DRENCH EFFECT OF ORTHOSILICIC ACID ON DROUGHT STRESS TOLERANCE ON MORPHOLOGICAL AND PHENOTYPIC TRAITS OF SORGHUM (Sorghum bicolor L. Moench) LANDRACES

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ABSTRACT

Drought stress is one of the most important abiotic factors that limit Sorghum (Sorghum bicolor L. Moench) production. The objective of this study was to ameliorate the effects of the application of orthosilicic acid on morphological parameters in sorghum landraces. A potted experiment was conducted under a controlled environment in Kitui County Kenya (01°21’48.0” N - 037°81’08.7” E) in the years 2020 and 2022 to evaluate sorghum landraces Machakos Local brown, Kitui rasta, and Kitui Local brown in a Completely Randomized Design (CRD)- in a 2 x 3 factorial arrangement with six treatments in 1-Si, high H2O, 1-Si, medium H2O, 1-Si, low H2O, 0-Si, medium H2O, 0-Si, low H2O and 0-Si, optimal H2O. In this study, a high phenotypic coefficient of variation was observed among the five traits. High heritability of 94.24%, 96%, and 98.3% was observed for plant height, and 46%, 43.08%, and 35% were observed for yield as well as a high genetic advance over mean (GAM) for final plant height 26%, 37.48%, 37.5% in the three landraces Machakos Local Brown, Kitui rasta and Kitui Local Brown respectively. A high water use efficiency (WUE) in landrace Kitui local brown a differential in the mean of observed 0.085 under silicon treatment and 0.06 under no silicon application were observed, which denotes 25% in differential values, a high grain yield, and a harvest index of 60% and 0.82, respectively was also noted in the landrace. The study showed that the composite application of Si and H2O in sorghum is key in improving the studied traits.

Keywords: PCV-Phenotypic coefficient of variation, Heritability and water use efficiency.

INTRODUCTION

Prevailing drought stress is one of the most important abiotic factors that reduce the production of Sorghum (Sorghum bicolor L.) worldwide. Sorghum is among the main cereal crops consumed globally and is mainly grown in arid and semi-arid regions owing to its ability to tolerate drought (Younis et al., 2007). In some parts of the developed world, sorghum is mainly grown as a fodder crop while in less developed countries, it is mainly processed into flour and consumed as fermented porridge (Muui et al., 2013). In Kenya, it is mainly grown in Eastern, Nyanza, Western, and Coastal regions (Ngugi et al., 2013). Sorghum cultivation in Kenya and the rest of Sub-Saharan Africa is dependent on erratic rainfall, resulting in decreased crop productivity (Mariara, 2015). The major challenge of rain-dependent agriculture is inadequate and unreliable rainfall coupled with increased temperatures caused by variable weather thus severe yield reduction and crop failure (Mariara, 2015). Silicon is the second most abundant element after oxygen on the earth’s crust (Meena et al., 2014). In terms of plant growth and development, silicon is considered a quasi-essential element. This has been demonstrated in cereal crops (Liu et al., 2014; Hattori et al., 2005; Chen et al., 2011), pulses (Hamayun et al., 2010), fodder crops, and many other important agronomic crops. Silicon (Si) fertilizers however remain underutilized even though silicon is a nutrient that causes no toxicity to the environment and living organisms (Meena et al., 2014). Genetic improvement of key breeding traits is pivoted on the strength of genetic diversity within the crop. Adequate variability in gene pools offers more options for crop improvement and hybridization. Genotypic correlations such as GCV (Genotypic coefficient of variation), PCV (Phenotypic coefficient of variation), and GA (Genetic advance) can be used as effective tools to determine relationships in genetically diverse populations for enhanced progress in crop improvement (Binodh et al., 2008). Advances in molecular biology with a particular bias to genomics and transcriptomics have demonstrated the effects of silicon on
the expression of aquaporin genes (Liu et al., 2015) that are essential in symplastic and transcellular pathways to water transport (Palakolanu et al., 2015). In particular, the importance of silicon in plants' drought tolerance has been shown in the effect on antioxidant enzymes (Habibi and Hajiboland, 2013). The benefit of Si resistance to biotic and abiotic stresses is thus one of the ways to exploit and ultimately improve crop productivity. The recent advances in molecular biology assist in going a step further in understanding the capacity of Si in the dictum of the proclamation of important genes associated with “aquacumption” under drought conditions (Palakolanu et al., 2015). The sorghum landraces identified have exemplary drought tolerance in the addition to Si fertilizer under drought stress and can be used in future breeding programs. Furthermore, silicon presents a climate-smart value in that its’ uptake mechanism leads to the loading of silicon through the channels whereby the silicic acid enhances water conduction through xylem vessels (Feng et al., 2004). Orthosilicic compound degrades to inorganic harmless ingredients, amorphous silica, and water vapor hence nontoxic to humans and environmentally friendly. Si offers a sufficient way of lowering the carbon footprint through its’ degradable nutrients; amorphous silica and water. The objective of this study was to determine (i) the effect of orthosilicic acid on sorghum traits and (ii) variability of broad-sense heritability and genetic advancement.

**MATERIALS AND METHODS**

**Experimental site**

The experiment was conducted at the South Eastern Kenya University greenhouse for two seasons 2020 (March – July) and 2022 (June – November). SEKU is located in Kwa Vonza, Kitui county, coordinates (01°21’48.0” N - 037° 81’08.7” E). The region experiences an arid and semi-arid climate with an elevation of 1,747 meters above sea level. The county undergoes adverse temperature changes; a high of 34°C within the hottest months (January- March) and a low of 14°C in the cold months (July-August). The region has a rainfall range of 500mm -1050mm in a year and an average of 900 mm annually.

**Landraces**

Ten locally cultivated sorghum landraces were evaluated, and the three highest-yielding lines were chosen; treated seeds of these sorghum cultivars were used in the research. The soil was prepared in a pit with farm yard manure before filling into planting bags. Five plants per 10 kg (0.01m²-soil volume) pots were subjected to six levels of; orthosilicic acid to soil water content ratio treatment. The three landraces were replicated three times with 18 pots per replication and a spacing of (70 x 16) cm instituted between pots. The silicon was drenched in the soil at an equivalent rate of 1 L / Ha (3% orthosilicic acid - H₂O₄Si) according to the manufacturer’s instructions 21 days post-planting.

Silicon was applied in conjunction with the soil water content based on the percentage water loss calculated after oven drying for 24 hours at 105°C. The experiment was conducted in a Completely Randomized Design (CRD), 2 × 3 factorial arrangement in the greenhouse with two observations.

Compound fertilizer NPK-20:11:7 was applied at an equivalent rate of 90 kg/ha at the base of the plant 25 days after planting and heading. Plants were top dressed with Calcium Ammonium Nitrate (CAN) at an equivalent rate of 50 kg/ha. The following conditions of the arched roof greenhouse prevailed: temperature at 25°C - 29°C, light intensity of 25,000-50,000 lux, 60% relative humidity (RH), and CO₂ intake of approximately 350 – 1000 concentration. Sorghum shoot flies (Atherigona soccata) and aphids (Aphis gosypii) were controlled by spraying ESCORT® 19EC (Emamectin benzoate at the rate of 19g ha⁻¹), Leaf spot (Alternaria spp.) was controlled by spraying RIDOMIL GOLD® MZ 68 WG (Mefenoxam, Mancozeb) fungicide at the rate of 2.5 kg/ha.

**Data collection**

The soil was sampled using the traverse method (Okalebo et al.,2002). Approximately 250 g of soil was collected for field capacity calculation, and oven dried at 105 °C for 24 hours. Plant phenotypic traits were measured 13 days post germination, at 8 and 17 weeks. Data on morphological traits were collected from the first node formation. Data collected included days to anthesis (DT), panicle length measured from the distal to the apex of the panicle, number of tillers per plant and stem girth which was determined by measuring a cross-section of the stem,
Peduncle length was determined by measuring from the base of the first node from the flag sheath to the bottom of the panicle. Duration it takes for germination to occur and the number of and the number of leaves per plant. The height of the plant was measured from the base of the plant to the tip of the panicle when the plant attained maturity. Leaf area index (LAI) was determined by taking a statistically significant sample of foliage from a plant canopy measuring the leaf area per sample plot and dividing by the plot land surface area. The shoot and root dry weight of the sorghum were sampled from each treatment and dried in an oven maintained at 75º C for 24 hours. When the plant attained physiological 17 weeks post-planting, maturity, yield data were collected. Kernels were then threshed, and sun-dried to approximate moisture content of 12.5% before measuring the mass (Mather 1949). The harvesting index was also computed from the data presented:

$$HI = \frac{G}{B} \times 100$$

where H. I = harvest index, G = Total kernel weight, and B = weight of Biomass

**Data analysis**

Box and whisker plot analysis was done for the two technical repeats. IQR (Interquartile range) to show the dispersion of data. Analysis of variance was conducted using SAS (SAS, NC, 2002) using the following statistical model:

$$Y_{ijkl} = \mu + B_i + V_j + S_k + VS_{jk} + e_{ijkl}$$

where, $$Y_{ijkl}$$ = dependable variables, $$\mu$$= general mean, $$B_i$$ = effect due to $$i^{th}$$ block, $$V_j$$ = effect due to $$j^{th}$$ landrace, $$S_k$$ = effect due to $$k^{th}$$ silicon, $$VS_{jk}$$ = interaction between $$j^{th}$$ landrace and $$k^{th}$$ silicon, and $$e_{ijkl}$$ = residual.

Means were separated whenever the main effects were significant at $$p<0.05$$ using the following formula: LSD =

$$t_\alpha \times \sqrt{\frac{2MSE}{r}}$$

where $$t_\alpha$$ is the critical t-value, $$\alpha$$ is the level of significance, MSE is the mean square error, and $$r$$ is the number of replicates.

Data were subjected to Pearson’s correlation analysis (Dodge et al.,1980) using the following formula:

$$r_p = \frac{n(\Sigma xiyi) - (\Sigma xi)(\Sigma yi)}{\sqrt{[n\Sigma x^2(\Sigma xi)^2][n\Sigma y^2(\Sigma yi)^2]}}$$

where, $$r_p$$ is Pearson’s correlation coefficient, $$n$$ is the number of samples, $$x$$ is the dependable variable and $$y$$ is the independent variable. The genotypic coefficient of variation and phenotypic coefficient of variation, mean squares, coefficients of variation, degree of freedom, and mean values were compared using Tukey’s HSD test.

GCV (Genotypic coefficient of variation) and PCV (Phenotypic coefficient of Variation) calculations were done according to (Bhagasara et al.,2017; Burton and Devane 1953.)

$$\text{GCV} = \frac{\sqrt{\sigma^2_g}}{x} \times 100$$

$$\text{PCV} = \frac{\sqrt{\sigma^2_p}}{x} \times 100$$

where: $$\sigma^2_g$$ = genotypic variance = (Mean sum of squares due to genotypes -Error mean sum of squares ÷ replications) $$\sigma^2_p$$ = Phenotypic variance, $$x$$ = General mean

**Broad sense heritability** was computed as follows:

$$H^2 = \frac{V_g}{V_p}$$

where: $$V_g$$ = genetic variance component, $$V_p$$ = phenotypic variance component

**Genetic advance** that was applied in this is defined as the degree of gain in a certain species under a particular selection pressure calculated as:

$$\text{GA} = K \times \sigma \times h^2$$

according to (Allard 1960.)

where K is the standardized selection differential constant (2.06) at 5% of selection intensity

$$\sigma_p$$ is the phenotypic standard deviation $$H^2$$ is the broad sense heritability;

**In this study, genetic advance over mean** was computed as follows:

$$\text{GAM} = \frac{GA}{x} \times 100$$
PCV, GCV, heritability, Genetic advance and Genetic advance over mean were applied as described by Sivasubramanian and Menon, (1973) and Johnson et al., (1955) that considered the following classes: Less than 10% = Low, 10-20% = Average / Moderate, Above 20 - 30% = High.

RESULTS

Phenotypic and Genotypic Variation

Significant \( p < 0.05 \) due to genotypic was observed for final plant height, days to maturity, harvest index, yield, days to anthesis, and stem girth. The variation was observed among landraces Kitui rasta, Machakos local brown, and Kitui local brown (TABLE I).

High variability was observed for phenotypic coefficient variation in selected traits i.e plant height and yield respectively in Machakos Local brown at 17.60% and 46%, Kitui rasta at 18.56% and 43.08%, and Kitui local brown at 16.76% and 35% as compared to genotypic coefficient of variation Machakos Local brown of 17.2% and 23.8%, Kitui rasta 14.6% and 30.04%, and Kitui local brown 15.5% and 33.1% 5 parameters excluding stem girth in Machakos Local brown (GCV 9.2% and PCV 8.5%) (Figure 1). From this study, the final plant height had a genetic advance (GA) of 59.4 with a heritability of 98.7%. However, in this study, a PCV value of 16.77% and a GCV value of 16.65% were observed (TABLE I).

### TABLE I- GENOTYPIC AND PHENOTYPIC VARIATION OF SORGHUM LANDRACES EVALUATED AT DIFFERENT LEVELS OF SILICON

<table>
<thead>
<tr>
<th>Landraces</th>
<th>Traits</th>
<th>Mean± S.E</th>
<th>GV</th>
<th>PV</th>
<th>GCV</th>
<th>PCV</th>
<th>H2b</th>
<th>G.A</th>
<th>G.A.M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machakos Local Brown</td>
<td>FPH</td>
<td>175.7±0.74a</td>
<td>61.85</td>
<td>69.48</td>
<td>17.20%</td>
<td>17.60%</td>
<td>94.24%</td>
<td>14.22</td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>DTM</td>
<td>109±3.213b</td>
<td>2.69</td>
<td>4.68</td>
<td>28%</td>
<td>31.20%</td>
<td>83%</td>
<td>15.47</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>H.I</td>
<td>0.73±0.015d</td>
<td>0.00118</td>
<td>0.0047</td>
<td>4.70%</td>
<td>5.40%</td>
<td>25%</td>
<td>0.06</td>
<td>8.20%</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>65.278±4.018c</td>
<td>6.11</td>
<td>26.67</td>
<td>23.80%</td>
<td>46%</td>
<td>47.50%</td>
<td>6.23</td>
<td>10.54%</td>
</tr>
<tr>
<td></td>
<td>DTA</td>
<td>55.44±0.52c</td>
<td>12.22</td>
<td>19.61</td>
<td>6.30%</td>
<td>8%</td>
<td>9.75%</td>
<td>6.89</td>
<td>1.42%</td>
</tr>
<tr>
<td></td>
<td>S.G</td>
<td>1.85±0.24d</td>
<td>0.025</td>
<td>0.029</td>
<td>9.20%</td>
<td>8.50%</td>
<td>2.40%</td>
<td>0.29</td>
<td>15.80%</td>
</tr>
<tr>
<td>Kitui Rasta</td>
<td>FPH</td>
<td>194.5±0.74a</td>
<td>1.29</td>
<td>25.59</td>
<td>14.60%</td>
<td>18.56%</td>
<td>96%</td>
<td>64.244</td>
<td>32.20%</td>
</tr>
<tr>
<td></td>
<td>DTM</td>
<td>92.56±3.213b</td>
<td>0.11</td>
<td>1.5</td>
<td>30.36%</td>
<td>31.32%</td>
<td>87.20%</td>
<td>17.12</td>
<td>7.20%</td>
</tr>
<tr>
<td></td>
<td>H.I</td>
<td>0.75±0.015d</td>
<td>0.0004</td>
<td>0.0044</td>
<td>2.70%</td>
<td>6.90%</td>
<td>3.30%</td>
<td>0.02</td>
<td>2.77%</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>81.389±4.018b</td>
<td>8</td>
<td>41</td>
<td>30.04%</td>
<td>43.08%</td>
<td>44.30%</td>
<td>37.48</td>
<td>19.10%</td>
</tr>
<tr>
<td></td>
<td>DTA</td>
<td>54.5±0.52c</td>
<td>0.07</td>
<td>0.37</td>
<td>0.50%</td>
<td>1%</td>
<td>50%</td>
<td>0.76</td>
<td>1.40%</td>
</tr>
<tr>
<td></td>
<td>S.G</td>
<td>1.83±0.24d</td>
<td>0.00122</td>
<td>0.0022</td>
<td>2%</td>
<td>2.40%</td>
<td>0.05%</td>
<td>0.01</td>
<td>0.60%</td>
</tr>
<tr>
<td>Kitui Local Brown</td>
<td>FPH</td>
<td>153.33±0.74a</td>
<td>0.53</td>
<td>0.93</td>
<td>15.50%</td>
<td>16.76%</td>
<td>98.30%</td>
<td>51.55</td>
<td>33%</td>
</tr>
<tr>
<td></td>
<td>DTM</td>
<td>100.5±3.213b</td>
<td>9</td>
<td>581.37</td>
<td>32.99%</td>
<td>34%</td>
<td>92.10%</td>
<td>24.7</td>
<td>5.70%</td>
</tr>
<tr>
<td></td>
<td>H.I</td>
<td>0.83±0.015d</td>
<td>0.001</td>
<td>0.002</td>
<td>3.80%</td>
<td>5.40%</td>
<td>3.30%</td>
<td>0.07</td>
<td>8.40%</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>106.944±4.018b</td>
<td>11.1</td>
<td>29.2</td>
<td>33.10%</td>
<td>35%</td>
<td>62%</td>
<td>37.5</td>
<td>17.60%</td>
</tr>
<tr>
<td></td>
<td>DTA</td>
<td>54.9±0.52c</td>
<td>0.022</td>
<td>0.051</td>
<td>0.27%</td>
<td>0.41%</td>
<td>1%</td>
<td>0.32</td>
<td>0.60%</td>
</tr>
<tr>
<td></td>
<td>S.G</td>
<td>1.53±0.24d</td>
<td>0.0003</td>
<td>0.0013</td>
<td>1%</td>
<td>2.40%</td>
<td>1.70%</td>
<td>0.4</td>
<td>8.60%</td>
</tr>
</tbody>
</table>

\( p \)-Value: 0.05, \( p < 0.001 \), \( p < 0.001 \), \( p < 0.001 \)

Means in the same column with different superscripts are significantly different at \( p < 0.05 \) Tukey’s HSD test. Superscripts a to e indicate high to low-value \( GV, PV, GCV, PCV, H2b, G.A, G.A.M \)
Broad sense heritability ($H^2$) had a graphical representation among the variables 94.24%, 96%, 98.3% for FPH and 83%, 87.2% and 92.1% in the three varieties respectively (Machakos local brown, Kitui rasta, Kitui local brown) for days to maturity which corresponded to the largest mean variation across the groups. (Figure 1). Genetic advance (0.29, 0.01 and 0.4) was observed for stem girth and a genetic advance over mean of 15.8%, 0.6%, and 8.6% respectively in Machakos local brown, Kitui rasta, Kitui local brown. Larger Mean sum of squares commensurate to high standard errors (TABLE I). The phenotypic coefficient of variation quadrated exorbitant values as compared to GCV except for stem girth in Machakos local brown; PCV (8.5%) and GCV (9.2%) but subsequently showed a genetic advance over mean of (15.68%) (Figure 1).

**Bivariate correlation studies between selected phenotypic characteristics**

Final plant height positively correlated to stem girth ($r = +0.742$), panicle length ($r = +0.501$), and the number of leaves three weeks post-germination ($r = +0.32$). Seed weight correlated significantly ($r = 0.404$) with the final plant height. Days to anthesis correlated negatively at $p<0.05$ ($r = -0.428$, $r = -0.147$, -0.347, -0.304, -0.536, -0.317) with the six parameters, respectively excluding the number of days to maturity (Table II).

![Figure 1](image-url)
### TABLE II-BIVARIATE CORRELATION STUDIES ON SELECTED SORGHUM MORPHOLOGICAL DATA.

<table>
<thead>
<tr>
<th>Traits</th>
<th>The final number of leaves at harvesting</th>
<th>Final plant height</th>
<th>Number of days to maturity</th>
<th>Stem girth</th>
<th>Panicle length (cms)</th>
<th>1000-seed weight</th>
<th>Number of leaves 3 weeks post-germination</th>
<th>Number of days to 50% anthesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>The final number of leaves at harvesting</td>
<td>1.00</td>
<td>-0.210</td>
<td>-0.128</td>
<td>0.179</td>
<td>0.349**</td>
<td>0.404**</td>
<td>-0.060*</td>
<td>-0.428**</td>
</tr>
<tr>
<td>Final plant height</td>
<td>-0.210</td>
<td>1.00</td>
<td>-0.192</td>
<td>0.742**</td>
<td>0.501**</td>
<td>-0.304*</td>
<td>0.320**</td>
<td>-0.147</td>
</tr>
<tr>
<td>Number of days to maturity</td>
<td>-0.128</td>
<td>-0.192</td>
<td>1.00</td>
<td>-0.003</td>
<td>0.128</td>
<td>-0.084</td>
<td>-0.0283*</td>
<td>0.146</td>
</tr>
<tr>
<td>Stem girth</td>
<td>0.179</td>
<td>0.742**</td>
<td>-0.003</td>
<td>1.00</td>
<td>0.863**</td>
<td>-0.109</td>
<td>-0.283*</td>
<td>-0.347**</td>
</tr>
<tr>
<td>Panicle length (cms)</td>
<td>-0.349**</td>
<td>0.501**</td>
<td>0.128</td>
<td>0.863**</td>
<td>1.00</td>
<td>-0.141</td>
<td>-0.012</td>
<td>-0.304*</td>
</tr>
<tr>
<td>1000 seed weight</td>
<td>0.404**</td>
<td>0.501**</td>
<td>-0.084</td>
<td>0.863**</td>
<td>-0.109**</td>
<td>1.00</td>
<td>0.268*</td>
<td>-0.347**</td>
</tr>
<tr>
<td>Number of leaves 3 weeks post-germination</td>
<td>-0.060</td>
<td>0.320**</td>
<td>-0.109</td>
<td>-0.141</td>
<td>0.339**</td>
<td>1.00</td>
<td>-0.536**</td>
<td></td>
</tr>
<tr>
<td>Number of days to 50% anthesis</td>
<td>-0.428**</td>
<td>-0.147</td>
<td>0.146</td>
<td>-0.347**</td>
<td>-0.304*</td>
<td>-0.536**</td>
<td>-0.317**</td>
<td>1.00</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level (1-tailed)  * Correlation is significant at the 0.05 level (1-tailed)

Total grain weight had a positive correlation ($r = +0.821$) with the weight of 1000 seeds. Days to anthesis correlated positively ($r = +0.414$) with WUE (Water Use Efficiency) (Table III).
Water Use Efficiency (WUE) and Biomass Prediction under Silicon Amendment

Assessment of WUE on the 3 accessions Machakos local brown, Kitui rasta, and Kitui local brown presented different results under silicon treatment. In this study, a WUE mean of 0.059 was exhibited under Si treatment and 0.05 mean under no silicon treatment in Machakos local brown (Figure 4), this accounts for a 9% difference in mean WUE. A 10% difference in mean WUE was noted in Kitui rasta in plants that received silicon and no silicon applications with a mean of 0.06 and 0.05 under Si-treatment and no-Si-treatment, respectively. In Kitui local brown a differential mean was noted with 0.085 under silicon treatment and 0.06 under no silicon application which translates to a 25% difference (Figure 2).

Comparison of WUE between Si and no-Si application (Figure 3); showed a positive skewed plot and less dispersed data under no Si application (0-Si) and a positively skewed plot with more dispersed data under Si-application (1-Si). Quantifiable dispersed data was observed in Machakos local brown, Also note, that the median line of 0-Si lied outside (1-Si) when comparing both plots. A 0.75 Interquartile range (IQR) was observed in the (1-Si) application box plot in Kitui Local Brown with

**Figure 2.** Effects of silicon on water use efficiency of sorghum landraces.
the largest upper whisker among the three landraces with a maximum mean value of 0.2 under the 1-Si treatment. The two box plots show data dispersal based on the plot sizes. An outlier in the upper whisker was observed on the accession Kitui Rasta under the application of (0-Si) at 0.1 WUE level. Positive skewness was noted in Kitui Rasta for both (0-Si) and (1-Si) treatments (Figure 3).

Effect of Silicon on sorghum grain yield

There were different responses to silicon mediation and water stress treatments among the three landraces. (Figure 4). In this study, the yield of Machakos Local Brown; (1-Si) with high water treatment produced a mean grain weight of 63% among the groups and also presented a 13% mean grain weight percentage difference as compared to the control that had a mean percent of (50%) in kernel weight. Kernels from the sorghum treated with (1-Si) and low water treatment showed a 35% mean weight while kernels from plants that received (0- Si) and low water treatment had a 25% mean kernel weight. With medium water treatment, (1-Si) had a 45% mean grain weight higher by 12% compared to (1-Si) with low water treatment but a 5% lower mean grain weight when compared to the control (50% mean grain weight). In the accession Kitui Rasta; a combination of (1-Si) with high water treatment produced sorghum kernel with 60%
mean grain weight. The combination is 0-Si with low water treatment resulting in a 50% mean sorghum grain weight. Sorghum treated with (0-Si) and medium water treatment showed sorghum kernels produced with 45% mean weight. However, (1-Si) with low water treatment produced kernels with 45% mean grain weight compared to the 54% in the control (Figure 11). The variable response was observed on sorghum accession *Kitui Local Brown*. In this study, a mean grain weight of 84% in (1-Si) with high water and 73% mean weight grain in the control were observed (0-Si) with low water treatment had the same mean grain weight as (1-Si) with water low treatment at 60%. (1-Si) with medium water treatment had a 75% mean grain weight percentage. (Figure 5).

**Effect of Silicon Addition on Harvesting Index (H.I)**
The harvest index is one of the indicators of the yield performance of a crop. In this study, HI ranged from 0.75 to 0.79 in *Machakos local brown* (Figure 6; Figure 7). HI observed on Landrace *Kitui rasta* ranged from 0.78 to 0.8.

![Figure 4. WUE under different dual applications of silicon and water levels.](image)

![Figure 5. Mean yield of three sorghum landraces under different silicon and water treatments, Tukey’s HSD p<0.05](image)
However, this study showed that Landrace *Kitui local brown* had a HI ranging from 0.82 to 0.84. HI difference was significant among the groups using Tukey-Kramer’s HSD $p<0.05$. The amount of variation shown discloses the fit of the data and the power of the model. The model shows a high value close to 1; 0.767 (TABLE V). The model shows a P-value of 0.042 analogous to $p \leq 0.05$ indicating that 95% confidence that the slope of the regression is not zero.

**Figure 6.** Mean H.I of the three accessions under different levels of silicon and water treatment for the first observation, Tukey’s HSD $p<0.05$. *Different letters indicate significant difference between means*

<table>
<thead>
<tr>
<th>Traits</th>
<th>Total grain weight in grams</th>
<th>Harvest index</th>
<th>Panicle grain weight in grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total grain weight in grams</td>
<td>1</td>
<td>0.792**</td>
<td>0.955**</td>
</tr>
<tr>
<td>Harvest index</td>
<td>0.792**</td>
<td>1</td>
<td>0.587**</td>
</tr>
<tr>
<td>Panicle grain weight in grams</td>
<td>0.955**</td>
<td>0.587**</td>
<td>1</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.01 level (2-tailed)

**TABLE V - REGRESSION ANALYSES USING SILICON AS A PREDICTOR AND HARVEST INDEX (H.I) AS THE DEPENDENT VARIABLE.**

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F</th>
<th>$R^2$</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>0.024</td>
<td>1</td>
<td>0.024</td>
<td>4.365</td>
<td>0.797</td>
<td>0.042b</td>
</tr>
<tr>
<td>Residual</td>
<td>0.289</td>
<td>52</td>
<td>0.006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>0.313</td>
<td>53</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent variable: Harvest index; b. Predictor: Silicon
DISCUSSION

**PCV, GCV, Heritability, GA and GAM**

Variability of traits is imperative to breeding in improving plant morphology and palatability traits (Bhagasara et al., 2017). Hence it is critical to have the data on GCV and PCV. GCV and heritability generate information that leads to efficient genotype selection through genetic advance and hence can be used for hybridization using a large parental panel as reported by Singh et al., (2016). Plant growth and development are greatly affected by drought (Nithya et al., 2017) and lead to morphological responses that help plants acclimatize to the ever-changing environment. The application of orthosilicic acid through photosynthetic and translocation pathways greatly influences plant growth parameters affirmed by contrasting studies (Rastogi et al. 2021). Analysis of accessions Kitui rasta, Kitui local brown and Machakos local brown showed higher PCV compared to GCV among the five traits in this study apart from stem girth which suggests the role of orthosilicic acid in influencing plant morphology (Godbharle et al., 2010) in sorghum. A high PCV observed in sorghum grain yield as affirmed by a similar study conducted by Swamy et al., (2018) and Badigannavar et al., (2017). However, a low difference between PCV and GCV indicates very little environmental influence on the expression of the characters.

Corresponding to Sivasubramanian and Menon (1973) and Johnson et al., (1955), the classification for GCV-a low Harvest index and stem girth which corresponds to a low selection chance of the traits exhibited by the genotypes (Elangovan and Babu, 2015). In a study conducted by Sharma et al., (2006), the most selection-responsive character was stem juiciness as it had higher GCV, PCV, genetic gain, and moderate heritability. Based on heritability and genetic gain, selection criteria based on several leaves per plant, leaf length leaf breadth, stem girth and juiciness, plant height, and protein percentage may be useful for further developing good quality and high-yielding forage sorghum cultivars. In this study, plant, days to maturity were high coupled with yield, and exorbitant heritability was exhibited in the study indistinguishable amongst plant height, days to maturity, harvest index, yield, and stem girth. This attests to the functioning of an additive gene through epigenetics in controlling the particular traits in question (Shivaprasad et al., 2019). All the study traits exhibited a high heritability apart from days to anthesis which states a minuscule variation that can be traced to genetic variability. High heritability is an indicator of the transmission of characters to the progeny and filial generations Kumar et al., (2016).

The genetic gain was high for plant height and moderate for yield. Low genetic gains were observed for harvest
A high genetic gain is expected according to Anand (2013) and Anand et al. (1998). This postulates that an improvement in stem girth indicating inadequate selection intensity despite high genetic variation (Tariq et al., 2012).

**Correlation of selected interjacent phenotypic characteristics**

A significant positive correlation was noted for stem girth, panicle length, and the number of leaves three weeks post-germination, application of silicon significantly enhances the aforementioned parameters, which is largely explicable by improved root hydraulic conductance and a better photosynthetic pathway. Seed weight correlated positively with the final plant height (Kamoshita et al., 1998; Utzurrum et al., 1998). This postulates that an increase in the sorghum height is due to Si amendment which predicates an improvement of LAI, peduncle length, and branch consequently improving the photosynthetic ability of the sorghum and assimilates production. This also postulates that an improvement in seed weight corresponds to the quality of the sorghum seed which is directly correlated to plant height.

**WUE and biomass prognosis**

Increases in water-use efficiency are cited as a response technique of plants in moderate to severe soil water deficits especially in drought-ravaged regions as reported by (Bacon 2004). A higher WUE % was observed under Si root drench application in the different varieties which connotes a study by Gong et al., (2003). Si build-up may be an agent for shoot growth in plants. A larger difference was detected in Kitui local brown under Si treatment as compared to Kitui rasta and Machakos local brown (Matoh et al., 1991), this also states Si enhances leaf water potential by reducing transpiration rate consequently improving WUE. Kitui rasta showed a wide range of data distribution and dispersal under the silicon application and both Machakos local brown and Kitui local brown showed that the mean is greater than the mode under Si application. The high % shown for WUE under (1-Si) with the water-low application shows the enhancement of integrated and instantaneous WUE (Agare, et al.,1998; Savant, 1996). The study further pinpointed that the transpiration rate was reduced by physically blocking cuticular transpiration using silica deposits on the cuticles, therefore maintaining leaf water potential under drought stress.

**Impact of orthosilicic acid on Sorghum Yield and harvesting index**

Yield and harvest index statistics showed that silicon amendment ameliorated grain weight. Si enhanced the turgor and sturdiness of the crop and improved the lodging of the crops as reported by a similar study by Ahmad et al., (2013) and Anand et al., (2018), which further showed that the rigidity of plant stature improved the assimilation of organic nutrients and photosynthetic activity which promoted crop growth and development. A high grain yield of 60% and harvest index of 0.82 was observed for Kitui local brown under silicon and high-water application, which signifies a composite of the two (silicon application and high-water capacity) improves grain yield significantly. The analysis also shows that HI as a measure of reproductive efficiency was more predominant in Kitui rasta and Kitui local brown, this concurs with breeding practices for the use of selection of the traits through introgression and hybridization. The harvest index is a ratio of the grain weight to the total above-ground biomass (grain plus vegetative tissue) at maturity. The closer the ratio is to 1 as shown in the study across the two observations, the more efficient the crop is in producing grain as the HI is determined by the interaction between (G) genotypes, (E) the environment, and crop management (M). Si might adjust the root growth and increase the root/shoot ratio, which together with the enhancement of aquaporin activity and osmotic driving force contribute to the improvement of root hydraulic conductance. A higher root hydraulic conductance results in increased uptake and transport of water in the sorghum shoots, which helps to maintain a higher photosynthetic rate and improve plant resistance to water deficiency as affirmed by a similar study by (Chen et al., 2018).

**Summary and Conclusion**

This study ranked Kitui local brown, Kitui rasta, and Machakos local brown, respectively according to performance. The sequence is based on the tolerance to drought and Si adsorption capabilities through regulation.
of (PIP) aquaporin gene expression, alleviating ROS-induced AQP gene inhibition, accumulation of soluble sugars to activate K⁺ translocation which increases osmolyte accumulation and osmotic driving force hence improving photosynthetic activity (Chen et al., 2018). A high and moderate PCV and GCV show traits that should be adopted through direct or indirect selection since the genotypic coefficient and phenotypic coefficient are helpful in the identification of such characteristics. High \( (HFb) \) affirms that the breeder can make selections based on phenotypic parameters and should use GAM and heritability together to predict effects during selection.

Si-application postulates an exponential increase of sorghum landraces in Kitui local brown and Kitui rasta, which in turn predicates an improvement of photosynthetic activity through revamping of LAI, peduncle length and branch length which in turn ameliorates the assimilates production in the improvement of panicle length, seed weight, stem girth and yield parameters. Application of Si to sorghum crops should be encouraged in the form of root drench as it improves the physiological and plant transcellular pathways by increasing the shoot-to-root ratio as shown in this study.

Heritability and genetic advance studies are to be instituted on landraces that have highly suitable traits for selection. Further studies coupling Si-mediation on promoter genes are to be studied through the binding of DNA sequences to initiate transcription of a single RNA-RNA-transcript and whether the promoter is tissue or cell-specific. This can help to enhance local landraces and cultivars since they possess a high genetic diversity for selection.

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REFERENCES


Drench Effect of Orthosilicic Acid on Drought Stress Tolerance on Morphological and Phenotypic Traits of Sorghum (Sorghum Bicolor L. Moench) Landraces


