Load connection factor
LF = Load location factor
P.D. = Pitch diameter of the sprocket, sheave or gear
RPM = Revolutions per minute of the shaft

**Results**

**Rice mechanization as labour saving strategy**

Data collected from demonstration trials in Mbarali and Kyela under different mechanization technologies for ploughing and puddling were compared (Table 1). Results indicate that use of power tiller and oxen in ploughing and puddling saves significantly more labour and time compared to hand hoe. Such technologies enable the farmer to do transplanting timely.
Table 1: Ploughing and puddling in rice production in Mbarali and Kyela, Tanzania

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ploughing (man-days ha(^{-1}))</th>
<th>Puddling (man-days ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Tiller</td>
<td>2.13a</td>
<td>0.513a</td>
</tr>
<tr>
<td>Oxen</td>
<td>2.75a</td>
<td>2.53b</td>
</tr>
<tr>
<td>Hand</td>
<td>7.05b</td>
<td>10.92c</td>
</tr>
<tr>
<td>GM</td>
<td>3.98</td>
<td>4.65</td>
</tr>
<tr>
<td>CV%</td>
<td>24.7</td>
<td>5.1</td>
</tr>
<tr>
<td>F Prob.</td>
<td>0.007</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LSD</td>
<td>2.23</td>
<td>0.54</td>
</tr>
</tbody>
</table>

Means along same column with similar letter(s) are not statistically different at (P > 5%) 
Note: 1 man-day = 6 hours of work per person

Puddling using oxen and power tiller in irrigated ecologies of Mbarali Tanzania, besides saving labour, the technologies have indicated to reduce drudgery.

Direct rice seeding and transplanting

Rice seeding and transplanting are dependent on ecologies where by rain-fed and irrigated ecosystems are dominated by direct seeding and transplanting respectively. Transplanting was done in irrigated rice ecosystem using walk behind motorized rice trans-planter (Plate 3) to transplant rice seedlings of 14 – 21 days old while direct seeding was done in rain-fed ecosystem using a planter that tapped power from a power tiller. Direct planter (Plate 4) open furrows, drop rice seeds and cover the seeds simultaneously.
Table 2: Direct sowing and transplanting in (man-days ha-1) in Mbarali and Kyela

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Direct seeding</th>
<th>Transplanting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Seeder /Transplanter</td>
<td>0.92a</td>
<td>1.5a</td>
</tr>
<tr>
<td>Oxen</td>
<td>21.20b</td>
<td>-</td>
</tr>
<tr>
<td>Hand</td>
<td>21.19b</td>
<td>12.5c</td>
</tr>
<tr>
<td>GM</td>
<td>14.44</td>
<td>7.0</td>
</tr>
<tr>
<td>CV%</td>
<td>41.0</td>
<td>6.6</td>
</tr>
<tr>
<td>F Prob</td>
<td>0.021</td>
<td>0.001</td>
</tr>
<tr>
<td>LSD</td>
<td>13.40</td>
<td>1.02</td>
</tr>
</tbody>
</table>

Means along same column with similar letter(s) are not statistically different at (p >5%)

Results show that direct seeder can save time by about twenty three times compared to oxen and hand (Table 2).
Plate 5. Ox-furrow opener, Kyela

Oxen open furrows only, seed placement remaining manual (Plate 5). Motorised transplanter has also shown to save labour eight times compared to hand (Table 2). However, there is no technology of transplanting in our area that uses oxen.

Rice Weeding

Weeding operation was assessed using herbicides, manual weeders and hand. The use of manual weeders in rice weeding helps to avoid bending for hand pulling of weeds that is back breaking. Results on weeding operation are presented in Tables 3 and 4 for the respective treatments.

Table 3: Rice weeding using push weeders, herbicides and hand, Mbarali and Kyela

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weeding (man-days ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbicide</td>
<td>0.48a</td>
</tr>
<tr>
<td>Manual weeders</td>
<td>10.17b</td>
</tr>
<tr>
<td>Hand</td>
<td>24.83c</td>
</tr>
<tr>
<td>CV%</td>
<td>2.4</td>
</tr>
<tr>
<td>LSD</td>
<td>0.65</td>
</tr>
<tr>
<td>SED</td>
<td>0.24</td>
</tr>
<tr>
<td>F Prob</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Means along same column with similar letter(s) are not statistically different at p >5%
Regardless of outstanding labour saving as a result of herbicide use, farmers prefer use of push weeders due to the cost implications. Transplanting using the transplanter maintained inter-row spacing which facilitated the use of push weeders for weeding (Figure 6).

Plate 6: Rice weeding using push weeders in Mbarali, Mbeya

Table 4: Effect of weed management on grain yield and benefit-cost ratio, Dakawa, Morogoro

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield (kg/ha)</th>
<th>Av. Income (Tsh)</th>
<th>Variable Cost (Tsh)</th>
<th>Benefit-Cost ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2011</td>
<td>2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two hand weeding</td>
<td>5600.0a</td>
<td>5597.2a</td>
<td>4,478,800.00</td>
<td>2,488,266.67</td>
</tr>
<tr>
<td>2,4-D</td>
<td>4400.0b</td>
<td>4347.2c</td>
<td>3,498,880.00</td>
<td>1,841,515.79</td>
</tr>
<tr>
<td>Roundup</td>
<td>4880.0ab</td>
<td>5111.1abc</td>
<td>3,996440.00</td>
<td>1,998,220.00</td>
</tr>
<tr>
<td>No weeding (control)</td>
<td>2160.0c</td>
<td>2777.8d</td>
<td>1,975,120.00</td>
<td>1,645,933.33</td>
</tr>
<tr>
<td>Tiller Gold (OD)</td>
<td>5360.0ab</td>
<td>5444.5ab</td>
<td>4,321,800.00</td>
<td>1,728,720.00</td>
</tr>
<tr>
<td>Solito</td>
<td>4560.0ab</td>
<td>3638.9d</td>
<td>3,279,560.00</td>
<td>1,490,709.09</td>
</tr>
<tr>
<td>Mean</td>
<td>4400.0</td>
<td>4427.1</td>
<td>3,530,840.00</td>
<td>2,076,964.71</td>
</tr>
<tr>
<td>SE</td>
<td>344.0</td>
<td>283.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means along same column with similar letter(s) are not statistically different at $p > 5\%$.
Rice Threshing

Rice threshing is generally labour and time consuming when manually done. Results (Table 5) showed that motorized thresher can save labour three times compared to manual threshing.

Table 5: Machine and Hand Threshing (Man-days andtha-1) in Mbarali and Kyela

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Threshing (man-days ha-1)</th>
<th>Yield (t/ha-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorised thresher</td>
<td>2.77a</td>
<td>3.0a</td>
</tr>
<tr>
<td>Oxen (Motorized Thresher)</td>
<td>3.05a</td>
<td>3.27a</td>
</tr>
<tr>
<td>Hand</td>
<td>9.1b</td>
<td>3.45a</td>
</tr>
<tr>
<td>GM</td>
<td>4.97</td>
<td>3.24</td>
</tr>
<tr>
<td>CV%</td>
<td>29.7</td>
<td>13.3</td>
</tr>
<tr>
<td>F Prob</td>
<td>0.027</td>
<td>0.501</td>
</tr>
<tr>
<td>LSD</td>
<td>3.943</td>
<td>0.978</td>
</tr>
</tbody>
</table>

Means along same column with similar letter(s) are not statistically different at P > 5%

Plate7: Demonstration of rice threshing using motorised Thresher, Mbarali
Seed Dressing

Table 6: Special features for the seed dresser

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Gasoline</th>
<th>Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drum size, m³</td>
<td>0.21</td>
<td>0.21</td>
</tr>
<tr>
<td>Prime mover rating, Hp</td>
<td>5.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Mean drum speed, rpm</td>
<td>41</td>
<td>37</td>
</tr>
<tr>
<td>Coating uniformity coefficient</td>
<td>0.98</td>
<td>0.96</td>
</tr>
<tr>
<td>Time to acquire desired coating, sec</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Offloading time, minutes</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Rate of output, kg/hr</td>
<td>545.5</td>
<td>490.9</td>
</tr>
<tr>
<td>Labour requirement, md</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cost of the assembly, $</td>
<td>568</td>
<td>524</td>
</tr>
</tbody>
</table>

Discussion

Results indicate that the most labour intensive operations in rice production were puddling, transplanting and weeding when done manually (man-days ha⁻¹). It is evident that such operations need mechanization interventions in order to enhance labour saving.

Ploughing and Puddling

The use of power tillers in Mbarali district for puddling and transplanters for transplanting operations have shown to greatly save labour ten and four times compared to hand and oxen respectively. The use of oxen in ploughing and puddling also saves labour when compared to hand hoe (Table 1). Results indicate that there were significant difference between power tiller and hand hoe as well as oxen and hand hoe but no significant difference between power tiller and oxen (P ≤ 0.007). Considering puddling, there was significant difference (P ≤ 0.001) between all the three treatments. Power tiller puddling was the most labour saving technology (0.513 man-days ha⁻¹) followed by oxen (2.53 man-days ha⁻¹) while hand being the least (10.92 man-days ha⁻¹).
Direct Seeding and Transplanting

Results showed that direct seeding and transplanting using motorized rice seeders and transplanters are labour saving compared to ox-direct seeders and hand transplanting, indicating significant difference at (P<0.021) and (P<0.001) respectively (Table 2). The use of ox-furrow openers for opening furrows followed by manual placement and covering of rice seeds did not significantly save labour and time for the activity.

Rice Weeding

Timely weeding has been difficult for most rice farmers especially because weeding is tedious and time consuming as it is done by hand leading to delayed weeding operations that result into reduced yields. When manual weeder were employed, they reduced the time of weeding by 2.4 times (Table 3) compared to hand weeding. Uprety (2010) also reported about 3 times saving in time and labour when push weeder were employed. Herbicides are more time saving than the two methods but considered expensive for most small scale farmers. Nevertheless, Tiller Gold - Fenoxaprop-ethyl + Ethoxy Sulfuron-sodium + Isoxadifen-ethyl (Safner) and Solito – Pyribenzoxim + Pretilachlor were highly accepted by farmers who were involved in testing because of their efficiency in controlling many weed species. These herbicides indicated high benefit-cost ratio when compared to other treatments.

Rice threshing

Threshing in Mbarali and Kyela in Tanzania is done manually which involves hitting the panicles against a stationary object like log of wood or beating the cut crop with a stick to remove the grain. Though popular because of its low cost, it is labour intensive. Results from the trials reported in this paper show that threshing rate and efficiency is very high when using motorized rice thresher and there was statistical significant difference (P ≤ 0.027) between hand threshing and use of motorized thresher (Table 6). This means that mechanizing rice threshing will greatly reduce time spent and fatigue to farmers on the same operation. It is simple to use, completely threshes the heads, performs winnowing, and reduces fatigue especially to women and encourages men participation in rice threshing.

Seed dresser

Carrying capacity rating for the two models tested was determined as 30 kg for the electric dresser and 50 kg for the gasoline one. The amounts of chemical used per kilogram were the same in each case according to their manufacturers’ recommendation. The coefficients of dye on individual seeds compare favourably in the two types of seed dressers, for which coefficients of variation approaching 100%. The difference between the two coefficients of variation in this study is likely due to the effects of the difference in prime mover capacity which led to a differential in ability to take overhanging load. Though increased motor horse power will lead to increased cost of production and power requirement, the ability to take overhanging load may disappear. Time for attaining those respective coefficients was found to be 30 and 40 seconds for electric and gasoline dressers respectively.

Conclusion

In order for rice growing farmers to realize the benefits accrued from mechanizing rice production, all levels of production from land preparation to harvesting should be mechanized. Farmers realized the fact that mechanizing rice production operations leads to labour and time saving at the same time profitable. Results show that full mechanization of main rice production activities from land preparation to harvesting can be 10 times labour saving compared to manual operation. However for rice mechanization to be successful local manufacturers and suppliers of implements should ensure they supply quality and reliable materials that will not discourage resource poor farmers. Output of the two models was found to be 515 kg/h and 720 kg/h for electric and gasoline driven dressers respectively. The treatment method outlined above provides relatively
uniform application of liquid seed dressings to batch quantities of seeds with less man-day requirement.

**Recommendations**

Implements for rice mechanization should be subsidized to enable majority of smallholder farmers to access them. Otherwise farmers’ mobilization into groups would help them join effort to purchase farm machinery that can serve 10-15 people e.g. motorized rice trans-planters and threshers. Building capacity among local manufacturers of rice mechanization implements would increase their accessibility and reduce cost for small scale farmers who consider imported machines and implements expensive. Work should be undertaken to standardize pesticide application in the drum and operators trained before using the machine. More work is required to establish energy requirement and germination trends of seed treated by the dresser.

**Acknowledgements**

Sincere thanks are to The World Bank through Ministry of Agriculture, Food Security and Cooperatives, Uyole Agricultural Research Institute-Tanzania, Mwea Agricultural Research Institute-Kenya, Chollima Dakawa, Mbarali and Kyela District Councils for their financial and human resource support that made the research successful.

**References**


Africa Rice (2011a). Boosting agricultural mechanization in rice - based systems in sub - Saharan Africa Funded by the Global Rice Science Partnership (GRiSP) AfricaRice, St. Louis, Senegal, 6 - 8 June 2011.


Rice value chain analysis in Tanzania: Identification of constraints, opportunities and upgrading strategies

Jackson, Nkuba.1,*, Agnes, Ndunguru.2, Ruth, Madulu.3, Deogratias, Lwezaura.1, Geophrey, Kajiru.4, Adventina, Babu.4, Betty, Chalamila.3 and George, Ley.5

1Department of Research and Development. P.O. Box 2066, Dar es Salaam, Tanzania; 2ARI Uyole, P.O. Box 400, Mbeya, Tanzania; 3ARI Mikocheni, P.O. Box 6224, Dar es Salaam, Tanzania; 4ARI Ukiriguru, P.O. Box 1433, Mwanza, Tanzania. 5ARI Mlingano, P.O. Box 5088, Tanga, Tanzania.
*Correspondence: jmnkuba@yahoo.com

Abstract

In 2012/13 rice value chain analysis study funded by EAAPP was conducted in rice farming systems of Lake, Eastern and Southern-Highlands zones of Tanzania by sampling 240 producers, 60 traders and 30 processors. Generally, rice actors have limited market access for both national and regional markets mainly among others due to inadequate support services. Also, previous studies covered little information about the economics of rice production and marketing. Therefore, the aim of this study was to enhance rice actors with knowledge and information of the rice value chain, and identify feasible upgrading strategies. It mapped the key rice actors who undertake marketing functions. The study results revealed that rice was staple crop by more than 50% in Kilombero, Kyela and Mvomero districts and less than 30% in Rorya, Mbarali and Maswa districts. On the other hand, it was important cash crop by 79% - 100% in all districts. About 44% and 61% of the total crop area cultivated per household in lowland rain-fed and irrigated ecosystems respectively were under rice cultivation. SARO 5 was the only improved variety widely grown by 27% of farmers out of 32 varieties. Rice yield ranged from 1.5 tons/ha to 4.3 tons/ha, varying greatly by ecosystem and variety. Farmers sold their rice paddy at farm gate by 61% - 93% to collectors who used non-standard measurements. Farmers’ profits ranged from TSh 329,000 to 1,584,000 per hectare. Producer’s share ranged from 34% to 40%. This implies that upgrading strategies are required that can increase producers’ market share and improve competitiveness of rice value chain. The recommended up-grading strategies include: increase rice productivity and quality; farmers perform vertical integration activities such as bulking and grading; and chain management activities such as strengthening of producer groups or associations and cooperatives.

Introduction

The project titled “Increasing Competitiveness of rice value chain in Eastern Africa region: rice value chain analysis and upgrading” funded by the Eastern Africa Agricultural Research Project (EAAPP) was conducted in Tanzania, Uganda and Kenya started in 2012. Of the four countries participating in EAAPP, Tanzania is the Regional Rice Centre of Excellence with an estimation rice production of about 1.2 – 1.4 million tons per year of milled rice of which 95% is under rain-fed system. Other EAAPP countries are Kenya with rice production of 33,000 - 50,000 metric tons per year of which 95% is under irrigation system, Uganda produced 165,000 and 334,000 metric tons in 2009 and 2013 respectively, of which 71% is upland rice and Ethiopia produced 498,332 tons in 2009 and estimated to reach 1.8 million tons in 2014 and 4 million tons in 2019. In Ethiopia, rice area increment was 156,000 ha in 2009 to 464,000 in 2014 and estimated to reach 774,000 ha in 2019, from 20 million ha under rain-fed system and only 3.7 million ha under irrigation system (MAFC 2009; UG 2009; EG 2009; Emongór, et al., 2009).
This rice value chain analysis was an entry point for rice value chain upgrading. It was deemed necessary to have an in-depth understanding of the structure and performance of the rice value chain in Tanzania as a case study that was conducted during cropping seasons of 2012/13 in the three agro-ecological zones of Lake, Eastern and Southern-Highlands of Tanzania. About 90% of the rice production in Tanzania is by smallholder subsistence farmers and production concentrated in Mbeya, Morogoro, Iringa, Mwanza, Shinyanga, Simiyu and Pwani Regions (ACT and TAP 2010; EAAPP 2011). Robust strategies are needed to change the subsistence farmers into smallholder commercial farmers. The rice value chain is highly fragmented with millers and brokers playing a central role in the trading process. The supply channels are generally long and the produce changes many hands before reaching the final consumer. Although in the past there had been some attempts to eradicate the problem of poor market access to rice farmers, they mainly addressed the production segment of rice value chain (Meertens et al., 1999; 2003; Ngailo et al., 2007). Previous studies on rice value chain analysis reported that rice value chain actors have limited market access for both national and regional markets (ACT and TAP 2010; MAFC 2009; and Mafuru J.M. 2007). Most of rice actors have limited knowledge and information of key value chain segments that constrains the facilitation and establishment of upgrading strategies or interventions along the chain. Thus, little is known about the economics of production and marketing along the value chain. Information on prices, marketing margins, extent of competition, production costs are currently insufficient available, making value chain upgrading recommendations challenging.

The aim of this project was to enhance knowledge and information of the rice value chain in Tanzania with a view of proposing means by which fair returns to chain actors and the value added throughout the chain can be improved. The prevailing situation necessities the creation of strategies to be put in place in the rice value chain to make it robust and competitive enough to contribute to poverty eradication and contribute to improved income and food security as stipulated in National rice development strategy (MAFC, 2009). Such strategies would spur increase in productivity and competitiveness of the rice value chain as stipulated in the national agriculture policy of 2013 (MAFC, 2013).

Methodology
The study adopted value chain principles to assess the rice value chain as way of gaining insight in potential productivity, competitiveness gains and improvements in supply chain efficiency. It highlighted the relationships between networks of value chain actors including the producers, collectors, traders, processors, exporters, retailers, consumers and the means by which such networks are, and/or can be accessed. The study approach emphasized the five topics of relevance to value chain analysis including trust and cooperation; governance; market power; innovation and knowledge; and focus/intervention points (Webber et al, 2010; Lesego, 2007; Frey and Sharon 2006; and Sturgeon, 2000; UNCTAD 2000; GTZ 2008; Kaplinsky and Morris 2001). Gross margins, net profits and returns to land and labour received by actors were computed to measure the efficiency of existing rice marketing at each segment along the value chain.

Both qualitative and quantitative methods were employed and additional information from secondary sources and value chain actors’ collected through interviews. The study was conducted in six sites located in Lake, Eastern and Southern highlands zones. In each zone two districts were selected, one with irrigated ecosystem and the other with rain-fed ecosystem. In the Lake zone the two sites were Irienyi Irrigated ecosystem in Rorya district and Shishiyu, a rain-fed ecosystem in Maswa district. The project areas in Eastern Zone were Komtonga rain-fed ecosystem in Mvomero district and Mkula irrigated ecosystem in
Kilombera district of Morogoro region. The project sites in the Southern Highlands zone were Utulo irrigated ecosystem in Mbarali district and Mpunguti rain-fed ecosystem in Kyela district. The types of value chain actors visited were input suppliers, rice producers, collectors, traders, processors, transporters, exporters, importers and consumers. Others interviewed were service providers and policymakers from local and central government authorities. Different survey instruments were administered for each key actor. Using the questionnaire, a total of 240 rice producers were interviewed. Information from traders, processors and actors was collected using both key informants and focused group discussions. Data descriptive analysis included cross tabulations of various variables, gross margins, marketing margins, means, proportions and test of significance were generated.

**Results and discussions**

**Mapping of rice value chain**

The study identified key rice value chain actors at micro-, meso- and macro-levels (Figure 1). At micro level the key actors are input suppliers (mainly of fertilizers, herbicides, seeds and implements), producers (small, medium and large farmers), collectors, processors, distributors (transporters, traders and wholesalers), retailers and consumers. These are key operators undertaking the marketing functions in a sequential manner (Figure 2). Apart from the key actors, the rice value chain is insufficiently supported by farmer groups and associations, lending institutions, research and extension services, and other service providers at the meso-level. They play roles of supporting, facilitating, advising, promoting, training, technology development and financial services.

At macro-level, the rice value chain is supported by local government authorities, central government and providers of utilities such as electricity, roads, irrigation infrastructures and storages facilities. The rice value chain enjoys from these instruments by getting the framework conditions for macroeconomic policy (such as subsidy and rice national development strategy) and economic infrastructure (markets and communication) and administration including business establishment and enforcement.
Figure 1: Typical mapping of rice sub-sector; functions and participants
In Tanzania, there is increasing number of smallholder rice farming households and by 2012, it was estimated about 1.2 - 1.8 million. This was further estimated at 18% of farming households in the country. Apart from smallholder farmers, the main chain actors identified along rice value chain in project areas were Kilombero High Quality Rice Growers Company (AKIRIGO) in Ifakara - Kilombero District, Southern Highland Company (SHC) in Mbarali District, Export Trading with headquarters in Dar es Salaam and Kilombero Plantation Limited (KPL) in Kilombero District. These actors provide various supports to key actors at micro level.

**Rice producers**

In Tanzania, there is increasing number of smallholder rice farming households and by 2012, it was estimated about 1.2 - 1.8 million. This was further estimated at 18% of farming households in the country. Apart from smallholder farmers, the main chain actors identified along rice value chain in project areas were Kilombero High Quality Rice Growers Company (AKIRIGO) in Ifakara - Kilombero District, Southern Highland Company (SHC) in Mbarali District, Export Trading with headquarters in Dar es Salaam and Kilombero Plantation Limited (KPL) in Kilombero District. These actors provide various supports to key actors at micro level.

**Importance of rice as staple and cash crop**

Importance of rice crop varied by zone and ecosystems in the country. Rice crop was recorded as important staple crop by 52% to 97% in Kilombero, Kyela and Mvomero districts while it was less important staple crop by 3% to 29% in Rorua, Mbarali and Maswa districts (Figure 3). However, the trend indicates that rice was increasingly becoming a staple food in both rural and urban areas. Rice was regarded an important cash crop by 79% to 100% of respondents in all project sites. About 70% of farmers’ rice harvest was for sales.
Figure 3: Importance of rice as staple and cash crop

Farm size

On average farm size owned per household was significantly different (P<0.05) between zones and ecosystems. Farmers in rain-fed rice ecosystems of Maswa, Kyela and Mvomero had 3.5 ha, 1.8 ha and 1.5 ha respectively, while in rice irrigated ecosystem of Rorya, Mbarali and Kilombero had 2.0 ha, 2.4 ha and 1.7 ha respectively. About 44% and 61% of the crop area cultivated in lowland rain-fed and irrigated ecosystems respectively were under rice cultivation. Despite increase in rice acreage in Tanzania since 1970s (Figure 4), rice area cultivated per household has been static or even declining. Expansion of rice acreage has been achieved through new entrants in rice cultivation mainly in new areas.

Figure 4: Trend of rice acreage from 1960 to 2011
Mechanisation of farm operations

Low level of mechanisation highly constrained timely farm operations in all rice ecosystems. In Lake Zone, the method of ploughing was 89% by ox-plough, 9% by hand hoe and only 3% by tractor. In Southern Highlands Zone, the method of ploughing was 73.8% by ox-plough and 8.8% by hand hoe. In Eastern zone the use of ox-plough in ploughing operation was minimal and use of hand hoe relatively high at 69% followed by use of tractor 23.8% and 7.1% by power tillers. In Tanzania about 64% of crop area is cultivated by hand hoe, 24% by ox-plough and 12% by tractor (MAFC, 2013).

In Lake zone, the method of weeding was entirely by hand hoe, while in Southern Highlands zone, 55% used hand hoe followed by combination of Hand hoe and herbicide (35%), Herbicides (6.2%), Push-weeder and herbicides (3.8%). In Eastern zone weeding was 85.7% by hand hoe, 11.9% by herbicides and 2.4% by push-weeder. In Lake zone, the use of power tillers, ox-cultivator, push-weeder and herbicides were not recorded being neither owned nor used by farmers in the two project sites. This implies that in Lake zone, there is low mechanisation in planting and weeding operations compared to other two zones. In all zones harvesting operation was done entirely by hand using sickles/slashers, knives and beating by poles.

Rice varieties grown by farmers

Nine rice varieties were planted by farmers in Lake zone, ten in Southern Highlands zone and thirteen varieties in Eastern zones. The most rice varieties cultivated by farmers in Lake zone were SARO 5, Bulungwa, Sukari, Supa and Kalamata. Other varieties were Lubunatela, Lugata, Furaha and Sokotu. SARO 5 was the only improved variety found planted by 27% farmers of Irienyi irrigation system. Farmers at Shishiyu did not prefer this variety due to its short height in the field in case of floods occurrence and its taste not preferred by farmers. Also in Southern Highlands zone SARO 5 was the only improved variety grown by 28% and 25% of farmers in Mbarali and Kyela respectively. The local varieties included: Kilombero, Morogoro, Zambia, Indiarangimkia, Fayadume, Mwasungo, Supa, Mwendambio and a mixture of several varieties. Kilombero, India rangimkia and Zambia were the first top local varieties grown by good number households from that zone.

In Eastern zone about 89% and 76% of farmers interviewed in Mvomelo and Kilombero respectively used SARO 5 variety during 2012/13 cropping season, showing that Eastern zone had the highest adoption of improved varieties compared to other zones. The local rice varieties grown by farmers in Eastern zone were Kaulimawangu, Super Mbeya, Super Zanzibar, Super Shinyanga, Mbwambili, UdongowaSongea, Msukuma, Zambia, Jaribu, Kula na Bwana, India, Kalimata and Sengo. The first three were the most grown local varieties.

Rice Productivity

In all project sites, paddy yield greatly varied by rice ecosystem and variety. In irrigated ecosystem of Erienyi in Rorya district, the average rice yield was 2.3 tons/ha while in rain-fed ecosystem of Maswa was 1.8 tons/ha. In irrigated ecosystem of Mbarali rice yield was relatively high at 4.05 tons/ha. In rain-fed system of Kyela the yield was 1.6 tons/ha almost same as that of Maswa rain-fed ecosystem.

Rice varieties had significantly different yields in different ecosystems as estimated by farmers. For instance India rangimbili had 3.8 tons/ha, Faya 3.7 tons/ha, Zambia 3.2 tons/ha and SARO 5 had 3.0 tons/ha under
irrigated rice system of Mbarali while under rain-fed ecosystem the average production of India rangimbili was 0.7 tons/ha, Zambia 0.9 tons/ha and SARO 0.6 tons/ha. Kilombero and morogoro variety which were common grown under rain-fed system had average yield of 1.2 tons/ha and 0.6 tons/ha respectively. In Eastern zone, irrigated ecosystem had rice yield of 4.3 tons/ha and rain-fed ecosystem had 2.5 tons/ha. Generally results revealed that, rice yields of irrigated ecosystem were two times or more than yields received under rain-fed ecosystem.

**Selling of rice**

Most of the farmers sell unprocessed rice, i.e., paddy. In Lake zone for instance, about 61% and 47% of rice harvest in irrigated and rain-fed systems respectively was sold as rice paddy immediately after harvest. Same situation was observed in Southern Highlands zone whereby 60.4% and 38.5% of rice harvest obtained by smallholder farmers in irrigated and rain-fed ecosystems respectively was sold immediately after harvest. Relatively, selling of paddy rice was higher in irrigated systems than in rain-fed systems. In rare cases, selling of paddy rice could take place while still in field (1% to 7%). The most market places for selling rice were at farm gate (home), village open market and urban markets (Figure 5).

![Figure 5: Farmers selling market places](image)

Most of farmers in Lake Zone (61%) and Eastern Zone (93%) sell their rice paddy at farm gate. Only small proportion sold their produce in open village-markets. Rice smallholder farmers have limited linkage with urban markets due to limited marketing information, lack of transportation facilities and strong farmers’ associations or organisations. Only 1% of farmers in Eastern zone and 11% in Southern Highlands zone sold rice to urban markets. This makes farmers sell rice in isolation thereby lacking collective bargaining power. The main rice buyers at farm gate level were collectors (70 - 76%) who are often based within the community, traders (7 - 14%) within or outside the community and retailers (7.0%), processors who are also owners of rice milling machines (6%) and consumers (2 - 4%).
Source and means of acquisition of farm inputs

The important farm inputs for rice cultivation included seeds, fertilizers, herbicides, insecticides and fungicides. In the six project sites, there were no formal distribution channels for these farm inputs and hence not available at village level. Generally, farmers recycled seeds for several years. For instance in Lake zone, 4% of all farmers interviewed used recycled seeds of varieties acquired 15 years previously and 35% were using seeds that acquired about five years previously. About 78% of rice farmers used their own seeds from the previous harvest during the 2011/12 cropping season. Similar situation was reported by farmers in Eastern zone where about 10% of farmers used local seeds acquired 15 years previously. In the Southern zone about 42% of farmers obtained their seeds from neighbours, 32% their own seeds, 11% from seed multipliers who produce Quality Declared Seeds, 10% from SACCOS and 5% from research institute (ARI Uyole). Source of fertilizers, herbicides and insecticides were 76% from stockist and 34% from local markets. In all sites farmers claimed low quality of inputs supplied by stockists and those obtained through local markets.

Farmers from Lake Zone acquired seeds by buying (41%), got free (27%) and exchange of seeds (31%). The same trend was observed in Southern zone, farmers obtained rice seeds from neighbours (42%), own seeds (32%) and other sources (26%). Means of seed acquisition in all zones were buying (34 - 60%), given free (8 - 25%), exchange seeds (10 - 18%) and own seeds (5 - 40%).

Uses of fertilizers, herbicides and insecticides

Unavailability of seeds, fertilizers, herbicides and insecticides at village level were the major constraints mentioned by farmers that varied by zones. The use of fertilizers and herbicides in rice cultivation was relatively high in Eastern zone. About 50% and 38% of farmers use fertilizers and herbicides respectively. The use of herbicides and insecticides by farmers in Lake zone was not common. Only two farmers were recorded to use herbicides for weeds control at Shishiyu. Farmers from irrigated scheme of Erienyi applied urea fertilizer that was obtained at village level under input voucher system or sometimes they got from extension agent, primary society and town markets of Tarime and Musoma. They used an average of 36.2 kg of urea per household with a 1kg to 100 kg range. None of the farmers from the rain-fed system applied chemical fertilizers for rice cultivation during 2011/12 cropping season. Other constraints mentioned by farmers were high prices and low quality of seeds and other farm inputs.

Group membership

A number of rice farmers were not members of marketing groups, cooperative societies, SACCOS or VICOBA. However, results show that 69%, 61% and 41% of farmers were group members in Southern Highlands, Lake and Eastern zones respectively. In Southern zone, the groups included SACCOS 38.2%, producer group 21.8% and VICOBA 12.7%. In Lake zone the groups included producer groups 45.1%, marketing groups 5.6%, Cooperative society 1.4%, SACCOS 2.8% and VICOBA 5.6% while in Eastern zone groups were producer group 59.4%, Cooperative societies 6.2%, SACCOS 6.2%, VICOBA 21.9% and FINCA 6.2%. Participation of farmers in cooperative societies was low in all zones mainly due to discouraging records of cooperatives.
Advices received from extension services

Extension service was inadequate to farmers in all zones. In Lake zone, about 80% and 14.6% of farmers interviewed from Irienyi irrigation scheme and Shishiyu rain-fed ecosystems received no advice from an extension agents during 2011/12 cropping season. In Southern Highlands and Eastern zones, 51.2% and 62.7% of rice farmers interviewed reported to obtain advice on rice agronomic practices of which 22.8% was irregular contact with extension agents, 22.5% once per year and 6% contact monthly, showing that extension services were irregular. Respondent sources of extension advice were 45.7% research institutes, 42.9% local government extension staff and 11.4 % NGOs and fellow farmers. However, extension services were relatively higher to farmers under irrigated system than under rain-fed system.

Rice storage

A World Bank- FAO study revealed that 8% to 26% of rice is lost in developing nations due to post harvest problems and poor infrastructure (FAO, 2012). This study indicated that 94 - 96% of farmers store rice paddy in bags, 3% use vihenge and 3% own godown.

Figure 6: Means of storing rice; separate or mix varieties

Mixing of varieties in storage of rice was highest in Lake region and lowest in Eastern zone (Figure 6), indicating that farmers were yet to realise importance of maintaining quality by storing each variety separately. Grading before selling was by 5%, 20% and 30% of farmers in Lake, Southern highlands and Eastern zones respectively. Access to marketing information ranged from 40 – 54% of farmers.

In general, challenges faced by farmers in paddy production included:

a. Small rice farms of about 0.5Ha and Low rice yield (rain-fed: 0.7 - 1.75 tons/ha and irrigated: 2.5 – 4.25 tons/ha) due to low use of improved technologies, declining soil fertility, increasing pressure of pests and diseases (rice yellow mottle virus, stalk-borer), birds and climate change. Other causes were unavailability and high prices of inputs, and low level of mechanisation of farm operations (use of push-weeder was less
than 5%) leading to high production costs and untimely weeding operation
b. Limited access to micro finance institutions for saving and credit services
c. Limited market information leading to low market prices. In all project sites there was no mechanism for
 dissemination market information to farmers.
d. Low use of appropriate pre and post harvest technologies, increasing rice loss from field through storage to
 processing.
e. Inadequate access to extension services (5-20%)
f. Farmers have no strong marketing groups, associations or cooperatives.

Rice collectors, traders and retailers

Three types of traders were identified; small traders (collectors), large traders including wholesalers and retailers.
Collectors and traders were mainly dominated by men, but participation of women as rice retailers was observed
in all sites. In Lake zone, women participation was low 5% but high (70%) in Southern-Highlands.

Rice collectors were mainly based in their respective zone: 27% and 73% within and outside ward respectively
in Lake zone; and 6.7% and 93.3% within and outside ward respectively in Southern zone. Collectors play the
marketing function of bulking the produce at centres easily reached by traders. They preferred to buy paddy rice
(83%) at farm gate using their own measurements such as tins and bags, while traders (60%) and retailers (75%)
prefer to buy milled rice. Usually collectors and traders have informal arrangement and were available at all times
where more than 20 per village was common. Sometimes they gave loans to farmers and paid back in form of
paddy rice at harvesting time. Challenges facing collectors were:

a. Lack of storage facilities; all collectors interviewed use bags to store rice and had no storage godown
b. Limited access to loans from institutions due to lack of collaterals
c. Lack of contractual agreement with traders
d. Unfaithful farmers

Large traders interviewed indicated buying paddy rice or milled rice in more than one production area or zone.
They buy directly from producers or through collectors (75%), from collectors (18.8%) and from village open
markets (6.2%). Usually they hire transport to far markets and only 15% used own transport. Factors considered by
traders when buying rice included price, proximity to transportation service and quality of rice. Quality attributes
were colour, size, aroma, origin, shape, proportion of impurities or broken, age and variety. Rice or paddy was
bought through collectors. Large traders had more market information compared to producers and collectors.
They stored before selling using own or hired storage facilities, mill and transport to far markets. Constrains cited
were low working capital, limited storage facilities, unreliable supply, price fluctuations and too many market
levies. They were also constrained by high transport costs from the supply to demand areas.

Rice retailers were widely available both in rural and urban areas but not organised in business sense. Their selling
points were town markets and at village centres. They operated on individual basis like farmers. In rural areas,
retailers buy paddy or rice from farmers or sometimes from collectors. In urban areas, the main supply of rice to
retailers is from traders. Rice retailers’ constraints were:

a. Limited by capital and storage facilities
b. Lack of market information on the supply side and
c. Frequent fluctuation in supply of rice from large traders of local and imported rice
d. No formal associations or groups registere

**Processors**

Large traders store paddy rice in godowns belonging to the owners of the milling machines and process when they have contacted traders in Dar es Salaam or Tanga, Mwanza, Mbeya and other towns. The owners of milling machines allow collectors and traders to store their paddy for few months with an agreement that they will mill at his/her milling machine. Godowns of millers visited had storage capacities of 100 tons to 300 tons at a time. The cost of milling paddy rice ranged from TSh 50 – 70 per kg of milled rice (equivalent to TS 35 - 49 per kg of rice paddy). There were few processing machines in all zones (2 to 3 milling machines per ward or located in one site due to limitation of electricity power supply). Available milling machines had 12 Tons per day processing capacity. They were normally underutilized due to supply shortage of paddy rice. On average a single rice miller processed only 225 tons of paddy rice per year.

Rice grading: Current rice grades were first (whole grain measuring 0.35mm), two (half cut grains 0.28mm) and third (several cuts measuring 0.24mm). The by-products are the rice husks used as fuel for burning bricks and by breweries. Rice polish is also a by-product used as livestock feed. Challenges faced by processors were:

- Irregular and unreliable supply of paddy rice due to fluctuation in production
- Unreliable markets where due to limited buyers, paddy is sold
- Product price fluctuations. Even with good quality and graded rice traders are not ready to purchase at high price.
- High cost of equipments installation. Machines are old and efficiency low.
- Small working capital caused by inaccessibility to bank loans due to lack of collateral
- High taxes charged by local government
- Inadequate training on processing techniques
- Unskilled labour in machine operation

**Gross margins, net profits and returns to labour**

Table 1 indicates that rice cultivation is both profitable both under irrigation and rain-fed systems. Farmers could improve their profits by increasing rice yields and selling at competitive prices. However, profits obtained under irrigation system were more than threefold that obtained under rain-fed conditions.
Table 1: Gross margins, net profits and returns to labour obtained by rice farmers

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Irrigated system</th>
<th>Rain-fed system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eastern zone - Kilombero</td>
<td>Southern Highlands - Mbarali</td>
</tr>
<tr>
<td>Yield (kg of paddy/ha)</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Price/kg of paddy rice (TSh) June - August 2013</td>
<td>800</td>
<td>760</td>
</tr>
<tr>
<td>TR/ha (TSh)</td>
<td>3,200,000</td>
<td>3,040,000</td>
</tr>
<tr>
<td>Mandays/ha incurred in various farm operations (ploughing, planting, weeding, harvesting, transportation and selling):</td>
<td>185</td>
<td>118</td>
</tr>
<tr>
<td>Cost/ha incurred in different farm operations (ploughing, planting, weeding, harvesting, transportation and selling):</td>
<td>1,616,000</td>
<td>1,802,000</td>
</tr>
<tr>
<td>Profit/ha</td>
<td>1,584,000</td>
<td>1,138,000</td>
</tr>
<tr>
<td>Return to land labour</td>
<td>8,562</td>
<td>6,151</td>
</tr>
</tbody>
</table>

Note: Assumption made is that farmers sell paddy just after harvesting and local buying units converted to price per kg of paddy rice; and yield per hectare.

Marketing margins by actor

A marketing margin measures the share of the final selling price that is captured by a particular actor in the value chain. The marketing margin was calculated by finding the price variations at different segments and then comparing them with the final price to consumers (Table 2). The final consumer price is considered as the base or common denominator for all marketing margins computed. Thus the total gross marketing margin (TGMM) is consumer price less farmer’s price divided by consumer price and expressed as percentage:

\[ \text{TGMM} = \frac{\text{Consumer price} - \text{farmer’s price}}{\text{Consumer price}} \times 100 \]

Producer participation or producer’s gross marketing margin (GMM producer) is the portion of the price paid by the end consumer that belongs to the farmer as a producer (Mendoza, 1995). Therefore, producer’s market share is given by: 100-TGMM. For example, rice bought in Shishiyu or Irienyi and sold after stored to the final consumer in the same markets, farmers’ market share is computed as:

\[ \text{TGMM} = \frac{1700-900}{1700} = 47\% \]

Then, farmers’ participation or farmers’ market share is given by: 100 – 47 = 53%.

Similarly, rice bought in Shishiyu or Irienyi and sold to the final consumer in urban markets of Mwanza is computed as:

\[ \text{TGMM} = \frac{2000-750}{1700} = 63\% \]
Then, farmers’ participation is given by: 100 – 66 = 37%

If the rice producer in Maswa and Rorya sold their rice at TSh 750 per kg as an average price and consumer price was TSh 2000 per kg in Mwanza markets, then the producer’s market share was 37% (Table 2: ). Also, producer’s share or participation is 34% if rice sold to consumers in Dar es Markets. This implies that based on the local rice markets available in Maswa and Irienyi rice producers do get market share which is less than the recommended farmers’ market share of 60 - 70%. Thus, large market share is absorbed by middlemen along the market value chain. Therefore, there is a high need to improve farmers’ share to reach at least 60%. Likewise, farmers’ profits can also be improved by increasing rice productivity and reducing farm operation costs.

Table 2: Example: Gross marketing margins by value chain actor

<table>
<thead>
<tr>
<th>Marketing chain participant</th>
<th>Market share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maswa and Rorya</td>
</tr>
<tr>
<td>TGMM for complete channel (%)</td>
<td>50.0</td>
</tr>
<tr>
<td>GMM for collector (%)</td>
<td>10.0</td>
</tr>
<tr>
<td>GMM for trader (%)</td>
<td>40.0</td>
</tr>
<tr>
<td>GMM for retailer (%)</td>
<td>26.7</td>
</tr>
<tr>
<td>Consumer (only buyer) (US $)</td>
<td>1500</td>
</tr>
<tr>
<td>GMM for Producer participation (%)</td>
<td>50.0</td>
</tr>
</tbody>
</table>

Conclusion and recommendations

Rice crop is considered by farmers as cash crop than stable crop. Rice production was profitable despite of low yields achieved by farmers. However, farmers’ market share was less that 40% against the recommended market share of 60% to 70% of the consumer prices. Rice farmers can effectively participate in value chain in core marketing activities through vertical integration; and involvement of farmers in chain management activities or horizontal integration.

Therefore, the following are suggested for up-grading of the value chain and increase farmers’ competitiveness:

a. Increase productivity (Process upgrading) – Farmers in all sites need training on producing rice in more efficiently using Good Agricultural Practices (GAP). These include use of improved technologies such as improved varieties and fertilizers; water management practices; control of pests attacks and save costs through integrated pest management and improved storage facilities.

b. Functional upgrading or vertical integration – At present, farmers are just mere producer of rice paddy. They have minimal involvement in other marketing activities such as bulking and grading. Therefore, it is recommended that farmers be involved in collecting and bulking rice paddy, grade and selling to traders. Farmers should be informed on the importance of linkages with other actors though value additional activities including bulking, storing, processing, grading and packaging.

c. Strengthening of producer groups or associations–. In order farmers to be fully and effective involved in chain management activities, the pre-condition is that they have to be organised in strong groups or cooperatives to acquire strong bargaining power in marketing decision making.
References


Enhancing the adoption of improved rice technologies along value chain, innovations and good agronomic practices through dissemination, up-scaling and knowledge management (The experience of T&D in Tanzania)

Introduction
Training and dissemination (T&D) sub-component need to have a regional focus and use participatory strategies and mechanisms to train extension staff, farmers in the latest innovations and to scale up application of technologies within the country and to other EAAPP countries. It creates partnership with a range of institutions, both public and private to facilitate the dissemination and adoption of improved technologies. A key element under training and dissemination is the documentation, publication and dissemination of the approaches, processes and outcomes of EAAPP.

The effectiveness of technology transfer is facilitated by the linkage between research, extension and farmers through participatory extension methodologies and communication support. The training and dissemination activities focused on: (i) ensuring increased availability and access of information and improved technologies; (ii) strengthening the capacity of the agricultural advisory service providers and farmers; (iii) strengthening linkages between research, extension and end users (farmers, farmers organizations, private sector actors); and (iv) establishing a regional platform for exchange/share of knowledge and experiences in scaling up agricultural technologies and innovations.

Objectives:
- To disseminate proven rice technologies, relevant information and management practices to farmers in EAAPP countries;
- To improve productivity and increase the area under improved rice varieties;
- To enhance capacity of rice growers to commercialize rice production, agro processing and value addition;
- To promote the agricultural machines and implements (labour saving) to actors along the rice value chain
- To improve knowledge, information management and sharing system

Expected outputs and outcomes
- Increased number of farmers adopting improved rice technologies and management practices;
- Increased area under improved rice seed;
- Increased productivity of rice in selected areas of EAAPP
- Increased use of improved rice seed varieties
- Increased adoption of new handling and processing methods
- Increased stakeholder satisfaction with the technologies, innovations and uptake pathways;
- Increased Regional technology uptake pathways
- Increased capacity of rice growers to commercialize rice production and agro processing
Scope of coverage under rice commodity: Six districts Kilombero, Mvomero, Kyela, Mbarali, Bunda and Sengerema with a total of 18 villages, however other non intervention areas were covered under T&D activities.

**Table 1: Rice intervention village and districts**

<table>
<thead>
<tr>
<th>District</th>
<th>Mbarali</th>
<th>Kyela</th>
<th>Sengerema</th>
<th>Bunda</th>
<th>Kilombero</th>
<th>Mvomero</th>
</tr>
</thead>
<tbody>
<tr>
<td>Villages</td>
<td>Mbuyuni</td>
<td>Mpunguti</td>
<td>Nyakasungwa</td>
<td>Nyatwali</td>
<td>Njage</td>
<td>Komtonga</td>
</tr>
<tr>
<td></td>
<td>Uturo</td>
<td>Lugombo</td>
<td>Kasisa</td>
<td>Mariwanda</td>
<td>Mkula</td>
<td>Mlali</td>
</tr>
<tr>
<td></td>
<td>Ilongo</td>
<td>Kisale</td>
<td>Luchili</td>
<td>Namhula</td>
<td>Michenga</td>
<td>Wami dakawa</td>
</tr>
</tbody>
</table>

**Methodology**

The methods used under T&D vary from country to country depending on the institutional arrangement and extension system. The approach used to disseminate the technologies are entirely based on participatory, client and market oriented with due emphasis to value chains. An exchange of experience on effective extension delivery methods were conducted among countries and within the country, successes and good practices were documented as part of knowledge sharing in this subcomponent. Technologies accepted by farmers were multiplied for further scaling up in the communities and other actors.

The T&D subcomponent under EAAPP was very effective in using a combination of technology dissemination pathways that have proved to be effective and accepted by farmers. A total of 26 dissemination pathways were used of which 12 were both regional and national pathways where EAAPP countries participated or shared.

**Table 2: List of Dissemination pathways used under EAAPP**

<table>
<thead>
<tr>
<th>NO</th>
<th>DISSEMINATION PATHWAY</th>
<th>USED FOR</th>
<th>REGIONAL/NATIONAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inventory of technologies</td>
<td>Identifying of existing technologies for scaling up and sharing</td>
<td>REGIONAL/NATIONAL</td>
</tr>
<tr>
<td></td>
<td>RRCoE web-site <a href="http://www.rails.net/TZ/RRCoE-EAAP">www.rails.net/TZ/RRCoE-EAAP</a></td>
<td>Awareness, sharing and exchanging information</td>
<td>REGIONAL/NATIONAL</td>
</tr>
<tr>
<td></td>
<td>RRCoE communication strategy</td>
<td>Facilitating dissemination, Sharing and exchanging</td>
<td>REGIONAL/NATIONAL</td>
</tr>
<tr>
<td></td>
<td>Technology Out-scaling strategy</td>
<td>Facilitating dissemination, sharing and out-scaling</td>
<td>NATIONAL</td>
</tr>
<tr>
<td></td>
<td>Radio programmes</td>
<td>Creating awareness, imparting knowledge and skills</td>
<td>NATIONAL</td>
</tr>
<tr>
<td></td>
<td>TV programs/video conferencing (video clips)</td>
<td>Creating awareness and sharing</td>
<td>NATIONAL/REGIONAL</td>
</tr>
<tr>
<td></td>
<td>Publications (training manuals, brochure, leaflets, books, fliers)</td>
<td>Sharing and imparting skills and knowledge</td>
<td>REGIONAL/NATIONAL</td>
</tr>
<tr>
<td></td>
<td>Farmer-to-farmer extension approach</td>
<td>Imparting knowledge and skills to be able to train other farmers</td>
<td>NATIONAL</td>
</tr>
<tr>
<td></td>
<td>Study tours/ exchange visits</td>
<td>Exposing to new technologies and experiences for sharing</td>
<td>REGIONAL/NATIONAL</td>
</tr>
<tr>
<td></td>
<td>Cinema shows/ Mass campaigns</td>
<td>Creating awareness and sharing</td>
<td>NATIONAL</td>
</tr>
</tbody>
</table>
### Innovation stakeholder platforms
- Linking stakeholders along value chain for sharing and exchanging knowledge

### Farmer Field Schools
- Practical experiences gaining knowledge and skills for adoption of technologies

### e-extension
- Facilitate accessing/sharing agriculture information

### Mobile phones
- Accessing market information

### Demonstration plots
- Gaining knowledge and skills for adoption of new or improved technologies

### Farmer field days
- Exposure, sharing and exchange of knowledge and new technologies

### Documentation of best bet practices and success stories
- Awareness and sharing

### Regional T&D planning meetings
- Planning, sharing and exchange

### Agricultural shows
- Creating awareness and sharing technologies

### Rice exhibitions
- Creating awareness and sharing technologies

### Capacity building of various stakeholders
- To impart knowledge and skills for training and adoption

### Partnerships/agreement with private services providers (Nuru Inforcom, Local Radios, etc)
- Facilitating dissemination of information/technologies

### Building capacity of training centres (Mkindo, FEU)
- Facilitating technology dissemination, accessibility of information, impart knowledge and skills

### Focus group approach - Youth sensitization
- Creating awareness, sensitization, imparting knowledge and skills in agriculture

### Retooling WARCs
- Facilitate accessibility of information through ICT, impart knowledge & skills

### VCA - Processor groups
- Imparting agribusiness skills

### Implementation status

For efficiency and effectiveness of implementation the initial activities were; (i) Take inventory of available technologies on rice recommended in Tanzania so that they could be disseminated and be used by farmers and other stakeholders along value chain; and (ii) to carry out a needs assessment among rice farmers and extension staff that led to development of training programme and dissemination strategies.
Inventory of Technologies

Inventory of 17 rice technologies was done from various sites in the country which included rice technologies and good agricultural practices (GAPs) of rice along the value chain. The sites were research stations of Kilombero Agricultural Training and Research Institute (KATRIN) Dakawa, Mkindo Farmers Training Centre, Agricultural Training Institutes of Kilimanjaro Agricultural Training Centre (KATC) and MATI Igurusi. Also inventories were carried out in farmers’ fields in irrigation schemes of Mkindo, Dakawa, Hembeti (Mvomero district, Morogoro region), Mbarali, (Mbarali district, Mbeya region) and Mwamapuli (Igunga district, Tabora Region). Other schemes included Lower Moshi (Moshi district, Kilimanjaro region), Mombo (Korogwe district, Tanga region) and Ruvu (Bagamoyo district, Coast region). The inventory also was done in rain fed rice systems at Bumva village, Segese ward, Kahama district. Other documentation sites included Igunga Rice Mills, DAD Rice Mills (Agrocom Kahama Ltd) and Bertha Masele Kinungu also of Kahama.

Some of technologies on rice by that time included TXD 306 (SARO 5) early maturity and high yielding with average of 4 - 6.5 t/ha, rice seed preparation techniques involving separation of unfilled grains from filled grains using salt water (Plate 1a), wet nursery bed (Plate 1b) for raising seedlings and rice bunds (Plate 1c).

Plate 1a, b, and c

**Plate 1 a: Seed sorting techniques, Plate 1 b: Wet nursery preparation Plate 1 c: Rice bunds**

Other practices include pudding, field levelling, fertilizer application, row transplanting, the use of push weeders and use of herbicides as mechanism for weed control, water management and timely harvesting and threshing. Also in some areas the high rice processing techniques were practiced such as cleaning, destoning, dehusking, polishing and grading machines.

Production of Training Manuals

Two training manuals of rice (GAP, Post- production and agribusiness skills) were developed as a guide to facilitate training for extension staff and farmers. About 200 draft copies of the training manuals were distributed and used during training of training of trainers (ToT). RRCoe Communication strategy, Regional Rice Centre o Excellence (RRCoe) website and a Technology out-scaling strategy for rice were developed to fast track dissemination of improved rice technologies.

Improved technologies and relevant information disseminated:

- GAPs for rice – seed selection to harvesting
- improved varieties e.g. SARO5, (early maturing, tolerant to pests and diseases)
sustainable use of soil and water management
Environment/Climate change issues e.g. SRI,
Promoting Labour saving technologies- e.g. push weeders, leveling board, rice transplanter
Value chain (post harvest and processing technologies),
Agribusiness and entrepreneur skills,
input and output markets,
production of seed - QDS,
rice residues for vegetable production
loan/credit,
group dynamics and conflict resolutions.

Achievements

Training of Trainers (Farmers and Extension staff)

A total of 1,699 rice farmers (846 M; 853 F) and extension staff 353 (258 M; 95 F) participated in ToT. The aim was to have competent farmers and extension staffs who are capable to train other farmers on GAPs, sustainable use of soil and water management, input and output markets, value chain, agribusiness and group dynamics. More than 5,000 farmers have been trained by their fellow farmer trainers.

<table>
<thead>
<tr>
<th>Type of Training</th>
<th>Farmers</th>
<th>Extension staff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Male</td>
<td>Female</td>
</tr>
<tr>
<td>Good Agric practices (GAPs) for ToT</td>
<td>743 378</td>
<td>365</td>
</tr>
<tr>
<td>Value Chain and Agribusiness Training for ToT</td>
<td>956 468</td>
<td>488</td>
</tr>
<tr>
<td>Total ToT</td>
<td>1,699 846</td>
<td>853</td>
</tr>
</tbody>
</table>

The trained farmers managed to train their fellow farmers as seen below.

Capacity building of stakeholders

Capacity building of various stakeholders along the rice value chain was done and 538 extension staff and 16,829 farmers including youth (9,664 M and 7,165 F). EAAPP contribution is provision of training through farmer field schools (FFS) and demonstration of GAPs which in turn resulted to increased production and household income. The Training sessions on improved rice technologies along value chain were conducted using various dissemination pathways.

Demonstration plots/FFS and field days

Demonstration plots are important tools in dissemination of new technologies and addressing the productivity challenges and gaps identified by Farmers and Extension staffs during ToT trainings. They are among methods which strengthen the linkages between research, farmers and extension staff. The inventorised/identified improved technologies and the documented best bet technologies and practices on rice commodity under EAAPP were demonstrated. These demonstration plots were conducted together with field days during several stages of pre and post harvest activities for rice.
A total of 141 rice demonstration plots were established where 1,426 farmers participated in the training (665 F; 761 M). Also, 166 FFS on rice were established where about 4,500 farmers participated.

**Establishment of Farmer Processor Groups**

The majority of farmers’ produce in our country are marketed in raw form with little or no value addition. Therefore, agro-processing provides an opportunity for increasing incomes and creating jobs along the value chain through expansion of forward and backward linkages in the economy. Establishment of processor groups aimed at equipping participants with agribusiness skills that involves profit margin analysis, farm budget, handling and managing of internal and external commodity markets, obtaining business license/permits and use of mobile phones in obtaining agriculture information especially market information. Also, the training aimed at linking farmers/processors with other service providers such as NMB, SIDO, RUDI, MUVI & MVIWATA that can assist with provision of loans, mobilizing farmer groups, processing and trading of commodity products. A total of 326 rice farmers (159 M; 167 F) and 93 extension staff (67 M; 26 F) participated in these training.

Seven rice processor groups have been formed and strengthened in agribusiness and one advanced to the extent of grading and packaging and labeling (for example, branding: *Mchele Safi wa CHAURU*).

**Field Days**

One major field day were conducted in 2013 at Nyatwali village Bunda district for rice farmers where various stakeholders 287 (91 F; 196 M) participated including district leaders, farmers from neighboring villages, researchers and extension staff. During the field day, the farmers in the intervention village and from neighboring villages, extension staff, researchers, leaders and other stakeholders have an opportunity to learn and share experiences on the practices and management of the demonstrated agricultural technologies on successes in use of System for Rice Intensification, (SRI).

**Study Tour and Exchange visits**

Study tours allow farmers to meet with their fellow farmers to exchange knowledge and experience on GAPs, processing and market related issues in rice production. A total of five study tours were conducted at regional and national levels where researchers, extension staff and farmers including platform members
were able to share and exchange experiences along rice commodity value chain; running platforms and in operating Agriculture centres (Kenya).

Two study tours in Kenya involved seven MAFC staff, five farmers and four extension staff from Bunda, Kyela, Mbarali, Mvomero and Kilombero who visited Mwea irrigation scheme (Kenya), Agriculture Training Centres and Kenya Agricultural Livestock Research Organisation (KALRO). The study tour in Kenya resulted into rehabilitation of Mkindo FTC and retooling some of the WARCs (to serve as Agriculture Training Centres in Kenya. Also our farmers gained experiences in value addition and started grading and packing.

Three in country study tour involved 24 farmers and 12 extension staff from Mvomero, Bunda and Sengerema visited Mwamapuli and Nyatwali Irrigation scheme; 48 farmers and 12 extension staff from Luchili, Kisasa, Nyakasugwa, Kisangwa, Kiroreli, Nsalala, Nyinda and Chela visited Nyinda Irrigation scheme; and 30 platform members of which 25 were farmers (15M; 10F) from the five districts of Sengerema, Kyela, Mbarali, Mvomero and Kilombero visited well organised platforms of Mang’ula Collective Rice Marketing and Tanga Dairy. The aim of the study visit was to learn and share experiences on how to operate and run the platform profitably and how to solicit funds for platform issues. At Mang’ula they visited Crop Bank system, VICOBA and Processing and grading Machine. At Tanga Dairy they visited Milk collection primary societies and Tanga dairy fresh Industry. Also they visited three dairy stakeholders’ stations and shared experiences in importance of shareholding.

Promoting fabrication and use of labour saving farm implements
During different training sessions, farmers were sensitized and exposed to different labour saving farm implements which among them were fabricated by their fellow farmers. For example weeding in rice fields was mainly done by women using hand hoes but after introduction of labour saving machines, men also can weed their farms.

Training on e-extension
Training on e-extension was conducted in collaboration with Sokoine University of Agriculture to facilitate extension staff and farmers to access agricultural information including market information. A total of 28 extension staff and 39 farmers (26 M; 13F) who have some basics of computer from Kilosa, Kilombero, Mvomero, Kyela, Mbarali, Sengerema, Bunda, Mkalam and Lushoto districts participated. Some of the extension staff came from WARCs of Sagamaganga (Kilombero DC); Igawa and Mdoele (Mbarali DC); Nyamapande (Sengerema DC); Mwangoi and Lushoto (Lushoto DC); Katumbasongwe, Kajunjumele and Ikama (Kyela DC); Gumanga and Mwanga (Mkalam DC). The participants created e-group eextensionmoro2015 to facilitate information sharing.

Enforcement of extension guidelines
Currently, the extension services in Tanzania are being provided by both public and private sector, therefore there is need to set standards that will guide the agricultural sector in the provision of extension services. A total of 25 technical staff from public and private sector reviewed the current extension guidelines and recommended that all agriculture service providers to adhere to extension guidelines and these recommendations be incorporated in the model by-laws at the Local Government (district councils). The MAFC will facilitate coordination and collaboration among various extension service providers and develop extension services legal framework.
Sensitization of Youth to engage in agriculture

Youth in Tanzania provide an opportunity for increasing economic development through their involvement in agriculture which is main activity in rural areas. A total of 538 youths from six regions were sensitized to engage in commercial agriculture particularly rice production.

Stakeholder Platforms

The stakeholders’ platforms provide common forums and partnerships that serve to ensure that rice production and development activities that are planned develop into appropriate, sustainable, well monitored community-based sub-projects. The outcomes are to contribute to improvements in paddy productivity, enhance household food security and improved incomes of stakeholders.

Platforms were formed in five intervention districts of Sengerema, Kyela, Mbarali, Mvomero Kilombero and other six rice producing districts of Magu, Kwimba, Bukombe, Kahama and Igunga. Sengerema, Kyela, Mbarali, Mvomero and Kilombero. The Platforms formed at Igunga and Kilombero districts have managed to open bank accounts for platform issues and Kyela platform participated in District Agriculture Development Plans preparation. Also one information platform was formed (using mobile phones to access market information through ‘One2Two network’ where farmers receive weekly market prices through NURU Infocom.

The district stakeholder platforms contributed to the formation of a National Platform for rice commodity where 76 rice stakeholders participated in a meeting from 4th -5th December 2012. The aim of the meeting was first to identify all key stakeholders along the value chain; second share challenges and opportunities in the rice sub-sector for improving the rice production and productivity and third to form a National Platform for the rice commodity. During the meeting different topics were presented and members formed the National platform and elected committee members to spearhead platform issues.

Mass Media

Mass media extension approach is designed to disseminate agricultural information, technologies and innovations in a wide coverage of project intervention areas and outside. More than 50,000 farmers received sensitization training and information on different technologies through radio/TV programmes, cinema shows, agricultural exhibitions (regional and national), stakeholder’s platforms meetings and publications.
Energetic and motivated youth from Komtonga irrigation scheme

(i) Radio and TV programmes

Airing 82 radio programs (29 TBC, 53 private FM radios) and 12 TV programmes including a Video episode about introduction of RRCoE (*Ijue Taasisi Mahiri ya zao la Mpunga*). Twelve video clips on rice were developed and also shown during cinema shows (*Kupembua Mbegu; Kanuni za Kilimo Bora cha Mpunga; Kilimo Shadidi cha Mpunga; Mafanikio ya Kilimo cha Mpunga (Bahi); Mradi Mahiri wa Zao la Mpunga – Mashamba ya Miano; Umuhimu wa Kusawazisha Majaruba; Matumizi Bora ya Maji; Kuandaa Kitalu; Maonyesho ya Mpunga; Kupandikiza Mpunga kwa Nafası Sahihi; Matumizi ya Mbolea za Kupandia na Kukuzia and Mafanikio ya Skimu ya Nyatwali – Part 1, II and III;*

(ii) Booklets and leaflets

Two titles of booklets one being *Kilimo bora cha mpunga wa mabondeni* and the second *Visumbufu vya zao la mpunga na udhibiti wake* were developed and distributed. Two titles of leaflets were developed one *Kilimo bora cha mpunga* and *Matumizi Sahihi ya Mbolea za Viwandani*. RRCoE Magazines- two issues were produced.

(iii) Agricultural shows/Exhibitions

The exhibition and symposium were conducted in the region to share knowledge and experiences of increasing production and productivity of EAAPP commodities. T&D conducted a Rice exhibition in June 2012 at Mnazi Mmoja grounds Dar es Salaam where a total of 2,960 stakeholders from public and private sector including Government Leaders, EAAPP staff from the four countries, processors, agro-dealers, machinery companies, researchers, farmers and extension staff along commodity value chain participated. Different technologies and rice products were displayed and sold during the event.
Some displays from private sector during rice exhibition

Also organized a first joint regional exhibition ‘Nane Nane’ at Nzuguni Dodoma in August 2013 (Tanzania, Kenya and Uganda) and a Second joint regional exhibitions Nairobi international trade fair Sept-Oct 2014 where technologies and products of the four commodities were displayed and sold.

Table 4: Exhibits from Regional Rice Center of Excellence – Tanzania for Nairobi International Trade Fair

<table>
<thead>
<tr>
<th>Item/exhibit</th>
<th>Commodity</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poster /Banners</td>
<td>Rice</td>
<td>6 titles</td>
</tr>
<tr>
<td></td>
<td>Cassava</td>
<td>2 Titles</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>1 Titles</td>
</tr>
<tr>
<td></td>
<td>Dairy</td>
<td>3 Titles</td>
</tr>
<tr>
<td></td>
<td>T&amp;D</td>
<td>3 titles</td>
</tr>
<tr>
<td></td>
<td>Seed Dissemination(ASA)</td>
<td>2 titles</td>
</tr>
<tr>
<td></td>
<td>Seed Certification(TOSCI)</td>
<td>3 titles</td>
</tr>
<tr>
<td>Samples of varieties</td>
<td>Rice</td>
<td>11 (5 upland, 6 lowland)</td>
</tr>
<tr>
<td></td>
<td>Wheat</td>
<td>8</td>
</tr>
<tr>
<td>Dairy Products - From dairy farmer</td>
<td>Cheese-Mozzerella, Provollane, Asiago, Tallegio, Ricota, Spreade, Yorghut</td>
<td></td>
</tr>
<tr>
<td>Extension Materials:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Leaflets</td>
<td>5 Titles</td>
</tr>
<tr>
<td></td>
<td>Brochures</td>
<td>3 Titles</td>
</tr>
<tr>
<td></td>
<td>DVD Documentaries</td>
<td>2 Titles</td>
</tr>
<tr>
<td></td>
<td>Booklet(Kilimo Bora cha Mpunga wa Mabondeni)</td>
<td>1 Titles</td>
</tr>
<tr>
<td></td>
<td>Inventory of technologies</td>
<td>1 rice, 1 wheat</td>
</tr>
<tr>
<td>Products from farmers/processors</td>
<td>DOFRA Trading Co. Ltd- Rice – Variety Kalamata of Different packages sizes/grades (I&amp;II)</td>
<td>25KG &amp; 1KG Packs (127kg total)</td>
</tr>
<tr>
<td></td>
<td>Rice from Dakawa farmer (Mr. Nassib Katoto) variety T&amp;D 306 (SARO 5) in grades(I, II, III)</td>
<td>40 kgs available</td>
</tr>
<tr>
<td></td>
<td>Rachel Group Ltd (processor from Mbeya)-Rice varieties: SUPA and SARO 5 Brown Rice and white (polished) rice By products (rice bran) Packed in 1, 2, 5, 10 and 20kg available for sale-all sold (150kg in total) Kamsamba rice was highly preferred by many people)</td>
<td></td>
</tr>
</tbody>
</table>

Rehabilitation of Mkindo FTC and Retooling WARCs

Mkindo Farmer Training Centre (FTC) was rehabilitated so as to attain a regional status to accommodate more rice farmers from within and outside the country. Also five Ward Agricultural Resource Centers (WARCs) of Kajujumele- Kyela, Kiberege-Kilombero, Sadani- Mufindi, Mampanta - Iramba, and Msanzi- Kalambo each one was provided with 3 office chairs, 3 office tables, 3 visitors’ chairs and 3 office cabinet facilities. ICT tools will be provided later (computer) to facilitate accessibility of agricultural information. These will facilitate dissemination of improved technologies and information at ward level. A total of 31,640 farmers
(18,218 M, 13, 430 F) participated on various aspects such as crop husbandry, livestock management and fish farming on these WARCs. This year the plan is to retool ten WARCs.

**Fostering partnership with private sector**

The training and dissemination sub component managed to foster partnerships with a range of stakeholders, both public and private (Researchers, LGAs, NMB, SIDO-MUVI, MIT, Oxfam, RUDI, MVIWATA, NURU Infocom, MIVARF, RUBADA, FM Local Radios, Weights and Measures Agency) to support and facilitate fast-tracking the dissemination of improved and new technologies and other relevant agricultural information. Also acquisition of loans/credit and strengthening farmer groups/association.

**T&D key results/outcomes**

EAAPP contribution is provision of training through demonstration of GAPs which in turn resulted into increased production and household income. Follow up activities were conducted in all EAAPP implementing districts for rice commodities involving village leaders, participating and non participating farmers, research, extension staff at Ministerial and Local levels. A lot of achievements and success stories were identified.

**Excelling farmer to farmer approach**

Trained farmers continued to train their fellow farmers for example one farmer from Wami Dakawa village - Morogoro (Mr. Katoto) have managed to train other 27 farmers on rice; another Nyakasungwa group of 25 farmers trained other 120 farmers and Kasisa group of 11 farmers trained 68 farmers.

**Increased production and income**

Farmers have gained knowledge and apply the improved GAP and therefore have increased production in irrigation schemes from the average production of 2.5ton/h to 6.5ton/h.

**For example:**

- **Nyatwali Irrigation scheme**: Rice farmers in Nyatwali Irrigation scheme comprise of 60 men and 49 women, before EAAPP intervention they harvested less than 9 bags of paddy per acre and majority were fishermen. Two years of EAAPP, they are converted to rice farmers and managed to increase production to 25 – 40 bags per acre as a result of using SARO 5, good management practices and out of them 19 farmers practice SRI. From the knowledge gained they trained other farmers from Maugu district and Southern Highlands.

- **Mariwanda Irrigation scheme**: Five farmers and one extension staff from Mariwanda participated in ToT and in a Farmer’s field day at Nyatwali and two of them had a study visit. They visited Mwapamulawi irrigation. The farmers...
together with their extension staff (Mr. Anthony Bujiku) managed to establish 0.8ha FFS and harvested 83 bags each having approximately 80kgs. After such big harvest, they managed to cultivate 46 acres of rice jointly.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Intervention District</th>
<th>Before EAAPP (T/ha)</th>
<th>2014 Season (T/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SARO 5</td>
<td>Sengerema</td>
<td>1.6</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>Bunda</td>
<td>2.0</td>
<td>8.5</td>
</tr>
</tbody>
</table>

**Agribusiness and Rice Processing skills (value addition)**

Nyinda irrigation scheme in Shinyanga DC has 308 farmers (M 200; 108 F) whom they got several training sessions under EAAPP. With knowledge gained and under facilitation of RUDI and LGA through DADPs managed to construct a warehouse, purchased milling and weighing machines and a moisture meter. Because of their success, EAAPP also facilitated exchange visit for 48 farmers and 12 extension staff from eight irrigation schemes to visit Nyinda Irrigation scheme to learn and share experiences in rice value chain.

**Farmer empowerment and improved livelihoods**

Farmers have managed to pay fees for their children, build modern houses, food security; farm and transport facilities. Also other farmer groups have constructed a warehouse, purchase milling machines.

- Farmers from Wami Dakawa irrigation scheme have formed a group led by Mr. Nassib Katoto and managed to acquire loan of 129 million Tshs. from financial institutions (CRDB Bank) for rice production. They managed to repay the loan and this year they have managed to secure another loan of 187 million Tshs. from the same bank.
- Mr. Malongo Mashimo Outshines: A Distinction Award in Agric. Cert. goes to Nyatwali rice farmer at Uyole Agriculture Training College for a certificate course in 2012/13 after being trained and sensitized by EAAPP (T&D)

**Emerging CBOs/SACCOS:**

Farmers have managed to establish strong SACCOS for example Nyatwali and Nyakasungwa farmers, and also Victoria SACCOS in Kasisa (Sengerema) with 53 rice farmers (20 F; 33 M) have established their own SACCOS by now they have a capital of 1.8m. Another farmer group from Wami Dakawa under Nasib Katoto have registered community-based organization known as Jikwamue Group.

**Production of QDS by Smallholder farmers**

Wami Dakawa Farmers under Nasib Katoto after getting several training under EAAPP, managed to get contract with TANSEED to produce 112 ton of rice Certified Seed. After consultation with Managing Director (MD) TANSEED, the office said the group is excellent and they complied with the standards on production of certified seed. Below is the Experience of TANSEED by the MD TANSEED.

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Mr. Malongo Mashimo (centre) during training sessions in 2011/2012 under EAAPP.
Smallholder Farmers’ Certified Rice Seed Production in Morogoro: The Experience of TANSEED International Ltd, Tanzania

TANSEED International Ltd is a private seed company engaged in quality seed production and marketing of crop varieties, provision of private agricultural extension services and other market support services in Tanzania. TANSEED is the first private seed company to engage in certified rice seed production in Tanzania 5 years ago. The company innovatively contracts smallholder rice farmers to produce certified rice seed class also certifies rice production with smallholder farmers is desirable approach for generating incomes and creating farm jobs in rural settings, and at the same time creating seed demand, and facilitating greater farmer-to-farmer knowledge transfer and exchanges.

In 2013, TANSEED received financial support from USAID FiF NAFAKA project for production of certified rice seed variety TXD 306 with smallholder rice farmers in Morogoro. The company innovatively contracted 56 smallholder rice seed growers to produce 250,000kg certified rice seed on 193 acres. This is first ever certified rice seed produced by contracting smallholder rice seed growers in Tanzania. A total of 238,172kg certified rice seed out of planned 250,000kg were produced, an achievement of 95%. This was a tremendous result from TANSEED/USAID NAFAKA PPP in smallholder farmers’ certified rice seed production in Tanzania.

The seed production fields were subjected to rigorous field inspections and passed as certified seed by the Tanzania Official Seed certification Institute (TOSCI) after attaining high quality standards of 99.5 – 99.8% purity and 84 – 91 pure seed germination. It is evident from this project that smallholder rice farmers can be good certified rice seed growers and contracted to produce certified rice seed, when properly trained and closely supervised in all critical stages of rice seed production.

The availability of certified rice seed improved access to quality rice seed by smallholder farmers, which in turn provided direct and immediate impact on agricultural productivity and livelihood of rice farm families. The production of 238,172kg certified rice seed earned Smallholder farmers rice seed growers an income totalling 119,289 US$for poverty alleviation. The availability of 238,172kg certified rice seed directly benefited nearly 23, 817 smallholder rice farm households with potential to produce nearly 47,634mt of rice grain for household food security and surplus for income generation.

TANSEED contract certified rice production with Morogoro smallholder farmers rice farmers continued through 2014 and 2015 production seasons and has been benefiting smallholder farmers rice seed growers, or smallholder farmers rice grain produces and also other key rice value chain actors.
Examples of intermediate outcomes

Annex 1

<table>
<thead>
<tr>
<th>S/N</th>
<th>SCHEME NAME</th>
<th>YIELDS USING LOCAL TECHNOLOGIES KGS/acre</th>
<th>YIELDS USING IMPROVED TECHNOLOGIES KGS/acre</th>
<th>INCREASED INCOME IN TANZANIAN SHILLINGS PER ACRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Momba (Kyela District)</td>
<td>900</td>
<td>3,150</td>
<td>1,552,500</td>
</tr>
<tr>
<td>2</td>
<td>Mpunguti (Kyela District)</td>
<td>750</td>
<td>3,000</td>
<td>1,552,500</td>
</tr>
<tr>
<td>3</td>
<td>Lugambo (Kyela District)</td>
<td>750</td>
<td>3,000</td>
<td>1,552,500</td>
</tr>
<tr>
<td>4</td>
<td>Kajunjumele (Kyela District)</td>
<td>900</td>
<td>3,300</td>
<td>2,760,000</td>
</tr>
<tr>
<td>5</td>
<td>Makwale (Kyela District)</td>
<td>600</td>
<td>1,800</td>
<td>1,794,000</td>
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<tr>
<td>6</td>
<td>Mbuyuni (Mbarali District)</td>
<td>1,200</td>
<td>2,640</td>
<td>993,600</td>
</tr>
<tr>
<td>7</td>
<td>Msomyanga</td>
<td>1200</td>
<td>2,400</td>
<td>828,000</td>
</tr>
<tr>
<td>8</td>
<td>Ilaji (Ilongo)</td>
<td>900</td>
<td>3,300</td>
<td>2,760,000</td>
</tr>
<tr>
<td>9</td>
<td>Igalako</td>
<td>1,050</td>
<td>2,700</td>
<td>1,138,500</td>
</tr>
</tbody>
</table>

Annex 2

<table>
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<tr>
<th>S/N</th>
<th>SCHEME NAME</th>
<th>YIELDS USING LOCAL TECHNOLOGIES KGS/acre</th>
<th>YIELDS USING IMPROVED TECHNOLOGIES KGS/acre</th>
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<tr>
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<td>Lugambo (Kyela District)</td>
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<td>3,000</td>
<td>1,552,500</td>
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<td>Kajunjumele (Kyela District)</td>
<td>900</td>
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<td>1,200</td>
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<td>Ilaji (Ilongo)</td>
<td>900</td>
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<td>Igalako</td>
<td>1,050</td>
<td>2,700</td>
<td>1,138,500</td>
</tr>
</tbody>
</table>

Problem statement

A total of nine villages were participating in EAAPP project in Mbeya region. The involved villages were Kamsamba, Mpunguti, Kajunjumele, Makwale, Lugombo, Mbuyuni, Msomyanga, Ilongo and Igalako villages. The following constraints established during the baseline survey were; unavailability of rice improved seed, negative attitudes towards use of inorganic fertilizer in rice farms, inadequate knowledge on herbicides and insecticides application, inadequate extension services, farmers felt that the use of proper spacing in rice production is tedious regardless its advantages in terms of yields, use of mixed seed varieties, inadequate use of rice proper agronomical practices, pests and diseases attack, untimely planting, weeding and harvesting, poor post harvesting handling and high rice breakage 18 to 30%.
Mr. Shabani Mbisha of Orongadida village in Babati district, once had barely enough food to sustain himself and his family. Now with an improved NERICA-7 rice variety obtained through EAAPP-supported project, he has enough for home consumption and for sale.

The EAAPP project introduced improved seeds such as TXD 306 (SARO 5), Komboka, Tai, Supa and NERICA varieties for farmers and processors to select the best varieties which will be able to compete for the targeted market. The farmers and processors selected SARO 5, Supa and Komboka for improving market.

The project also introduced best agronomical practices through Farmers Field School (FFS) and demonstrations. The disseminated technologies were proper land preparation using oxen, power tillers and tractor. Proper utilization of herbicides such as pre-emergency and post emergency, application of fertilizers such as basal and top dressing fertilizers and use of System for Rice Intensification (SRI).

Through use of improved technologies the participating farmers gained knowledge in rice production and post harvest handling. The production average increased from 600kg per acre to 3,300 kgs per acre this is equivalent to increase in income from 828,000/=TAS or (487 USD) 2,760,000/= TAS or (1,623 USD) per acre.

The farm operations such as ploughing, transplanting, weeding and threshing mandays are highly reduced something which gives opportunities to farmers to get time for resting or performing other activities. But also this attracts farmers to increase rice production area and also to attract other farmers to be engaged in rice production. The average time for ploughing one acre by hand hoe is normally 4.4 mandays (1 manday = six hours) while using oxen or power tiller is only 0.16 to 0.2 Mandays to accomplish the work. In case of transplanting for one acre it takes 8.5 mandays, by using transplanter you can transplant the same in 0.37 Mandays. Hand weeding normally takes 9.9 mandays per acre while herbicide application takes only 0.18 mandays per acre. Also the farmers indicated threshing of one acre by hand it takes 4 mandays but if you use a motorized thresher it takes only 0.18 Mandays per acre.

Annex 2

Volume 05

Issue No. 03

February 2015

Raphael Group Company Limited increasing number of rice contract farmers from 3,000 last season to 6,500 in the 2014/2015 crop season due to increased rice market

Problem statement

Market for Tanzanian rice for the last decade is decreasing due to many reasons. The main reason is plating mixed varieties in the same plot. During baseline survey it was observed that in a plot of one acre you can find five to seven different rice varieties this situation will never give an opportunity for processor to brand the intended rice product. But also it is quite difficult to find a good market for mixed rice varieties. Another constraint was high rice breakage percentage which was above 15% while the markets allow only 8% of rice breakage. Selection of rice varieties by farmers were not market oriented. It is crucial to select rice varieties that can compete to the market; therefore in order to fetch market first of all we have to know what market needs in order to identify the rice varieties to be grown for specific market. Increased production per unit area (productivity) is very important in order to have reasonable price to last consumer. Most beneficiaries in rice business in Tanzania are middle men compared to farmers and a processor, to abolish this link between farmers and processors is extremely important.
Farmers from six irrigation schemes in Mbeya region participating on rice processing and variety selection at Raphael Group Company Limited in the effort to improve rice quality and marketing.

Through EAAPP project ASA introduced improved seeds such as TXD 306 (SARO 5), Komboka, Tai, Supa and Nerica varieties to processors and farmers to select best varieties to market. Training of farmers supervised by processor and service providers to ensure good agronomical practices for increased production per unit area, proper post harvest handling for improving rice quality and finally to increase income to farmers and processor. Contract farming was introduced to ensure direct market to the farmers but also for processor to have good quality of rice that can be easily marketed.

In year one a total of 100 farmers were involved for demonstrations. The involved farmers were from Kamsamba, Madibira, Ilongo, Mbuyuni, Ghana and Kilasiro villages. Due to vivid impact to farmers and other stakeholder now the consortium already in place whereby Processor, researcher, seed company, fertilizer company, farmers, local government and Kilimo trust CARI-TZ are joining the initiatives. Up to last season a total of 3,000 farmers were involved in contract farming and for the coming season a total of 6,500 farmers will be contracted by Raphael Group Company Limited (RGCL) to produce rice.

Annex 4

Volume 05  Issue No. 05  February 2015

Promotion of rice machines and implements in EAAPP; Participating farmers improved access to labour saving animal traction and walking tractor powered machinery. The case of Kyela and Mbarali Districts, Mbeya Region.

Problem statement

To increase rice crop yield and area under cultivation through improved access to labor saving animal traction and walking tractor powered machinery for smallholder farmers.

Testing and promotion of rice machines and implements for labour saving was carried out in all project villages of Mbarali (Ilongo, Igalako, Nsonyanga, Uturo, Chamoto, Motombaya and Mbuyuni) and Kyela (Mpunugut, Lugombo, Kapwili, Tenende and Kisle) for on-farm demonstration trials and two on-station trials for the respective districts. The project reached 228 farmers in those project areas through on-farm trials and individual farmer fields. The activities included land preparation, puddling and harrowing, rice sowing and transplanting, weeding, field visit tour and data collection.

Rice Mechanization

<table>
<thead>
<tr>
<th>S/N</th>
<th>Ploughing</th>
<th>Mandays/Acre</th>
<th>Puddling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power Tiller</td>
<td>0.85</td>
<td>1.2 hrs</td>
</tr>
<tr>
<td>2</td>
<td>Oxen</td>
<td>1.1</td>
<td>1.01 days</td>
</tr>
<tr>
<td>3</td>
<td>Hand Hoe</td>
<td>2.82</td>
<td>4.368 = 4.4</td>
</tr>
</tbody>
</table>

Rice mechanization using Power tiller has shown to save labour using 0.85 mandays/acre compared to Oxen which use 1.1mandays/acre and 2.82mandays/acre when done by Hand hoe.
Transplanting

<table>
<thead>
<tr>
<th>Sn.</th>
<th>Direct Seeder/Transplanter</th>
<th>Direct Seeding – Kyela Mandays / acre</th>
<th>Transplanting – Mbarali</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power Tiller</td>
<td>0.34</td>
<td>0.6 hrs ≈ 3.6 hrs</td>
</tr>
<tr>
<td>2</td>
<td>Oxen</td>
<td>8.48</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Hand Hoe</td>
<td>8.47</td>
<td>5.0 md</td>
</tr>
</tbody>
</table>

Transplanting using motorized transplanter has shown to save labour using 1.5 mandays/ha compared to hand transplanting which use 12.5 mandays/ha (1 manday = 6 hours of work). Thresher uses 2.8 mandays/ha compared to 9.1 when done by hand.

Weeding

<table>
<thead>
<tr>
<th>S/N</th>
<th>Treatment</th>
<th>Mandays/Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Herbicides</td>
<td>0.19</td>
</tr>
<tr>
<td>2</td>
<td>Manual weeders</td>
<td>4.06 - 4.1</td>
</tr>
<tr>
<td>3</td>
<td>Hand</td>
<td>9.9</td>
</tr>
</tbody>
</table>

Demonstration of herbicides efficiency on weed control was done on 7 individual farmer plots where by Tiller Gold and Sollito indicated to perform better than 2,4D as post emergence herbicides.

Threshing

<table>
<thead>
<tr>
<th>S/N</th>
<th>Ploughing</th>
<th>Mandays/Acre</th>
<th>Yield/Acre (Acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motorized Thresher</td>
<td>1.1</td>
<td>1,200kgs/acre</td>
</tr>
<tr>
<td>2</td>
<td>Oxen</td>
<td>1.22</td>
<td>1,310kgs</td>
</tr>
<tr>
<td>3</td>
<td>Hand Hoe</td>
<td>3.64</td>
<td>1,380kgs</td>
</tr>
</tbody>
</table>

Demonstration of threshing using motorized thresher in Mbarali. Motorized rice thresher was compared with hand threshing where by rice thresher indicated to save labor far better than hand threshing. The thresher besides threshing, it performs winnowing at the same time.
Improving standard of living by building new house through EAAPP intervention: a case study of Ms. Rozalia Elias of Nyakasungwa village Sengerema district, Tanzania

Ms. Rozalia Elias 35 years a rice farmer from Nyakasungwa village Sengerema district, before EAAPP was harvesting 500kg of rice from 0.75 of an acre. After attending trainings on good agricultural practices in 2011 she managed to improve agricultural practices in her land field of 0.75 an acre in 2012 and harvested 1.5 tones. After selling paddy she started to construct a new house by using burnt bricks. In the following season 2013/2014 she cultivated 1 acre and managed to harvest 2.4 tones and continued with construction and she was able to buy timber for roofing and after reaching at this stage she decided to sell cattle and buy iron sheet to roof her house. The house is at finishing stage and she is planning to complete in the coming season 2014/2015 by using fund she is expecting to get from paddy cultivation see picture below.

Increasing house hold income by diversification of enterprise through EAAPP intervention: a case of Mr. Abel J. Mafuso from Nyakasungwa village Sengerema district

Mr. Abel J. Mafuso a rice farmer from Nyakasungwa Village Sengerema district was able to access loan of Tsh. 300,000 from Victoria SACCOS to add on his capital for cultivation of rice farm. He was able to cultivate 3.5 acres and harvest 5.4 tones after repaying the loan he constructed the chicken house and started the new enterprise of chicken rearing and by now has a flock of 70 chickens (picture below).

Training on good agricultural practices through EAAPP intervations improved production,productivity and household income: Mohamed Dadi Ase of Mkula irrigation scheme Kilombero district

The TXD 306 (SARO 5) which was developed at KATRIN-Ifakara and released in 2002, is the widely used improved variety for the last 12 years. It has high yield potential compared to local varieties; thus, farmers in the visited areas prefer it mostly. The TXD 306 potentially gives an average yield of 7 t/ha under good
agricultural practices conditions. Its adoption rate in irrigation schemes as observed through the farmers interviewed during the visit is estimated to be 99%. Mkula irrigation scheme used to produce 2 to 2.7 tons per hectare before EAAPP interventions. During the EAAPP implementation, farmers started to adhere to good agronomic practices, utilize effectively the knowledge acquired in training and use appropriately the improved varieties; consequently, the yield increased to 5-9 t/ha. The positive results of EAAPP interventions are visible to other irrigation schemes in Morogoro region. At Komtonga irrigation scheme, Mvomero district, the yield has increased from 1.7 - 4.6 to 7.4-9.7 t/ha.

**Kilombero: Mkula Irrigation Scheme**

Mr. Mohamed Dadi a rice farmer from Mkula irrigation scheme received training on good agricultural practices (water management, irrigation techniques and the use of fertilizers) in rice production at Igurusi Agricultural Training Institute. Before training he was producing 4 bags per acre, after receiving training production increased from 25 – 40 bags of 80kg acre. He was able to construct a new modern house from the income generated from rice cultivation.

**Youth farmers transformed by EAAPP interventions: case study of Komtonga irrigation scheme at Mvomero district**

There are young motivated farmers; transformed by EAAPP interventions which improved rice productivity in the scheme hence increased their incomes and standard of living. Most of the farmers interviewed own mobile telephone sets, some have started to build modern houses; they can manage to pay school fees and other materials for their children. Happiness on their faces is an indication of their improved livelihoods. More than 105 farmers adopted new technologies from lead farmers (farmer to farmer technology adoption).
Mr. and Mrs. Mohamed Dadi standing in front of their new house

Energetic and motivated youth from Komtonga irrigation scheme

Discussion Session

Question: - What type of manure did you use and did you involve soil scientists? Result is strong on use of technology, did you use a local check and how many farmers were involved?
Answer: -On manure – the innovation was there and cassava production was not good but with the manure it improved

Question: - How would you manage knowledge management with small farmers who manage more than one enterprise and engage with many external dealers like stockists, extension etc
Answer: No response

Question: - The lack of fertilizers before EAAPP what is about? Policies improvement? Issue of fertilizers was a matter of understanding and intervened to encourage the small farmers to use it
Answer: -Issue of fertilizers was a matter of understanding and intervened to encourage the small farmers to use it
Success Stories in Rice research and development

A testimony by Zawadi Kanuti of Komatonga, Tanzania on the benefits of rice research

The project started in Komtonga in November 2012 with training in both theory and practical on good agricultural practices for rice production.

The farmers received training in the following areas;
- Seed sorting to remove un-filled grain using salt and water
- Wet nursery preparation
- Land preparation and banding
- Rice transplanting in rows with spacing of 20 cm x 20 cm
- Efficiency use of water for irrigation using System of rice intensification (SRI)
- Weed control using push weeder and herbicides
- Proper use of fertilizer based on research recommendation
- The stages of growth for rice plant and proper management for each stage Proper harvesting techniques;
- Value addition and marketing of rice
- Group formation and its importance
Farmers’ Demonstrations

Land preparation and Planting

Weeding of rice

Weeding of rice
Achievements

1. Increased productivity from 5 bags (375 kg)/acre to 30 bags (2,250 kg)/acre
2. Increased income that has enabled the farmer to educate her children
3. Paid medical bills
4. Purchased a piece of land for rice expansion (1 acre)
5. Construction of a new permanent residential house
6. Purchase of new items such as bicycles, radio and mobile phones
7. Established a brick making business

Conclusion

She concluded that farmers were full of praise for the project having benefitted them tremendously. The project has uplifted the lives of fellow farmers and hence they hope for Phase II. The farmer thanked EAAPP, the Tanzanian government and the Agricultural officers.
Pesticide Application Techniques and Guidelines on Environmental and Social Safeguard (ESS) - Guidelines on Pesticide Application Techniques and Safety

Mr. Yeraswork Yilma

Introduction

When using pesticides the prime objective is to distribute the correct dose to a defined target with the minimum of wastage due to drift using the most appropriate spraying equipment. Pesticides only give acceptable field results if they are delivered precisely and precisely. Unlike other field operations, the results from poor spraying may not become apparent for some time so that it is essential that those involved in pesticide selection and use are fully aware of their responsibilities and obligations, and are trained in pesticide use and application.

This manual is prepared to improve the safety and efficiency of pesticides within systems of sustainable agriculture and integrated pest management (IPM). It offers practical help and guidance to all those involved in using pesticides for agricultural crops production. It covers the main terrestrial spray application equipment such as knapsack sprayers and air assisted sprayers using hydraulic spray nozzles. It is also designed to provide supportive information and practical advice on acceptable safe practices once a decision has been taken to use a pesticide.

It is aimed to assist district level agricultural development officers and development agents at village level. This guideline covers a lot of issues which are relevant to application of pesticides using any ground based field crop sprayers, including operator carried and tree and bush crop sprayers. It is also prepared to offer practical help and guidance to all those involved in using pesticides.

Pest management

Pest management options

a. Biological Control: deliberate use of natural enemies;
b. Cultural Control: use of management practices that make up the environment less favorable to pest reproduction, dispersal, survival, etc…;
c. Physical or Mechanical Control: measures taken to destroy pests. They are specifically taken to control pests;
d. Chemical Control: use of synthetic pesticides for the control purpose as a last resort;
e. Integrated Pest Management (IPM): use of combined management options;
Integrated Pest Management (IPM)

The approach entails careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.

Pesticides are used to control various pest groups such as insects, disease causing organisms, weeds, rats, birds, mice, and mosquitoes.

Pesticides are chemicals that we use to control undesirable organisms that are harmful to us. Some of these organisms, or “pests,” eat our crops, while others spread diseases. Weeds can be considered a pest for just growing in the wrong places. Pests include insects, weeds, and disease causing organisms like fungi, bacteria, virus and other microorganisms, nematodes and other organisms that affect normal development of plants. Insecticides, herbicides, defoliants, desiccants, fungicides, nematicides, avicides, and rodenticides are some of the many kinds of pesticides.

Pesticide classification

Chemical composition:
- Organic pesticides.
- Inorganic pesticides

Chemical compounds:
- Organochlorines (=chlorinated hydrocarbons):
- Organophosphates:
- Carbamates.
- Pyrethrum

Insecticides containing pyrethrins are neurotoxic to nearly all insects. They are harmful to fish, but are far less toxic to mammals and birds than many synthetic insecticides and are non-persistent, breaking down easily on exposure to light. They are considered to be amongst the safest insecticides for use around food.

- Pyrethroids - are synthetically produced molecules that are chemically similar to pyrethrins. Pyrethroids are not persistent and break down quickly in sunlight, and are rarely present after just a few days. The mode of action of pyrethroids is the same as that of pyrethrins.

- Biorationals (biorational pesticides or biopesticides) - are a group of pesticides that are considered relatively non-toxic to humans and are also environmentally safe.

- Microbial pesticides kill arthropods either by toxins released by microbial organisms, or by infection by the organisms.)
Target Pest type and Pesticide Function

The most common pesticide classification is by the type of pest against which they are directed or the way the pesticide functions. Each is meant to be effective against specific pests. Some examples types include:

- Insecticides to control insects.
- Herbicides to control or inhibit the growth of unwanted plants, also known as weeds.
- Fungicides to control fungal problems like molds, mildew, and rust.
- Bactericides to control bacteria.
- Rodenticides to control rodents like mice, rats, and gophers.
- Miticides/Acaricides to control mites.
- Nematodes to control nematodes.
- Avicides to control birds.

Formulation types

- Emulsifiable Concentrates (EC): these chemicals consist of concentrated oil solutions of technical grade pesticides combined with an emulsifier added to permit further mixing with water.
- Wettable Powders (WP or W): these dispersible powders are finely ground, dry powders consisting of active pesticide ingredients mixed with other ingredients to aid in mixing and dispersion.
- Soluble Powder (SP): these powders are similar to wettable powders, except that the active ingredient, as well as the diluents and all formulating ingredients are completely soluble in water. Uses of soluble powders are similar to those of wettable powders.
- Dusts (D): pesticides formulated as dusts are finely ground mixtures of active ingredient and a carrier material. Dust formulations are intended for direct application without further mixing.
- Granules (G): in a granulated formulation, the active ingredient is mixed with various inert clays to form particles of various sizes. Granules used in vector control operations are usually from 20 to 80 meshes in size.
- Fumigants: volatile chemicals stored as liquids under pressure, or incorporated into a solid form with clay which releases toxic gas when combined with water vapor. Fumigants are used in stored products and structural pest control.
- Baits: contain active ingredients that are mixed with a pest food or attractant. Principal uses include control of household pests such as ants, mice, rats, roaches, and flies; they are used outdoors to control birds, ants, slugs, snails, and agricultural pests such as crickets and grasshoppers.
- Aerosols: pressurized cans which contain a small amount of pesticide that is driven through a small nozzle under pressure from an inert gas. Organisms that may be killed using aerosols include weeds, flies, for a variety of greenhouse pests, and in structural pest control.
- Water-Soluble Concentrate (WS): these liquid formulations form true solutions in water and require no agitation once mixed.
- Ultra Low Volume Concentrates (ULV): Ultra Low Volume (ULV) concentrates are sold as technical product in its original liquid form, or solid product dissolved in a small amount of solvent. They are applied using special ground or aerial equipment that produces a fine spray at very low application rates.

Toxicity level

Toxicity of a pesticide is usually measured in milligrams of active ingredient for each kilogram of body
weight (i.e. parts per million) of the test organism. This is measured as the dose required to kill 50 percent of a sample of test animals in a specified time (often 24 hours) and is referred to as the LD50 dose. The World Health Organization (WHO) has classified commercially available pesticides into five classes according to the LD50 data for solid and liquid formulations (Table 1).

Table 1: The Five classes of pesticides based on level of toxicity

<table>
<thead>
<tr>
<th>Class</th>
<th>Hazard level</th>
<th>Oral toxicity LD50 (mg/kg)</th>
<th>Dermal toxicity LD50 (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Solids</td>
<td>Liquids</td>
</tr>
<tr>
<td>I (1a)</td>
<td>Extremely hazardous</td>
<td>&lt; 5</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>I (1b)</td>
<td>Highly hazardous</td>
<td>5 – 50</td>
<td>20 – 200</td>
</tr>
<tr>
<td>II</td>
<td>Moderately hazardous</td>
<td>50 - 500</td>
<td>200 - 2000</td>
</tr>
<tr>
<td>III</td>
<td>Slightly hazardous</td>
<td>500 - 5000</td>
<td>2000 - 20000</td>
</tr>
<tr>
<td>IV</td>
<td>Not likely hazardous</td>
<td>&gt; 5000</td>
<td>&gt; 20000</td>
</tr>
</tbody>
</table>

Pesticide Label

The product label is usually the first reference for guidance on handling the formulated pesticide products.

Registered pesticides

In many countries legislation is in place to control and regulate the manufacture, importation, distribution and sale of pesticides. Pesticides should be registered for use, after local field evaluation for safety and efficiency and only approved and recommended products can be used. List of registered pesticides; Insecticides, Herbicides, Fungicides and Other pesticides are made available in the respective countries.

Pesticide Application

Pesticide application techniques

There are a variety of techniques for the application of pesticides depending upon the type of pesticide, type of formulation, type of target and its size. The main purpose of all techniques of pesticide applications is to cover a target area or space with a uniform cover of the pesticide so that there will be good contact between the pest and the pesticide. The main types of pesticide application techniques include:

1. Spraying: the application of (using sprayers) known volume of minute particles of liquids containing a pesticide to a designated target area, with a regular and even spread of droplets.
2. Dusting: the process of spreading dust formulated pesticides (i.e. compound absorbed on or impregnated into an inert solid carrier (dust and granules)) using duster or granule applicator.
3. Seed dressing: coating (either dry or wet) of protectant pesticide applied to seeds before planting.
4. Fumigation: the application of pesticides in volatile form i.e. burning a fumigant compound to create a pesticidal smoke which will penetrate all parts of a more or less enclosed space (e.g., in dense orchard, a glass house, packed soil).
5. Bait treatment: the application of carrier (foodstuff) mixed with a poison (toxicant) attractant and additive to control pests.
6. Drenching: the application of a liquid spray to an area/soil until the area is completely soaked.
Most techniques involve equipment, to save labor and time and to ensure efficient application. Essential features in pesticide application are:

- Proper training of the operator applying the pesticide
- Safety of the operator applying the pesticide, other people and the environment
- Choice of the correct pesticide, appropriate formulation and appropriate equipment.
- Application of the correct dosage
- Uniformity of application
- Proper usage and maintenance of equipment

**Volume of spray to use**

The quantity of liquid used to apply pesticide is called volume of spray. The total amount of spray liquid needed to give an efficient coverage of the target area can physically be determined by the size of droplets produced by the machine, the total of the collecting surface to be protected and the density of coverage required to control the pest.

The coverage of leaf area is a more complex factor to assess in pest control than the coverage of ground area. The required amount of spray can be affected by the type and growth stage of the crop. Seedling crops require lower volume than fully grown crops.

**Droplet distribution and coverage**

The size of spray droplets are measured in micrometers (1µm = 0.001mm). Pesticide sprays are generally classified according to droplet size (Table 2)

<table>
<thead>
<tr>
<th>Droplet Diameter, µm</th>
<th>Droplet Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50</td>
<td>Aerosol</td>
</tr>
<tr>
<td>51-100</td>
<td>Mist</td>
</tr>
<tr>
<td>101-200</td>
<td>Fine spray</td>
</tr>
<tr>
<td>201-400</td>
<td>Medium Spray</td>
</tr>
<tr>
<td>&gt;400</td>
<td>Coarse Spray</td>
</tr>
</tbody>
</table>

a. Aerosol sprayers are used principally for drift spraying against flying insects.
b. Mist sprays are ideal for treating foliage with very low volume or ultra low volume rates of application.
c. Medium and coarse sprays are required for herbicide application.

**Pesticide application equipment**

**Hydraulic knapsack sprayers**

Hydraulic knapsack sprayers have long been standard equipment for applying pesticides as they are still the most versatile and widely used small sprayers available to farmers and plantation owners.
They have the following advantages.

a. Suitable for general spraying on small farms
b. Ideal for spot treatment on larger farms
c. They are successfully used in all cases where the use of large equipment is not feasible.
d. They are versatile; i.e. depending on the fittings herbicide, insecticides, fungicides or other pesticides can be applied.
e. They are relatively inexpensive and are simple to operate and maintain.
f. They can be carried on the spray-man’s back and have a capacity of up to 20.1t.

**Types**

There are two main types of hydraulic sprayers’ compression and lever-operated knapsack sprayers.

**Compression Knapsack Sprayer**

In compression (or pneumatic) sprayers the tank acts as a pressure reservoir and can vary between 3 and 20 liters in capacity.

**Lever Operated Knapsack Sprayer**

These are generally more common than compression sprayers and they consist of metal or plastic tank fitted with a lever to operate a pumping mechanism and a hose and spray lance fitted with an on-off trigger.

**Nozzle selection**

Nozzles are devices that determine the flow rate, droplet size, and discharge pattern of a pesticide application. Nozzles are mounted in various ways, usually at the ends of wands or along spray booms. Main types of nozzles include cone nozzle, fan nozzle and deflector nozzle.

**Calibration for knapsack sprayers**

Calibration is the measurement and adjustment of pesticide application equipment to apply a pesticide formulation at a desired application rate.

The principal factors for accurate application using knapsack sprayers are as follows:

1. Dilution of the concentrate: - the strength of the concentrate needs to be known and the quantities of concentrate and water calculated for dilution. Dilution should be careful and there should be no risk of the active ingredient settling out in the spray tank or in the bulk container of spray mixture.
2. Flow rate i.e. the volume of liquid delivered by the sprayer per minute. This will depend upon the pressure in the sprayer and the type of nozzle.
3. Swath width, this depends upon the type of nozzle and its distance from the target. If this distance is short the swath will be narrow and there will be more pesticide per square meter of target than in a wide swath.
4. Walking speed, obviously if the operator walks quickly then the amount of pesticide delivered per square meter of target will be less than that from a slow walking speed.
5. Pumping rate - in lever operated sprayers the pumping rate, i.e. number of lever strokes per minute,
is critical. If the rate is too slow the pressure will be low and the delivery rate will be low; the droplet size might also be too large. If the rate is too high energy will wasted. The pumping rate must be uniform to ensure constant delivery.

There are two calibration methods that can be used for either compression or lever operated sprayers. These are as follows.

**Method**

1. _Determine swath width_: fill the sprayer partly with water and attach the appropriate nozzle. Select a dry target area, e.g. wall or ground; holding the nozzle at the correct distance spray it whilst walking at a suitable speed for about 5m; the swath should show as a uniform dark band. Measure the width of this band in a few places to check on uniformity and calculate the average swath width in meters.

2. _Determine walking speed_: mark out a line at least 100m long and put a stake at each end. Start spraying and walk at a comfortable speed along the line while spraying correctly. Measure the distance walked in exactly one minute. Repeat the operation and calculate the average walking speed in meters per minute (m/min). For most spraying a speed of about 1m/sec. is used.

3. _Determine sprayer output_: pump the sprayer using steady strokes and collect the spray in a dry bucket, or other container, for exactly one minute; measure the water collected in the bucket. Repeat the operation and calculate the average output in liters per minute (l/min).

4. _Cleaning and maintenance of sprayers and storage_: After work, the spray equipment should be washed both internally and externally in the field and the rinse liquid sprayed onto a crop on which the product is registered, making sure that the recommended dose rate is not exceeded by repeatedly spraying the same area. Personnel protective equipment must also be fully decontaminated after use, dried, and then stored in a well-ventilated store.

5. _Spray equipment storage_: Spray equipment should be dried before storage.

**Motorized knapsack sprayers**

Motorized knapsack sprayers were designed to reduce manual effort and to speed up application. They are portable and easy to use and some models can be quickly converted from liquid sprayers to dust blowers. Instead of forcing liquid through a hydraulic nozzle, as in lever operated sprayers, they use an air blast to break liquid up into droplets and then disperse them as a spray. They can project spray much further than a lever operated sprayer and are of value in spraying trees etc.

A motorized knapsack sprayer comprises three sub-units (figure 1).

1. A frame,
2. A petrol engine,
3. A pesticide reservoir,

**Spinning Disc Sprayers**

These light weight sprayers produce droplets centrifugal force from a high-speed rotating disc. Very strong ultra low volume formulations which do not require dilution with water are applied by this type of sprayer.
Ultra Low Volume (ULV) Applicator

Controlled droplet application (CDA) can be achieved by this sprayer by applying the correct size of droplets for a given target.

**Pesticide handling: transport and storage**

If improperly used, pesticides can poison people, pets and livestock. They also can damage beneficial insects, birds, fish and other wildlife; harm desirable plants; and they may contaminate soil and groundwater. It is necessary to maintain careful and continuous control over the use and handling of these chemicals during the transport, storage, mixing, loading, application and disposal.

**Storing Pesticides**

It is necessary and legally required that pesticides be stored in a safe, secure and well-identified place. Here are some rules which pertain to pesticide storage:

- Always store pesticides in their original, labeled container with the label clearly visible.
- Always store pesticides in tightly sealed containers and check containers periodically for leakage, corrosion breaks, tears, etc.
- Always store pesticides where they are protected from freezing or excessive heat.
- Always be certain that pesticide storage areas are well-ventilated to prevent the accumulation of toxic fumes.
- Always store different types of pesticides in different areas, to prevent cross contamination and the possibility of applying a product inadvertently.
- Never store pesticides in old bottles or food containers where they could be mistaken for food or drink for humans or animals.
- Never store pesticides near food, feed, or seed.

Requirements for Pesticide Storage
- Locking doors
- Adequate lighting
- Adequate ventilation
- Fire extinguishers readily available
- Spill containment design or equipment
- Warning placards if Category I or II pesticides are stored – including emergency contact information
- Personal protective equipment readily available
- Wash water and eye wash stations available

Toxicity of Pesticides
Pesticides are poisons and vary greatly in the toxicity and hazard they represent to humans and domestic animals.

Toxicity and Hazard
Toxicity refers to inherent poisonous potency of a material. Its toxicity is evaluated in toxicology laboratories and is always expressed in quantitative terms such as LC50 (lethal concentration-50, the concentration at which a material will kill 50% of some reference organism. Hazard, on the other hand, depends not only on the toxicity of a material, but also on the risk of toxic exposure when used.

Toxicity levels/classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Hazard level</th>
<th>Oral toxicity LD50 (mg/kg)</th>
<th>Dermal toxicity LD50 (mg/kg)</th>
<th>Signal words</th>
<th>Symbols</th>
<th>Color code</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Extremely hazardous</td>
<td>&lt; 5</td>
<td>&lt; 20</td>
<td>Toxic</td>
<td>Cross bone</td>
<td>Red</td>
</tr>
<tr>
<td>Ia</td>
<td>Highly hazardous</td>
<td>5 - 50</td>
<td>20 - 200</td>
<td></td>
<td>Cross bone</td>
<td>Red</td>
</tr>
<tr>
<td>Ib</td>
<td>Moderately hazardous</td>
<td>50 - 500</td>
<td>200 - 2000</td>
<td>Harmful</td>
<td>X</td>
<td>Yellow</td>
</tr>
<tr>
<td>II</td>
<td>Slightly hazardous</td>
<td>500 - 5000</td>
<td>2000 - 20000</td>
<td>Caution</td>
<td></td>
<td>Blue</td>
</tr>
<tr>
<td>III</td>
<td>Not likely hazardous</td>
<td>&gt; 5000</td>
<td>&gt; 20000</td>
<td></td>
<td></td>
<td>Green</td>
</tr>
</tbody>
</table>

Note: The terms “solids” and “liquids” refer to the physical state of the active ingredient being classified.
Pesticide poisoning to human beings

The signs and symptoms of acute pesticide poisoning are well known. Symptoms are what a person feels and can express to others. Signs are things one person can observe in another person, even if that person is unconscious. Pain and nausea are symptoms. Redness of skin, swelling, and hot, dry skin are signs. You should learn and be alert to the signs and symptoms of the early stages of poisoning. If any sign of poisoning develops, you should immediately and completely remove the source of exposure. By doing so, you may prevent additional exposure and minimize injury. Early recognition of the signs and symptoms of pesticide poisoning, and immediate and complete removal of the source of exposure may save a person’s life. This is especially critical if the person is unconscious, or otherwise unable to communicate clearly.

Dermal exposure represents the most common hazard. Avoiding exposure by using Personal Protective Equipment (PPE) and by paying attention to personal hygiene by washing exposed parts of the body after work and before eating, smoking and toileting will minimize risk. Personnel Protective equipment must be comfortable to wear/use and be made of material, which will prevent penetration of the pesticide.

A complete set of Personal Protective Equipment (PPE)

First aid treatment for pesticide poisoning

It is essential that pesticide poisoning incidents be recognized immediately, because prompt treatment may mean the difference between life and death. General instructions as a first aid for pesticide poisoning

1. Stop the exposure immediately by separating the victim and the pesticide source.
2. If the victim is unconscious, check to see if the victim is breathing. If not, give artificial respiration. If highly toxic material is present in the victims’ mouth or respiratory path, use chest compression, not mouth-to-mouth.
3. Decontaminate the victim immediately by washing off any skin residues of pesticide, and remove any contaminated clothing. Speed is absolutely essential in this step.

After the victim has been fully cared for and professional help has been sought, these additional steps should be taken. As with the first aid procedures, due consideration must be given to your safety and those around you.

1. Bring the label to provide to the physician or poison control center. You should also save the pesticide container and any remaining pesticide should an official request to see it
2. Eliminate the source of the contamination to prevent or reduce the risk that others may be exposed to the pesticide. In the case of a significant pesticide spill, this will have to be done by professionals trained to respond to these kinds of emergencies.
3. Decontaminate any clothing or equipment as needed. Never put on clothing previously contaminated with pesticide, and always wash contaminated clothing by itself with detergent and water.

Below are some of the more common instructions to consider depending on the poisoning. Poison in Eyes: Hold eyelids open; wash eyes immediately with a gentle stream of clean running water. Use large amounts of water. Delay of only a few seconds can greatly increase the extent of injury. Continue
washing for 15 minutes or more. Do not use chemicals or drugs in the wash water. They may increase the extent of injury.

Inhaled Poisons: If victim is in an enclosed space, do not attempt a rescue without proper respiratory equipment. Call for emergency help. Prevent chilling (wrap patient in blanket but don’t overheat). Keep patient as quiet as possible. If patient is convulsing, watch his or her breathing and protect the patient from falling and striking his or her head on the floor or wall. Keep the patient’s chin up so air passage will remain free for breathing.

**Minimum personal protective equipment (devices) required for pesticide application**
Swallowed poisons

Call for emergency help immediately. If a non-corrosive substance has been swallowed, label directions, or medical personnel from a Poison Control Center may direct you to induce vomiting. If vomiting is to be induced, place the blunt end of a spoon (not the handle), or your finger, at the back of the patients’ throat; or use an emetic of two tablespoons of salt in a glass of warm water. When retching and vomiting begin, place patient face down with head lowered, thus preventing vomit from entering the lungs and causing further damage. Do not let patient lie on back.

Never induce vomiting unless directed by the pesticide label, MSDS, or a medical professional to do so. Do not induce vomiting if:

- Patient is unconscious or experiencing convulsions.
- Patient has swallowed petroleum products (kerosene, gasoline, lighter fluid, etc.).
- Patient has swallowed a corrosive poison (strong acid or alkaline products).

Chemical burns of skin

Remove contaminated clothing. Wash with large quantities of running water. Immediately cover with loosely applied clean cloth (any kind will do). Avoid use of ointments, greases, powders, and other drugs. Treat shock by keeping patient flat, warm, and reassured until the arrival of a doctor.

Minimizing pesticide impact on the environment

Container and washings disposal

At the end of an application, a significant amount of pesticide spray mixture is left in the sprayer.

1. Flush clean water through the equipment and sprayed out in the field, however it should be noted that legislation in some countries restricts the disposal of these washings which will contain an unknown quantity of pesticide
2. Rinse pesticide container three times by adding sufficient clean water to fill the container to about 20-25% of its capacity, replace the lid securely and shake the contents vigorously so that all inside surfaces, including the lid, are cleaned; the contents are then poured into the spray tank and the container allowed to drain for at least 30 seconds before the process is repeated at least twice until the container is visually clean

Clean and well drained containers should be punctured and buried in a deep pit (at least 1.5 m in depth), avoid sandy sites and heavy clay or other areas liable to cracking, well away from any river or stream to avoid pollution of water supplies. The pit must be covered with at least 0.5 m of soil. Clean, rinsed empty agro-chemical containers, plus outer packaging and related materials, should preferably be delivered to a licensed incinerator or to an approved landfill site. However in situations where no approved or licensed facilities exist, on-farm disposal is a possible solution. Options for this in order of priority are, (a). On-farm burning using a hot fire or (b).On-farm burial: it is essential that any method adopted does not conflict with any relevant local laws and regulations.
Protecting surface water and groundwater

Both surface water, visible bodies of water such as lakes, rivers, and oceans and groundwater: water beneath the earth’s surface, are subject to contamination by point and non-point source pollution. When a pollutant enters the water from a specific source, it is called point source pollution. For example, a factory that discharges chemicals into a river is a point source. Non-point source pollution refers to pollution from a generalized area or weather event, such as land runoff, precipitation, acid rain, or percolation rather than from discharge at a single location.

Keeping pesticides out of groundwater and surface water

A pesticide that has not become a gas (volatilized), absorbed by plants, bound to soil, or broken down can potentially migrate through the soil to groundwater. Groundwater movement is slow and difficult to predict. Substances entering groundwater in one location may turn up years later somewhere else. A difficulty in dealing with groundwater contaminants is discovering the pollution source when the problem is occurring underground, out of sight. Also, microbial and photo degradation (by sunlight) do not occur deep underground, so pesticides that reach groundwater break down very slowly.

The following are certain practices that reduce the potential for pesticide contamination of groundwater and surface water:

1. Use integrated pest management. Minimize pesticide use by utilizing other pest management practices to reduce or eliminate pesticide use.
2. Consider the geology of your area when locating wells, mix/load sites, or equipment washing sites. Be aware of the water table depth and how fast water moves in the geological layers between the soil surface and the groundwater.
3. Select pesticides carefully. Choose pesticides that are not likely to leach (move downward) in the soil into groundwater or run off into surface water. Pesticides that are very water soluble and not easily bound to soil tend to be the most likely to leach. Read pesticide labels carefully, consult pesticide application guidelines, and/or seek advice from crop protection specialist.
4. Follow pesticide label directions. Container and supplemental pesticide labels are the law. Labels provide crucial information about application rates, timing, and placement of the pesticide. Consult all labels before using the pesticide.
5. Calibrate accurately. Calibrate equipment carefully and often to avoid over- or under-application.
6. Measure accurately. Carefully measure concentrates before placing them into the spray tank. Do not “add a little extra” to ensure that the pesticide will do a better job.
7. Avoid back-siphoning (this is applicable only to tractor mounted sprayers). Make sure the end of the fill hose remains above the water level in the spray tank at all times. This prevents back-siphoning of the pesticide into the water supply. Use an anti-backflow device when siphoning water directly from a well, pond, or stream. Do not leave your spray tank unattended.
8. Consider weather conditions. If you suspect heavy rain will occur, delay applying pesticides.
9. Mix on an impervious pad. Mix and load pesticides on an approved impervious mix/load pad where spills can be contained and cleaned up. If mixing in the field, change the location of the mixing area regularly. A portable mix/load pad is required if you fill at the same location ten or more times per year.
10. Dispose of wastes and containers properly. All pesticide wastes must be disposed of in accordance...
with the environmental regulation laws. Triple-rinse containers. Pour the rinse water into the spray tank for use in treating the labeled site or crop. After triple rinsing, perforate the container so it cannot be reused/dispose of them in a landfill. Dispose of all paper containers in a landfill or in a municipal waste incinerator. Burning does not allow for complete combustion of most pesticides, resulting in pesticide movement into the air.

11. Store pesticides safely and away from water sources. Pesticide storage facilities should be situated away from wells, cisterns, springs, and other water sources. Pesticides must be stored in a locked facility that will protect them from temperature extremes, high humidity, and direct sunlight. The storage facility should be heated, dry, and well ventilated. It should be designed for easy containment and cleanup of pesticide spills and made of materials that will not absorb any pesticide that leaks out of a container. Store only pesticides in such a facility, and always store them in their original containers.

Protecting non-target organisms

Pesticides kill bees and other pollinating insects. To reduce the chance of bee poisoning:

1. Select the least hazardous pesticide formulation for bees. Dusts are more hazardous to bees than sprays. Wettable powders are more hazardous than emulsifiable concentrates (EC) or water-soluble formulations. Micro-encapsulated pesticides are extremely dangerous to bees because the very small capsules can be carried back to the hive. Granular insecticides are generally the least hazardous to bees.

2. Do not apply pesticides that are toxic to bees if the site contains a blooming crop or weed. Remove the blooms by mowing before spraying.

3. Minimize spray drift by selecting appropriate nozzles, adding an adjuvant, or postponing the application to a less windy time.

4. Time pesticide applications carefully. Evening applications are less hazardous than early morning ones; both are safer than midday applications.

5. Do not treat near beehives. Bees may need to be moved or covered before you use pesticides near hives.

- The best way to avoid injury to beneficial insects and microorganisms is to minimize the use of pesticides. Use selective pesticides when possible. Apply pesticides only when necessary and as part of an integrated pest management program.

- Pesticides can also be harmful to vertebrates such as fish and wildlife. Fish kills may result when a pesticide (usually an insecticide) pollutes water or changes the pH of the water. Pesticides may enter water via drift, surface runoff, soil erosion, and leaching. Pesticides may result in bird kills if birds ingest granules, baits, or treated seed; are exposed directly to the spray; drink and use contaminated water; or feed on pesticide-contaminated prey.

Notifying neighbors

Good public relations are extremely important when applying pesticides. It is the joint responsibility of landowner and applicator to see that neighboring landowners are not subjected to acts of trespass or exposed to spray drift. As a matter of courtesy, it is a good idea to inform adjacent landowners, neighbors, and beekeepers in advance of any large-scale pesticide application. If off-target pesticide drift is expected, it is necessary to develop drift management plan (it is a written plan prepared by pesticide applicator whenever there is a chance of a spray application drifting from the target onto non-target and off-site sensitive areas). A drift management plan should contain:
1. A map of all areas (locations) where pesticide applications occur
2. A list of pesticide sensitive sites located near an application area for example includes schools, markets and sensitive crops.
3. Pesticide label and mandated restrictions that relate to setback provisions from sensitive areas.
4. Information for persons in sensitive areas regarding the type of pesticide used, the method of application, and the applicator’s plan to minimize pesticide drift.

**Indicators of Environmental and Social safeguards (ESS)**

1. Type of pesticide in use as per registration by toxicity level
2. Intensity of pesticide use by farmers
3. Number of individuals have got acute symptoms (Abdominal pain, dizziness, headaches, and nausea, vomiting, skin and eye irritations) due to fungicide application
4. Number people died due to pesticide application
5. Number of individuals hospitalized in association with pesticide applications
6. Number of pesticide empty containers at the hands of farmers
7. Type and number of facilities suitable for pesticide storage
8. Number of farmers or other workers using protective equipments
9. Number of farmers cleaning protective equipment after fungicide handling
10. Distance of pesticide storage places from streams, drinking water, fish ponds
11. Number of farmers washing hands and face after handling (transportation, storage, load and mix, application and disposal) but before eating, drinking and smoking or going to toilet
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Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA)
Plot 5, Mpigi Road,
P. O. Box 765, Entebbe (Uganda)
Tel: +256 414 320 212/320 556/321 885
Fax: +256 414 321 126/322 593
Email: asareca@asareca.org
Website: www.asareca.org