Chapter

Influence of Soil Moisture Stress on Vegetative Growth and Root Yield of Some Cassava Genotypes for Better Selection Strategy in Screen House Conditions and Different Agro-Ecologies in Nigeria

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Abstract

Cassava is a vital staple crop for many African populations particularly in Nigeria. This study was conducted to determine the effect of soil moisture on the performance of selected 12 cassava genotypes that were evaluated for yield and related traits under three percentages of field capacity (75% – control, 50%, and 25%) in the screen house and field conditions in three agro-ecologies (Ibadan-Derived Savanna, Mokwa-Southern Guinea Savanna, and Zaria-Northern Guinea Savanna) and randomized complete block design was used. Data were collected on plant height, stem girth, number of nodes and leaves, shoot weight, stomata conductant, stay-green, fresh root weight, and dry matter percentage and were analyzed using descriptive statistics and ANOVA. Genotypes differed significantly across and within locations. The higher stress level (25% field capacity – F.C.) resulted in a more significant reduction in vegetative growth than the moderate stress level of 50% F.C.; moisture levels were uniform over time for plant height and stem girth. The response to moisture levels varied widely among genotypes, indicating that they experienced a higher stress condition. Genotypes IITA-TMS-IBA980581, IITA-TMS-IBA010040, and IITA-TMS-IBA010034 were identified with good drought tolerance. Integrating physiological research with breeding efforts will help in the selection of suitable varieties for release.

Keywords: soil moisture, cassava, agro-ecologies, root yield, selection

1. Introduction

Cassava is a major staple food and widely grown across Nigeria owing to its wide adaptability, economic importance, and acceptance both in rural and urban regions being a common staple consumed by Nigerians. It is also increasingly becoming raw materials for food, feed, and industrial applications. In 2018, worldwide production of cassava stood at about 278 million tons (t). In the same period, Nigeria produced about 60 million t [1], and Africa's total production was about 170 million t (about 56% of the world production) [1]. It is a source of calcium, vitamins B and C, and other essential minerals [2]. However, several biotic and abiotic constraints, such as drought, pests, diseases, low soil fertility, shortage of planting material, postharvest physiological deterioration, and access to markets, limit cassava production [3, 4].

A major impact of climate change is drought or water deficit, which imposes limited water environment on plants [5]. Global monitoring and analysis of climatic variables have provided evidence that the countries where cassava is cultivated are experiencing impacts of climate change [6]. Under drought conditions, water available for plant uptake for metabolic reactions falls below requirement, thus adversely impacting growth and physiological processes. The effects of water deficit on cassava plants are many and vary depending on length and intensity of drought and stage of growth of the plant [7].

Drought or water deficit remains the major impact of climate change, which imposes limited water environment on plants and seriously affected tuber yield [5]. Crops are dependent on rainfall, and so water scarcity is the primary productivity constraint in arid and semiarid tropical areas [8]. As a meteorological event, drought is a period in which the potential evaporation exceeds the rainfall. Agricultural drought is the result of water flow imbalance between the environmental demands of evapotranspiration and water transport in the soil-root system [9]. Water stress increases abscisic acid (ABA) concentration in plant, which in turn increases root resistance by affecting membrane permeability and root tuberization (**Figure 1**) [10, 11].

The morphophysiological responses to drought stress increases abscisic acid (ABA) concentration, ion transport, and the induction of the associated signaling pathway genes in plant, which in turn increases root resistance by affecting membrane permeability and root tuberization [14]. Under water deficit, cassava leaves rapidly accumulate large amounts of ABA and young leaves halt leaf expansion growth and transpiration rate decreases. Young leaves accumulate more ABA than mature leaves, but the high ABA levels under water deficit are completely reversed to control levels after one day of re-watering, corresponding with a rapid recovery of leaf area growth rate. The rapid reduction in leaf area growth and stomatal closure might be due to cassava's ability to rapidly synthesize and accumulate ABA at an early phase of a water deficit episode [15]. Plants have developed defense mechanisms, which enable them to adapt and survive under drought condition in their life cycle [16].

1.1 Biochemical and molecular mechanisms known to contribute to water-deficit stress tolerance in cassava plants

The defense strategies against drought environment also vary from different cassava cultivars. During a prolonged drought stress condition, reactive oxygen species (ROS) generate excessively and cause oxidative damage [17]. ROS can damage multiple cellular components such as proteins and lipids, and unlimited disruption will finally lead to cell death [18].

1.2 Use of crop diversity in plant breeding for drought-tolerance traits

Valuable genes from natural inter- and intraspecific diversity can be used to take advantage of several mechanisms of survival and coadaptation in plants produced by

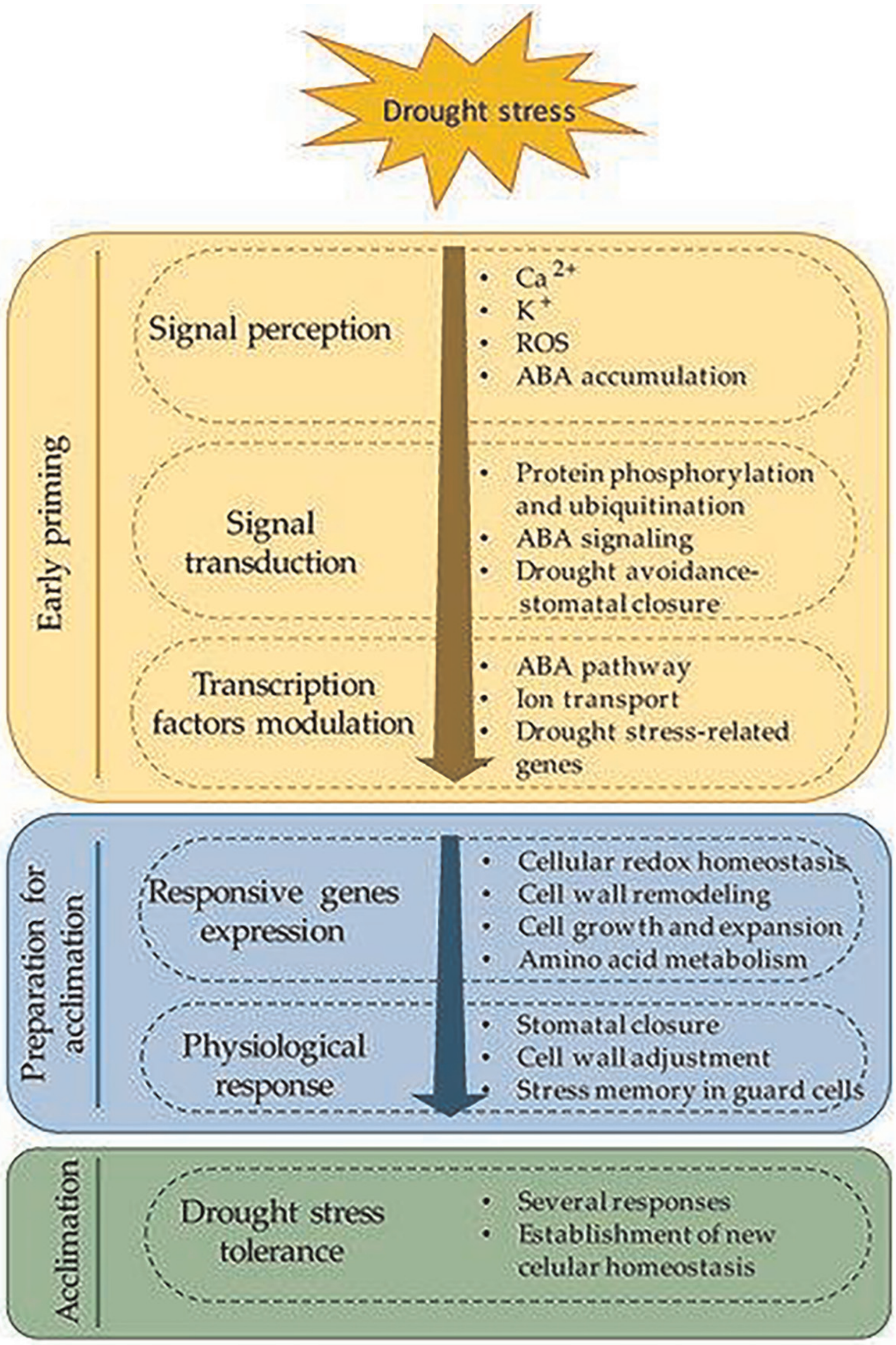

Figure 1.
General description of physiological responses of plants to drought stress conditions. ROS: Reactive oxygen species and ABA: abscisic acid [12, 13].

natural selection [19]. Some of these genes are conserved by farmers (in landraces) or are present in crop wild relatives and the narrow genetic base of modern cultivars; therefore, crop wild relatives have been extremely valuable in adapting crop varieties to changing climatic conditions [20].

Cassava grows and produces well in the Nigerian environment but shows different growth behavior and yields in different years due to differences in annual weather conditions. The water regime of an environment is an essential factor that affects the growth of crops. Differential soil water and nutrient regimes have been reported to affect yield stability in cassava [21]. Although it is incredibly tolerant to water stress, a long dry period has been reported to decrease yields [22]. Similarly, prolonged moisture deficiency leads to a reduction in growth, development, and root yields [23].

In the past, decade the International Institute of Tropical Agriculture (IITA) had developed improved varieties, which were selected from diverse source crosses; that are resistant to the crops, major pests, and diseases. As these new genotypes are developed, there is need to evaluate their performance under different moisture regimes to identify those that are stable across varying moisture environments. This study evaluates the vegetative growth parameters and root yield of selected genotypes under different moisture conditions in the screen house and three different agro-ecologies. The objectives of the study are to determine the influence of soil moisture stress on vegetative growth and root yield of selected cassava genotypes.

2. Materials and methods

Twelve genotypes (IITA-TMS-IBA010040, IITA-TMS-IBA011086, IITA-TMS-IBA011663, IITATMSIBA020131, IITA-TMS-IBA30572, IITA-TMS-IBA91934, IITA-TMS-IBA920067, IITA-TMS-IBA920326, IITA-TMS-IBA950166, IITA-TMS-IBA980510, IITA-TMS-IBA980581, and TMEB 1) were selected based on their field performance for root yield, root numbers, and dry matter and were evaluated in the screen house at IITA, Ibadan. The plants were raised in large polythene bags of 36 cm length and 156 cm circumference for 6 months under three moisture conditions: 75% (control), 50%, and 25% F.C. using the procedure of Anderson and Ingram [24].

The F.C. moisture levels at 75% (well-watered), 50% (moderate), and 25% (severe) were used to simulate stress conditions in the field. The polythene bags were filled with 86 kg of topsoil (obtained from Ibadan) to a height of 36 cm and made firm by being doubled. The soil used was classified as Ferric Luvisol with sandy-loam texture (USDA); pH (water) was 5.4, organic carbon (C) 1.26%, and total nitrogen (N) 0.12%. Available phosphorus (P) was 34.4 mg/kg, calcium (Ca) 5.8 cmol/kg, and magnesium (Mg) 0.7 cmol/kg. The experiment was laid out in a 3 by 12 factorial arrangement (moisture level × clones) in a completely randomized design (CRD) and replicated three times. Each of the replicates had a total of 36 bags in three rows of 12 bags per row. Healthy stakes of uniform length (25 cm) were planted vertically in the central portion of the bags. Holes at the bottom of the bags allowed easy draining. Following the procedure of Anderson and Ingram [24], plants were watered to field capacity for the first 4 weeks to ensure good plant establishment, after which moisture treatments were imposed by irrigation once a week with 5.58 liters for 75% F.C., 3.72 liters for 50% F.C., and 1.86 liters for 25% F.C. Measurements on vegetative traits were taken at 4, 8, 12, 16, and 20 weeks after planting (WAP) for plant height (cm), and stem girth (cm). Yield parameters were taken at 24 WAP.

These 12 genotypes were also evaluated on the field using healthy stakes of 25 cm length planted in a slanting position on ridges 30 cm high with two-thirds of the length buried in the soil. Mokwa [(Southern Guinea Savanna (SGS), Lat.9°29^{1}N and Long. 5°04^{1}E and 152 masl] and Zaria [Northern Guinea Savanna (NGS), Lat.11°11^{1}N and Long.11°78^{1}E and 610 masl]. The three locations represent different agro-ecologies with varying climatic and soil characteristics. Planting was done in each location when soil moisture was sufficient to sustain establishment. Weeding was manual at 1 month after planting (MAP), and herbicides were applied at 3, 6, and 9 MAP. Harvesting was done at 12 MAP.

2.1 Data collection

Data collected in the screen house were **Plant height** at 4, 8, 12, 16, and 20 WAP; **Stem girth** at a uniform stem length of 50 cm from ground level; **Fresh shoot weight** was obtained in kg as the fresh weight of shoots per plot; **Fresh root weight** per plot and estimated in t/ha at 24 WAP; **Number of stems per plant; Number of leaves** per plant was counted per plot and Screening genotypes for resistant to Cassava Mosaic Disease (CMD), Cassava Bacteria Blight (CBB), and Cassava anthracnose (CAD). The incidence and severity of genotypes to the African cassava mosaic disease (CMD) were evaluated at 1, 3, and 6 months after planting (MAP) at 3 and 6 MAP for cassava bacterial blight (CBB) and CAD at 6 and 9 MAP; since the symptom would not have expressed at 1 month after planting. Disease incidence was taken as proportion of plants units that are visibly diseased relative to total number of plants, while disease severity = volume of plant parts affected compared with the whole plant unit.

Disease incidence = Number of infected plants/plot/Total number of plants/plot.
Severity of genotypes to CMD was recorded based on a scale of 1–5 [25].

Leaf Chlorophyll: The leaf chlorophyll contents of four selected leaves in each plot were measured at 4, 8, 12, 16, and 20 WAP using Chlorophyll Meter Model SPAD-502 (Minolta Co. Ltd. Japan).

Leaf stomata conductance: A steady-state porometer (Licor Instrument Corporation, Model Li-1600) was used to measure diffusive resistance and transpiration rate on the abaxial surface of the uppermost fully expanded leaves of four plants per plot. The sensor head with a narrow leaf aperture (LI 1600–01) with an area of 1cm^2 was used. Measurement was taken when sun was not too low or high in the morning (900–1100 h) and afternoon (1330–1530 h) on a clear sunny day at 3, 6, and 9 months after planting (MAP) in all locations [26].

The dried sample was weighed, and root dry matter percentage was calculated as follows.

$$\text{Percent root cortex DM} = \text{dry weight/Fresh weight} \times 100$$

***Gari* production**: Cassava roots were converted to fermented roasted granules called *Gari*. Ten kilograms of roots were taken from each genotype harvested, washed with water, and grated with a grating machine. The pulp was put in a jute bag, and pressure was exerted on it to remove water from the pulp. Dewatering took up to 3 days and the pulp was also undergoing fermentation while being dewatered. The pulp was sieved to remove chaff and toasted in a pot until gelatinized grains were formed.

2.2 Statistical analysis

All data obtained were analyzed using the Statistical Analytical System (SAS) (9.2 version). The model used was the factorial arrangement in a CRD. Least Significant Difference (LSD) at 5% probability was used to separate mean squares.

Sources of variation	DF	Plant height	Stem girth	Fresh Root weight	Leaf number	Fresh Shoot weight	Stem number	Leaf chlorophyll
Rep(R)	2	84.15^{ns}	0.02^{ns}	14.81^{ns}	127.86^{ns}	399.98^{ns}	0.18^{ns}	7.95^{ns}
Trt (T)	2	16492.35***	0.44***	16336.57***	3412.78***	19628.18***	3.13**	505.89***
Rep×Trt	4	722.37^{ns}	0.01^{ns}	302.34^{ns}	39.16^{ns}	3367.64*	0.65^{ns}	5.03^{ns}
genotype	12	2758.90***	0.08**	642.83^{ns}	245.47**	1593.05^{ns}	2.60***	27.10***
Trt × genotype	22	311.85^{ns}	0.05^{ns}	449.85^{ns}	92.22^{ns}	1610.94^{ns}	0.63^{ns}	12.77*
Error	65	408.34	0.04	530.91	88.86	1227.67	0.43	6.57
R^2		0.74	0.54	0.59	0.68	0.58	0.66	0.80

****, **, * means significant at p ≥ (0.001, 0.01, 0.05) and ns means not significant.*

Table 1.
Pooled analysis of variance for yield and yield related traits of 12 cassava genotypes evaluated in the screen house Ibadan Nigeria.

3. Results

3.1 Performance of selected genotypes in different moisture conditions in the screen house and field environments

Mean squares (MS) from the combined analysis of variance (ANOVA) for root and shoot characters of the twelve cassava genotypes in the screen house at Ibadan are presented in **Table 1**. The result shows highly significant ($p < 0.001$) mean squares (MS) for all sources of variations. However, MS for all traits studied were significant for more than one source of variations. The mean squares (MS) for treatment were highly significant so also mean square for except for fresh root weight and fresh shoot weight. Whereas the interaction between replicate and the treatments was not significant except for fresh shoot weight as well as the interaction between treatment and genotype except for leaf chlorophyll. But the mean square for replicate was not significant for all the traits studied. Mean values at 75% and 25% FC differ significantly for all parameters at 24 WAP, except for leaf number, leaf chlorophyll content, and fresh root weight.

When mean values at 25% FC were compared with mean values at 75% FC, it was observed that mean plant height decreased by 29.33%, stem girth by 17.32%, root weight by 61.76%, and shoot weight by 29.27% at harvest (**Table 2**). There was no significant difference in mean values at 75% and 50% FC for plant height at harvest

	Plant	% diff.	Stem	% diff.	Root	% diff.	Shoot	% diff.
	height		girth		weight		weight	
TRT	(cm)		(cm)2		(Kg)		(kg)	
75%FC (T3)	144.98		1.27		0.068		0.164	
50%FC (T2)	127.93	11.7	1.2	5.5	0.044	35.3	0.142	13.41
25% FC (T1)	102.46	29.33	1.05	17.32	0.026	61.76	0.116	29.27

*% diff = (T3-T1/T3) *100.*

Table 2.
Mean and percentage differences of 12 cassava genotypes in the greenhouse at different moisture levels for different traits at 24WAP.

24WAP. Similar growth pattern was observed for plant height and stem girth over time at 75% and 50% FC (**Table 3**).

IITA-TMS-IBA010040 had the highest fresh root weight of 70.2 g, followed by IITA-TMS-IBA920326(55.4 g) and IITA-TMS-IBA980581 had fresh root weight of 50.9 g; while IITA-TMS-IBA30572 had the least fresh root weight of 38.4 g (**Table 4**).

Treatment	pltht	stmgrth	stmno	lfno	lfchlorph	rtfrhwt	shtfrhwt
High water treatment (75%)	145.0^{a}	1.3^{a}	1.7^{a}	43.3^{b}	33.4^{b}	68.7^{a}	116.5^{b}
Low water treatment (25%)	102.5^{b}	1.1^{b}	1.7^{b}	30.8^{c}	39.3^{a}	26.3^{c}	142.1^{ab}
Medium water treatment (50%)	127.9^{a}	1.2^{a}	2.2^{a}	50.1^{a}	40.4^{a}	44.1^{b}	164.6^{a}

Same numbers are not significant from each other while numbers together mean they are over lapse and a separate number is significantly different.
pltht: plant hight, stmgrth: stem girth, lfchorph: leaf chlorophyll, rtfrhwt: root fresh weight, shtfrhwt: shoot fresh weight, stmno: stem number.

Table 3.
Mean differences of 12 cassava genotypes in the screen house at different moisture levels for different traits.

clone	mpltht	mstmgrth	mlfno	mlfchlorph	mrtfrhwt	mshtfrhwt	mstmno	Genotype mean
010040	109.3	1.2	37.9	37.3	70.2	140.4	1.5	56.8
011086	108.6	1.1	39.0	39.9	41.3	107.1	1.4	48.3
011663	149.4	1.2	34.8	38.4	40.9	142.9	1.2	58.4
020131	133.2	1.2	43.2	34.8	41.9	146.8	1.7	57.5
30572	144.0	1.2	46.9	39.7	38.4	145.8	1.8	59.7
91934	102.8	1.0	52.0	38.8	45.2	151.6	2.6	56.3
920067	140.4	1.1	36.9	38.3	41.0	131.0	1.7	55.8
920326	106.1	1.1	48.4	38.0	55.4	150.4	3.2	57.5
010034	102.9	1.2	42.3	37.1	42.3	141.9	2.0	52.8
980510	121.8	1.4	42.0	38.9	44.1	126.2	1.6	53.7
980581	141.4	1.2	36.9	34.1	50.9	152.2	1.9	59.8
TME 1	141.6	1.3	36.8	37.3	44.8	156.3	1.8	60.0
Mean	125.1	1.2	41.4	37.7	46.4	141	1.9	56.4
SE	5.3	0	1.6	0.5	2.6	4	0.2	2.0
Min	102.8	1	34.8	34.1	38.4	107.1	1.2	45.6
Max	149.4	1.4	52	39.9	70.2	156.3	3.2	67.5
CV(%)	16.2	17	22.8	6.8	49.7	24.8	35.1	24.6
Pr. > F	***	*	**	***	ns	ns	***	
LSD(0.)	24.25	0.24	11.31	3.08	27.65	42.05	0.79	7.9

****, **, * means significant at $p \geq (0.001, 0.01, 0.05)$ and ns means not significant.*
Mpltht: mean plant hight, mstmgrth: mean stem girth, mlfchorph: mean leaf chlorophyll, mrtfrhwt: mean root fresh weight, mshtfrhwt: mean shoot fresh weight, mstmno: mean stem number.

Table 4.
Overall means of yield and yield related traits of 12 cassava genotypes evaluated in the screen house at 24 WAP.

The mean reduction in genotypes performance at moisture stress levels of 25% and 50% FC ranged from 15.9% (30572) to 44.3% (010040) for plant height, between 7.7% (020131) and 41.6% (920326) for stem girth, between 40.8% (011086) and 85.7% (30572) for root weight, and between 12.8% (TMEB 1) and 63.9% (011086) for shoot weight. The mean plant height was 125.1 cm with 011663 having the tallest while 980510 and 91934 being the shortest 102.8 cm. Stem girth ranged from 1 cm (91934) to 1.4 cm (980510); leaf number ranged from 34.8(011663) to 52 cm (91934). The coefficient of variation for the traits was quite low (**Table 5**).

3.2 Overall fields disease means scores, yield, and yield-related traits of 12 cassava genotypes evaluated for 2 years at three locations in Nigeria

There was significant ($P \leq 0.05$) difference in genotypes performance with respect to stay green, mean diseases score, fresh root yield, harvest index, root yield and size, shoot weight, and gari yield except for dry matter content. 80% of tested genotypes performed better than the checks in terms of stay green, mean diseases score, fresh root yield, and shoot weight while 70% and 30% of the genotypes outperformed checks with respect to root size and gari weight. The genotypes with outstanding field performance across the three locations were IBA980581, IBA010034, and IBA010040 (**Table 6**).

3.3 Morphological and physiological field performance of 12 cassava genotypes evaluated at three locations in Nigeria for 2 years

There is significant difference ($p \geq 0.05$) in genotypes morphological and physiological traits except for stem girth. More than half of tested genotypes perform better than checks in all traits except for stomata, level of branching, and number of leaves. The genotypes that recorded highest and least score for plant height were (IBA920067, IBA91934), number of nodes (IBA980510, IBA91934), chlorophyll content (IBA011663, IBA980581), and Leaf Area (IBA011663, TME 1). Genotypes IBA011663, IBA980510, IBA010040, IBA010034, IBA30572 were identified for being stable across three locations for physiological and morphological traits (**Table 7**).

3.4 Location means recorded by 12 genotypes evaluated for 2 years at three locations in Nigeria

Ibadan location recorded the highest score for level of branching, chlorophyll content, plant height, gari weight, number of leaf, fresh root yield, harvest index with least score for cassava bacteria blight severity (CBBS), Mokwa location had highest mean score for shoot weight, number of nodes, stem girth, stomata, and least mean score for cassava anthracnose disease severity (CADS) while Zaria location recorded highest mean score for stay green, dry matter content, and least mean score for cassava mosaic disease severity score (CMDS). Zaria and Mokwa location recorded the same mean score for Harvest Index while Ibadan and Mokwa location also recorded the same score for root size (**Table 8**).

3.5 The correlation coefficients for traits measured for 2 years at three locations in Nigeria

Most of the traits show significant correlation *inter se*. Notably, Fresh root yield was positively correlated garri, harvest index, and cassava mosaic disease, Fresh root

Genotypes	Plant Height (cm)				Stem girth (cm^2)				Root weight (Kg)				Shoot weight (Kg)			
	T1	T2	T3	% diff.	T1	T2	T3	% diff.	T1	T2	T3	% diff.	T1	T2	T3	% diff.
010040	76.5	114.1	137.3	44.3	0.9	1.3	1.3	30.8	0.055	0.049	0.105	47.6	0.114	0.14	0.166	31.3
011086	85.5	122.7	117.6	27.3	0.9	1.3	1.3	30.8	0.04	0.041	0.042	40.8	0.056	0.109	0.155	63.9
011663	127.7	142.6	177.9	28.2	1	1.3	1.2	16.7	0.02	0.044	0.058	65.5	0.103	0.152	0.172	40.1
020131	107.5	142.4	149.8	28.2	1.2	1.2	1.3	7.7	0.02	0.042	0.062	67.7	0.121	0.152	0.166	27.1
30572	129.5	148.6	154	15.9	1.1	1.2	1.2	8.3	0.01	0.034	0.07	85.7	0.145	0.111	0.181	19.9
91934	83.6	100.8	124.1	32.6	1	0.9	1.1	9.1	0.025	0.035	0.074	66.2	0.099	0.186	0.169	41.4
920067	110.8	155.5	154.7	28.4	1	1	1.3	23.1	0.022	0.034	0.066	66.7	0.091	0.138	0.162	43.8
920326	87.1	106.4	124.7	30.2	0.7	1.4	1.2	41.6	0.024	0.07	0.071	66.2	0.139	0.142	0.169	17.8
010034	88.8	92.8	127.2	30.2	1	1.1	1.4	28.6	0.023	0.031	0.072	68.1	0.116	0.142	0.166	30.1
980510	104.3	121.1	139.8	25.4	1.3	1.3	1.5	13.3	0.027	0.033	0.071	70	0.08	0.129	0.168	52.4
980581	107.5	160.1	156.6	31.4	1	1.3	1.2	16.7	0.019	0.072	0.06	68.3	0.135	0.155	0.165	18.2
TMEB1	120.7	127.9	176	31.4	1.2	1.2	1.4	14.3	0.027	0.038	0.068	62.3	0.143	0.16	0.164	12.8
Means	102.46	127.93	144.98		1.05	1.2	1.27		0.03	0.04	0.07		0.12	0.14	0.16	
SE	5.19	6.37	5.76		0.04	0.04	0.04		0.003	0.003	0.004		0.009	0.005	0.003	
LSD	25.88	35.3	39.29		0.31	0.64	0.25		33.06	48.12	33.01		64.76	34.65	71.4	

*T1 = 25% FC, T2 = 50% FC, T3 = 75% FC, % diff = (T3-T1/T3) *100.*

Table 5.
Overall mean performance and percentage difference among 12 cassava genotypes under different moisture conditions in the greenhouse for four traits.

Genotypes	**S.G.**	**mean diseases score**	**FYLD(t/ha)**	**HI**	**DM (%)**	**nrt**	**rtsz**	**htwt (kg)**	***Gari* wt (kg)**	**Rank_Total**	**Final rank**
IITA-TMS-IBA980581	2.5(8)	1.97(7)	22.32(1)	0.5	32(1)	86.7(4)	5.9(2)	32.5(1)	1.7(2)	21	1
IITA-TMS-IBA010034	3(3)	2(8)	21(3)	0.5	32(1)	88(3)	5.8(4)	30.8(2)	1.9(1)	31	2
IITA-TMS-IBA010040	2.2(12)	1.87(5)	21.6(2)	0.5	29(8)	76.7(6)	5.9(2)	29(6)	1.4(4)	34	3
IITA-TMS-IBA920067	2.3(11)	1.67(1)	17.4(10)	0.5	31(3)	76.1(7)	5.6(5)	24.4(11)	1.2(9)	48	4
IITA-TMS-IBA020131	2.7(5)	1.9(6)	18.07(7)	0.4	31(3)	68.4(10)	5.4(9)	30.7(3)	1.5(3)	48	5
IITA-TMS-IBA011086	2.7(5)	1.73(2)	18.68(5)	0.5	27(10)	95.7(1)	5(12)	30.2(4)	1.2(9)	50	6
IITA-TMS-IBA980510	2.5(8)	1.80(3)	18.05(8)	0.5	27(10)	82.5(5)	5.3(10)	27.5(8)	1.1(11)	55	7
IITA-TMS-IBA91934	3(3)	2.4(12)	18.13(6)	0.5	30(5)	75.4(8)	6.2(1)	25.4(10)	1.4(4)	55	8
IITA-TMS-IBA920326	2.6(7)	2.07(9)	19.6(4)	0.5	29(8)	73.3(9)	5.6(6)	28.5(7)	1.3(8)	57	9
IITA-TMS-IBA30572	3.1(2)	2.23(11)	17.65(9)	0.5	30(5)	88.6(2)	5.1(11)	25.8(9)	1.4(4)	62	10
IITA-TMS-IBA011663	2.5(8)	1.83(4)	15.02(11)	0.4	24(12)	61(11)	5.6(7)	29.6(5)	1.1(11)	64	11
TMEB1	4.7(1)	2.2(10)	13.48(12)	0.5	30(5)	53.8(12)	5.5(8)	20(12)	1.4(4)	75	12
Mean	2.8	1.9	18.3	0.5	29	74.3	5.6	27.8	1.4		
Min	2.2	1.67	13.48	0.4	24	53	5	20	1.1		
Max	4.7	2.4	22.32	0.5	32	95.7	6.3	32.5	1.7		
SE	0	0.06	0.67	0	3	3	0.1	0.98	0.05		
CV	14	16.5	28.8	59	13	26.8	17	27.3	27.6		
Pr. > F	*	***	***	**	ns	***	***	**			

****, **, * means significant at $p \geq (0.001, 0.01, 0.05)$ and ^{ns} means not significant, Number in parenthesis represents the rank/position of each genotype, S.G.: Stay-green, FYLD: Fresh root yield, nrt: number of roots harvested, rtsz: root size, shtwt: shoot weight, HI: harvest index,*

Table 6.
Overall disease mean scores, yield, and yield-related traits of 12 cassava genotypes evaluated for 2 years at three locations in Nigeria.

Genotypes	Pltht (cm)	Stem girth (cm)	Nnode	Stomata	Chlorophyll content	Lbrch	Nleaf	LA (m^2)	Rank_ Total	Final Rank
IITA-TMS-IBA920067	100 (4)	8.7(1)	40.6 (11)	125(6)	36.7(4)	1.2 (10)	34 (12)	0.01 (6)	54	7
TMEB1	103 (8)	7.7(4)	41.7 (10)	138.7(1)	34.6(9)	1.1 (12)	36.7 (11)	0.01 (6)	61	12
I IITA-TMS-IBA920326	94.2 (10)	7.5(7)	45(6)	127.8(4)	35.5(5)	1.2 (10)	38.4 (10)	0.01 (6)	58	9
IITA-TMS-IBA980581	105 (6)	7.6(6)	45(6)	132.6(2)	31.1(12)	1.4(8)	40.6 (9)	0.01 (6)	55	10
IITA-TMS-IBA91934	87.3 (12)	6.3(12)	38.2 (12)	127.5(5)	37.3(2)	1.8(3)	41(8)	0.01 (6)	60	11
IITA-TMS-BA980510	109 (3)	7.7(4)	50.5 (1)	123.5(7)	37.3(2)	1.8(3)	49(2)	0.01 (6)	28	1
IITA-TMS-IBA30572	92.1 (11)	8.6(2)	44.4 (9)	120.5 (10)	35(7)	2(1)	49.3 (1)	0.01 (6)	47	2
IITA-TMS-IBA010034	110 (2)	7.4(9)	46.8 (4)	120.2 (11)	35(7)	1.7(6)	48.3 (4)	0.012 (4)	47	2
IITA-TMS-IBA010040	104 (7)	7.4(9)	48.8 (2)	122.1(9)	33.4(10)	1.8(3)	48.8 (3)	0.012 (4)	47	2
IITA-TMS-IBA020131	109 (3)	7.5(7)	45.1 (5)	114.4 (12)	33.2(11)	1.7(6)	43.5 (7)	0.013 (3)	54	7
IITA-TMS-IBA011086	132 (1)	6.9(11)	44.5 (8)	123.2(8)	35.4(6)	1.9(2)	48.1 (5)	0.014 (2)	42	6
IITA-TMS-IBA011663	109 (3)	7.8(3)	47.7 (3)	132.4(3)	38(1)	1.2(9)	45.1 (6)	0.015 (1)	28	1
Grand Mean	105	7.59	44.9	125.7	35.21	1.6	43.6	0.01		
Min	87.3	6.3	38.2	114.4	31.1	1.1	34	0.01		
Max	132	8.7	50.5	138.7	38	2	49.3	0.02		
SE	2.97	0.15	0.97	2.42	0.55	0.1	0.85	0		
CV	18.2	18.97	12.1	14.4	6.85	20.5	17.67	51.9		
Pr. > F	*	ns	**	*	***	*	***	*		

***, **, * means significant at $p \geq (0.001, 0.01, 0.05)$ and ^{ns} means not significant, Number in parenthesis represents the rank/position of each genotype Nnode: number of nodes, Lbrch: level of branching, Nleaf: number of leaves, LA: leaf area.

Table 7.
Overall means morphological and physiological traits of 12 cassava genotypes evaluated for 2 years in three locations in Nigeria.

yield was however negatively correlated to cassava bacterial blight (−0.28) and cassava anthracnose disease (−0.29).

Chlorophyll content was positively correlated to fresh root yield (0.25), but negatively correlated to dry matter (−0.14).

Stomata had significantly negative correlation with harvest index (−0.11) and number of root (−0.15).

Shoot weight correlated with chlorophyll content (0.19), and fresh root yield (0.79) but had negative correlation with dry matter (−0.17) (**Table 9**).

Traits	**Location means**			**Across mean**
	Ibadan	**Mokwa**	**Zaria**	
Level of branching	2 (1)	1.6 (2)	1.4 (3)	1.60
Chlorophyll	36.5 (1)	36.1 (2)	33.5 (3)	35.40
Stomata	120.7 (3)	133.7 (1)	129.1 (2)	127.80
Stem girth	4.4(2)	14.3 (1)	3.4 (3)	7.30
Plant height (cm)	134.1 (1)	115.1 (2)	68.5 (3)	105.90
Number of nodes	49.7 (2)	54.6 (1)	29.9(3)	44.70
Gari weight (kg)	2.1 (1)	0.9 (3)	1.5 (2)	1.50
Number of leaves	86 (1)	29.7 (2)	24.5 (3)	46.70
CMDS	1.6 (3)	1.4 (2)	1.1 (1)	1.40
CBBS	1.8 (1)	2.1 (2)	2.6 (3)	2.20
CADS	2.2 (2)	0 (1)	2.3 (3)	1.50
Fresh root yield (t/ha)	28.9 (1)	20.3 (2)	8 (3)	19.10
Harvest index	0.6 (1)	0.5 (2)	0.5 (2)	0.50
Shoot weight (kg)	34 (2)	35.7 (1)	12.2 (3)	27.30
Stay-green	2.7 (2)	2.7 (2)	2.9 (1)	2.80
Root size	6 (1)	6 (1)	5 (3)	5.70
Dry matter content (%)	29.7 (2)	26.7 (3)	33.9 (1)	30.10
Number of roots	96.8 (2)	97.7 (1)	42.4 (3)	79.00

Table 8.
Overall mean location values for morphological, physiological, and yield traits at three locations for 2 years in Nigeria.

4. Discussions

As an important environmental limitation, drought has become a rising concern due to its harm to the development and productivity of crop plants [27]. Cassava is a major staple food to resource-limited people in marginal areas because of its ability to survive and produce in such poor land with infrequent rainfall and low fertility [28]. The present study by using 12 cassava genotypes can provide a fundamental basis for the identification of drought-tolerant germplasm resources.

Plants are known to respond to water deficit with some adjustment at morphological, physiological, cellular, and metabolic levels. These responses are, however, dependent upon the duration and severity of stress, the type of genotype/the stage of development, and the organ and cell in question [29]. Reduction in photosynthesis results in the inability of the genotypes to produce tuberous roots compared with conditions with relatively higher moisture levels. Any factor in the plant's environment that is not the optimum, being either deficient or in excess, will limit plant growth. Moisture stress at 25% F.C. in the screen house led to a reduction in root weight by over 61%, and this is indicative that severe moisture stress that occurs within a period of 8–24 WAP can lead to a very high level of yield loss [30]. Porto [30] also reported that water stress from 4 to 20 WAP led to a reduction of storage root

	mcbbs	**Mcmds**	**Mcads**	**chlrphy**	**Stomata**	**stgth**	**pltht**	**Nnode**	**Nleaf**	***Gari* wt**	**FYLD**	**HI**	**DM**	**shtwt**	**Rtno**	**Rtsz**
mcbbs	1	-0.34^{***}	-0.14^{**}	-0.14^{***}	-0.01^{***}	-0.02^{ns}	-0.31^{***}	-0.15^{***}	-0.57^{***}	-0.39^{***}	-0.28^{***}	-0.23^{***}	0.27^{***}	-0.19^{***}	-0.06^{ns}	1
mcmds	-0.32^{***}	1	0.19^{***}	0.03^{ns}	0.01^{ns}	-0.05^{ns}	0.18^{***}	0.02^{ns}	0.52^{***}	0.29^{***}	0.13^{***}	0.12^{**}	-0.24^{***}	0.08^{ns}	-0.02^{ns}	-0.32^{***}
mcads	0.19^{***}	-0.06^{ns}	1	-0.049^{ns}	-0.455^{***}	0.19^{***}	-0.03^{ns}	-0.54^{***}	0.29^{***}	0.01^{ns}	-0.29^{***}	-0.01^{ns}	-0.05^{ns}	-0.21^{***}	-0.28^{***}	0.19^{***}
chlrphy	0.09^{ns}	-0.02^{ns}	-0.19^{***}	1	-0.15^{***}	0.19^{***}	0.23^{***}	0.11^{**}	0.08^{ns}	-0.18^{***}	0.25^{***}	0.05^{ns}	-0.14^{***}	0.19^{***}	0.19^{***}	0.09^{ns}
stomata	0.11^{***}	-0.28^{***}	0.08^{ns}	0.27^{***}	1	-0.11^{***}	0.01^{ns}	0.55^{***}	-0.32^{***}	0.26^{***}	-0.04^{ns}	-0.11^{**}	-0.04^{ns}	0.029^{ns}	-0.15^{***}	0.11^{***}
stgth	0.12^{***}	0.19^{***}	-0.21^{***}	-0.24^{***}	-0.23^{***}	1	0.24^{***}	0.25^{***}	-0.1^{*}	-0.63^{***}	0.24^{***}	-0.12^{**}	-0.16^{***}	0.55^{***}	0.49^{***}	0.12^{***}
pltht	0.18^{***}	-0.15^{***}	0.19^{***}	-0.05^{ns}	0.12^{**}	-0.28^{***}	1	0.41^{***}	0.68^{***}	0.18^{**}	0.49^{***}	0.09^{*}	-0.25^{***}	0.54^{***}	0.37^{***}	0.18^{***}
Nnode	0.24^{***}	0.49^{***}	0.029^{ns}	-0.14^{***}	-0.01^{ns}	0.13^{***}	-0.39^{***}	1	-0.17^{***}	0.07^{ns}	0.44^{***}	-0.08^{*}	-0.19^{***}	0.56^{***}	0.33^{***}	0.24^{***}
LA	0.22^{***}	0.37^{***}	0.55^{***}	-0.04^{ns}	0.05^{ns}	-0.29^{***}	0.29^{***}	-0.57^{***}	-0.22^{***}	0.18^{**}	0.09^{*}	-0.01^{ns}	0.01^{ns}	0.31^{***}	0.06^{ns}	0.22^{***}
Nleaf	-0.01^{ns}	0.33^{***}	0.54^{***}	-0.16^{***}	-0.11^{**}	0.25^{***}	0.01^{ns}	0.52^{***}	1	0.58^{***}	0.46^{***}	0.31^{***}	-0.35^{***}	0.26^{***}	0.12^{**}	-0.01^{ns}
Gari wt	0.40^{***}	0.06^{ns}	0.56^{***}	-0.25^{***}	-0.12^{**}	-0.04^{ns}	-0.18^{***}	0.29^{***}	-0.15^{***}	1	0.23^{***}	0.35^{***}	0.40^{***}	-0.09^{ns}	-0.12^{*}	0.40^{***}
Fyld	0.17^{**}	0.12^{**}	0.31^{***}	-0.19^{***}	0.09^{*}	0.24^{***}	0.26^{***}	0.08^{ns}	0.02^{ns}	-0.31^{***}	1	0.43^{***}	-0.09^{***}	0.79^{***}	0.77^{***}	0.17^{**}
HI	0.43^{***}	-0.12^{*}	0.26^{***}	0.01^{ns}	-0.08^{*}	0.49^{***}	-0.63^{***}	-0.32^{***}	-0.54^{***}	0.18^{***}	-0.02^{ns}	1	0.05^{ns}	-0.06^{ns}	0.24^{***}	0.43^{***}
DM	0.26^{***}	0.77^{***}	-0.09^{ns}	-0.35^{***}	-0.01^{ns}	0.44^{***}	0.18^{**}	-0.1^{*}	0.11^{**}	-0.03^{ns}	-0.05^{ns}	-0.01^{***}	1	-0.17^{***}	-0.02^{ns}	0.26^{***}
shtwt	-0.27^{ns}	0.24^{***}	0.79^{***}	0.40^{***}	0.31^{***}	0.09^{*}	0.07^{ns}	0.68^{***}	0.55^{***}	0.23^{***}	0.19^{***}	0.01^{ns}	-0.14^{***}	1	0.78^{***}	-0.27^{ns}
rtno	0.39^{***}	-0.02^{ns}	-0.06^{ns}	-0.09^{***}	0.35^{***}	0.46^{***}	0.18^{**}	-0.17^{***}	0.25^{***}	0.01^{ns}	0.19^{***}	-0.455^{***}	0.03^{ns}	-0.14^{**}	1	0.39^{***}
rtsz	1	0.78^{***}	-0.17^{***}	0.05^{ns}	0.43^{***}	0.23^{***}	0.58^{***}	-0.22^{***}	0.41^{***}	0.24^{***}	-0.11^{***}	-0.15^{***}	-0.049^{ns}	0.19^{***}	-0.34^{***}	1

****,**,*: significant at ($p \leq 0.001$, 0.01 and 0.05) while ns represents not significant at ($p \leq 0.05$), cbbs: cassava bacteria blight mean severity, cassava mosaic disease severity, cads: cassava anthracnose disease severity, chlrphy: chlorophyll, stmata: stomata, stmgrt: stem-girth, ptlht: plant height, LA: leaf area, fyld: fresh yield, Nleaf: Number of leaves, HI: harvest index, DM: Dry Matter, Nroot: Number of roots, rtsz: root size, shtwt: shoot weight,* Gari *wt:* Gari *weight.*

Table 9.
Correlation coefficient for morphological, physiological, yield, and related traits of 12 cassava genotypes evaluated for 2 years at three locations in Nigeria.

yield by 32–60%. Shoot weight at 25% F.C. was also reduced by 22.4%. Reduction in plant height was 29.3%, leaf chlorophyll content was reduced by 17.7%, leaf number had a reduction of 28.9%, whereas stem girth had a reduction of 15.4%. The implication is that moisture stress could hinder the manifestation of the genetic potentials of cassava. Therefore, a variety that is the best for a trait offers the opportunity (genetic base) for improving such trait through selection or hybridization and further selection. Even with significant differences in the traits that should contribute to root yield, fresh root weight was still not significantly different among genotypes. This also goes along with the result of the screen house experiment by [7]. The presence of the tonoplast sugar transporter (for roots and tubers) to transport the assimilates from the source to the sink (roots) enhances root formation and development. If not, the yield would not be significantly different as shown in this result. Ludewig and Flügge [31] and Cho *et al.* [32] also report similar observations. There should be continued work on several of the implied and not yet confirmed transport steps within plants, which frequently turn out to be the rate-limiting step to production of valuable compounds in storage sinks.

Plants respond to drought conditions either by increasing or decreasing their root growth.

Relatively higher stomata conductance observed in most genotypes in this study implies that the genotypes would have high photosynthetic potential although not translated to the highest levels of dry matter and root yield. The essence is that this attribute alone might not be a strong contributor to high yield under water-limited conditions. Measurements of leaf diffusive resistance reflected bulk resistance to water loss, combining activities of both the stomata and genotypes. In the dry savannas, genotypes with the ability to optimize water use are desirable due to limited availability of cultivable soil during the dry season [33]. A major component parameter associated with high Water Use Efficiency (WUE) is rapid stomata closure. Generally, stomata resistance of all the genotypes was low in the morning but increased in the afternoon and showed an increase in response to light and vapor pressure deficit (VPD) [34]. The morphophysiological responses to drought stress increases abscisic acid (ABA) concentration, ion transport, and the induction of the associated signaling pathway genes in plant, which in turn increases root resistance by affecting membrane permeability and root tuberization [14]. The rapid reduction in leaf area growth and stomatal closure might be due to cassava's ability to rapidly synthesize and accumulate ABA at an early phase of a water deficit episode [15].

Plants obtained energy and virtually all their structural materials by photosynthesis and the leaves are the main photosynthetic organ. Jarvis and Morison [35] and Akparobi *et al.* [36] had similar results. This may indicate that the higher the number of photosynthetic organs, the higher the photosynthetic rate. In this study, correlation between leaf number and root yield was positive and significant. Also, chlorophyll, harvest index, and plant height correlated positively with leaf number.

However, genotypes IITA-TMS-IBA30572 and IITA-TMS-IBA980510 with higher leaf numbers yielded less than IITA-TMS-IBA980581, which had fewer leaves. High leaf number in these genotypes is largely due to their branching habit. Shoot apices and storage roots compete for available carbohydrate in cassava [37, 38]. The high number of branches (level 2) may have caused higher competition for available carbohydrate in IBA30572 than in the other improved genotypes, which probably reduced the root yield in the former genotype despite its high number of leaves. Experiments have shown that production (formation) and growth (elongation) of cassava's adventitious and lateral roots are suppressed by deficit in soil moisture [7, 39].

The higher leaf area observed in genotype IITA-TMS-IBA011663 did not translate to higher root and dry matter yield. This did not go along with the results of Enyi [37] and [40]), who observed that high yielding cultivars had high leaf area but also validated the findings of (Ludewig and Flügge [31] and Cho *et al*. [32] that a plant with a good number of stems, better plant height, enough leaf chlorophyll content without the presence of the tonoplast sugar transporter (for roots and tubers) that transports the assimilates from the source to the sink (roots) will not translate to high yields as shown in this result. This might suggest that other parameters of canopy function such as leaf, carbon fixation, and assimilate use and partition could interact significantly in yield formation. Among the improved genotypes, IITA-TMS-IBA011663 possibly partitioned the highest amount of dry matter into leaves, petioles, stems, and fibrous roots and was not the highest in root yield; thus, partitioning of dry matter partially explained the lower yield of IITA-TMS-IBA011663 than in other improved genotypes even though its L.A. was higher.

A better value was observed for stay-green in the improved genotypes IITA-TMS-IBA010040 and IITA-TMS-IBA980581 compared with the value in the local variety TME 1. This implies that the improved genotypes would be expected to be more efficient in supporting photosynthesis, stomata conductance, and carbon fixation. The better stay-green values for IITA-TMS-IBA010040 and IITA-TMS-IBA980581 may be a contributor to their root yield being the best compared with TMEB1, which had the overall worst root yield and the worst stay-green value. However, this finding does not go along with the finding by Oluwafemi *et al*. [41], which reported that the local variety with high stay-green yielded better than the improved ones.

The lower values that were observed in CMD for new improved genotypes IITA-TMS-IBA980581, IITA-TMS-IBA010040, and IITA-TMS-IBA010034 compared with the checks (local variety TMEB1 and the old-improved varieties IITA-TMS-IBA30572) implied that the new improved genotypes would have healthy clean leaves for better photosynthesis compared with the local variety and the old-improved genotypes. This might be a contributing factor for these genotypes exhibiting better root yields than the old but improved varieties while the local variety had the worst root yield. Cassava mosaic disease was positively correlated with plant height, *Gari* weight, harvest index, root size, and fresh root yield, whereas CBB was negatively correlated with yield and yield-related traits such as harvest index, plant height, chlorophyll, stomata, root size, and root number.

The significant positive correlations that existed between storage root yields and harvest index indicated that these traits were important in improving root yield. Makame [42] also reported a strong association between storage root yield and root size, while the works of (Radhakrishnan and Gopakumar [43] and Rubaihayo *et al*. [44] also revealed a strong association between storage root yield and harvest index.

Dry matter in this study was not correlated with storage root yield, thus signifying that dry matter was not an important indicator of storage root yield. Similar observations were also made by Ntawuruhunga [45], Varma and Mathura [46] and Makame [42]. Stomata conductance also showed negative association with storage root yield, indicating this was not an important index of yield. Selections in favor of any of these traits would result in simultaneous decrease in root yield. Negative association between root yield and other traits has also been reported by Makame [42] and Rubaihayo *et al*. [44].

The high variation that was observed in this study for storage root yield across the different environments indicated that these environments differed greatly as reflected in each location being categorized as a unique agro-ecological zone. The expression of yield, therefore, depends on the genetic factors and on the environmental factors. The genetic factors, which promoted yield, will only be able to express themselves to full capacity when the environmental conditions needed for its expression are found and where this is limiting, yield will be reduced.

Furthermore, effect of storage roots on storage root yield appeared to be positively influenced by root size, root number, and harvest index. [47] made similar assertions and reported that yield increase was mainly due to increase in both numbers of storage roots and individual root weight. Mahungu [48], however, observed that number of tuberous roots contributed more to the final yield than root size. Radhakrishnan and Gopakumar [43] also observed that a high value for harvest index indicated a correspondingly higher yield for storage roots. These three characters can thus be regarded as the most reliable components of yield for selection of high yielding genotypes. A similar assertion was made by [47], who reported that storage root number was more closely correlated with root dry weight than with the individual weight of storage roots and consequently yield increase was mainly due to increase in both numbers of storage roots and individual root weight. Storage root yield, number of storage roots, and root sizes had the greatest contribution to total observed variability, thus suggesting that these characters were the most important of all that were evaluated and improvement on them will lead to improvement in yield and hence, bring progress in crop improvement. The plant breeders and agronomists are, however, interested not only in high yields but also on the ability of genotypes to produce such high yields across diverse environments over several years. Therefore, breeders are interested in identifying genotypes that are stable across environments as well as those that are well adapted and suitable for a specific agro-ecology [49, 50]. Results from the field experiment were able to identify IITA-TMS-IBA980581, IITA-TMS-IBA010034, and IITA-TMS-IBA010040 as having good drought tolerance.

This experiment explained the use of eco-physiological research to improve the genetic base and develop clones that are more adaptable to the drought environments of the tropics. Interdisciplinary research that combines physiology and breeding approach will help in selection of good varieties for release since the performance of a genotype is a function of its adaptability and the availability of conducive environment along with better genetic composition.

Further research is needed and investigation on nutrient transportation, the effect of source and sinks, and their relationship as these affect yield.

Acknowledgements

The authors thank the technical staff of International Institute of Tropical Agriculture (IITA) cassava breeding program that assisted with the fieldwork, screen house evaluation, and laboratory analyses. We also extend our appreciation to the Bill & Melinda Gates Foundation and the United Kingdom's Foreign, Commonwealth & Development Office (FCDO) for funding this research through the "Next Generation Cassava Breeding Project."

Contributions

ANA, conceived, designed the study, implemented field trials, performed analyses, and wrote the manuscript, ANA and SM, performed analysis. SM, edited the manuscript, generated, and curated data.

Funding

This research work was generously funded by the Bill & Melinda Gates Foundation and the United Kingdom’s Foreign, Commonwealth & Development Office (FCDO) through the “Next Generation Cassava Breeding project” (award number OPP1048542) managed by Cornell University.

Declaration of interest

The authors have not declared any conflict of interest.

Data availability statement

All relevant data supporting findings in this study are available on request from the corresponding author.

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