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FORESTRY

Bulking Rate of Pro-Vitamin A Cassava (*Manihot esculenta Crantz*) Genotypes and the Effect of Locations on Root Yield Parameters at Southern Guinea Savannah and Forest Transition Agroecological Zone of Nigeria

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ABSTRACT

Human population is increasing at an alarming rate, so also the need for food production which necessitates clearing up new lands for cultivation. For most farmers, because of the existing land tenure system, manage to cultivate their existing farmlands most times in mixed cropping. Cassava farmers engage in piecemeal harvesting ultimately to make room for cultivation of other crop but the underlying reasons for doing this is as a result of longer time it takes for Cassava roots to achieve marketable root size and the problem of bush fires that affect their farms during the long stay of the crop on the farm in a bit to attain maturity. Hence, the need to provide farmers with cassava genotypes that bulks early so that they can be sure of reasonable marketable root sizes before the usual maturing time. This study evaluated cassava genotypes at different harvesting months of 3, 6, 9, and 12 months after planting (MAP) to evaluate their bulking rate at different agroecology of Mokwa and Ubiaja. Data were collected on Fresh Storage Root Yield (FSRY), Harvest Index (HI), and Dry Matter (DM) content. This study show that location was not significant on the fresh root yield and fresh root yield either decreases or increases after 3 months after planting (MAP) until 12MAP where it had the highest size. The genotypes with highest root yield across the months (IKN120036 and IBA090581) showed discontinuity in their root yield during their growth stage and the onset of rainfall reduces dry matter accumulation. Genotypes IBA090525, IBA070593, IBA141092, IKN120016 and IKN120036 maintained higher root yield at 6MAP when there was no rainfall than at 9MAP when there was rainfall. Root yield generally reduces at the onset of rainfall with corresponding reduction in dry matter. There was variability among the genotypes for yield related traits as fresh storage root yield (FSRY), harvest index (HI), and dry matter (DM) were significant at $P<0.001$, $P<0.001$ and $P<0.01$ respectively and MAP was significant for FSRY and DM. Early bulking may not necessarily be high yielding as shown in the study but may be exploited via selection and breeding for higher yields and this is because cassava genotypes vary in terms of dry matter accumulation at different months with environment (location) and dry matter accumulation reduced at 9MAP during the onset of rainfall while rainfall was higher in Ubiaja with higher root yield.

HIGHLIGHTS

- Dry matter reduces with rainfall.
- Discontinuity in root yield at some points in their growth stages had no effect on their final root yield at 12 MAP.
- Root yield generally increase at 12 MAP.

Keywords: Early bulking, dry matter, harvest index, fresh root yield, location

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Cassava provides dietary source of energy for millions of people particularly in Africa (Tize *et al.* 2021). For human well-being and health, there must be an adequate supply of food in terms of nutrition and calories. Due to the resilience of the crop and the ability to thrive and survive harsh weather condition, cassava portends itself as a "savior" crop (Amelework *et al.* 2021). However, the problem of malnutrition is being compounded by the versatility of cassava crop and its ability to thrive despite all odds which then makes farmers rely heavily on cassava root crops which is high in carbohydrates and low in other micronutrients, especially provitamin A carotenoid contents (Montagnac *et al.* 2009). Consumption of carbohydrate-rich cassava with low pro-vitamin A content could lead to the problem of malnutrition and hidden hunger as a result of insufficient intake, absorption or utilization of essential vitamins and minerals (Stephenson *et al.* 2010). The rapid population growth not only front up as a resultant negative effect on the rural poor farmers who are majorly subsistent farmers but also leads to land unavailability and this problem of population growth may lead to food insecurity and unavailability of lands for farming owing to the exponential growth rate and therefore farmers who prefer cassava varieties that can bulk and mature early for early harvest without occupying their farmland for an extensive period of time (Okechukwu & Dixon 2009). On the other hand, farmer's livelihood is being also hampered as a result of low yield therefore causing long stay of cassava on the field in a bid to attain reasonable yield before harvest and therefore, engaged in piecemeal harvesting in order meet their livelihoods. Another problem caused by late bulking and low yielding cassava is the challenges of cattle invasion owing to long staying of cassava on farmers' field. Late bulking cassava stays longer on farmers' field thereby exposing it to bush fires and animal invasion. High yielding and early bulking genotypes could guarantee higher yields when harvested at 12 MAP (Nweke 2004). Early bulking in cassava will provide farmers with cassava varieties that reaches reasonable and appreciable root yield before 12 MAP so as to solve the problems being faced by farmers. Hence, providing farmers with early bulking cassava genotypes will provides farmers with cassava genotypes that could be harvested on time with higher yields therefore preventing overstaying on the field and cattle invasion. As a result of this, farmers need cassava genotypes that could have attained a reasonable yield at any harvesting periods they desire. Therefore, the study aims to identify cassava with early bulking traits among cassava genotypes and to understand the contribution of dry matter to root yield at different months and locations.

MATERIALS AND METHODS

The study was conducted at the International Institute of Tropical Agriculture (IITA) Trial Fields, Mokwa, Niger state. (Southern Guinea Savannah Zone with Global Positioning System (GPS) coordinates of 06.32812°N, 005.63599°E and altitude of 212.7 m) and IITA Ubiaja sub-station, Edo state (Rain-forest zone with global positioning system (GPS) coordinates of N06'40.339, E006°20.722 with altitude of 201 m) from 2018 to 2019. Ten genotypes namely, IKN120036, IKN120016, IBA070593, IBA130896 and IBA141092, TMEB419, IBA090525, IBA090581, IBA130818, IBA980581 sourced from IITA germplasm were used for this study. These treatments were planted in a randomized complete block design with three replications and with harvesting periods of 3, 6, 9 and 12MAP. The land was prepared with tractor and cassava stakes was planted on the ridge with a spacing of 1 x 0.8 m in three replicates and was evaluated for four different harvesting periods of 3, 6, 9 and 12months after planting (MAP). The 4 m ridges are 1 m apart. Data were taken from the net plots only. Weeding on the field was controlled manually. And harvesting was done by pulling the cassava with hands at different harvesting periods. Yield parameter data (fresh storage root yield (FSRY), harvest index (HI) and dry matter content (DM)) were taken from the net plot at different evaluated months of 3, 6, 9 and 12MAP. In this study, Genotype that bulks over 60% of their final root yield at 3MAP were regarded as early bulking, genotype that bulks 35-43% of their final root yield at 3MAP were regarded as mid-bulking while those that bulks between 22-34% of their final root yield at 3MAP were regarded as late bulking.

Data were statistically analyzed using analysis of variance (ANOVA) with mixed model procedure of SAS (version 9.4) to determine the significance of the main effects and interactions. And mean separation carried out using Fisher's highest significant difference.

RESULTS

The cassava genotypes performance at different months of evaluation at different location is as shown in the Fig. 1 which shows the cassava genotypes performance at different months of evaluation at two locations. Cassava genotypes varies in their performance across different months and locations.

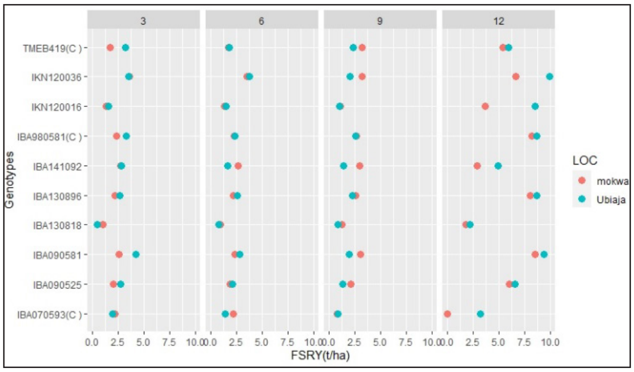

Fig. 1: Genotypes performance across different months of evaluation

Table 1: Analysis of different traits at 3rd, 6th, 9th, 12th map and across locations

Source of Variation	DF	FSRY (t/ha)	DM (%)	HI
Genotype	9	3.14***	36.7**	0.41***
MAP	3	3.11**	29.9***	0.37^{ns}
Gen × MAP	27	0.87***	6.79**	0.00***
Location	1	0ns	0^{ns}	0^{ns}
Rep (Location)	6	0.14^{ns}	0^{ns}	0^{ns}
Location × Genotype	18	0.05^{ns}	2.30^{ns}	0^{ns}
Location × MAP	3	3.27^{ns}	65.9^{ns}	0.00***
Location × Gen × MAP	27	0.25*	3.16^{ns}	0.49^{ns}

,, *** are significant at 0.5, 0.05 and 0.001 respectively. GEN-Genotype, MAP- Month After Planting, Rep-Replicatio, FSRY= Fresh Root Yield, HI-Harvest Index, DM-Dry Matter Content, ns-non-significant, Rep-Replication, DF-degree of freedom.*

As shown in the table 1 which shows the contribution of main effects to variation for evaluated traits at two growing seasons. Genotype, month after planting and the interaction of genotype by months after planting were significant for traits under consideration. Genotype was variable for evaluated traits and there was variability among cassava genotypes based on these traits. Month after planting (MAP) affects the variability of genotypes in terms of FSRY and DM but had no effects on HI. Location by month was not significant for fresh storage root yield (FSRY) and dry matter (DM) but was highly significant for harvest index (HI) at $p<0.001$ while the interaction of location, genotype and months was significant for FSRY at $p<0.05$. For all genotypes, it is either FSRY decreases after 3 MAP or there was little or no increase until 12MAP (see Fig. 1). The best linear unbiased estimate (BLUE) shows that fresh root yield, harvest index and dry matter were significant at $p<0.01$, $p<0.001$ and $p<0.001$ respectively as shown in table 2 which implies that these genotypes are variable with respect to these traits. The performance of genotypes at different months after planting shows that fresh storage root yield, harvest index and dry matter were significant at different months of evaluation except harvest index which was not significant at 9MAP (Table 3).

Table 2: Best Linear Unbiased Estimate (BLUE) of Root Yield, HI and DM

Traits	BLUE	Pvalue
FSRY(t/ha)	3.14**	0.01
HI	0.42***	0.00
DM(%)	36.67***	0.00

, **, * are significant at 0.5, 0.05 and 0.001 respectively. FSRY= Fresh Root Yield, HI-Harvest Index, DM-Dry Matter Content, BLUE-Best Linear Unbiased Estimates.*

As shown in Fig. 2, cassava genotypes had lower dry matter at the onset of rainfall and six genotypes

Table 3: performance of genotypes in terms of yield related traits at different months

Character	Mean	CV	Range Min	Max	3 MAP df = 156	6 MAP df = 156	9 MAP df = 156	12MAP df = 156
FSRY (t/ha)	2.35	20.94	0.72	3.56	2.35**	2.07**	1.98**	6.32***
HI	0.39	12.07	0.11	0.6	0.39***	0.33***	0.38^{ns}	0.37***
DM (%)	35.28	12.35	20.82	39.78	31.8***	35.48***	16.87***	35.28***

,, *** are significant at 0.5, 0.05 and 0.001 respectively. FSRY-fresh storage root yield, HI-harvest index, DM-dry matter, CV-coefficient of variation, Min-minimum, Max-maximum, df-degree of freedom, MAP-month after planting.*

(IBA090525, IBA070593, IBA090581, IBA141092, IKN120016 and IKN120036) yielded more at 6 MAP when there was no rainfall than at 9 MAP. There was variability in dry matter assimilation to root yield across different months as shown in Fig. 3 and it was worthy of note that dry mater reduced at 9 MAP at the onset of rainfall for all genotypes (Fig. 3).

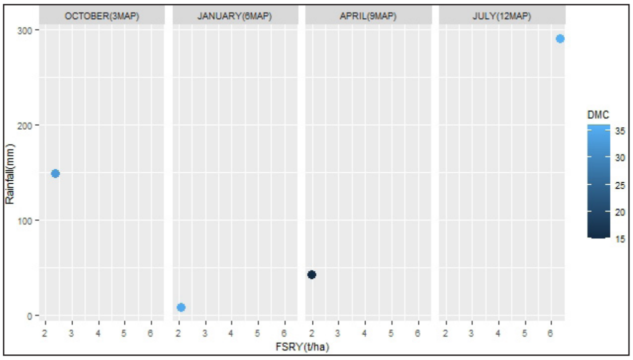

Fig. 2: Fresh Storage Root Yield and Dry Matter relationship with rainfall

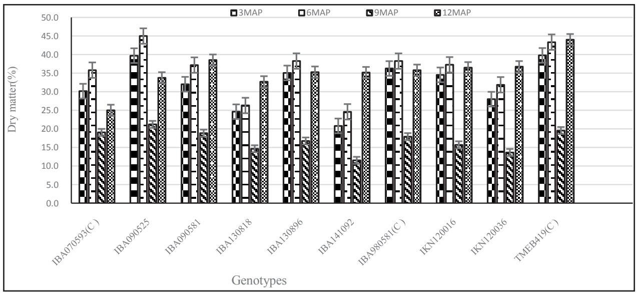

Fig. 3: Dry Matter percentage at different months of evaluation

Across the months, although fresh storage root yield (FSRY) were not significantly different at Mokwa and Ubiaja (see Fig. 4). FSRY of genotypes IBA130818 and IKN120036 increased after 3 MAP. Genotypes IBA90581 had the highest root yield of 9.0 t/ha at 12MAP while IBA130818 had the least root yield of 2.0 t/ha at 12 MAP (Fig. 5).

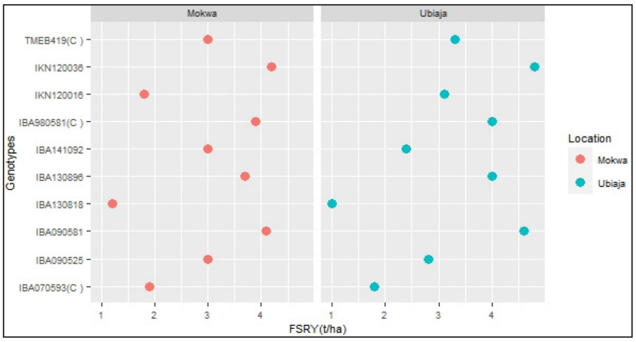

Fig. 4: Performance of genotypes across location

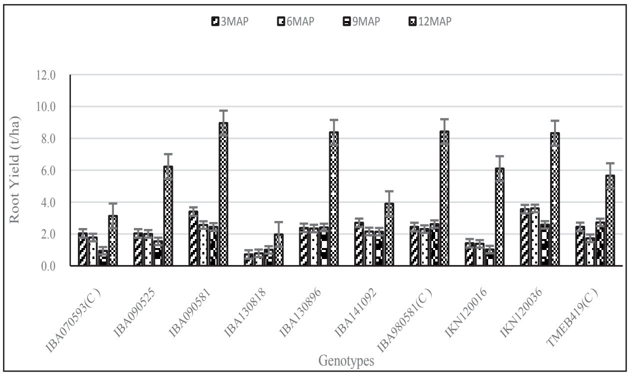

Fig. 5: Root yield performance at different evaluated months and across locations

From the yield parameter of evaluated cassava genotypes as shown in table 4, genotype IKN141092 had the highest harvest index of 0.6 while the least was recorded for genotype IBA130818. In terms of fresh root yield, IKN120036 had the highest root yield of 3.56 t/ha while genotype IBA130818 had the least root yield of 0.72 t/ha. The dry matter content was highest for TMEB419(c) with 39.78% while the least was recorded for IBA141092 with 20.82%.

Table 4: yield parameters of evaluated genotypes

GEN	HI	FSRY(t/ha)	DM(%)
IBA070593(C)	0.33	2.04	30.16
IBA090525	0.51	2.34	36.89
IBA090581	0.48	3.41	32.03
IBA130818	0.11	0.72	24.62
IBA130896	0.31	2.39	35.06
IBA141092	0.6	2.7	20.82
IBA980581(C)	0.39	2.44	36.26
IKN120016	0.21	1.42	34.55
IKN120036	0.54	3.56	28
TMEB419(C)	0.41	2.45	39.78
CV	23.95	21.03	16.62
SE	0.07	0.46	3.88

GEN-Genotype, HI-Harvest index, FSRY-Fresh Storage Root Yield, DM-Dry matter, C-Check.

In this study, the cassava bulking rate shows that IBA070593(c) and IBA141092 were early bulking, genotypes IBA090581, IBA130818, IKN20036 and TMEB419(c) were mid-bulking while genotypes IBA090525, IBA130896, IBA980581(c) and IKN120016 were late bulking as shown in the table 5. As shown in table 6, Cassava genotypes that had the highest root yield across the months (IKN120036 and

Table 5: bulkiness across the months of evaluation

Genotype	3 MAP		6 MAP		9 MAP		12 MAP	Across MAP	
	FSRY (t/ha)	EB%	FSRY (t/ha)	EB%	FSRY (t/ha)	EB%	FSRY (t/ha)	FSRY (t/ha)	Bulkiness
IBA070593 (C)	2	64	1.8	58	1	32	3.1	1.98	EB
IBA090525	2	32	2	32	1.5	24	6.2	2.93	LB
IBA090581	3.4	37	2.6	28	2.5	27	9	4.38	MB
IBA130818	0.7	35	0.8	40	1	50	2	1.13	MB
IBA130896	2.4	28	2.3	27	2.4	28	8.4	3.88	LB
IBA141092	2.7	69	2.2	56	2.1	53	3.9	2.73	EB
IBA980581 (C)	2.4	28	2.3	27	2.6	30	8.4	3.93	LB
IKN120016	1.4	22	1.4	22	1	16	6.1	2.48	LB
IKN120036	3.6	43	3.6	43	2.6	31	8.3	4.53	MB
TMEB419 (C)	2.4	42	1.7	29	2.7	47	5.7	3.13	MB

FSRY-Fresh Storage Root Yield, MAP- Month After Planting EB-Early Bulking, MB-Mid-Bulking, LB-Late Bulking.

IBA090581) showed discontinuity in their root yield at some point during their growth stage and were mid bulking and late bulking respectively. Across location, there was no significant difference in root yield performance of cassava genotypes.

The relationship between rainfall, root yield and dry matter at different months after planting as shown in table 7 shows that at 6 MAP when there was low rainfall (8 mm), dry matter was highest (35%) while root yield was 2 t/ha, at 9 MAP, when rainfall was starting and at 43 mm, dry matter reduced to 15% and root yield slightly reduced to 1.90 t/ha. At 12 MAP, while rainfall was highest (291 mm), dry matter was 36% and root yield was highest with 6.30 t/ha. Across the location, there was no significant difference in terms of genotype performance for root yield as shown in Fig. 4. And root yield increased for all genotypes at 12 MAP (Fig. 5).

Table 6: Root yield discontinuity value at 6 and 9 MAP

Genotype	FSRY (t/ha) 6 MAP	9 MAP	Discontinuity Yield Value	Bulking Rate
IKN120036	3.61	2.58	1.03	MB
IKN120016	1.38	1.03	0.35	LB
IBA070593	1.78	0.95	0.83	EB
IBA090525	2	1.5	0.5	LB
IBA090581	2.6	2.5	0.1	LB
IBA141092	2.2	2.1	0.1	EB

MAP=Month After Planting, EB = Early Bulking, MB = Mid-Bulking, LB = Late Bulking.

Table 7: Effect of rainfall, location and months after planting on Fresh root yield and dry matter

MAP	Rainfall (mm)	FSRY (t/ha)	DM (%)
3MAP (October)	149.00	2.30	33.00
6MAP (January)	8.00	2.00	35.00
9MAP (April)	43.00	1.90	15.00
12MAP (July)	291.00	6.30	36.00
Location	Rainfall (mm)	FSRY (t/ha)	DM(%)
Mokwa	1178.89	12.48	30.00
Ubiaja	2023.73	12.90	29.99

DISCUSSION

Fresh storage root yield among genotypes across months and locations

Cassava genotypes for fresh storage root yield of cassava was highly significant ($P < 0.001$) across location in this study and there was significant difference among the yield component traits for the genotypes evaluated across the months and locations. This is an indication that genotypic variability among the genotypes is responsible for the performance of the genotypes in terms of yield related traits and variation exists among genotypes used for the study. One of the targets of the cassava breeding program is cassava root yield which is a complex trait, and which depends on different factors which directly or indirectly affect root yield (Tewodros & Ayenew 2012). Yield is polygenic and different favorable alleles are involved in the control of most important agronomic traits (Olasanmi *et al.*

2014). Cassava root yield component in terms of fresh storage root yield (FSRY) was significant in the study and shows that the traits is controlled more by genetic variability than the environment and this is also confirmed by Adu-Gyamfi *et al.* (2006) where they noticed significant difference in the root formation at 4, 5 and 6 MAP.

Source of variation for traits and early bulking rate among genotypes

Genotype and MAP were significant for FRSY and DMC across location and across the evaluated months while location was not significant. In breeding, genotypes must be evaluated in different locations in order to study their performance in terms of yield and response to pest or disease in such location such that best genotypes can be selected (Adetoro *et al.* 2021; Akinwale *et al.* 2011). However, in cases where there is no significant interaction between the genotype and the environments (location), as in this study, it means the genotypes have a very high additive genotypic variance and low phenotypic variance with little effect of the environmental.

Genotypes that bulks over 60% of their final yield at 6MAP can partition DM production into their storage root earlier (Akinwale *et al.* 2011). The early bulking genotypes in this study were able to bulk over 60% of DM into their roots at 3MAP. This is an indication of qualitative nature of the evaluated traits and it means that the traits are controlled by few genes that are less prone to the environment (Ssemakula *et al.* 2007) (see Table I).

Fresh storage root yield (FSRY), harvest index (HI) and dry matter (DM) of the genotypes were significant at $p<0.001$, $p<0.001$ and $p<0.01$ respectively showing that there is variability among the genotypes for these traits and selection for highly performing genotypes could be made by selecting based on HI and FSRY (Mbanjo *et al.* 2021; Badewa *et al.* 2020) as genotypes were highly significant for these traits (see Table 1). Genotype by months was also highly significant at $p<0.001$ for FSRY, HI. While months were not significant for HI showing that their performance is not affected by months but was very significant for FSRY at $p<0.00$ and highly significant for DM at $p<0.01$. Location by months was highly significant for HI. This means that the effectiveness with which genotype partition assimilates varies with the interaction of location. Location by genotype was not significant for DM, FSRY and HI. Location by month was not significant for FSRY and DM but was highly significant for HI at $p<0.001$ while the interaction of location, genotype and months was significant for FSRY at $p<0.05$ (see Fig. 1). FSRY, HI and DM were significant across the months for all the genotypes as shown in table 2 except that at 9MAP, HI was not significant (Table III). Genotype IBA141092 had the highest HI of 0.60, genotype IKN120036 had the highest root yield value of 3.56 and the check TMEB419 had the highest DM value of 39.78 (Table 4).

In this study, genotypes that bulk at 3 MAP over 60% of their final yield at 12 MAP were regarded as early bulking (EB) while genotypes that bulk at 3 MAP between 35-43% of their final yield at 12 MAP were regarded as mid-bulking (MB) and late bulkers (LB) are genotypes that at 3 MAP bulks between 22-32% of their final yield at 12MAP. Early bulking genotypes in this study were genotypes IBA141092 and IBA070593 (Table 5) and were not high yielding as shown in Fig. 1. This shows that these genotypes were able to develop the above ground part and root yield simultaneously (Adjebeng-Danquah, 2016).

The highest yield at 12MAP must have used their above ground part as the major sink before partitioning materials into their storage root yield as reported by Adjebeng *et al.* (2016) . The first three months coincides with rainfall onset and must have helped in early bulkiness recorded for genotypes IBA070593(c) and IBA141092, as Adjebeng *et al.* (2016) also reported that storage root bulking was slow under no irrigation. Root bulking increased with time, and it differed among cultivars and varies over a long period of time due to changes in environmental conditions. In this study, FSRY begins to increase at rainfall onset and reduces at 6MAP when there was no rainfall and increases from 9-12 MAP due to rainfall.

Bulking percentage of early bulking genotypes declines from 3 MAP to 9MAP. This confirms Adjebeng *et al.* (2016) where they reported that storage roots of early bulking genotypes reduced in the early or later during the period of their growth. For late bulkers, bulking rate increases in the middle and later period (Adjebeng-Danquah, 2016) and this is contrary to what was obtained in this study as the bulking rate of low bulking genotypes either increased, became stabled or reduced during the period of growth.

From 3 MAP to 9 MAP, there are manifestations of accumulated performance in what Adjebeng *et al.* (2016) termed "Crossover Interaction" in yield performance of genotypes as lower yield performing genotypes at earlier month were high performing at later months. In addition to the crossover interaction, there was also discontinuity in yield performance during the growth period in which genotype performs higher earlier in the month and then reduces in performance at subsequent month of evaluation. This however does not affect their overall yield performance as the genotypes are either EB, MB or LB.

According to Adjebeng *et al.* (2016), early bulking partition DM earlier into their storage root by bulking 60% of their final root yield by 6 months. These two early bulking genotypes are efficient in DM partitioning as they bulk over 60% of their root yield at 12 months by 3MAP. Early bulking in cassava genotypes is an important farmers' preferred trait and this is usually because this could avert the threat of drought, bushfires, and invasion by animals (Adjebeng-Danquah 2016) and also effective farmland use where land are used for other crop cultivation without 'long-waiting' for cassava root crop to attain a marketable root size.

The best performing genotypes from this study were from the 6 genotypes that yielded more at 6MAP than at 9MAP. This means that genotypes at this stage had higher partitioning efficiency, and this is confirmed in the study by Adjebeng-Danquah *et al.* (2016) who indicated that genotypes that partitioned DM production into storage root earlier than others are characterized by high source to sink abilities which translated into early bulkiness.

Relationship between early bulking and high yielding among genotypes

High yielding genotypes at 12MAP are not part of the early bulking category but are middle and low bulking genotypes. Early bulking genotypes are low yielding relative to other studied genotypes. The genotypes that bulked highly at 3MAP still had the highest root yield at 12MAP; for these genotypes, IKN120036, IBA980581, IBA130896, IBA090581, they were not early bulking but high yielding.

Early bulking genotypes are IBA070593 with 2.0 t/ha and IBA141092 with 2.7 t/ha. Mid-bulking genotypes are IBA090581 with 4.3t/ha, IBA130818 with 1.1 t/ha, IKN120036 with a yield of 4.5 t/ha and TMEB419 with 3.1 t/ha while late bulking genotypes are IBA090525 with 3.0 t/ha, IBA130896 with 3.9 t/ha, IBA980581 with 3.9 t/ha, IKN120016 with 2.5 t/ha are late bulking.

Early maturing genotypes bulk at an early stage (Suja *et al.* 2009) just as the early bulking genotypes in this study bulk over 60% of their final root yield at 12 months by 3MAP. Root bulkiness is related to early bulkiness, and this varies with cultivar. Differences in bulking rate among various genotypes and bulking periods are the major determinant for high or low yielding cassava (Suja *et al.* 2009). Early bulking genotypes may not necessarily be high yielding and may not automatically translate to high yielding but may be exploited for higher root yield through successive selection and breeding.

In this study, high yielding performing genotypes across the MAP include IKN120036, IBA980581(C), IBA141092, IBA130896 and IBA090581 except IBA141092 which reduces at 12 months. These four genotypes maintained their high yielding across the months and none of these genotypes were early bulking but mid and late bulking. In other words, a genotype may be early bulking and not high yielding. High and early storage root bulkiness among genotypes has been linked to genotypic variability (Okogbenin *et al.* 2008).

Early bulkiness genotype has high source and sink capacities which translate into total biomass for the early bulking group as recorded in this study (Okogbenin *et al.* 2008). Slow bulking or late bulking genotypes develop sufficient above ground mass before they start storage root bulking. Early bulking genotypes on the other hand begin storage root development and shoot at the same time (El-Sharkawy 2004).

Sink and Source capacity of genotypes at different growth stages

The study shows that genotype IKN120036 performed best among the genotypes across the months and above the checks (TMEB 419, IBA 980581 and IBA 070593) followed by IBA090581 across the evaluated months and locations in terms of FSRY while IBA090581 was the highest performing genotype at 12 months. As shown in Fig. 2 and 3 at 6MAP, when the dry matter (DM) was accumulating while there was no rainfall; six genotypes (IBA090525, IBA070593, IBA090581, IBA141092, IKN120016 and IKN120036) yielded more at 6 MAP than at 9 MAP and this shows that it was at this stage that dry matter began to accumulate into the source. Storage root becomes the major sink from 5MAP (El-Sharkawy 2004). Generally, across the two locations, FSRY reduces at 9MAP. From 1 MAP to 5 MAP, the shoot is the major sink but at later stages from 5 MAP, the storage root becomes the sink because the distribution of carbohydrates to different parts varies with the growth cycle and it is responsible for the secondary thickening due to storage root formation and development (El-Sharkawy 2004) as storage root expansion begins to form from the cassava fibrous root system as from 2-3 MAP.

At 9MAP, DM reduced and there was a slight reduction in the root yield and hence low relationship between FSRY and DM content at this stage (see Fig. 3). All cassava genotypes increased in their root yield at 12MAP. Roots begin to increase in starch accumulation at 12MAP. Fresh storage root yield reduces after 3MAP, when there was a reduction in rainfall, and increases at 12MAP for all the genotype when the rainfall was highest. This increase in yield is as a result of an increase in rainfall as noted by Okoye *et al.* (2020). Roots begin to accumulate starch from 12 MAP.

At 6MAP, when assimilates are being partitioned, this coincides with the period when there was no rain. Four genotypes (IBA130818, IBA130896, IBA980581(c), TMEB419) yielded more at 9 months when dry matter reduced, and root yield reduced. These four genotypes increased in their root yield from previous months while others reduced. This shows that for these genotypes, as dry matter reduces, their root yield increased. There was no strong relationship between DM and FSRY at this stage. This shows that these genotypes were efficient in partitioning assimilates during this period. Also, at 9MAP, all the genotypes increased in yield while the DM production was at the lowest and highest DM production was recorded at 12MAP when the rainfall was highest. At 12MAP when the rainfall was highest, FSRY was highest, and this may be due to the accumulation of DM content at this period.

At the 12th month, genotype IBA090581 (9.0 t/ha) recorded the highest, followed by IBA130896 and IBA980581 with 8.4 t/ha, respectively; this was because the genotype was efficient in allocating assimilates to the storage root part of the plant (Table 5).

Genotype IKN120016, a late-bulking genotype had the highest shoot weight and a very low yield. This is because late bulking genotypes develop sufficient above ground mass before storage root bulking (Alves 2002) and this could also mean that the genotype was not efficient in partitioning assimilates because much of its assimilates were partitioned in favour of the shoot weight at the expense of the root yield while early bulking genotypes begins storage root development and shoot simultaneously and usually due to genetic variability among genotypes. Shoot and storage root of the crop develop at the same time (Lahai and Ekanayake, 2009) and hence, the highest shoot weight to low root yield of the genotype is an indication that more assimilates were apportioned to the shoot weight at the expense of the storage root yield by the genotype (Edvaldo *et al.* 2008).

Root yield pattern of cassava genotypes and their bulking rate at different growth stage

The discontinuity and reduction in root yield at 9MAP do not affect their final root yield performance at 12 months as the highest performing genotypes (IBA90581 and IKN120036) in terms of root yield at 12 months and across the months were also discontinuous in their root yield at some points across the months of evaluation.

Early bulking genotype IBA141092 was not the highest yielding genotype at 12 months rather a mid-bulking genotype (IBA90581) and a genotype (IBA130896) in the late bulking category. Even though the early bulking genotypes had the highest measure of partitioning efficiency with the HI of 0.60, genotype IBA090581 with HI of 0.48 was the highest at 12 MAP (Table 2).

Genotypes perform differently across the months in terms of root yield before the 12MAP. Across the months, genotypes either declined in root yield, increased or became stabled. But all genotypes increased at 12 months. The early bulking genotypes retrogressively reduced in their root yield from 3 to 9 months. This led to discontinuity in their root yield at 9 months in that their root yield at 6 months was higher than at 9 months (Table 6). The discontinuity might be as a result of reduction in number of newly formed roots and biotic impacts (Bararyenya *et al.* 2020) as a reduction in DM owing to onset of rainfall at this stage. Since carbohydrates demand of different parts varied across the growth cycle, the discontinuity may also be due to remobilization of dry matter (DM) from the sink behaving as source. This however does not affect their overall yield performance as the genotypes are either early bulking (EB), Mid-bulking (MB) or late bulking (LB).

The early bulking genotypes have more energy for biomass production and for early remobilization for storage root bulking (Bararyenya *et al.* 2020). It is possible that remobilization could turns sink into source in order to subsidize reproduction or regrowth. This pattern of discontinuity was seen among the genotypes across the months. The growth pattern of genotypes from 3MAP to 9MAP at Mokwa location was continuous and discontinuous for some but increased at 12MAP. The growth pattern of genotypes from 3 MAP to 9MAP at Ubiaja was discontinuous for some while it was continuous for others.

For genotype IBA130818, a mid-bulking which recorded the least yield, the growth pattern of genotypes is in agreement with basic growth curves in many crops (Schur *et al.* 2006) however, it was the least performing genotype among the studied genotypes. Across locations, the growth pattern was discontinuous at some point and later continuous and increased at 12MAP.

Across locations and evaluated months, genotypes IKN120016, IKN120036 and IBA070593 show discontinuity in their yield at 9MAP. Genotype IKN120036 was the mid-bulking and the best performing genotype from this study and reduces from 3.61 t/ha (6 MAP) to 2.58 t/ha (9 MAP). The discontinuity in their yield however does not affect their final yield at 12MAP. The discontinuity of root development for most of the genotype may be as a result of DM remobilization and in the case of these three genotypes; it is possible that the reduction was as a result of more assimilates towards the storage roots most especially during the onset of rainfall at 9MAP(see Fig. 2). And therefore, the 'negative' difference in yield at 9MAP may be necessary for higher storage root yield recorded at 12MAP.

Discontinuity in yield may not necessarily translate into yield reduction for some genotypes while it may for some other genotypes. Although genotypes IKN120016 and IBA070593 were discontinuous in storage root yield from 6-9 MAP, genotype IKN120016 was a late bulking genotype, while genotype IBA070593 was an early bulker. Genotypes with discontinuous root yield may be genotype or environmental dependent.

Genotype IKN120036, IBA90581, IBA980581 and IBA130896 recorded higher root yield at 3, 6, 9 and also at 12MAP. Therefore, earliness in root yield is related to rapid bulking and it varies according to genotypes. For these higher yielding genotypes, there is the possibility of a high source to sink ratio which leads to their high yielding at early months till the 12th month. The high yielding accessions may be as a result of an effective transport and partitioning system regarding the source-sink relationship and photosynthesis process (Ainsworth & Bush 2011) although, environmental factors, abiotic and biotic could also affect allocation of sucrose to the root (Lemoine *et al.* 2013). Moreover, for low root yield, it may be as a result of their growth rate because it determines the sink strength, and competition between the sinks (roots, flowers, seeds) may affect partitioning of DM (Obata *et al.* 2020)

Across the months, IKN120036 was the highest performing genotype in terms of yield (4.52 t/ha) considering the period from 3 MAP to 12 MAP relative to other genotypes, followed by IBA090581(4.35 t/ha), while the least performing genotype is IBA130818 (1.12 t/ha), and genotype IBA090581 was the highest performing genotype at 12 months with 9 t/ha.

Root bulking begins about 3 MAP and this could be observed from genotype IKN120036 but rapid starch deposition does not occur before 6MAP (Gonzalez *et al.* 2011). In this study, storage root begins to increase in starch accumulation from 9 MAP when DM production was at its lowest.

Tuber bulking starts from 2MAP, but it was observed from 3 MAP in this study and was discontinuous for most of the genotypes over the growing period as observed in this study. Bulking rate in this study varies with genotype, months and prevailing environmental conditions.

At 3 months, genotype IKN120036 rapidly bulked relative to other genotypes and had the highest yield of 3.6 t/ha followed by genotype IBA141092 with 2.7 t/ha while the least of 0.7 t/ha was recorded by IBA130818. At 6 months, genotype IKN120036 still maintained the highest yield of 3.6 t/ha followed by IBA090581 with 2.6 t/ha while the least yield was recorded by IBA130818 with yield of 0.8 t/ha. At 9 months, virtually all the genotypes reduced in their yield except genotype IBA130818 which had a pattern of increase from the 3rd month; however, the highest yield was recorded by TMEB419 with 2.7 t/ha followed by IBA120036, IBA980581 with each one of them recording 2.5 t/ha. At 12 months, genotype IBA090581 had the highest yield of 9.0 t/ha followed by IBA980581 and IBA130896 with 8.4 t/ha while the least remained IBA130818 with yield value of 2.0 t/ha.

Bulkiness (at 3 MAP) in this study shows that IBA141092 and IBA070593 were the only early bulking genotypes among the studied cassava genotypes. Cassava IKN120036, TMEB419, IBA130818 were middle bulking while low bulking genotypes comprise IBA980581, IBA130896, IBA090581, IKN120016 and IBA090525.Although, genotype IBA141092, IBA070593 may not be the highest yielding at 12MAP relative to other genotype in this study, these genotypes were effective in partitioning DM production into storage root yield.

Root yield performance of cassava genotypes at final harvest across locations

From the study, high yielding genotypes at 12MAP across locations are not of the early bulking genotypes. In other words, the high yielding genotypes are not constituted of the EB category but some of the middle and low bulking genotypes category. Contrary to report of Okogbenin *et al.* (2013) which found that early bulking genotypes are also high yielding, early bulking genotypes in this study are low yielding relative to other genotypes in the study, although all bulking categories increase in yield at 12 MAP.

The best performing genotype is IBA090581, followed by genotypes IBA130896, IBA980581 and IBA120036 while the least performing was genotype IBA130818. This result further reveals that most of the genotypes attain highest yield at 12MAP (see Fig. 5). Genotype IBA130818 was the least performing at 3 MAP and 6 MAP which shows that this genotype was not efficient in partitioning assimilates to the storage roots at the months of evaluation while genotype IBA070593 was the least performing genotype at 9 MAP and 12 MAP.

CONCLUSION

The genotypes performed differently based on DM and FSRY. DM was higher at 6 MAP and reduced at 9 MAP and at 12MAP for most of the genotypes. From the results it was observed that for the best performing genotypes at 12 MAP and across the MAP, their DM at 12 MAP was higher than the DM at 6 MAP and also a similar pattern was noticed in the least performing genotype IBA130818, showing that DM partitioning for root yield varies with genotype and the prevailing environmental conditions. There was no significant difference for root yield at 3 MAP and 6 MAP, and all genotypes reduced in root yield at 9 MAP; this may be due to a reduction in DM at this stage as a result of remobilization for growth. However, their yield increased at 12 MAP which may also be as a result of rainfall and DM accumulation over time. This study shows that the high yielding genotypes may not necessarily be early bulking but may rapidly bulk relatively to others and this can be improved by exploiting the early bulking traits via breeding. The discontinuity in yield performance observed in early bulking and the high yielding genotypes did not affect the root yield performance. Bulking rate among genotypes varies and it is genotype dependent. It was also discovered from the study that the genotypes that attained highest yields at 3MAP were the higher yielding genotypes at 12MAP. Theses genotypes are IKN120036, IBA980581, IBA130896 and IBA090581 and are therefore regarded as high bulking and yielding genotypes but were not early bulking. Although early maturing genotypes are determined by their early bulkiness, early bulking genotypes were not high yielding at 12MAP. Early bulking may not necessarily result in a high yield but does have high yielding potential which may be achieved via selection and breeding.

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