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Article

Effect of Rainfall on Yield Related Traits and Total Carotenoids Contents of 42 Accessions of Provitamin A Cassava at Two Cropping Seasons in Ibadan

Olusegun David Badewa [1,2,*] Elizabeth Parkes [1], Eli Kolo Tsado [2], Andrew Saba Gana [2], Kehinde Dele Tolorunse [2], Patrick Akpotuzor [1], Peter Iluebbey [1], Toye Ayankanmi [1]

[1] International Institute of Tropical Agriculture, Ibadan, Nigeria
[2] Federal University of Technology, Minna, Nigeria

*Correspondence: Olusegun David Badewa (s.badewa@cgiar.org)

Abstract: Cassava crop improvement is a function of selecting superior genotypes that meets the end-users needs and preference. This is done via genotype testing at different environments thereby subjecting the materials to the elements of climate and other environmental factors. In pro-vitamin a cassava genotypes, dry matter (DM), total carotenoids (TC), and fresh root yield (FYLD) are important traits for improving economic status, nutritional health and livelihoods of farmers and processors. This study evaluated the effect of rainfall patterns on 42 provitamin A Cassava accessions for FYLD, DM, TC at different months (6,9&12 months after planting) and for two seasons (2019/2020 and 2020/2021) in Ibadan. The study shows that the relationship between TC and FYLD were more variable at second season than in the first season. The relationships between TC & DM and FYLD & DM at both seasons showed similar variability. The rainfall pattern shows that higher rainfall trend was noticed at the first cropping season (2019/2020) than 2020/2021 cropping seasons. At different months categories and across cropping season, rainfall recorded the least value of 4.58mm at 6 Months After Planting (MAP) which was in the month of December, increased at 9 MAP (Mar) and all through the 12 MAP (107.05mm). Traits relationship with rainfall shows that yield increased with rainfall, DM (25.70%) was highest during the months of least rainfall (4.58mm) and decreased (16.40%) as rainfall (52.09mm) starts during the 9 MAP and at 12 MAP, when the rainfall was 107mm, the DM was 18.76%. Total carotenoids were highest at 6 MAP with 13.76 µg/g when the rainfall was least and decreased (13.04 µg/g) with increased rainfall. During the first cropping season, DM and TC were higher with higher rainfall but with reduced fresh root yield while at second season, when the rainfall was lower, fresh root yield was higher.

Keywords: Rainfall; Dry matter; Fresh root yield; Total carotenoids contents; Bulkiness

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1. Introduction

Cassava is a perennial crop grown for its starchy roots[1] and it is mostly cultivated subsistently by rural farmers[2]. It is produced predominantly (99 %) by small-scale farmers with 1-5 ha of land intercropped with yams, maize, or legumes in the rainforest and savannah agro-ecologies of southern, Central, and lately Northern Nigeria[3].

Cassava is regarded as a staple food providing source of calories for about 500million of people in the world [4]. It belongs to the kingdom Plantae, family *Euphorbiaceae*, subfamily *Crotonodeae*, tribe *Manihoteae*, genus *Manihot* and species *esculenta* [5]. Out of numerous species that belong to the genus *Manihot*, cassava is the only species that is widely cultivated for food production [6-8]. It is a food security crop and form part of major meal of some households [9].

Nigeria is the largest producer, but the yield is still low due to other factors such as pest, diseases, soil fertility and management practices [10]. It is majorly cultivated by millions of people particularly in Africa. The crop cassava is deficient in essential micronutrients like carotenoids, a precursor of Vitamin A and the lack of which cause night blindness in children, affect fetal development in pregnant women and affect the maternal health of lactating women and her offspring. Vitamin A deficiency (VAD) which as a result of diet low in Vitamin A is a preventable tragedy that affects millions of people, particularly in sub-Saharan Africa according to World Health Organization [11].

Production of cassava has a great potential for providing raw material for the food needs of ever-increasing population of the world [12]. Latin American countries, particularly Brazil and Colombia have made progress in developing and marketing cassava snacks food like potato chips as well as frozen, heat and serve cassava product [12].

Agriculture contributes to climate change as a result of emission of anthropogenic greenhouse gases and this has led to the unpredictability of the parameters of the climate especially the elements of rainfall. Stresses related to moisture and temperature are the resulting effect of climate change [13] which can affect cassava production by 18% without climate mitigation or adaptation practices [14].

Cassava yields varies from seasons to season due to the variability in the trends of weather patterns [15]. Water stress affects the physiology of cassava crops. Although, it can withstand drought by reducing water loss though the leaf via decreased stomatal conductance and this subsequently affects its photosynthetic ability [16].

Climate change effect as measured by increase in temperature, drought, rise in atmospheric CO_2 , Ozone affects crop productivity [17]. In Nigeria and Africa, most farmers depend on rainfed agriculture. And due to the effect of climate change which results in unpredictable weather patterns, farmers' production would always be hinged on rainfall for their cultivation as they may not have the capability for irrigation means.

Root yield has been found to increase with rainfall [15]. However, Low yield in cassava production has been ascribed to poor farm management and low soil management [18, 19]. Cassava cultivation is subjected to climatic conditions as farmers depends solely on rainfall [20, 21] and while environmental effect information on cassava yield compared to other crop is limited [22], there exist no much information on the effect of rainfall on Carotenoids contents of cassava, farmers thus need to understand how root yield and carotenoid contents are affected by climatic parameters such as rainfall. It is therefore important to evaluate the impact different seasons and especially rainfall have on cassava genotypes in order to understand how the element of climate affect cassava production. Hence the objectives of this study was to evaluate the effect of rainfall at different seasons on the performance of 42 Pro-Vitamin A cassava accessions in Ibadan in terms of yield related and nutritional traits.

2. Materials and Methods

The study was conducted at the international institute of tropical agriculture, Ibadan, a derived savanna zone with global positioning system of 07.488249^{0}N, 003.904875^{0}E and altitude 207m from 2019 to 2020 cropping seasons. Forty-two yellow cassava accessions with white checks (TMEB419, TME693and IBA980581) and yellow check (IBA070593) were sourced from IITA, Ibadan. The treatments were the 42 accessions arranged in a split plot design with two replications and the different harvesting months. The 42 accessions were randomized within replicates for the three harvesting periods of 6th, 9th, and 12th Months After Planting (MAP) at two cropping seasons. Each plot per accessions was 4mx2m of two rows containing 10 plants in spacing of 1m x 0.8m. Each block contained 7 accessions of 14 rows of 4m length and with area of 56m^2. Area per replicate for each harvesting periods was 293m^2 while total plot per replicate with different harvesting periods of 6th, 9th and 12th months was 879m^2 while total replicated area was 1758m^2. The accessions were planted at a spacing of 1x0.8m in 2 replicates in 2019/2020 and 2020/2021 cropping season. The accessions were evaluated for yield related traits at 6th, 9th, 12th and their total carotenoid analysis was done at each of the evaluated month. Data was analyzed using the restricted maximum likelihood/best linear unbiased prediction (REML/BLUP) procedure, proposed by Piepho *et al* (2008)[23] using R statistical analysis (R version 4.0.3). Data visualizations were carried out using R statistical software(2018)[24].

3. Results

The scatterplot of relationship between total carotenoids and fresh root yield shows that there was more variability for these traits during the second cropping season than the first season. There were more variability among the accessions for fresh root yield and carotenoids contents during the second seasons more than in the first season (Figure 1). Also, relationship between fresh root yield and dry matter revealed that variability was favoured by lesser rainfall in the second cropping season as shown in the study where some accessions had higher root yield with higher dry matter at the second season (Figure 2). Except for relationship between TC and DM which was favoured by higher rainfall, higher variability among the accessions were noticed in the first season where there was higher rainfall (Figure 3). During the first season (when the rainfall was higher) and at 6MAP, the variability was low, so also the dry matter while at the second season (when the rainfall was lower), During the first season and at 9 MAP, dry matter reduced but with larger variability for the accessions while at the second cropping season, the dry matter was higher but with low variability among the accessions. During the 12 MAP and at first season, the dry matter increased from what it was during the 9MAP and while at the second cropping season, the dry matter reduced. The boxplot of dry matter at different months after planting shows that first season favoured higher dry matter production considering the performance at 6MAP and 12MAP. Dry matter production at 6MAP was higher at second seasons where there was less rainfall (Figure 4). Across the cropping seasons, during the 6MAP when there was no or little rainfall (5mm), dry matter was highest (26%) with lowest fresh root yield (3.63t/ha). At the 9MAP when the rainfall was less than 60mm, the dry matter was lowest (16%) and the fresh root yield increased to 14t/ha. While at 12MAP, when the rainfall was highest(107mm), the fresh root yield was highest (20t/ha) with the dry matter (19%) increasing from where it was at 9MAP through 12MAP (Figure 5). During the first season (2019/2020), rainfall was higher while it was lower during the second season (2020/2021) (Figure 6). During the first season which had the higher rainfall, dry matter was higher with lower fresh root yield and during the second season with the least rainfall, lower dry matter content was recorded by accessions and with higher fresh root yield (Figure 7). During the first season when the rainfall was highest, accessions had the highest total carotenoid content (TC) and Dry matter (DM) while in the second season, the accessions had the lowest TC with lowest Dry matter when the rainfall was lowest (Figure 8 and Figure 9).

The average total carotenoids recorded among the accessions was 13.44μg/g, the highest was recorded by accession IBA180058 with 18.40μg/g above the yellow root check IBA070593 (10.80 μg/g) while the least was recorded by accession IBA180031 (7.01 μg/g). The white check TMEB693 had the highest dry matter content with 30.52% above the average value of 20.29% recorded by the accessions while the least (10%) was recorded by IBA180031 and another white check, TMEB 419, IBA980581 had 25.99% , 26.18%

respectively and the yellow check IBA070593 had 17.31t/ha. The accessions IBA180146 recorded the highest root yield of 26.33t/ha above the average yield for the accessions (12.37t/ha) while the least was recorded by IBA180018 with 5.87t/ha. The fresh root yield recorded by the accession IBA180146 (26.33t/ha) was greater than the white checks and the yellow checks namely IBA070593(Ychk) (15.55t/ha), IBA980581 (Wchk) (21.42t/ha), TMEB693 (Wchk) (13.47t/ha) and TMEB419(Wchk) (9.15t/ha) (Appendix A; Table 1)

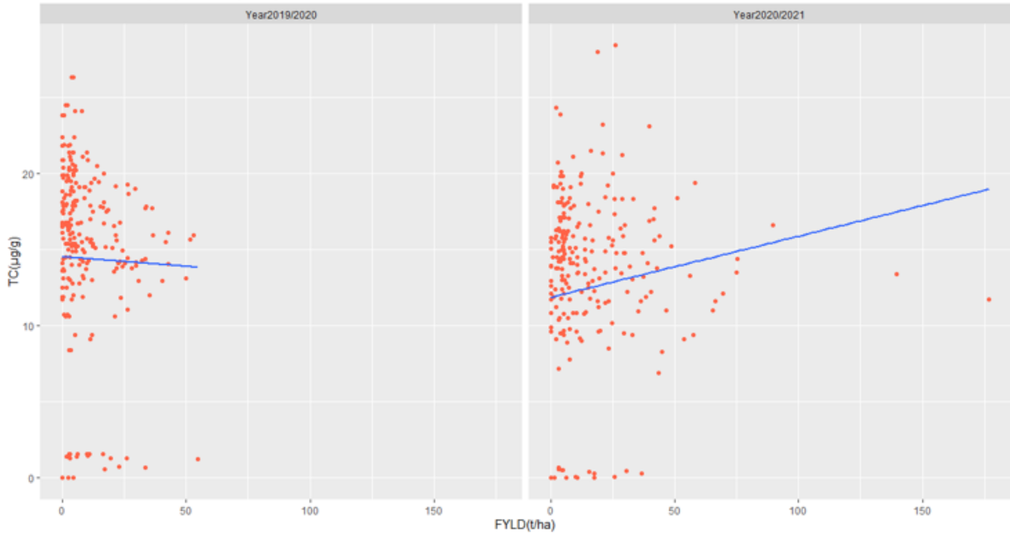

Figure 1. Relationship between fresh root yield and total carotenoids of accessions at different seasons.

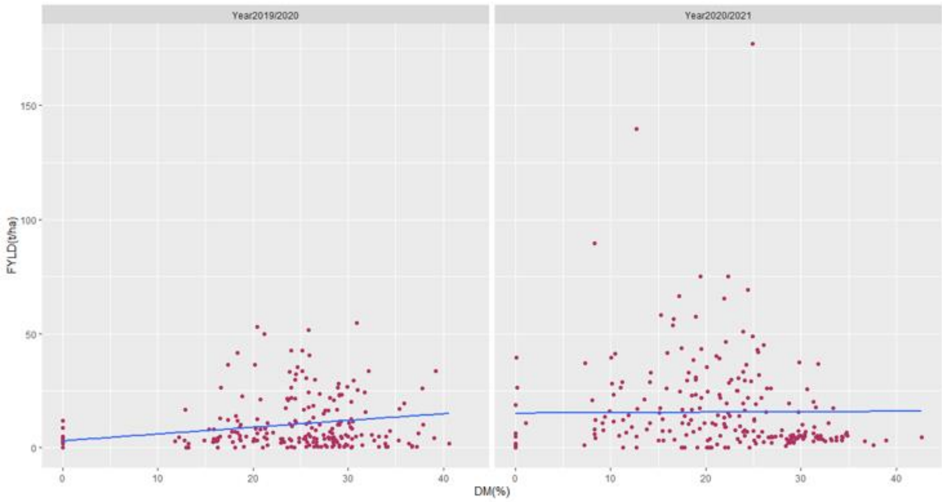

Figure 2. Relationship between fresh root yield and dry matter content of accessions at different seasons

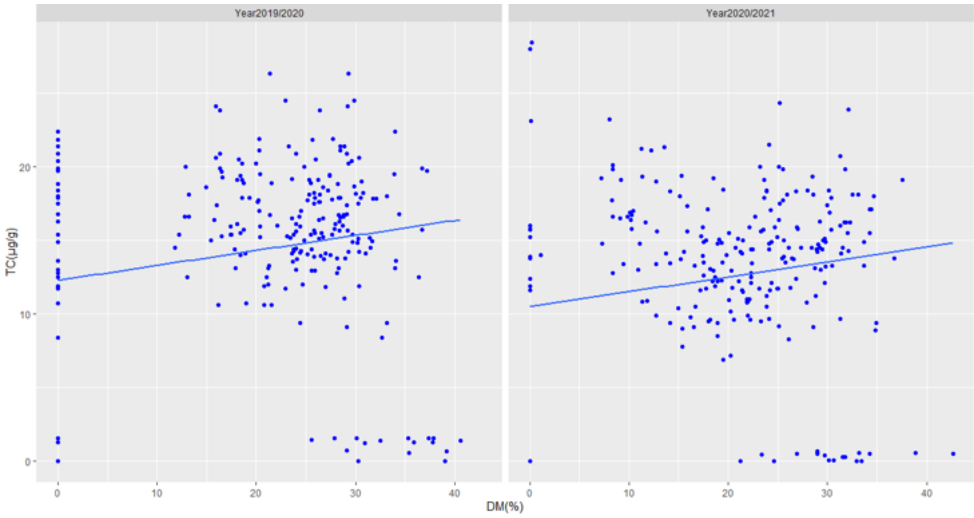

Figure 3. Relationship between total carotenoids and dry matter content of accessions at different seasons

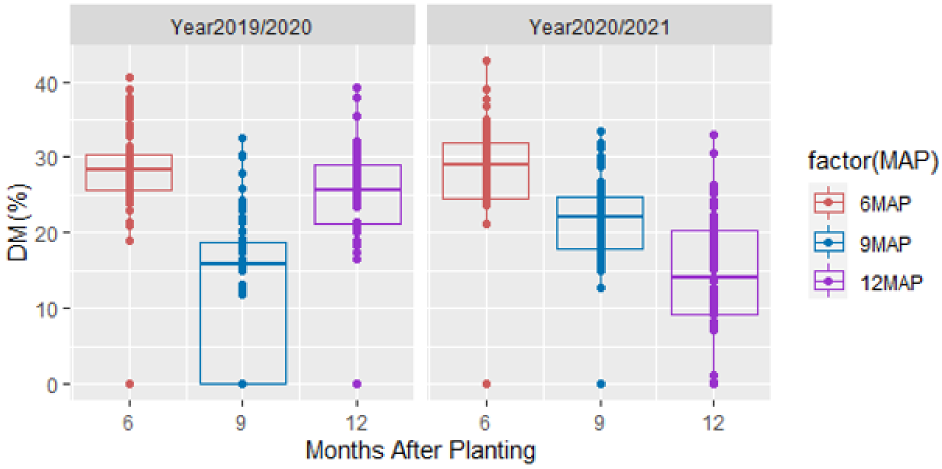

Figure 4. Boxplot of dry matter of accessions at different months categories at two cropping seasons

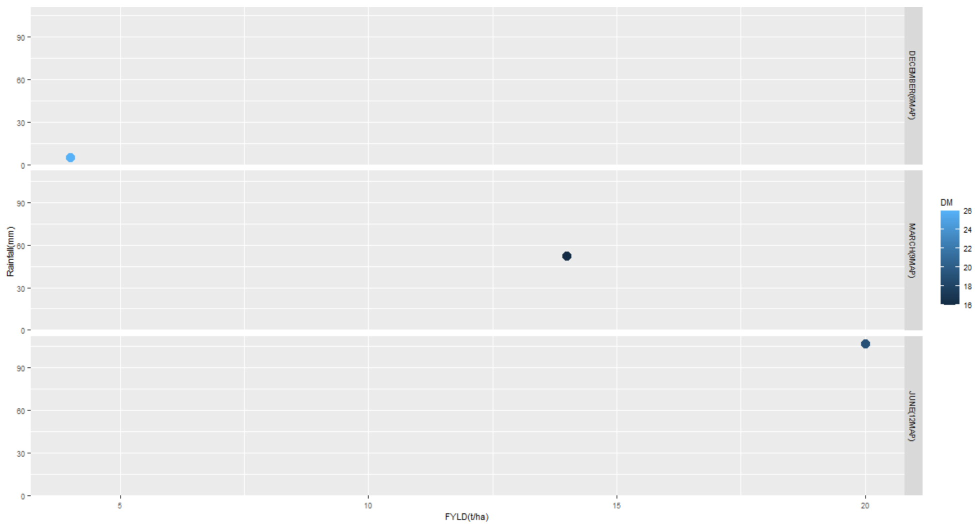

Figure 5. Performance of accessions for FYLD and DM at different months after planting and rainfall

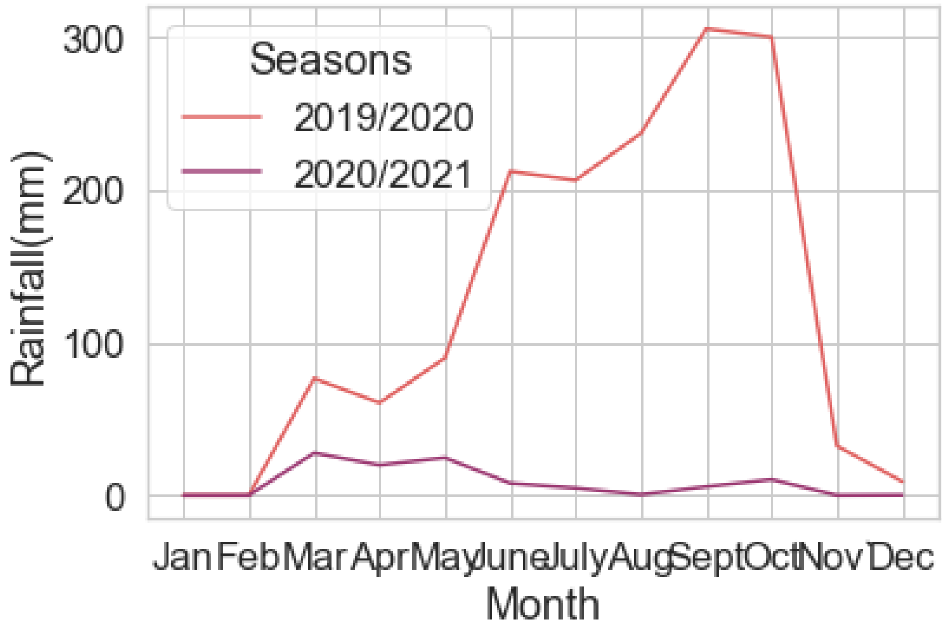

Figure 6. Rainfall trends at two cropping seasons

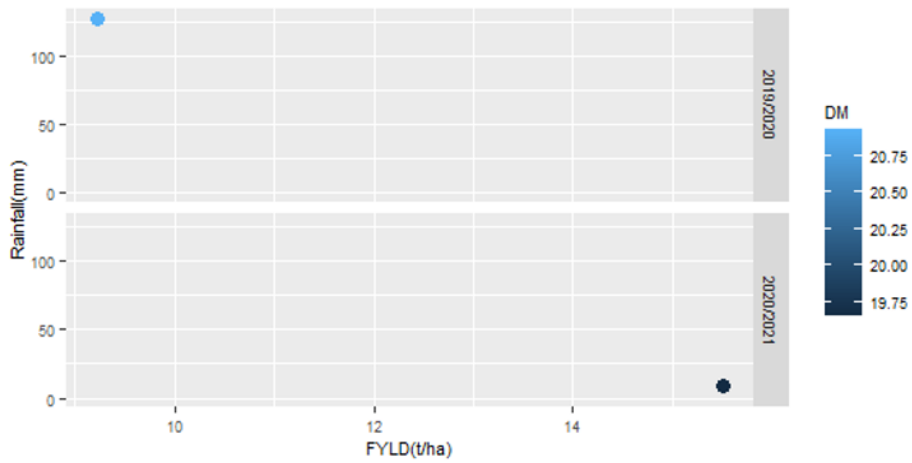

Figure 7. Performance of accessions for fresh root yield (FYLD) and dry matter content (DM) at different rainfall and cropping seasons

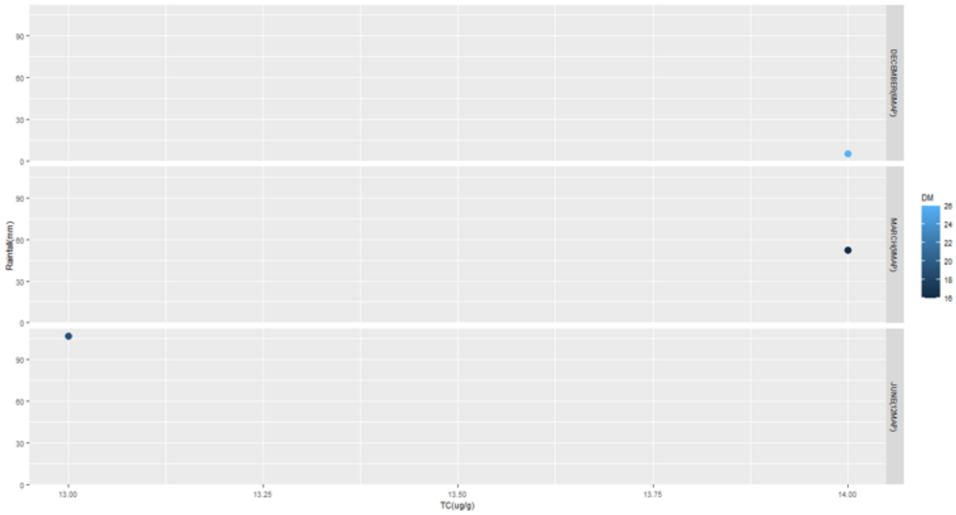

Figure 8. Performance of accessions for total carotenoid (TC) and dry matter (DM) at different rainfall and at different months after planting

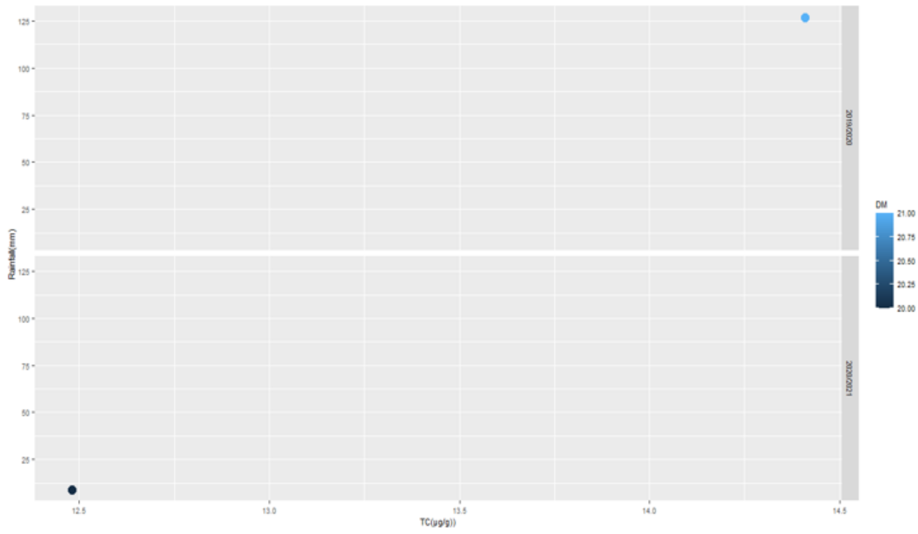

Figure 9. Performance of accessions for TC at different rainfall at different cropping seasons

4. Discussion

4.1. Variability among accessions across different months and seasons

There were more variability among the accessions for fresh root yield and carotenoids contents during the second season than in the first season. And the relationship between fresh root yield and the dry matter revealed that variability was favoured by lesser rainfall as shown in this study where some accessions had higher root yield with higher dry matter at the second season. Except for relationship between TC and DM which was favoured by higher rainfall, dry matter has also been found to be linked with TC [25] and higher variability among the accessions were noticed for these traits in the first season where there was higher rainfall.

4.2. Rainfall effect for performance of total carotenoids among accessions

The accessions in the study are high in total carotenoid contents and carotenoids have been found to reduce with rainfall in this study and fresh root yield reduced with carotenoid content however, as a result of variability observed in the second season which had less rainfall compared to the first season, there were accessions with higher TC and fresh root yield. Therefore, for pro-vitamin A carotenoids cassava with higher TC, less rainfall allows for more variability among the accessions for TC and fresh root yield.

4.3. Effect of rainfall on Dry matter among accessions

Dry matter (DM) has been found to be reduced with onset of rainfall [6], at 12 MAP, it was higher for accessions at the first seasons when there was higher rainfall than for accessions at the second seasons. Dry matter was higher for both seasons at 6 MAP. The higher DM at 6MAP at both seasons occurs at a period where rainfall has not begun at both seasons. But it was more in the environment with low rainfall. This is to show that environment with low rainfall favours dry matter production during the first 6months of growth. To further confirm the effect of rainfall on dry matter production, during 9MAP for first season (April) when rainfall was just starting, dry matter became low and in the second season at 9MAP (March) when there was less or no rainfall, dry matter at this stage was higher than in the first season. But during period of general less rainfall, dry matter accumulation at 12MAP which typifies period of no rainfall, was reduced. From this study, it was observed that, cassava has two period of higher dry matter production(6MAP and 12 MAP) although, production at one stage of growth is more than the other which is dependent upon the cropping seasons. Another stage where there is higher DM is during 12MAP although, dry matter production here is less than production at 6MAP. This could be due to environmental factors, genotype and other biotic factors [26].

In this study, accessions at 12MAP in the first seasons had higher dry matter production than the accessions at the same stage in the second seasons and the reason for the low production in the second season could be as a result of less rainfall observed in the second seasons. Cassava starts to bulk within first 5-6MAP [16] and this means that at earlier stage of cassava bulking, low rainfall is required for dry mater and assimilates partitioning into storage roots. During later period before 12MAP, rainfall has fully established and assimilates from photosynthesis is needed for both shoot growth and root development [6] and although rainfall may have impact on dry matter production and partitioning, it is needed to maintain the process of photosynthesis and growth, and this could be the reason for the lower DM at 12 MAP compared to 6 MAP when the root is bulking. And for second season where there was less or no rainfall, at 12 MAP, the less rainfall could have been responsible for the low DM at this stage as a result of less or no rainfall to augment the growth maintenance of the shoot and root growth and development.

4.4. Total Carotenoid, Dry Matter and Fresh Root Yield Relationship

Dry matter content, Fresh storage root yield, Starch, Cassava Mosaic Disease, Mealiness, Root number are traits that determines end user acceptability and variety adoption [27, 28]. Total carotenoid content in this study was highest at 6map, reduced at 9map and slightly increased at 12 MAP. Variability may be seen across the months for all the accessions. This variability shows that accessions performed above and below the average total carotenoid values across the months. The relationship between total carotenoid and dry matter shows that there is a linkage between the two. This shows that selection is possible for accessions with higher root yield with dry matter and total carotenoids as a result of variability among accessions for these traits in the study

Total carotenoids (TC) have been reported to prevent some form of cancers and other degenerative diseases [29] while dry matter is one of the preferred traits by end users, most especially farmers (Tumuhimbise, 2012, Ceballos, [30, 31]. The relationship between TC and DM shows that they are linked. Although, the accessions are population of high total carotenoids, it is not surprising that the results shows that the accessions were significant for TC and DM. At 6 MAP, as fresh root yield reduced, TC increased and at 9MAP when root yield increased, TC slightly reduced and at 12MAP when root yield increased, TC became stable. This shows there are accessions that is high in root yield with higher dry matter and TC among the accessions in the study.

As reported by Ceballos et al., [31] that there was no association between DM and TC, however, dry matter has been found to be linked with TC in this study. There existed some accessions with higher DM and TC, although low dry matter has been associated with total carotenoids [32, 33]. However, this study shows some accessions had their dry matter increases with TC. As reported by Ceballos et al [31] that the negative relationship between DM and TC would be a challenge in breeding for total carotenoids as high total carotenoids would only be selected with acceptable level of dry matter in cassava breeding improvement program. However, as a result of variability among accessions for TC and DM observed in this study, where there were cassava ccessions with higher DM and TC, the implication of this is that, soon there will be a breakthrough in breeding program for high total carotenoids because accessions with high pVAC and high DM could be easily selected for further improvement.

In this study, TC and DM increased at 6MAP, reduced at 9MAP but at 12MAP, DM increased, and TC slightly reduced. The stability of TC across the months is as a result of the high heritability of the trait. This is to confirm that both TC and DM are linked. The dry matter content in cassava is linked with its carotenoids content and research is ongoing to break the linkages such as to have accessions with high dry matter and appreciable carotenoid content [34] and the result obtained from this study confirmed and showed that this is a possible breeding goal.

The total carotenoid content among the accessions shows that at 12 MAP, accession IBA180088 had the highest total carotenoid contents of 18.37μg/g than the yellow check IBA070593 with 13.49 μg/g and 10.81 μg/g across the months, while across the month, accession IBA180058 had the highest total carotenoid content of 19.42 μg/g. The two accessions had total carotenoids content greater than the yellow check.

The dry matter content revealed that accession TMEB693 had dry matter content of 26.90% at 12 MAP while across the months, the same accession had the highest dry matter content of 30.52%. Both accessions had higher dry matter content than the yellow check which had 13.59% at 12 MAP and 10.81% across the months. The dry matter relationship with total carotenoid shows that there is increase in dry matter as their total carotenoid increases. While there are some accessions that shows increases in their DM as their total carotenoid reduced, some accessions shows reduction in their dry matter as their total carotenoid increases.

However, most accessions show linkage relationship between total carotenoid and dry matter therefore allowing selection to be made among the accessions for higher root yield and higher total carotenoid concurrently. Since most of the cassava accessions shows linkage between the two traits, the interesting thing is that the relationship for the studied accessions is positive. A single locus for dry matter has been found to be collocated with carotenoids. And this is responsible for the strong relationship between the total carotenoid contents and dry mater contents. Phenotypic variations expression at these loci is accountable for 70 and 37% for root yellowness and dry matter respectively as a result of this physical linkage rather than pleiotropy [25].

Total carotenoids increased with reduction in fresh storage root yield. However, some accessions have higher root yield with higher total carotenoid contents. Therefore, as a result of this variability among the accessions for root yield and total carotenoids, selection can be made for cassava genotypes with higher root yield and total carotenoids.

Although, some accessions reduced in DM with increased in their TC content, however, some other accessions increased in DM with increased in their TC content. Variation seems to exist among all the accessions, and this shows that possible future selection could be made for genotypes with higher TC, DM and Fresh root yield on the basis of these variability.

4.5. Root yield at different cropping seasons

The aim of every breeding objective is to increase root yield, early bulking, and tolerance to abiotic and abiotic stresses of cassava genotypes [35]. Root yield varies with cropping seasons and rainfall favoured higher yield at 12MAP at both seasons. However, root yield was higher at period of low rainfall at the second seasons where there was low rainfall. Many environmental factors have important role to play as temperature has been found to be essential for cassava development and photosynthesis [17]. Temperature between 16^0 C and 18^0 C has been found to delay leaf formation and consequently hinder biomass partitioning to the cassava storage roots [36]. In the study conducted by Okoye et al,a [15], it was reported that increase in temperature increased the root yield of pro-Vitamin A cassava while reduction in temperature was found to reduce the root yield. Root yield depends on the trends of climatic parameters [15] and it is highly favoured by factors such as sunshine hours, rainfall, and soil conditions [37]. Crops yield depends on factors such as climate, soil, and farm management practices [19, 38]. Therefore, the higher root yield observable during the second cropping season with less rainfall could be as a result of other conditions of growth such as the soil, pest and climatic properties. Where climate has been found to be less favourable for cassava production, soil conditions have been found to be largely accountable [37]

Usually, during the first six months after planting, assimilates are partitioned into the storage roots [17].This emphasizes the importance of soil moisture in the first six months after planting. The impacts of rainfall are measured through soil moisture. And the higher root yield when the rainfall was low during the second season shows that even with low rainfall, the accessions were effective in partitioning of assimilates into the roots and in conserving water through their stomata which in turns helps in their photosynthesis capacity. In trying to minimize water loss by plants especially during the period of low rainfall where soil water is reduced, stomata conductance is also reduced due to stomatal closure which therefore affects nutrients uptake, carbon assimilate and transpiration [39] and thus the accessions could be said to be of good yield and effective in partitioning assimilate during period of of low rainfall.

5. Conclusions

There exist some accessions with higher root yield, dry matter and total carotenoids among the populations of accessions studied. Total carotenoids were stabled at different month categories of 6, 9 and 12MAP while cropping season with higher rainfall had the highest total carotenoids. Root yield of accessions response to rainfall at different seasons were highly variable as low rainfall season had higher root yield while cropping seasons with higher rainfall had the lower root yield. Also, dry matter was higher when rainfall was low, and reduces when rainfall was higher considering the different months after planting. This shows that dry matter accumulation is not dependent only on rainfall but on other climatic parameters. The cropping season with higher rainfall had the higher dry matter while the season with lower rainfall had lower dry matter. Also, Cassava root yield of accessions respond differently to rainfall patterns depending on their inherent genotypic traits, soil conditions and other factor of climatic conditions.

Author Contributions: "Conceptualization OB, AG, EK. and KD.; methodology, EP, and OB.; software, OB.; validation, AG., KD. and ET.; formal analysis, OB.; investigation, PA, PI, TA and OB.; resources, EP; data curation, PA, OB.; writing—original draft preparation, OB.; writing—review and editing, TA.; visualization, OB.; supervision, EP, AG, ET, KD.; project administration, EP and PI. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table 1. Performance of traits at different months across cropping seasons

TRAITS	TC(μg/g)				DM(%)				FYLD(t/ha)			
Accession_name	6 MAP	9MAP	12MAP	mean	6MAP	9MAP	12MAP	Mean	6MAP	9MAP	12MAP	Mean
IITA-TMS-IBA180022	13.05	14.13	17.49	14.89	27.83	20.2	24.87	24.3	6.05	11.63	22.1	13.26
TMEB419(WChk)	1.1	0.95	7.6	3.22	32.15	22.3	23.53	25.99	4.38	7	16.08	9.15
IITA-TMS-IBA180221	14.2	13.3	12.17	13.22	27.23	17.08	18.65	20.98	2.83	13	23.69	13.17
IITA-TMS-IBA180148	18.53	17.4	17.66	17.86	20.2	17.58	20.85	19.54	3.55	7.5	28.42	13.16
IITA-TMS-IBA180047	17.98	15.68	14.12	15.92	28.7	15.48	21.51	21.9	2.08	21.85	14.11	12.68
IITA-TMS-IBA180064	19.45	18.95	15.75	18.05	32.43	17.53	22.71	24.22	3.45	16.13	14.78	11.45
IITA-TMS-IBA180081	15.28	16.73	13.99	15.33	30.58	20.75	20.79	24.04	4.48	27.43	34.74	22.21
IITA-TMS-IBA180037	18.13	16.85	15.6	16.86	29.23	23.88	22.02	25.04	8.25	18.03	18.3	14.86
IITA-TMS-IBA180124	15.93	14.35	15.35	15.21	33.9	20.18	23.05	25.71	4.63	14.4	18.52	12.51
IITA-TMS-IBA180071	15.85	12.58	15.57	14.67	26.78	19.55	18.21	21.51	3.85	9.5	30.62	14.66
IITA-TMS-IBA180106	16.1	13.38	14.76	14.75	30.08	17.6	21.06	22.91	2.8	15.23	23.93	13.98
IITA-TMS-IBA180271	9.35	9.38	8.83	9.18	19.85	14.55	14.07	16.16	2.2	3.48	10.71	5.46
IITA-TMS-IBA180090	16.55	17.68	14.85	16.36	27.63	15.58	18.38	20.53	5.23	10.23	12.48	9.31
IITA-TMS-IBA180084	19.48	22.53	15.73	19.24	32.28	17.4	18.82	22.83	3.2	5.38	13.64	7.4
TMEB693(WChk)	0.63	0.43	7.51	2.85	40.3	24.35	26.9	30.52	3.53	10.83	26.06	13.47
IITA-TMS-IBA180031	5.8	8.95	6.28	7.01	10	7.63	12.38	10	0.18	0.53	3.29	1.33
IITA-TMS-IBA180034	15.88	13.58	14.99	14.81	28.13	18.9	18.1	21.71	2.15	15.08	18.09	11.77
IITA-TMS-IBA180058	21.38	20.18	16.64	19.4	20.53	18.8	20.47	19.93	4.2	14.8	24.45	14.48
IITA-TMS-IBA180244	17.23	13.8	9.73	13.59	27.18	20.15	16.8	21.38	6.03	15.93	33.17	18.37
IITA-TMS-IBA070593(Ychk)	9.03	9.83	13.59	10.81	33.9	20.5	22.51	25.64	5.08	12.63	28.96	15.55
IITA-TMS-IBA180259	14.2	15.93	10.36	13.5	22.43	16.63	14.39	17.81	2.98	9.45	5.48	5.97
IITA-TMS-IBA180173	9.65	10.3	15.24	11.73	17.03	11	22.99	17.01	0.55	1.23	7.02	2.93
IITA-TMS-IBA180231	9.48	14.08	7.47	10.34	17.48	8.58	12.33	12.79	0.28	17.98	10.98	9.74
IITA-TMS-IBA180049	13.75	15.88	17.29	15.64	22.55	15.95	19.07	19.19	5.25	20.83	26.17	17.41
IITA-TMS-IBA180294	12.8	13.55	4.47	10.27	30.78	4.35	7.63	14.25	2.7	10.95	2.85	5.5
IITA-TMS-IBA180210	18.3	18.85	10.86	16	29.78	17.33	14.88	20.66	5.45	16	38.03	19.83
IITA-TMS-IBA180146	11.75	13.48	17.05	14.09	22.33	19.18	20.33	20.61	2.28	47.5	29.23	26.33
IITA-TMS-IBA180088	16.5	14.03	18.37	16.3	31.88	18.23	22.6	24.23	4.8	10.05	20.22	11.69
IITA-TMS-IBA180070	17.8	16.95	17.07	17.27	21	14.1	22.84	19.31	1.7	22	6.59	10.1

IITA-TMS-IBA180256	12.13	10.3	10.23	10.88	22.7	9.88	10.11	14.23	3.4	20.4	10.56	11.45
IITA-TMS-IBA180017	14.48	13.4	14.7	14.19	26.65	16.43	19.19	20.76	5.25	11.25	37.59	18.03
IITA-TMS-IBA180067	17.48	17.15	16.35	16.99	32.8	16.1	22.47	23.79	2.13	6.2	22.24	10.19
IITA-TMS-IBA180098	12.55	14.5	11.86	12.97	18.4	17.05	13.74	16.4	7.43	5.35	11.54	8.11
IITA-TMS-IBA180065	12	14.38	13.8	13.39	12.68	14.68	17.98	15.11	0.6	36.35	13.45	16.8
IITA-TMS-IBA180051	18.45	17.3	17.3	17.68	27.18	19.65	20.53	22.45	4.43	5.23	14.09	7.91
IITA-TMS-IBA180158	16	11.75	10.19	12.65	22.9	8.53	20.18	17.2	2.2	1.43	5.45	3.03
IITA-TMS-IBA180182	11.68	12.65	10.97	11.77	20.18	19.23	13.94	17.78	3.4	18.1	26.1	15.87
IITA-TMS-IBA980581(WChk)	1	0.9	6.39	2.76	35.33	22.35	20.88	26.18	9.4	17.88	37	21.42
IITA-TMS-IBA180018	10.55	12.28	8.61	10.48	13.4	8.95	10.31	10.89	0.3	13.05	4.26	5.87
IITA-TMS-IBA180073	17.18	15.05	13.8	15.34	26.98	12.6	20.12	19.9	3.08	22.1	30.81	18.66
IITA-TMS-IBA180180	12.3	11.25	12.62	12.06	18.4	14.2	16.53	16.38	2.38	13.65	14.26	10.09
IITA-TMS-IBA180147	17.33	13.3	14.76	15.13	27.9	14.23	19.65	20.59	4.63	7.38	30.89	14.3
Mean	13.77	13.52	13.05	13.44	25.7	16.41	18.77	20.29	3.64	13.93	19.55	12.37
SD	4.94	4.61	3.68	4.02	6.63	4.52	4.29	4.38	2.06	8.98	10.21	5.44
SE±	0.76	0.71	0.57	0.62	1.02	0.7	0.66	0.68	0.32	1.39	1.58	0.84
CV	0.36	0.34	0.28	0.3	0.26	0.28	0.23	0.22	0.57	0.64	0.52	0.44

References

[1] Chetty, C.C, Rossin, C.B, Gruissem, W, Vanderschuren, H, Rey, M. E. Empowering biotechnology in southern Africa: establishment of a robust transformation platform for the production of transgenic industry-preferred cassava. New Biotechnology, **2013** 30: 136–143.

[2] Nassar, N., Ortiz, R. Breeding cassava. Scientific American, **2010** 302: 78–84.

[3] FAOSTAT, Production, Crops, Cassava. Food and Agriculture Organization. **2010** http://www.fao.org/faostat/en/#home.

[4] Burns, A., Gleadow, R, Cliff, J., Zacarias, A., Cavagnaro, T. Cassava: The drought, war and famine crop in a changing world. *Sustainability*. **2010**; 2:3572-3607.

[5] Allem, A.C., The origins and taxonomy of cassava. In: R.J. Hillocks, et al. (eds.), Cassava: Biology, production and utilization. CABI, Wallingford, UK. **2002**. p. 1- 6.

[6] Alves, A.A.C. Cassava botany and physiology. In: R.J. Hillocks, J.M. Thresh and A.C. Bellotti. Eds. Cassava: biology, production and utilization. CABI Publishing, Wallingford, United Kingdom, **2002**, 67-89

[7] Mkumbira, J. Cassava development for small scale farmers: approaches to breeding in Malawi. PhD. Thesis, **2002** Swedish University of Agricultural Sciences, Uppsala, Sweden.

[8] Nassar, N.M. Chromosome doubling induces apomixis in a cassava x *Manihot anomala* hybrid. *Hereditas,* **2006,** 143, :246-8. doi: 10.1111/j.2006.0018-0661.01957.x. PMID: 17362361

[9] Nweke F.I, Spencer D.S.C, Lyam J.K. The cassava transformation: Africa's best-kept secret. **2002**

[10] Dixon, A. G. O. et al. The Five New CMD-resistant Cassava Varieties as released in Nigeria. ICP, IITA, Ibadan Nigeria. **2005**

[11] W.H.O. Global prevalence of vitamin A deficiency in populations at risk 1995–2005. **2009**, Geneva: World Health Organization

[12] Raheem, D., & Chukwuma, C. (2001). Foods from Cassava and their relevance to Nigeria and other African countries. Agriculture and Human Values. **2001**, 18: 383-390.

[13] IPCC. Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, eds. Climate Change 2014. The physical basis of climate change – Working Group I contribution to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, **2014**, UK: Cambridge University Press.

[14] Schkenker, W& Lobell, D.B. Robust negative impacts of climate change on African agriculture. *Env. Res. Letters***, 2010,** 5: 014010.

[15] Okoye N.N, Nwagbara M.O, Ijioma M.A. Root Yield Response of Pro-Vitamin 'A'Cassava to Climatic Parameters in Umudike, Southeastern Nigeria. *J Climatol Weather Forecast* **2021** 8:253. doi: 10.35248/2332-2594.2020.8.253

[16] El-Sharkawy, M.A. Cassava biology and physiology. *Plant Mol Biol*, **2004**, 56, 481–501. https://doi.org/10.1007/s11103-005-2270-7

[17] De Souza, A. P, Lynnicia N. Massenburg, Deepak Jaiswal, SiyuanCheng, Rachel Shekar and Stephen P. Long Rooting for cassava: insights into photosynthesis and associated physiology asa route to improve yield potential. New Phytologist **2016**, 213:50–65

[18] Jiang, D., Wang, Q., Ding, F., Fu, J. & Hao, M. Potential marginal land resources of cassava worldwide: A data-driven analysis. Renew. Sust. Energy Rev. 104(C), 167–173 (**2019**). https://doi.org/10.1016/j.rser.2019.01.024

[19] Kintchéa, K. Hauserb, S, Mahungua , N.M, Ndondaa , A, Lukomboa ,S, Nhamoc, N., Uzokwed ,V.N.E., Yomenie ,M., Ngamitsharaf ,J., Ekokog , B., Mbalaf ,M., Akemb ,C., Pypersh, P., Matungulua ,K.P., Kehbilaa , A., Vanlauweh, A.B. Cassava

yield loss in farmer fields was mainly caused by low soil fertility and suboptimal management practices in two provinces of the Democratic Republic of Congo. European Journal of Agronomy, **2017** 89, 107–1232017 http://dx.doi.org/10.1016/j.eja.2017.06.011

[20] Adefisan, E. A. & Abatan, A. A. Agroclimatic zoning of Nigeria based on rainfall characteristics and index of drought proneness. *J. Environ. Earth Sci*. 2015 5(12), 115–128

[21] Omotosho, J. B., Agele, S. O., Balogun, I. A. & Adefisan, E. A. Climate variability, crop-climate modelling and water ecophysiology research: Implications for plant's capabilities for stress acclimatization, yield production and food security. Glob. J. Plant Ecophysiol. **2013**, 3(2), 56–69.

[22] Oche, C. Y. Agro-climatic Zonation for Wheat Production in the Savanna Region of Nigeria. *J. Trop. Geogr*. **1998** 19(1), 39–50

[23] Piepho H. P., Mohring, J., Melchinger, A.E., & Buchse, A. BLUP for phenotypic selection in Plant Breeding and variety testing. *Euphytica* **2008** 161:209-228. https://doi.org/ 10.1007/s10681-007-9449-8.

[24] R Development Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, **2008**, Vienna, Austria. http://www.r-project.org/.

[25] Rabbi, I.Y., Udoh, L.I., Wolfe, M., Parkes, E.Y., Gedil, M.A., Dixon, A.G.O., Ramu, P., Jannink, J., & Kulakow, P. Genome-Wide Association Mapping of Correlated Traits in Cassava: Dry Matter and Total Carotenoid. *Plant genome*. Volume 10: no. 3, pp 1-14. https://doi.org/10.3835/plantgenome, 2016. 09.0094

[26] Lemoine, R., La Camera, S., Atanassova, R., Dedaldechamp, F, Allario, T, Pourtau, N, Bonnemain, J.L., Laloi, M., Coutos-Thevenot, P., Maurousset, L., Faucher, M., Girousse, C., Lemonnier, P., Parrilla, J., & Durand, M. Source-to-sink transport of sugar and regulation by environmental factors. *Front Plant Sc*i **2013** 4: 272

[27] Abdoulaye, T., Abass, A., Maziya-Dixon, B., Tarawali, G., Okechukwu, R., Rusike, J., Alene, A., Manyong, V., & Ayedun, B. Awareness and adoption of improved cassava varieties and processing technologies in Nigeria*. J. Dev Agric Econ* (2014) 6:67–75. https://doi.org/10.5897/JDAE2013. 00

[28] Esuma, W., Kawuki, R.S, Herselman, L., & Labuschagne, M.T (2016). Stability and genotypes by environment interaction of provitamin A carotenoid and dry matter content in cassava in Uganda. *Breed. Sci.* (**2016**) 66:434–443. https://doi.org/10.1270/ jsbbs.16004.

[29] Maziya-Dixon, Carotenoids quantification in Cassava, Food and Nutrition Sciences Laboratory. Presentation, IITA, Ibadan, Available at Carotenoids quantification in Cassava (slideshare.net), assessed on 26thMay, 2022

[30] Tumuhimbise, R., Rob, M., Shanahan, P., & Kawuki, R. Farmers' Perceptions on Early Storage Root Bulking in Cassava (Manihot esculenta Crantz) in East and Central Uganda and their Implication for Cassava Breeding. World J. Agric. Sci., **2012** 8 (4): 403-408

[31] Ceballos, H., Davrieux, F., Talsma, E. F. , Belalcazar, J., Chavarriaga, P., & Andersson, M. S. Carotenoids in Cassava Roots. In D. J. Cvetkovic, & G. S. Nikolic (Eds.), Carotenoids. IntechOpen. **2017**, https://doi.org/10.5772/intechopen, 68279

[32] Jos, J.S., Nair, S.G., Moorthy, S.N., & Nair, R.B. (1990) Carotene Enhancement in Cassava. *J. Root Crops,***1990**, 16, 5–11.

[33] Moorthy, S.N., Jos, J.S., Nair, R.B., & Sreekumari, M.T. (1990**)** Variability of carotene Content in Cassava Germplasm. *Food Chem*., 36, 223–236.

[34] Parkes, E., Cassava Breeding Unit, International Institute of Tropical Agriculture, Ibadan, Oyo state, Personal Comm, **2021.**

[35] Okechukwu, R. U. & A.G.O. Dixon Journal of Crop Improvement Genetic Gains from 30 Years of Cassava Breeding in Nigeria for Storage Root Yield and Disease Resistance in Elite Cassava Genotypes Journal of Crop Improvement, **2008** Vol. 22(2) (#44) **2008** Available online at http://www.haworthpress.com, doi:10.1080/15427520802212506, assessed 24th May, 2022

[36] Akparobi SO, Togun OA, Ekanayake IJ, Dris R. . Effect of low temperatures on dry matter partitioning and yield of cassava clones. *Trop. Sci*, **2002**, 42: 22–29.

[37] Akinola S. A, Adelodun, A.A & Orimoogunje. O.I, Agro-Climato-Edaphic Zonation of Nigeria for a Cassava Cultivar using GIS-Based Analysis of Data from 1961 to 2017. *Sci. Rep*, **2020** 10:1259 https://doi.org/10.1038/s41598-020-58280-

[38] Sarr, P. S., Araki, S. & Njukwe, E. Interactions between cassava varieties and soil characteristics in crop production in eastern Cameroon. *Afri. Study Monogr*. **2013**, 34(4), 187–202.

[39] Moreno-Cadena ,Patricia, Gerrit Hoogenboom, James H. Cock, Julian Ramirez-Villegas, Pieter Pypers, Christine Kreye, Meklit Tariku, Kodjovi Senam Ezui, Luis Augusto Becerra Lopez-Lavalle, Senthold Asseng, (2021)Modeling growth, development and yield of cassava: A review, *Field Crops Research* **2021**,Volume 267, 108140,ISSN 0378-4290, https://doi.org/10.1016/j.fcr.2021.108140