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Evaluation of the Performance of Sweet Potato (*Ipomoea batatas*) Clones under Water Stress in the Coastal Lowlands of Kenya

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Abstract The production of sweet potato (*Ipomoea batatas* (L.) Lam.) in coastal Kenya is diminishing due to unreliable rainfall, coupled with farmers' use of unimproved sweet potato varieties that are not drought tolerant. A study was conducted at Pwani University from 2016 to 2017, to identify sweet potato clones with best performance under low water stress. Nine clones (6.1A, 4.10, 7.8, 15.10, 7.6AO, 10.10B, 4.2B, 7.6B and 4.2A) and a farmer-preferred variety "Rabai" were evaluated under the following four water stress levels: (i) Watering for the first two months after planting and stressing the plants for the next three months - S3, (ii) Watering for the first three months after planting and stressing the plants for the next two months - S2, (iii) Watering for the first four months after planting and stressing the plants for the next one month - S1, and (iv) Watering throughout the growing period and not stressing the plants at all - S0. A randomized complete block design was used, with factorial arrangement of treatments. Treatments were replicated three times. Tuber circumference was reduced by low water stress irrespective of the time it started, relative to the growing season. Water stress that was imposed early in the season, at three or two months after planting, reduced tuber yield by about 52 and 70%, respectively. Sweet potato clones C2 and C8 performed relatively well across seasons, irrespective of the water stress level. Farmers are likely to realize improved tuber yields by planting sweet potato early in the rainfall season to ensure adequate soil water during the first four months of crop growth. Sweet potato clones C2 and C8 are therefore recommended for multi-locational trials in coastal lowland Kenya, to ascertain their performance across agro-ecological zones.

Keywords: *drought tolerance, Ipomoea batatas, sweet potato clones, tuber yield, water stress levels*

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1. Introduction

Sweet potato is among the most important food crops in the world [1]. It is the second most important tuber crop after potato in the world [2]. About 92M ton of sweet potato was produced globally, under an area of 8M hectares with a yield of 11.4 t ha^{-1} in 2018 [3]. The crop is regarded as both food security and cash crop in sub-Saharan African countries [4] and can contribute to sustainable agricultural development, boost economic growth and reduce poverty and, hence, reduce malnutrition and hunger in the region. The crop requires rainfall of between 750 to 1000 mm during the growing season [5]. Production of sweet potato is inexpensive because it does not require much labor or fertilizer, making it adaptable by the resource-poor farmers. Sweet potato is a tropical American crop belonging to the family Convolvulaceae. Varieties of this crop vary widely in their agronomic and botanical characteristics. They can easily be differentiated on the basis of their morphological traits such as size, shape, and flesh and skin color of the tubers.

In coastal lowland Kenya, sweet potato is an important food crop. Its tuberous roots are commonly taken for breakfast, lunch or supper, either as the main meal or part of the meal. Demand for the crop is very high in the local markets of Kwale, Mombasa and Kilifi counties, which cannot be met by the local supply. Additional supply of sweet potato in the major markets is therefore obtained from outside the region.

Currently, sweet potato is mainly grown in agro-ecological zones Coastal lowland II (CL2) and Coastal lowland III (CL3), receiving an average annual rainfall of 1,000-1,400 mm [6]. The crop is produced on smallholder farms, on which other food and cash crops are grown. Expansion of sweet potato production in the high rainfall areas is limited by competition between the crop and the other food and cash crops for the arable land. The only option would be to expand production of the crop in areas with less rainfall than those currently under production. Such an expansion would require the use of drought tolerant sweet potato varieties.

Information is lacking on availability of drought tolerant sweet potato varieties that are adaptable to the drier zones of coastal lowland Kenya that receive average annual rainfall of 600 to 900 mm. Identification of such varieties is crucial if sweet potato production has to be expanded into the low rainfall areas in the region. Considering that sweet potato is a supplementary staple for cereals and a household food security crop, efforts should be made to increase its production by addressing the above constraint. This study was therefore conducted to identify sweet potato clones with best performance under low water stress.

2. Materials and Methods

2.1. Site Description

The study was conducted between December 2016 and November 2017, at the Pwani University farm in Kilifi County. The site is located within the Coastal Lowland Agro-ecological Zone IV (CL4), at an altitude of 15 meters above sea level. It lies between latitudes 3° and 4° South and longitudes 39° and 40° East [6]. The site receives bimodal rainfall, with the annual rainfall ranging from 1,000 to 1,100 mm. The long rains (LR) season is received from April to July/August while the short rains (SR) season is received from October to December. The site has a long dry season from January to March. The ambient temperature ranges from 22°C to 30°C and the mean relative humidity is about 80%. The soils at Pwani University farm are mostly ferralsols, with low organic matter, low fertility and a pH between five and seven. Phosphorus was therefore applied at planting as Di-ammonium phosphate (DAP) fertilizer, at the rate of 50 kg P_2O_5 ha^{-1}.

2.2. Sweet Potato Clones

Nine clones (6.1A, 4.10, 7.8, 15.10, 7.6AO, 10.10B, 4.2B, 7.6B and 4.2A) that had been reported to be drought tolerant were obtained from KALRO-Muguga for use in this study. A farmer-preferred variety from Kilifi namely, "Rabai," was included as a local check.

2.3. Treatments

The following treatments were evaluated in the experiment:

Factor A: Nine sweet potato clones reported to be drought tolerant and one farmer-preferred variety

i) Farmer-preferred variety (Rabai) - (VR)
ii) 6.1A - (C1)
iii) 4.10 - (C2)
iv) 7.8 - (C3)
v) 15.10 - (C4)
vi) 7.6AO - (C5)
vii) 10.10B - (C6)
viii) 4.2B - (C7)
ix) 7.6B - (C8)
x) 4.2A - (C9)

Factor B: Water stress levels

i) Watering for the first two months after planting and stressing the plants for the next three months - (S3)

ii) Watering for the first three months after planting and stressing the plants for the next two months - (S2)

iii) Watering for the first four months after planting and stressing the plants for the next one month - (S1)

vi) Watering throughout the growing period and not stressing the plants at all - (S0)

2.4. Experimental Design

A randomized complete block design was used, with a factorial arrangement of treatments. The treatments were replicated three times.

2.5. Crop Establishment

Trials were conducted for two seasons (December 2016 to April 2017 and July 2017 to November 2017). The sweet potato vines were planted in plots measuring 3.75 x 0.9 m (3.375 m^2) in a structure to keep off rain (Plate 1). This was done to ensure that the water stress treatments were not interfered with by rainfall and also to mimic the dry spells experienced in some parts of the region. The field was ploughed to a medium tilth and plots demarcated followed by ridging. Each plot consisted of three ridges, each 0.9 m long and 45 cm high. The ridges were spaced 1.25 m apart. Each ridge was planted with three vine cuttings (each 30 cm long), spaced 30 cm apart. Di-ammonium phosphate (DAP) fertilizer was applied at planting, at the rate of 50 kg P_2O_5 ha^{-1}.

Plate 1. Structures used to keep rainwater off the experimental plots

2.6. Crop Management Practices

The plots were hand weeded when the crop was in the early growth stages before formation of tubers. An insecticide, Dynamec 1.8 EC (Abamectin 1.8g/l), was applied at the rate of 250 ml/ha as required to control insect pests (leaf defoliators and mites). Vines were trained to minimize their spread into adjacent plots, as well as preventing them from forming adventitious roots along the stems. Soil was carefully hoed back onto the ridges to fill cracks on the ground, which had formed as a result of tuber expansion. This was carried out to avoid exposure of the tubers to weevils and light.

2.7. Data Collected

The following data were collected from the experimental plots:

a) Tuber yield

The sweet potato crop was harvested at five months after planting. Harvesting of each plot was done by digging out the tubers from the soil and detaching them from the mother plants. All the tubers from each plot were then weighed (using a digital weighing balance) to get plot weight. A sample of two tubers was then randomly selected from each plot and weighed to get wet weight. The random samples were then oven-dried at 105°C for 48 hours and weighed for dry matter (DM) determination. The following formula was used to calculate DM:

$$DM\left(kg.ha^{-1}\right)=\frac{S_{oven}\left(g\right)}{S_{fresh}\left(g\right)}\cdot\frac{PW\left(kg\right)}{A\left(m^2\right)}\cdot 1,000m^2ha^{-1} \quad (1)$$

where S_{oven} = sample oven weight; S_{fresh} = sample fresh weight; PW = plot weight; A = net-plot area.

Sweet potato yield was then derived using the following formula:

$$Y=\frac{SW\left(kg\right)}{A\left(m^2\right)}\cdot\frac{10,000m^2ha^{-1}}{1,000kgt^{-1}} \quad (2)$$

where Y = sweet potato yield (t ha^{-1}); SW = field wet weight; A = net-plot area.

Tuber dry weight (DW) was then derived using the following formula:

$$DW=WW_{tuber}\left(kg\right)\cdot DM\cdot\frac{1,000}{100} \quad (3)$$

where DW = tuber dry weight (t ha-1); WW_{tuber} = wet weight of tubers; DM% = percent dry matter of tubers

b) Tuber characteristics

The number, length and circumference of marketable tubers per plant were recorded after harvesting. Tuber circumference was determined using a tape measure around the thickest part of a tuber picked at random (Plate 2). The length of a tuber was measured as the length of the edible portion of the tuber, as shown on Plate 2.

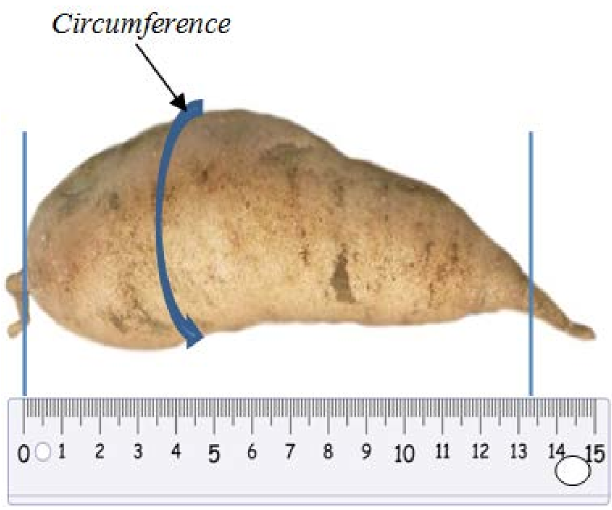

Plate 2. Measurement of tuber circumference and length

2.8. Data Analysis

All the data collected were subjected to the analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS) Version 9.1 [7]. Because of the high variability observed in the data, square root transformation of the original data (n) was performed before analysis so as to improve the normality of the data. Where the F values were significant, treatment means were separated using the Least Significant Difference (LSD) at the 5% level of significance.

3. Results and Discussion

3.1. Effect of Low Water Stress

Water stress levels had significant effect (P = <.0001) on number and circumference of marketable tubers per plant (Table 1). Plants under the water stress levels S0 and S1 did not differ in their marketable tuber numbers but had significantly higher number of marketable tubers per plant compared with those under S2 and S3. Plots under the water stress level S3 had the smallest number of marketable tubers per plant. The results of this study are in agreement with those by Kivuva [8] and Khalel [9] who reported decreased number of sweet potato tubers under water stress condition. Plots that were watered throughout the growing season (S0) had significantly thick tubers, followed by those where the watering was stopped four months after planting (S1), three months after planting (S2) and lastly two months after planting (S3).

Table 1. Effect of Water Stress Levels on Number and Circumference of Marketable Tubers per Plant

Water stress levels	Number of marketable tubers per plant	Tuber circumference (cm)
S0	2.42 [a]	12.19 [a]
S1	2.37 [a]	11.01 [b]
S2	1.86 [b]	8.98 [c]
S3	1.43 [c]	6.34 [d]
LSD	0.2845	0.9993
Pr>F	<.0001	<.0001

Water stress levels: S3 = stressed for three months, S2 = stressed for two months,
S1 = stressed for one month, S0 = no water stress (i.e. watered up to the time of harvesting)
Means within a column followed by same superscript are not significantly different at P<0.05.

The number of marketable tubers per plant in plots that were watered throughout (S0) and those that were subjected to water stress after four months (S1) did not differ probably because, by the time stress commenced in the S1 treatment, the tubers were already fully formed. According to Ekanayake *et al*. [10], any water provided late in the growing period only encouraged vegetative growth. The results of this study are in agreement with the findings by Ekanayake *et al*. [10] who observed fewer marketable tubers in sweet potato plants subjected to water stress than those in plants that were watered throughout the growing season. Water stress that set in early in the season, at three (S2) or two (S3) months after planting, reduced tuber circumference by 26 and 48%, respectively. Similarly, such stress reduced the number of marketable tubers per plant by 23 and 41%, respectively.

Water stress levels also differed significantly (P = <.0001) in their effect on tuber yield per hectare (Table 2). Plants that had been watered throughout the growing season (water stress level S0) had significantly higher tuber yield expressed on wet-weight basis than those subjected to water stress four months after planting (water stress level S1). The prolonged watering, beyond four months after planting, probably led to increased water content in the tubers hence their higher wet weight. However, the two water stress levels (S0 and S1) did not differ in their effect on tuber yield expressed on dry-weight basis. This probably shows that the water applied after four months from planting had effect on adding water only to sweet potato tubers. Therefore, farmers growing sweet potato for processing need not water the plants after four months. Low water stress that set in early in the season at three (S2) or two (S3) months after planting reduced tuber yield by about 52 or 70%, respectively, irrespective of the basis in which the yield was determined. The results of this study are in agreement with the findings by Ekanayake and Wanda [11] and Laurie *et al*. [12] who observed significant differences between irrigation treatments in their effect on marketable tuber yield. The significant reduction in yield under water stress condition could be due to closure of stomata, with the resultant decline in photosynthetic and transpiration rates, as suggested by Laurie *et al*. [12].

Table 2. Effect of Water Stress Levels on Sweet Potato Tuber Yield (Wet-Weight and Dry-Weight Basis)

Water stress levels	Tuber yield (wet-weight basis)	Tuber yield (dry-weight basis)
	(t $^{ha-1}$)	
S0	6.40 ^{a}	1.57 ^{a}
S1	5.31 ^{b}	1.43 ^{a}
S2	3.15 ^{c}	0.75 ^{b}
S3	1.99 ^{d}	0.46 ^{c}
LSD	0.6714	0.206
Pr>F	<.0001	<.0001

Water stress levels: S3 = stressed for three months, S2 = stressed for two months,
S1 = stressed for one month, S0 = no water stress (i.e. watered up to the time of harvesting)
Means within a column followed by same superscript are not significantly different at P<0.05.

Rodriguez-Delfin *et al*. [13] reported that water stress decreased plant growth by affecting N and Mg uptake required for cell growth and chlorophyll synthesis. The observed high sweet potato tuber yields where watering was done throughout the growing season was probably due to improved cell growth and chlorophyll synthesis leading to increased photosynthesis. Increased chlorophyll content leading to higher yields in unstressed crops than stressed crops was also reported in olive [14]. Inadequate rainfall amount has been reported to reduce the rate of photosynthesis and efficient partitioning of assimilates leading to low yields [15]. The observed yield reduction in sweet potato subjected to water stress in this study was probably the result of reduced rates of photosynthesis and inefficient partitioning of assimilates.

A study by Saqib *et al*. [16] showed that sweet potato yield parameters (tuber length, tuber diameter, number and fresh weight of marketable tubers per plant) were directly linked with vegetative growth, especially in summer crop. As vegetative growth decreased due to moisture stress, tuber yield was also reduced [16].

4.2. Effect of Water Stress Levels and Clones

Results of the study showed significant (P = <.0001) interaction effect of water stress levels and sweet potato clone on tuber length (Figure 1). Clone C2 performed relatively well across water stress levels in terms of tuber length. The tuber length in C9 was reduced by more than 35% irrespective of the water stress level. While farmer-preferred variety (VR), and clones C3, C4, and C7, were not significantly different when watered throughout the growing season, the farmer-preferred variety (VR) produced shorter tubers than clones C3, C4, and C7, when watering was stopped at four months after planting. When watering was stopped as early as two months after planting, clone C2 produced longer tubers than the farmer-preferred variety (VR) and the rest of the clones. When watering was stopped at three months after planting, clones C2, C5 and C8 did not differ in their tuber length. These observations indicate that the response of sweet potato to water stress is dependent on both the variety and the duration of water stress. The result of this study do not conform with those by Ekanayake *et al*. [10] who observed no significant interaction effect of sweet potato clone and water stress level on sweet potato yield indices.

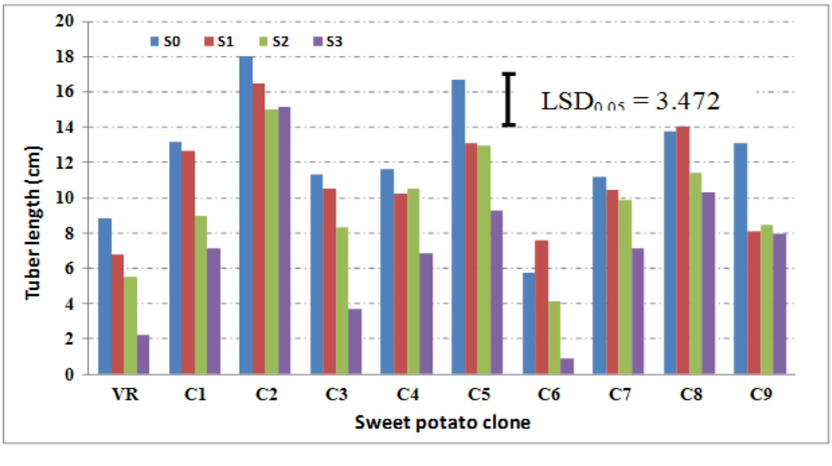

Figure 1. Effect of water stress levels and sweet potato clone on tuber length (cm)

4.3. Effect of Clones and Seasons

The results of this study showed significant (P = <.0001) interaction effect of season and clone on both fresh and dry tuber yield (Figure 2 and Figure 3). Sweet potato clone C2 had significantly higher fresh or dry tuber yield than the farmer-preferred variety (VR) and the rest of the drought tolerant clones (C1, C3, C4, C5, C6, C7, C8 and C9) across seasons. While clone C8 gave similar fresh tuber yield across seasons, clones C1 and C9 gave higher yield in season 1 than in the second season (Figure 2). The fresh tuber yields of clones C3 and C7 were lower in the first season than those realized in season 2. While clone C2 had significantly higher dry tuber yield in season 1 than in season 2, clones C3, C7 and C8 gave lower dry tuber yields than those realized in the second season (Figure 3). Osiru *et al.* [17], in a study conducted in Uganda, observed variable yield response of sweet potato genotypes across seasons and concluded that within each cropping season, the ranking of the genotypes for yield stability was not consistent. This probably explains the variable yield responses of the drought tolerant clones and farmer-preferred variety across seasons in this study.

Clone C2 was superior in its performance probably because it was more tolerant to water stress than the farmer-preferred sweet potato variety and the rest of the clones. Mbinda *et al*. [18] associated better performance of sweet potato under water stress to high capacity for water retention, expressed as relative water content (RWC), which makes the crop survive water stress for longer periods. This probably explains the superior performance of clone C2 compared with the farmers' sweet potato variety and the other clones.

The results of this study showed significant (P = <.0001) interaction effect of season and clone on tuber circumference and length (Figure 4 and Figure 5). While marketable tubers of farmer-preferred variety (VR) and clones C3 and C7 had significantly smaller circumference in season 1 than in season 2, the reverse was true for clone C9 (Figure 4). Tuber circumference for clones C1, C2, C4, C5, C6, and C8 did not vary significantly from one season to the other. While tuber length for farmer-preferred variety (VR) was significantly smaller in season 1 than in season 2, the reverse was true for clone C1, C4, C5 and C9 (Figure 5). Tuber length for clones C2, C3, C6, C7, and C8 did not vary significantly from one season to the other. The observed seasonal variability in the size of tubers of the drought tolerant clones and farmer-preferred variety in this study is in agreement with the observation by farmers in coastal lowland Kenya that the performance of some of the varieties they grow is season specific (B. Abdallah, Personal communication).

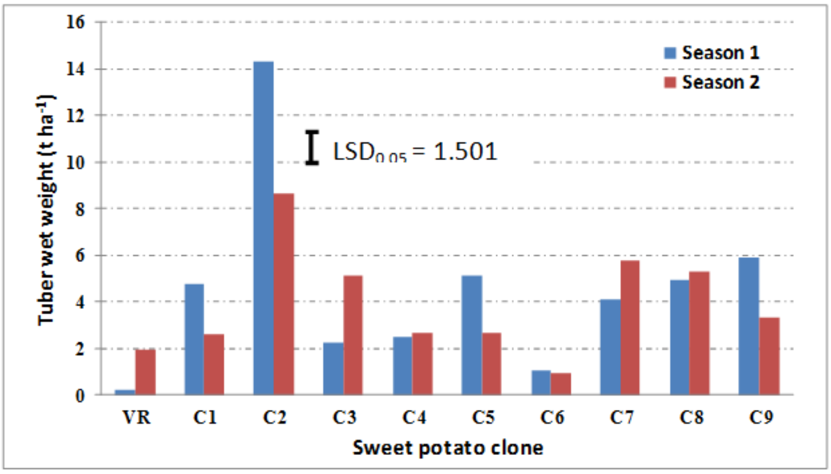

Figure 2. Effect of cropping season and sweet potato clone on sweet potato fresh tuber yield (wet-weight basis)

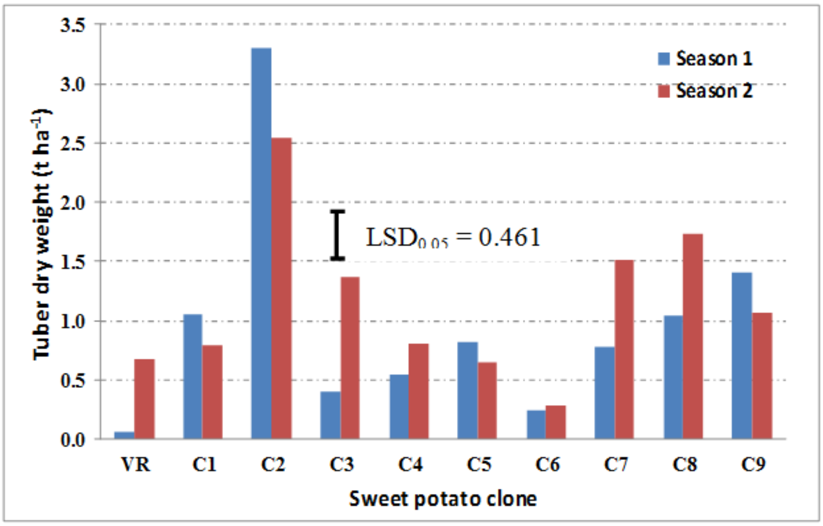

Figure 3. Effect of cropping season and sweet potato clone on sweet potato dry tuber yield (dry-weight basis)

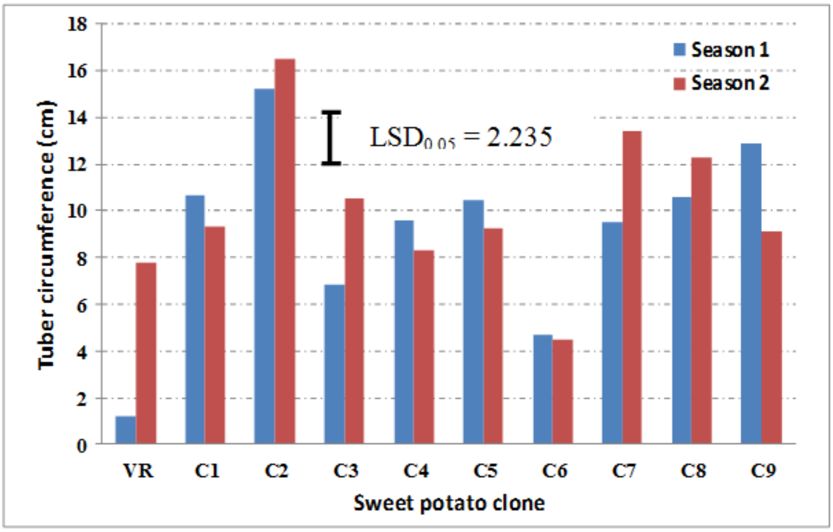

Figure 4. Effect of cropping season and sweet potato clone on sweet potato tuber circumference

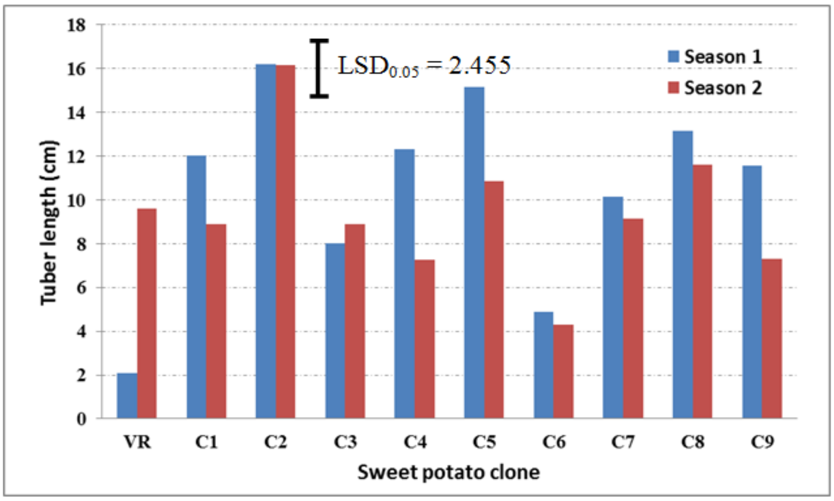

Figure 5. Effect of cropping season and sweet potato clone on sweet potato tuber length

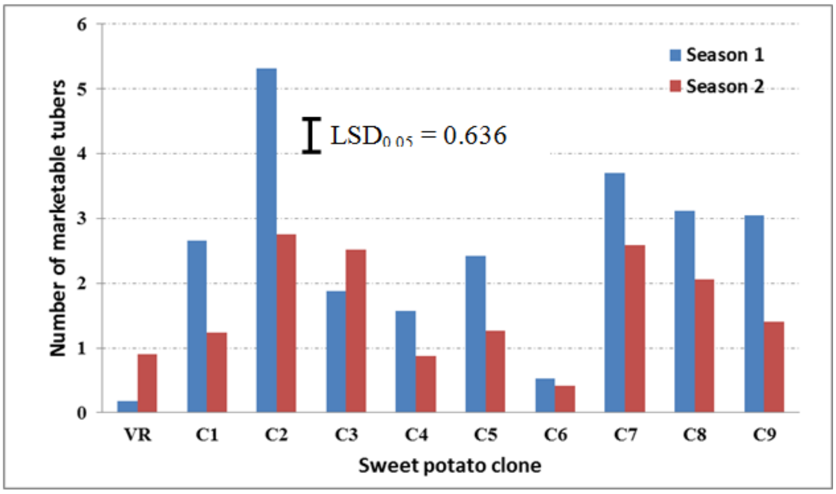

Figure 6. Effect of cropping season and sweet potato clone on the number of marketable sweet potato tubers per plant

The results showed significant (P = <.0001) interaction effect of season and clone on number of marketable tubers per plant (Figure 6). Clone C2 performed relatively well across seasons in terms of number of tubers. While clone C2 had significantly higher number of marketable tubers than the farmers' sweet potato variety and the rest of the clones in season 1, it did not differ with clones C3, C7 and C8 in the second season. The number of marketable tubers for clones C3, and C6 did not vary significantly from one season to the other. While clones C1, C2, C4, C5, C7, C8, and C9 had significantly higher number of marketable tubers in season 1 than in the second season, the reverse was true for the farmer-preferred variety (VR).

4. Conclusion

Sweet potato clones C2 and C8 showed yield stability across seasons, irrespective of the water stress level. Low water stress that was imposed early in the season at two or three months after planting caused significant reduction of sweet potato tuber yield.

Clones C2 and C8 are therefore recommended for multi-locational evaluation in coastal lowland Kenya to ascertain their superiority to the farmer-preferred varieties. The best candidate(s) from the evaluation may then be multiplied for use by farmers in the drought prone areas of coastal lowland Kenya. For improved sweet potato tuber yields, it is recommended that farmers plant the crop relatively early in the rainfall season so that it is not exposed to low water stress within the first four months of growth.

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Statement of Competing Interests

The authors have no competing interests.

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