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Genetic variability in storage root bulking of cassava genotypes under irrigation and no irrigation

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Abstract

Background: Early bulking in cassava (*Manihot esculenta* Crantz) is a very important trait in semi-arid ecologies of the tropics. Farmers tend to select early-maturing cassava varieties to escape terminal drought and destruction by domestic animals during the dry season. However, early harvesting is associated with yield penalty due to unavailability of high-yielding early-maturing cassava varieties. In order to develop early-bulking cassava varieties for the savanna ecologies, this study was carried out to assess genetic variation in the pattern of storage root bulking and as well as traits associated with early storage root bulking under moisture stress and well-watered conditions.

Methods: Twenty cassava genotypes were arranged in a randomised complete block design with three replications under irrigation and no irrigation. The genotypes were sequentially harvested at 6, 8, 10 and 12 months after planting to study their pattern of dry matter accumulation. Irrigation water was supplied using a drip irrigation system with a discharge capacity of 1.6 l/h.

Results: Analysis of variance indicated significant effect of genotype, harvesting time and irrigation on most of the yield traits studied. The interaction between genotype and irrigation effect was significant for all traits except mean storage root weight, storage root girth, storage root length and storage root dry matter content. Apart from storage root girth and storage root dry matter content, genotype × harvesting time interaction was not significant. Pearson correlation analysis of root yield at different times showed significant positive correlation between early storage root yield and final root yield indicating the possibility of selecting early-bulking genotypes with high yield potential.

Conclusion: The study indicated that dry matter is partitioned more for root elongation than expansion in root girth under moisture stress conditions compared with irrigation, resulting in high storage root length: girth ratio. This ratio can be used to study the pattern of photosynthates accumulation in cassava roots under stress conditions. The study helped to provide improved understanding of the genetic basis and the mechanism of storage root bulking in cassava under moisture stress conditions, which can be exploited to develop high-yielding cassava varieties for drought-prone areas to ensure food security.

Keywords: Cassava (*Manihot esculenta* Crantz), Early bulking, Moisture stress, Photosynthates accumulation, Storage root length: girth ratio

Background

Cassava (*Manihot esculenta* Crantz) has the ability to grow in marginal ecologies where other crops fail [1, 2].

In the tropics, the starchy roots provide a major staple for millions of people, especially rural dwellers [3, 4]. Several studies have attributed cassava's ability to grow in these ecologies to its hardiness and ability to tolerate dry conditions through enhanced water-use efficiency [1, 4, 5]. Many cassava varieties are drought tolerant, resistant to

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most diseases and pests and can survive in harsh environments [6].

Cassava is naturally a perennial shrub but has been grown for its starchy roots on annual basis [2, 7, 8]. The duration of the crop depends on the growing conditions and the environment [8, 9]. Wahid et al. [10], however, indicated that plant responses to environmental stress vary and depend on the species and phenological stages. Partitioning of dry matter is directed either towards shoot production or root production depending on the environmental conditions [4, 7]. This has led to different times of maturity for different cassava genotypes with some maturing earlier than others [11, 12]. For instance, it is harvested early in hot humid climates but grown for up to 2 years in cooler or drier areas. These hot and dry environments are often characterised by 4–5 months of rainy season followed by a long dry season lasting up to 7 months. Farmers therefore adopt crop varieties that fit into the short growing season. According to Annor-Frempong [13], early maturity was the most frequent attribute desired by farmers in the transitional ecological zone of Ghana. Several studies have revealed that late bulking is the single most important reason for the rejection and abandonment of cassava varieties in African countries [13–16]. Late-bulking cultivars occupy land for extended periods of time, and consequently the land cannot be effectively utilised for the sequential cultivation of other crops.

Early storage root yield (bulking) in cassava has also been identified as a very important trait in drought tolerance [14, 17]. In some cases, earliness enables escape from late season droughts, pests and diseases and is perceived as a key control strategy for cassava brown streak disease (CBSD), which is currently epidemic in east, central and southern Africa [8, 16, 18, 19]. It is also important in situations where pressure on agricultural lands forces farmers to intensify production and harvest their crops after only one cycle of rain, particularly in semi-arid regions. However, extreme earliness comes with a yield penalty due to a reduction in the period of dry matter accumulation [19]. Varietal selection, if done carefully, will be useful in identifying cassava varieties which partition dry matter into the storage roots at an earlier stage in order to minimise the yield loss due to early harvesting.

Efforts to develop early-bulking cassava varieties have been hampered by the absence of distinct indicators of the trait in cassava. Though Alves [7] reported that storage root bulking in cassava begins after sufficient shoot growth has occurred, Okogbenin and Fregene [11] suggested that certain cassava varieties undergo shoot growth and storage root bulking simultaneously. The efficiency of partitioning carbohydrates into shoots and storage roots

depends on environmental conditions that influence storage root growth. Under deficit moisture, root growth continues, whereas shoot growth is limited, resulting in higher root-to-shoot ratio [20]. This arises as a result of selective allocation of photosynthates below the soil surface to permit greater exploration of soil moisture while preventing water loss through the shoots [21]. Thus, most drought-tolerant crop varieties have been associated with deep root system and high root densities in addition to stomatal sensitivity to low moisture in the air in the case of cassava [2, 5, 22]. However, there is limited information on the relationship between these structural adaptations for drought tolerance and productivity in terms of storage root yield in cassava. This calls for an in-depth study into the relationship between the growth pattern of storage roots and productivity in cassava under limited moisture and well-watered conditions to assess the pattern on dry matter accumulation. Careful exploitation of the reported genetic variation in the rate and pattern of accumulation of dry matter in the storage roots [17, 23] has to be made to develop early-bulking cassava varieties with acceptable yields in savannah ecologies.

The aim of this study was to assess the genetic variability in storage root bulking under limited moisture and well-watered conditions.

Specific objectives were to:

1. determine genetic variation in storage root bulking
2. identify traits associated with early storage root bulking in cassava
3. determine the relationship between early dry matter accumulation in storage roots and final storage root yield.

Methods

Study site

The experiment was carried out at the CSIR-Savanna Agricultural Research Institute located at Nyankpala (9°25'N, 0°58'W) in the Guinea Savannah agro-ecological zone of Ghana. The Guinea Savannah zone covers over 40 % of the entire land area of Ghana and is characterised by high temperatures and low humidity for most parts of the year [24]. The rainfall pattern is monomodal and erratic with an annual mean of 1100 mm, which usually begins in April–May and ends in October. The area is also characterised by a long dry season (4–5 months), which normally begins in November and lasts till April. Intermittent dry spells, often lasting up to 2 weeks, also occur during the rainy season.

Germplasm and planting materials used for the study

Twenty cassava genotypes obtained from local and exotic sources were evaluated in this study. The genotypes were

selected based on storage root yield, storage dry matter content, harvest index and plant height in an earlier preliminary evaluation trial. They included six local landraces collected from farmers' fields, seven drought-tolerant genotypes collected from the International Institute of Tropical Agriculture (IITA) and seven varieties from the International Center for Tropical Agriculture (CIAT), Colombia.

Land preparation, experimental design and planting

The land was first slashed, ploughed and harrowed. The experiment was then laid out in a randomised complete block design with three replications in each of the irrigated and the no irrigation trials. Ridges were manually raised using a spacing of 1 m between adjacent ridges. Good quality cassava cuttings measuring 25–30 cm were planted on the top of ridges using within row spacing of 1 m. A plot consisted of four rows per genotype with 10 plants in a row. No fertiliser was applied to the trials, but weeds were controlled as and when necessary. Reshaping of ridges was done to prevent exposure of the roots.

Irrigation water application

During the dry season, irrigation was applied using a drip irrigation system until the rains began the following season. Drip holes spaced at 30-cm interval on each line had a discharge capacity of 1.6 l/h. This gave a discharge rate of 5.33 l/m²/h. Water was supplied twice a week for 4 h each day until May 2014 when the rains stabilised.

The irrigation commenced when visible signs of moisture stress appeared on the plants. No irrigation was applied to drought-stressed plots.

Data collection

Fresh storage root yield (t/ha) and yield components

Four sequential harvests were done at 6, 8, 10 and 12 months after planting (MAP) under both irrigation and no irrigation. At each harvest, number of storage roots per plant was recorded. Ten roots were purposefully selected from four plants and measured from one tip to the other with a tape to determine storage root length (cm). Storage root girth (cm) was also determined by measuring the widest portion of the same roots using vernier callipers. Storage root length: girth ratio was also calculated to determine the pattern of dry matter accumulation in the storage roots, for extension or expansion. Mean storage root weight (g) was determined from the weight of storage roots divided by the total number of storage roots harvested from each plot.

Storage root dry matter content

Storage roots were first chopped into pieces (about 1 cm thick) and mixed thoroughly. Afterwards, 100 g of each sample was taken and dried at 80 °C for 48 h and

weighed. Percentage dry matter content was obtained by expressing the dry weight as a percentage of the fresh weight of the sample taken.

Harvest index

Harvest index was estimated as the ratio of the storage root weight to the total biomass weight (shoots plus storage roots).

Data analysis

General analyses of variance were performed for all traits using the GenStat statistical package [25]. Irrigation and harvesting times were considered as fixed factors, whilst genotypes were considered as random factor. To estimate genotypic variability in storage root yield at different times under irrigation and no irrigation, harvest time, genotypes and their interactions were considered as independent factors. Pearson's correlation was used to determine relationships between storage root yield at different times and final storage root yield at 12 months after planting. Two sample t tests were performed to compare the mean performance of all genotypes under irrigation and no irrigation using the GenStat version 12.1 [25].

Results

Weather conditions during the period of the experiment

Total rainfall recorded over the experimental period was 1181.1 mm, whilst the evaporation was 1823.26 mm (Table 1). In addition, a total of 853.3 mm of water was applied to the irrigated plots. This gave a total quantity of 2034.43 mm of water for use by the plants under irrigation. Monthly fluctuations in rainfall, evaporation, relative humidity and temperature were observed during the study (Fig. 1). The highest amount of rainfall (217.4 mm) was recorded in August 2013, whilst no rain was recorded in December 2013 and January 2014. Average minimum temperature and maximum temperature for the entire season were 24.16 and 33.67 °C, respectively, with a mean of 28.71 °C. The highest monthly temperature is 37.5 °C that was recorded in March 2014, which also had an evaporation of 223.32 mm. There were fluctuations in the distribution of rainfall and evaporation. Monthly evaporation exceeded rainfall from November 2013 to May 2014. Relative humidity also declined from September 2013 to February 2014 before it started to rise again. Temperature fluctuations were also observed over the period of the experiment.

Analyses of variance for storage root yield and yield components

Highly significant ($P < 0.001$) genotype and irrigation treatment effects were observed for storage root yield (t/

Table 1 Total water and evaporation under irrigation and no irrigation

	Irrigation	No irrigation
Irrigation water applied (mm)	853.33	0.00
Amount of rainfall (mm)	1181.1	1181.10
Total water supplied	2034.43	1181.10
Evaporation (mm)	1823.26	1823.26

ha) and all yield components (Table 2). With the exception of number of storage roots per plant, harvest time had highly significant effect ($P < 0.001$) on storage root yield and yield components. Genotype by irrigation effect was highly significant ($P < 0.001$) on storage root yield (t/ha) and very significant ($P < 0.01$) for harvest index and significant ($P < 0.05$) for number of storage roots per plant. However, its effect on mean storage root weight

(g), storage root length (cm) and storage root dry matter content was not significant ($P > 0.05$). Interaction of genotype and harvest time effect was insignificant ($P > 0.05$) for yield and all yield components except storage root girth and dry matter content. Three-way interaction of genotype by irrigation by harvest time effect for all the root yield and yield components was not significant ($P > 0.05$).

Relationship among traits

Pearson correlation analysis indicated significant associations between most of the traits and storage root yield (Table 3). Storage root yield was positively correlated with all the traits except storage root length: girth ratio and storage root dry matter content, which were negative. The strongest correlated variable was storage root girth ($r = 0.78$), which was followed by mean storage root weight ($r = 0.69$), storage root length ($r = 0.36$),

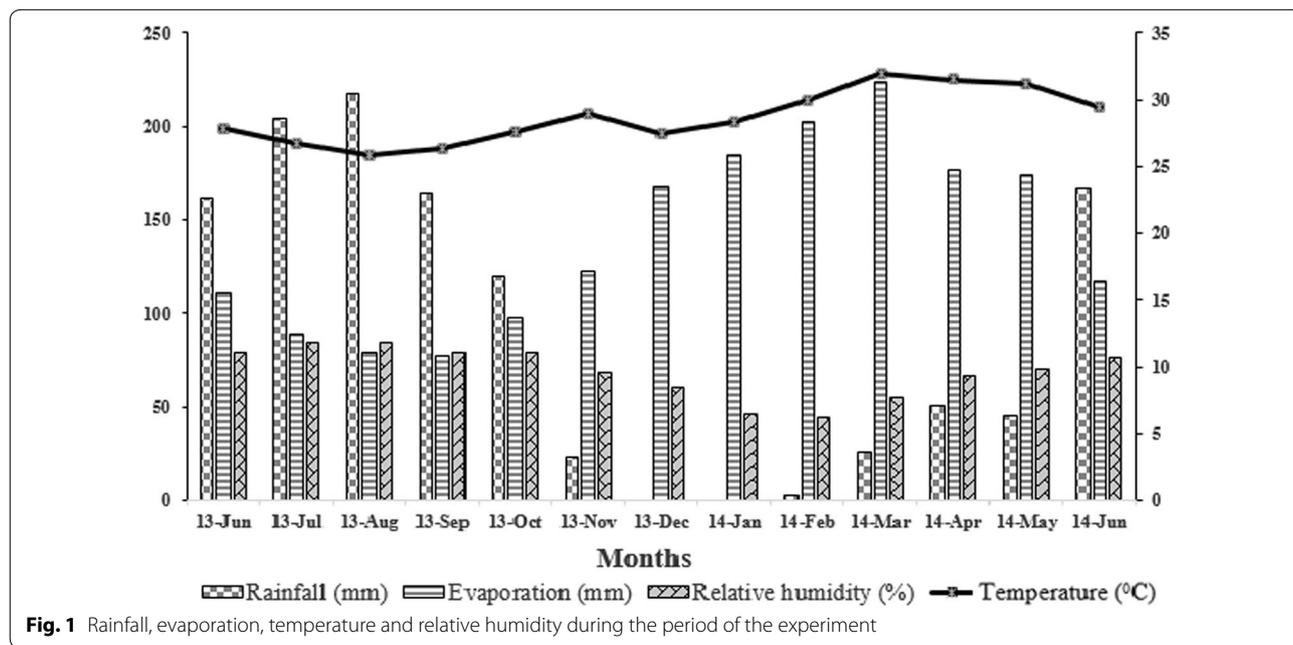


Fig. 1 Rainfall, evaporation, temperature and relative humidity during the period of the experiment

Table 2 Mean squares for storage root yield and yield components

Source of variation	Df	Rt_yld (t/ha)	HI	MRW (g)	Rt_girth [G] (cm)	Rt_length [L] (cm)	L/G ratio	Rt_no/plt	DM%
Genotype (G)	19	195.86***	0.094***	47741***	5.61***	443.69***	69.73***	37.29***	140.18***
Irrigation (I)	1	2047.91***	0.039***	269826***	93.69***	3235.29***	1389.10***	192.22***	87.85***
Harvest time (H)	3	2705.53***	0.216***	392571***	143.83***	3709.37***	156.79***	3.40NS	880.85***
Gxl	19	23.91***	0.007**	6158NS	0.72***	33.39NS	9.61**	8.04*	10.52NS
GxH	57	12.01NS	0.003NS	3757NS	1.13***	32.85NS	4.72NS	3.02NS	11.96**
GxIxH	57	6.99NS	0.003NS	4471NS	0.68NS	34.52NS	4.54NS	2.98NS	7.764NS
Error	308	9.21	0.003	3881.00	0.60	33.40	4.11	4.86	7.46

***, ** P < 0.05, P < 0.01, and P < 0.001, NS Not significant (P > 0.05). Rt_yld (t/ha), storage root yield (t/ha); HI, harvest index; MRW (g), mean storage root weight (g); Rt_girth (cm), storage root girth (cm); Rt_length (cm), storage root length (cm); L/G ratio, storage root length: girth ratio; Rt_no/plt, number of storage roots per plant; DM%, storage root dry matter content (%)

Table 3 Correlation among storage root yield and other yield components

	1	2	3	4	5	6	7	8	
Rt_yld (t/ha)	1	-							
HI	2	0.18***	-						
MRW (g)	3	0.69***	0.32***	-					
Rt_girth [G] (cm)	4	0.78***	0.13**	0.71***	-				
Rt_length [L] (cm)	5	0.36***	0.09NS	0.40***	0.29***	-			
L/G ratio	6	-0.45***	-0.02NS	-0.37***	-0.62***	0.45***	-		
Rt_no/plt	7	0.24***	-0.16***	-0.26***	0.05NS	-0.08NS	-0.09*	-	
DM %	8	-0.28***	0.04NS	-0.15***	-0.26***	-0.30***	0.11*	-0.03NS	-

***, ** P < 0.05, P < 0.01, and P < 0.001, NS not significant (P > 0.05). Rt_yld (t/ha), storage root yield (t/ha); AGB (t/ha), above ground biomass (t/ha); HI, harvest index; MRW (g), mean storage root weight (g); Rt_girth (cm), storage root girth (cm); Rt_length (cm), storage root length (cm); L/G ratio, storage root length: girth ratio; Rt_no/plt, number of storage roots per plant; DM%, storage root dry matter content (%)

storage root number per plant ($r = 0.28$) and harvest index ($r = 0.18$). The correlation between storage root yield and storage root girth ($r = 0.78$) was stronger than between root yield and root length ($r = 0.36$). Root length to girth ratio had negative correlation with most of the traits that were positively correlated with storage root yield. Analysis of the relationship between storage root length: girth ratio under no irrigation, irrigation and combined analysis gave a negative slope (Fig. 2). The coefficients of determination (r^2) were 0.25 under irrigation, 0.13 under no irrigation and 0.30 in the combined analysis.

Performance of genotypes

Significant differences ($P < 0.05$) in storage root yield were observed for genotypes at the different harvesting times under irrigation and no irrigation (Table 4). Mean storage root yields at six MAP for all genotypes were 10.54 and 10.91 t/ha under irrigation and no irrigation, respectively. Genotype 96/1708 had the highest storage root yield (19.25 t/ha) under irrigation, whilst CTSIA 48 had the lowest (7.0 t/ha). Under no irrigation, root yield ranged between 7.5 and 17.0 t/ha for *Biabasse* and 96/1708, respectively. Mean storage root yield under irrigation increased to 14.47 t/ha at 8 MAP, whilst under no irrigation, it only increased to 12.28 t/ha. Storage root yields varied from 10.17 t/ha for CTSIA 48 to 22.25 t/ha for 96/1708 under irrigation. Under no irrigation, root yields ranged between 9.08 and 18.0 t/ha for CTSIA 48 and 96/1708, respectively. Storage root yield rankings of genotypes changed at 10 MAP under irrigation and no irrigation. The highest root yield (25.67 t/ha) under irrigation was obtained from 00/0203 with CTSIA 48 giving the lowest root yield (12.08 t/ha). Under no irrigation, 96/1708 had the highest storage root yield of 19.67 t/ha whilst CTSIA 48 had the lowest (11.42 t/ha) at 10 MAP.

Average storage root yields at 12 MAP were 16.39 and 26.58 t/ha under no irrigation and irrigation, respectively. Five genotypes (96/1708, I91934, TME 419, 00/0203

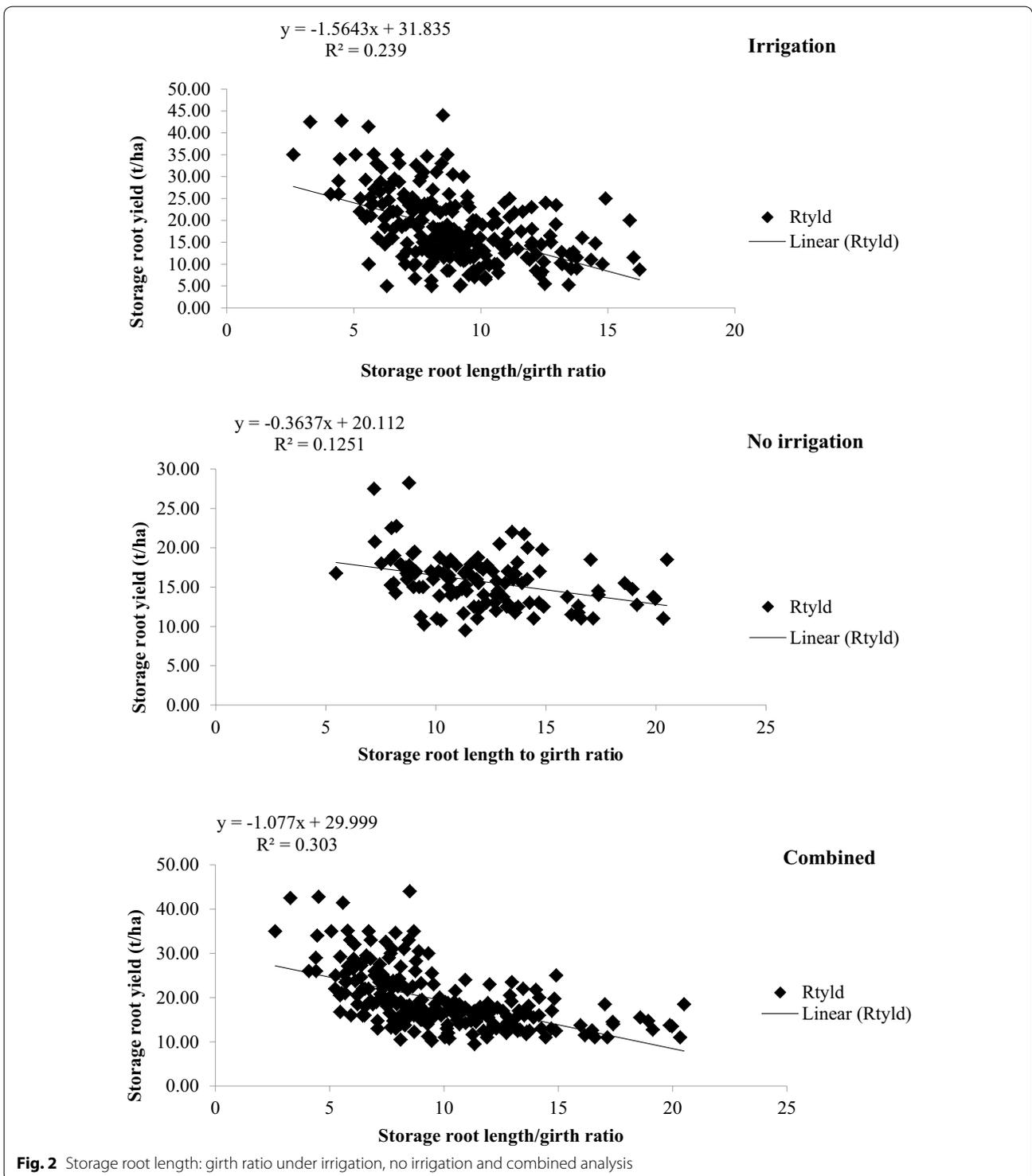
and UCC2001/449) had significantly higher storage root yield than the best local farmer preferred variety, *Pontisange*, under irrigation. Two genotypes, I91934 and UCC2001/449, also had significantly higher storage root yield than *Pontisange* under no irrigation. Genotype 96/1708 had the highest root yield under irrigation (38.25 t/ha), whilst CTSIA 48 had the lowest yield (19.0 t/ha). Under no irrigation, I91934 had the highest yield (21.67 t/ha) and CTSIA 48 had the lowest (11.08 t/ha).

Pattern of fresh storage root yield and dry matter accumulation in roots

There was an increase in root bulking during the course of the experiment (Fig. 3). Storage root bulking rate was slow under no irrigation when compared with the rate under irrigation. There was only a marginal increase in mean storage root yield from 8 MAP to 12 MAP under no irrigation. Storage root dry matter content (%) was fairly stable under irrigation but declined sharply from 8 MAP to 12 MAP under no irrigation (Fig. 4).

Relationships between storage root yield at different harvests and final root yield (12 MAP)

High phenotypic correlations were observed between storage root yields at different harvest times and the final storage root yields under no irrigation and under irrigation. The strongest correlation with final root yield under no irrigation was storage root yield at 10 MAP (Fig. 5). A large proportion of the dry matter obtained at the final harvest under stress was dependent on what was accumulated during the first few months (6–8 MAP) before the stress period. However, storage root yield at 12 MAP under no irrigation depended more on the yield at 10 MAP ($r^2 = 0.8$). However, under irrigation, storage root yield at final harvest depended on the entire activities by the plants before the final harvest. Significant genotypic variations were again observed in the rate of storage root bulking when storage root yield at the different harvests was expressed as a percentage



of the final storage root yield at 12 MAP under irrigation and under no irrigation (Table 5). At 6 months after planting, most of the genotypes had accumulated more than 50 % of their final storage root yield at 12 MAP under no irrigation but only four genotypes (96/1708,

CTSIA 110, CTSIA 230 and TME 435) had produced 50 % or more of their final storage root yield under irrigation. At six MAP, genotype 96/1708 had accumulated 55.8 and 81 % of its final root yield under irrigation and no irrigation, respectively.

Table 4 Storage root yield (t/ha) of 20 cassava genotypes at different harvest times under irrigation and no irrigation

Genotypes	Storage root yield (t/ha)							
	6 MAP		8 MAP		10 MAP		12 MAP	
	Irri	No irri	Irri	No irri	Irri	No irri	Irri	No irri
00/0203	9.08	11.67	14.50	12.17	25.67	15.50	33.56	16.00
96/1708	19.25	17.00	22.25	18.00	24.33	19.67	38.25	20.75
96/409	10.33	12.75	15.42	13.50	18.67	15.33	28.42	17.46
ATR 002	9.42	8.67	12.50	11.50	16.92	15.42	25.33	16.50
ATR 007	9.42	8.42	12.25	10.92	15.58	13.00	23.08	13.38
Biabasse ^a	7.75	7.50	11.42	9.92	17.33	12.92	23.50	14.33
CTSIA 110	12.17	8.42	13.83	11.17	15.50	14.00	21.50	14.72
CTSIA 112	10.83	11.25	13.83	13.33	15.75	15.58	26.42	16.17
CTSIA 230	10.83	10.60	14.83	11.42	15.92	13.50	21.67	14.58
CTSIA 45	8.83	9.67	13.75	10.60	17.92	12.50	25.63	14.58
CTSIA 48	7.00	7.67	10.17	9.08	12.08	11.42	18.29	11.08
CTSIA 65	8.50	9.92	10.92	11.33	14.67	12.42	20.46	13.42
CTSIA 72	7.67	8.08	11.42	9.34	16.42	12.24	20.75	14.96
I91934	12.83	11.17	20.83	13.83	25.50	18.83	37.42	21.67
MM 96/1751	10.75	12.83	14.67	14.75	23.42	16.92	29.29	19.97
NWA 004	8.75	12.50	12.83	13.27	17.50	15.00	21.75	15.96
Ponstisange ^a	8.58	11.42	12.75	14.02	18.33	15.62	25.50	16.83
TME 419	11.83	11.42	18.42	13.17	22.08	16.25	33.54	17.50
TME 435	14.83	12.83	18.00	13.33	20.00	14.67	29.50	15.75
UCC 2001/449	12.17	13.33	14.83	14.58	24.08	17.50	33.38	21.25
Mean	10.54	10.91	14.47	12.28	18.88	14.91	26.58	16.34
SED	1.07	0.88	1.09	1.07	1.66	0.85	2.98	2.11
t (cal)(means)	NS		2.33		3.90		7.45	
t _{0.05(2), 38}	2.02		2.02		2.02		2.02	

^a Local farmer—preferred varieties, NS not significant (P = 0.706), Irri, irrigation; No irri, no irrigation

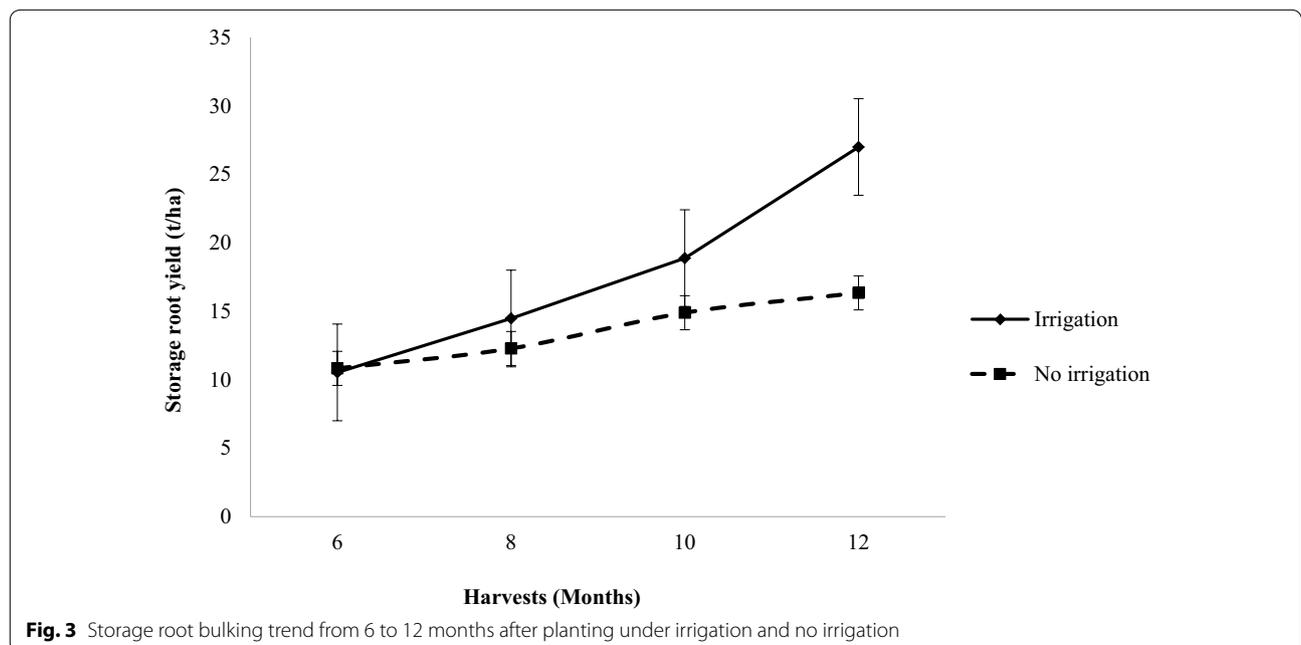
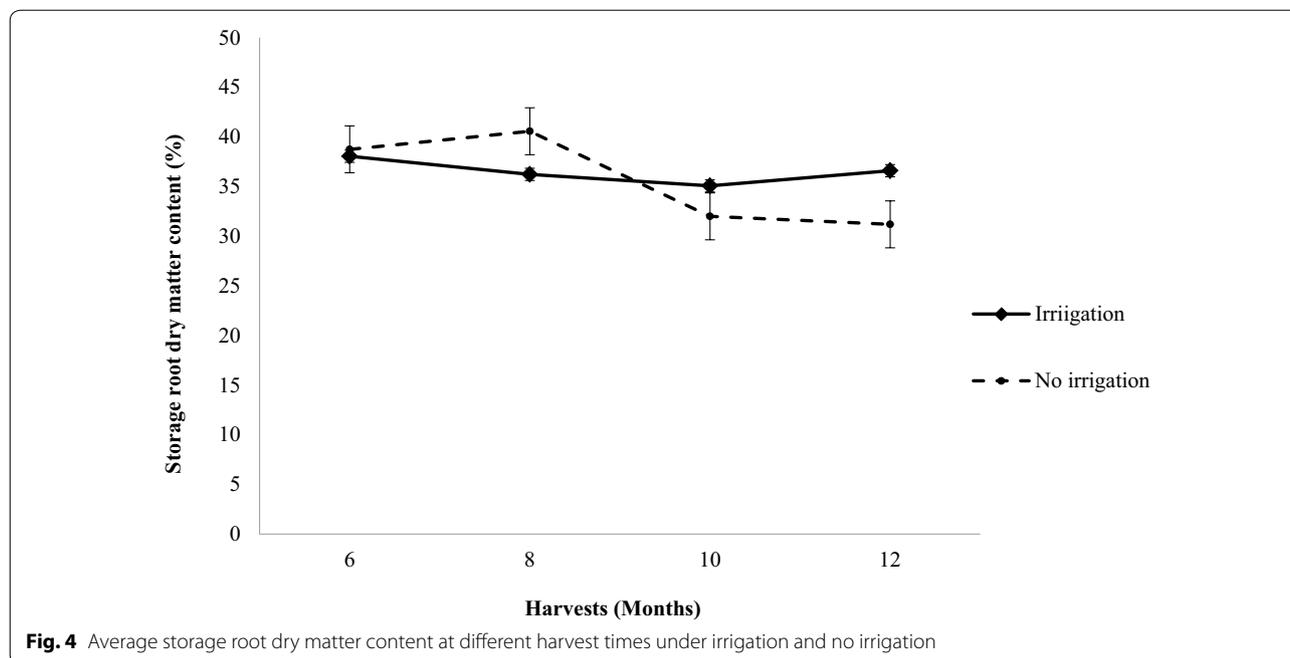


Fig. 3 Storage root bulking trend from 6 to 12 months after planting under irrigation and no irrigation



Discussion

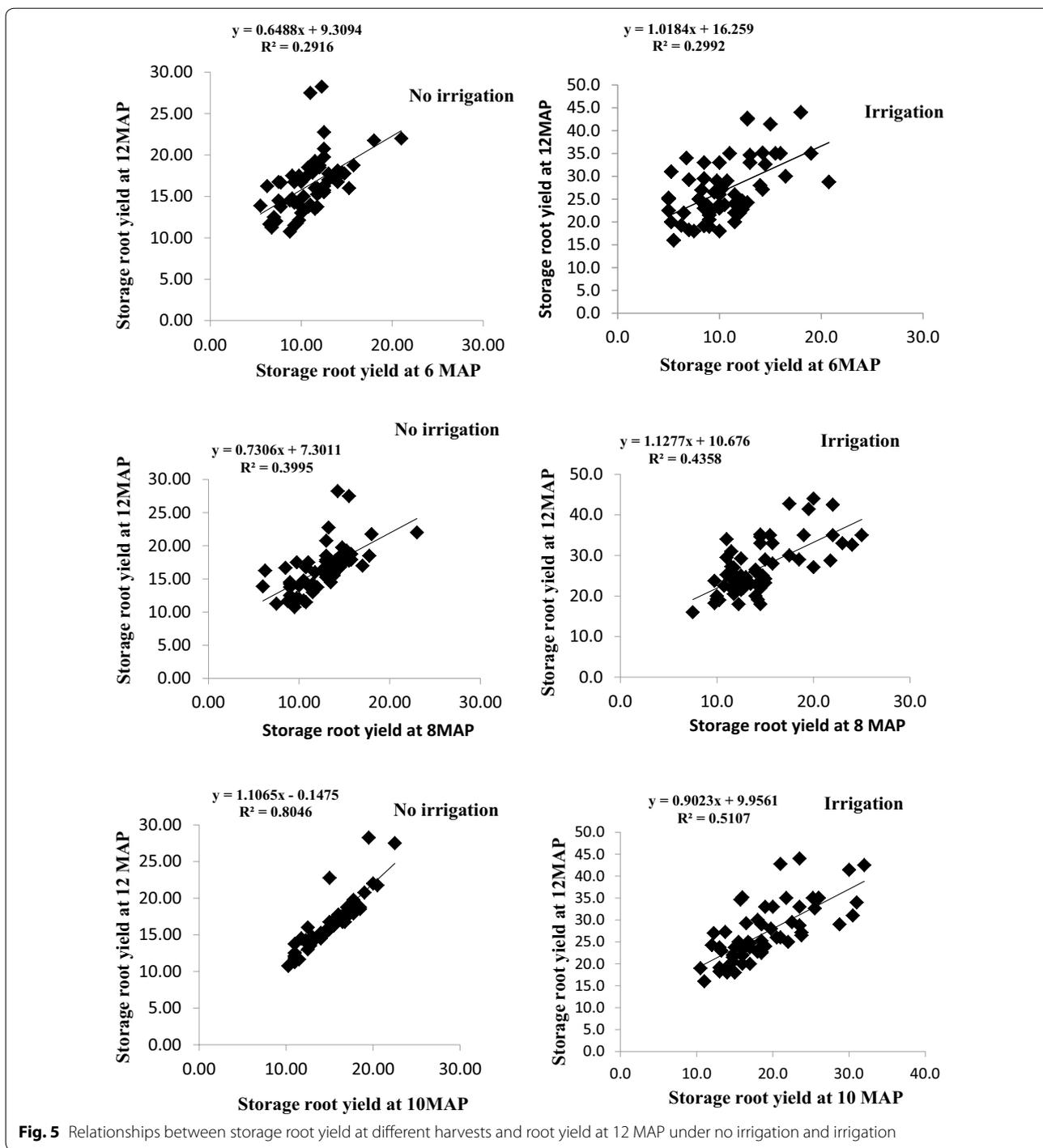
Pattern of storage root bulking

According to El-Sharkawy [4], cassava plants begin root bulking at 90 days after planting but roots become a major sink only between 180 and 300 days after planting. The cassava plant is naturally a perennial shrub and can grow indefinitely alternating periods of vegetative growth and root bulking [7]. However, the rate of storage root bulking in cassava varies over a long period due to prevailing changes in the environmental conditions [9]. The application of irrigation facilitated continuous accumulation of dry matter in the storage roots, which was not the case in the no irrigation plots. The rate of average dry matter accumulation was lower in the stressed plots, which confirms similar observations made by Bitai and Lian [26] in sweet potato. They found that early-maturing cultivars rapidly initiated storage roots development, thereby reaching their maximum yield within a short growing period. They also indicated that the bulking rate of storage roots of early-maturing cultivars declines in the early (or later) period of growth, whereas for the late-maturing cultivars, the bulking rate increases at the middle and later growth periods. Therefore, environmental conditions that curtail storage root bulking will adversely affect late-bulking genotypes compared with early-bulking genotypes due to their differential sink–source relationships at the different stages in their phenology [21]. Though most crops have specific phases in their phenology that can be targeted for improvement against drought, it has not been easy to do so for cassava due

to differential partitioning of dry matter into the above ground biomass and roots [4, 7]. High-yielding cassava cultivars have a high bulking rate over a long period of time, whereas cultivars with intermediate and low storage root yield have a low bulking rate of shorter duration or lower bulking rate for longer duration [17, 23].

Differential response of genotypes in storage root bulking was observed in this study, resulting in crossover interactions as some genotypes that had lower yield at 6 months had higher yield at 12 months than most of the ones that showed good yield at 6 months. This observation was contrary to the prediction by Hershey [23] and Okogbenin et al. [17] who indicated that productivity in cassava at six MAP can be used as a criterion to screen for high-yielding cassava varieties because early fresh storage root yielders are the higher yielders at later stages of growth. Genotypes that had low storage root yield at 6 months but high yield at 12 MAP might have used the above ground part as the major sink before partitioning materials into storage roots. El-Sharkawy [4] reported that distribution of carbohydrates to the different organs of cassava changes during the growth cycle, with the shoot being the major sink during the first 5 months and storage roots the major sink later. Previous study by Adjebeng-Danquah et al. [19] indicated that genotypes that partitioned dry matter production into storage roots earlier than others were able to bulk over 60 % of their final storage root yield by 6 months after planting.

Okogbenin and Fregene [11] linked high early storage root yield to genotypic variability in the rate of storage



root bulking. Fast bulking genotypes begin storage root development and shoots simultaneously, which varies from those of late- or slow-bulking genotypes, which develop sufficient above ground biomass before storage root bulking commences [4, 7]. Suja et al. [27] also indicated that differences in bulking rate and the period

over which bulking lasts are responsible for differences in high- and low-yielding cassava cultivars. Early-maturing genotypes exhibit maximum bulking rate during their early growth stages compared with late-maturing genotypes. This pattern depends on the growth conditions, particularly moisture, which may affect the choice of sink

Table 5 Storage root yield as percentage of final storage root yield at 12 MAP under irrigation and no irrigation

Genotypes	% of storage root yield at 12 MAP					
	6 MAP		8 MAP		10 MAP	
	Irri	No irri	Irri	No irri	Irri	No irri
00/0203	25.70	73.10	42.31	76.20	75.74	95.66
96/1708	55.80	81.00	64.20	85.91	69.81	95.05
96/409	36.30	72.80	53.70	77.11	64.51	87.47
ATR 002	36.80	52.50	49.11	68.05	65.9	93.09
ATR 007	41.00	64.00	53.41	81.71	67.78	96.95
<i>Biabasse</i> ^a	33.50	53.20	49.80	70.21	75.91	90.06
CTSIA 110	54.60	58.40	62.30	77.50	70.27	95.24
CTSIA 112	40.60	69.90	52.60	82.51	60.07	96.31
CTSIA 230	50.00	74.04	70.41	78.92	73.95	92.25
CTSIA 45	37.10	65.81	57.32	72.20	74.81	85.40
CTSIA 48	37.10	65.50	52.90	77.40	63.69	94.24
CTSIA 65	40.20	74.50	52.71	84.80	71.00	92.79
CTSIA 72	34.90	59.90	51.12	63.90	72.65	91.03
I91934	33.10	53.31	54.10	65.50	65.21	87.65
MM 96/1751	39.90	65.20	54.01	75.20	86.25	86.20
NWA 004	38.20	78.41	56.13	83.09	76.72	93.96
<i>Pontisange</i> ^a	34.70	68.51	52.40	81.31	72.61	91.64
TME 419	35.40	65.60	55.21	74.90	65.96	92.61
TME 435	51.80	81.70	62.40	84.70	69.00	93.20
UCC 2001/449	34.90	66.60	42.61	72.21	69.62	84.98
Mean	39.58	67.20	54.44	75.68	70.57	91.79
SED	6.12	10.40	8.42	12.56	11.23	12.65
t (cal)(means)	10.56		8.24		13.68	
t _{0.05(2), 38}	2.024		2.024		2.024	

^a Local farmer—preferred varieties; Irri, irrigation; No irri, no irrigation

[4, 20]. Different plant organs are affected differentially by stress conditions and could show different trends [28, 29].

The pattern of storage root development in this study varied among the genotypes under irrigation and no irrigation as shown by the trend in the storage root length:girth ratio. The pattern of storage root bulking under the different conditions indicates that in cassava, dry matter is partitioned for root elongation compared to expansion under stress. This corroborates the findings of El-Sharkawy et al. [30] who reported that cassava extends its roots to lower soil depths for moisture extraction under stress conditions. Storage root length:girth ratio was found to be negatively correlated with storage root yield, indicating that elongation of storage roots to lower depths could be detrimental to yield. This presupposes that the amount of photosynthates utilised for storage root growth was not as important as the pattern of accumulation, whether for elongation or for expansion in girth. Since the storage roots of cassava represent the economic part, utilisation of the photosynthates for

storage root expansion will be more beneficial for storage root yield. However, the significant genotypic variation observed for this trait means that genotypes with good partitioning efficiency for storage root expansion could be selected for further improvement. Though deeper storage roots may be good adaptation for survival under drought conditions in other crops [31–33], it could be detrimental in cassava if expansion in storage root girth is compromised. Root growth exhibits positive hydrotropism and gravitropism, therefore, there is a natural tendency for storage root extension to prevail over expansion due to the need to explore lower soil depths for moisture [21, 34]. The results of this study indicated that even though severe yield losses in cassava may occur due to moisture stress [22, 35, 36], genotypic variation exists in the extent of reduction due to variations in the pattern of photosynthesis accumulation.

Conclusion

Genotypes exhibited different storage root bulking patterns under irrigation and no irrigation. Genotype

96/1708 that had the highest yields from 6 MAP till 12 MAP is early bulking and can be a strong candidate for adaptation to the short rainy season of the Guinea savannah ecology. According to the findings of this study, genotypes that utilised photosynthates for storage root extension instead of expansion in storage root girth can survive under the drought conditions but root yield may be compromised. Significant genotypic variability exists for ratio of storage root length to storage root girth; therefore, it can be used as an index for selecting genotypes with the natural affinity for expansion is storage root girth even under limited moisture. Five genotypes (96/1708, 00/0203, I91934, UCC2001/449 and TME 419) produced storage root yields that were higher than the better widely cultivated local farmer—preferred variety (*Pontisange*) under irrigation, whereas two genotypes (I91934 and UCC2001/449) had better yields than the farmer preferred variety (*Pontisange*) no irrigation. These should be further tested to determine their broad adaptability and yield stability.

Abbreviations

AGRA: Alliance for a Green Revolution in Africa; CIAT: International Center for Tropical Agriculture; cm: centimetres; CSIR: Council for Scientific and Industrial Research; fig: figure; g: gram; IITA: International Institute of Tropical Agriculture; m: metres; MAP: months after planting; mm: millimetre; SED: standard error of the difference; t/ha: tons per hectare; l/h: litres per hour.

Authors' contributions

JAD is the principal investigator. VEG, SKO, IKA and JMA were the academic supervisors of the PhD Thesis research of the principal investigator. They provided technical advice in formulation of the research objectives, conducting the experiment and the review of the write up. All authors read and approved the manuscript.

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Competing interests

The authors declare that they have no competing interests.

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