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Research Article

PERFORMANCE OF SOME SELECTED CASSAVA PROGENIES FROM A BIPARENTAL POPULATION OF TWO NON-INBRED PARENTS

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ABSTRACT. Cassava is an important root crop in sub-Saharan Africa and is a crop of choice for resource-poor farmers in savannah areas, where its production faces dry spells at certain periods of the year. This study was carried out to evaluate some selected progenies of a drought-tolerant mapping population of two non-inbred cassava parents. The study was based on 30 genotypes comprising 25 progenies and five checks which included the two parents which were arranged in a 6 × 5 alpha lattice design with three replications. These genotypes were assessed for growth and yield parameters including plant height, storage root yield, and yield components. Analysis of variance indicated significant ($p < 0.05$) genotypic variability in all the traits except mean root weight. A greater proportion of the observed phenotypic variability for all the traits (apart from mean root weight) was due to the genotypic effect which indicated strong genetic influence. A significant positive correlation was found between storage root yield and girth, harvest index, and mean root weight, making these traits suitable secondary traits for indirect selection for root yield. The principal component analysis further identified plant height, storage root yield, mean root weight, and storage root girth as the key productive traits contributing to the variability among the cassava genotypes. Five of the progenies; 061A (36.55 t ha^{-1}), 126A (28.73 t ha^{-1}), 175A (27.65 t ha^{-1}), 067A (26.53 t ha^{-1}), and 026A (26.34 t ha^{-1}) had a significantly greater root yields than the highest yielding check variety, TMS98/0505 (23.42 t ha^{-1}). The superior progenies would be selected for further testing towards release.

Keywords: *Genotypic effect, yield components, principal component analysis, key productive traits*

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) serves as a major staple food crop for more than 800 million people in sub-Saharan Africa who depend on it for their calorie needs [1]. The crop is resilient to several environmental stresses and can produce appreciable yields when subjected to adverse environmental conditions such as low soil fertility, soil water deficits, and low input farming systems [1, 2]. It possesses several adaptive features that ensure survival in these stressful environments [3, 4, 5, 6]. Due to its low input requirements, it is mostly cultivated by resource-poor farmers and therefore serves as a food security crop in areas where most crops would fail. For this reason, cassava is one of the most important staple foods in Ghana and is gaining popularity, especially in the Guinea savannah ecology of northern Ghana where it is cultivated by most farm households [7]. However, root yields in this ecology are far lower than those reported elsewhere. This could be due to several factors including erratic rainfall, high temperatures, low soil fertility, intermittent drought, etc.

Low storage root yield of cassava in savannah ecologies has been attributed to factors such as limited soil moisture, heat [5, 6], poor soil fertility as well as incidence of diseases and pests such as mealy bugs and green spider mites [8, 9, 10]. Among these, soil moisture stress is one of the major constraints and it is expected to escalate with the changing climate, especially in the Northern Region of Ghana [5, 6]. Consequently, it could negatively impact cassava growth and storage root yield, especially in drought-susceptible cultivars [5, 11, 12]. This calls for the development of new improved cassava varieties that are resilient to this constraint. Oliveira et al. [13] and Duque and Setter [14] reported that cassava responds to limited moisture through the development of longer roots that can scavenge for moisture from lower soil depths, an attribute that allows the crop to survive in moisture-stress environments. El-Sharkawy [5] and Okogbenin et al. [6] also reported the existence of genotypic variability within the cassava gene pool for adaptive traits in dry ecologies which can be targeted to identify and develop adapted cassava varieties for marginal ecologies. Understanding the mechanisms governing the genotypic variability in these adaptive traits in cassava will facilitate the development of new improved varieties capable of overcoming the emerging climatic challenges in the Guinea savannah ecology of Ghana which covers about 40 % of the total land area of Ghana. This area is characterized by a monomodal rainfall pattern which often lasts five months and is followed by a long dry season that can last up to six to seven months with an average annual rainfall of 1100 mm, which is sporadic [15].

The mechanism of tolerance to dry conditions in crops is exhibited through escape, avoidance, and tolerance, among others [16]. Drought escape refers to a plant's ability to complete its life cycle before serious soil and plant water deficits occur [17]. Drought avoidance is the ability of plants to maintain relatively high tissue water potential despite a shortage of soil moisture [18]. This is achieved through the maintenance of turgor that results from increased rooting depth, efficient root systems, increased hydraulic conductance, and reduced epidermal conductance [19]. Drought tolerance also refers to the ability to withstand soil water deficit with low tissue water potential [18]. All these attributes are regulated by several genes which may be influenced by the prevailing environmental factors in the ecology. For instance, Turyagyenda et al. [4] reported the presence of three candidate genes that regulate drought tolerance in cassava. Breeding efforts are thus targeted at exploiting this inherent genotypic variability conferred by these genes among cassava genotypes for the traits and mechanisms governing drought tolerance in cassava.

The processes that confer tolerance to moisture stress such as stomatal closure and reduced leaf area usually result in reduced assimilation of carbon dioxide [20]. Premachandra et al. [21] and Sanchez et al. [22] reported that certain traits are associated with tolerance and survival of crops under dry conditions and are often associated with reduced photosynthesis and yield potential. It is therefore necessary to understand the genetic basis of such traits as well as their relationships with yield so that they can be exploited in a breeding programme. Crops must therefore balance the mechanisms of escape, avoidance, and tolerance to be productive [23]. As such, in cassava breeding for dry ecologies, these traits are targeted in multiple selection schemes to indirectly select for superior cassava root yield. This is because root yield has low heritability and direct selection often results in slow progress [24]. A better understanding of these mechanisms, their associated genetic parameters, and heritability could result in much faster progress than direct selection for yield.

Though several indirect selection approaches are often utilised in plant breeding, recent studies have used approaches such as correlation, path analysis, and principal component analysis to identify traits that are closely linked to root yield for indirect selection [25, 26, 27, 29].

In the present study, a set of cassava progenies developed from a cross between two non-inbred parents made up of a drought-tolerant variety and a high-yielding but drought-susceptible parent, were selected from a series of trials conducted at the CSIR-Savanna Agricultural Research Institute, Nyankpala in the Guinea savannah ecology of northern Ghana. The objective was to evaluate them for yield performance and identify superior candidates for multilocational evaluation in the Guinea savannah and transition ecologies of Ghana.

MATERIALS AND METHODS

The Study Area

The experiment was carried out for two growing seasons (2016 to 2018) at the research fields of the Savanna Agricultural Research Institute, Nyankpala which is located in the Guinea savannah ecology of northern Ghana. The area is noted for its monomodal rainfall pattern which begins in late April and lasts till October. Though characterized by average annual rainfall estimated to be around 1033mm, intermittent dry spells which sometimes last for two to three weeks occur even during the rainy season. The rainy season is followed by a long dry season which often begins in November and ends in March. Long-term annual average relative humidity and average temperature have been reported to be 61 % and 28.1 ^{0}C respectively. Average potential evaporation (1720 mm) normally exceeds annual rainfall [15, 30]. These two scenarios make the area dry with its concomitant effect on crop growth and productivity.

Cassava genotypes used for the study.

The study was based on 30 genotypes which were made up of 25 cassava progenies, the two parents and two farmer-preferred landrace which is widely cultivated in the Northern region of Ghana, and one improved variety, Eskamaye which was released in 2003. The population was developed from a cross between two non-inbred parents made up of a drought-tolerant variety (TMS98/0505) and a high-yielding but drought-susceptible parent (TMS97/0510). Both parents have been officially released in Nigeria. The selected progenies were chosen based on their performance in a preliminary trial involving 207 pseudo-F_2 individuals from the original cross between the two parents.

Experimental Design and Planting

The land was ploughed and harrowed after which ridges were manually raised using a spacing of one metre between adjacent ridges. The experiment was then laid out in a 6 x 5 alpha lattice design with three replications. Each plot consisted of four rows of five plants in each row. Mature cassava cuttings measuring 25-30 cm were planted on top of the ridges using an intra-row spacing of 1 m. The two central rows were used for data collection. The plants were harvested at 12 months after planting in both years and the following data were collected; plant height at harvest, fresh storage root weight per plot (kg) which was used to compute storage root yield (t ha^{-1}), above-ground biomass weight (kg), harvest index (storage root weight as a percentage of total biomass), mean root weight (g; total root weight over number of roots), storage root length (cm), and storage root girth (cm). Storage root length to girth ratio was subsequently estimated.

Data Analysis

The data was subjected to analysis of variance for alpha lattice design using the R statistical package [31]. Genotypes were considered as fixed factors whilst replicates and years were considered as random factors. Treatment means were separated using the standard error of the difference ($p < 0.05$). Genetic parameters and variance components were computed according to Ntawuruhunga and Dixon [32]. Genotypic coefficient of variation (CV_g), environmental coefficient of variation (CV_e), and relative coefficient of variation (CV_r) were estimated as suggested by Oliveira et al. [33]. Principal component analyses were carried out based on variance-correlation ratio using Genstat 12.1

[34]. Biplot analyses were also carried out to illustrate the relationship between genotypes as well as the association between traits using the R statistical package [31].

RESULTS AND DISCUSSION

Genotypic variability among genotypes for traits studied

Genetic improvement in any crop depends on the extent of diversity inherent in the population and progress made depends on the heritability of the traits concerned [35]. Understanding the inherent genetic variation in a population and the genetic relationship among genotypes are key considerations in determining the amount of progress that can be made [36]. In the current study, significant variation was detected among the cassava genotypes for all the traits. Combined analysis of variance indicated a highly significant ($p < 0.001$) effect of genotype on all the traits measured apart from mean root weight (Table 1). This suggests the presence of ample genotypic variation to warrant selection based on any of these traits. However other considerations need to be made on the extent of genetic and environmental influence on these traits in making that decision. For instance, the effect of year on the measured traits was also highly significant ($p < 0.001$) except for storage root yield. Due to the variations in conditions that may arise in different years and their significant effect on storage root yield, genotypes need to be tested across several years and locations to identify stable genotypes [37-39. The interaction effect of genotype and year (G × Y) was however not significant ($p > 0.05$) for any of the traits. This suggests that the rankings and/or the variance among genotypic means did not change year after year and hence, selection based on a single year's data could be effective in identifying superior genotypes.

Table 1. *Combined analysis of variance for plant height, root yield, harvest index, number of roots per plant, mean root weight, root girth, root length and root length to girth ratio.*

Source of variation	**d.f.**	**Plt_ht (cm)**	**Rt_yld ($t\ ha^{-1}$)**	**HI**	**Rt_no plt^{-1}**	**MRW (g)**	**Rt_girth (cm)**	**Rt_lent (cm)**	**L:G ratio**
Rep	2	1255.10	107.52	0.03	152.12	2099986.00	3.24	62.37	54.37
Rep (Blk)	12	1049.50	130.2	0.01	6.33	212385.00	1.33	36.89	6.47
Genotype (G)	29	2248.80***	156.98***	0.02***	14.51***	76892.00ns	2.79***	97.86***	14.74***
Year (Y)	1	153631.00***	0.02ns	1.24***	188.09***	1926085.00***	63.11***	1464.81***	98.75***
G×Y	29	650.60ns	55.17ns	0.02ns	6.79ns	84558.00ns	1.12ns	41.45ns	5.58ns
Residual	106	517.90	50.60	0.01	5.31	83083.00	1.62	34.93	5.24

,,*** = significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$ respectively, ns = not significant ($P > 0.05$). d.f. = degrees of freedom, Rep = Replication, Rep (Blk) = Block within replication, Plt_ht (cm) = Plant height (cm), Rt_yld ($t\ ha^{-1}$) = Storage root yield ($t\ ha^{-1}$), HI = Harvest index, Rt_no plt^{-1} = Number of storage roots per plant, MRW (g) = Mean root weight (g), Rt_girth (cm) = Girth of storage roots, Rt_lent (cm) = Length of storage roots (cm), L:G ratio = Storage root length: girth ratio.*

Variance components, broad sense heritability, phenotypic and genotypic coefficient of variation

Analysis of the variance components indicated that most of the traits apart from mean root weight had a greater proportion of their phenotypic variance being accounted for by the genotypic variance (Table 2). This indicates a stronger genetic influence on these traits compared to traits that showed greater environmental variance than genotypic variances [40]. In the present study, the environmental variance estimate of mean root weight was greater than the genotypic variance, implying a stronger environmental influence. Therefore, selection for mean root weight in this population would be less effective and result in slow progress [33]. Broad sense heritability ranged from moderate (43 %) to high (> 50%) for most of the traits. Harvest index had the highest broad sense heritability (66.6 %)

whilst mean root weight had the least (43 %). Selections based on the harvest index could result in much greater progress. Oliveira et al. [33] and dos Santos Silva et al. [41] indicated that traits for improving cassava productivity must have high heritability when selecting superior genotypes. This is because the level of advancement in the breeding process is slow in traits with low heritability [42]. For traits with high broad sense heritability estimates, simple selection methods especially in clonally propagated crops like cassava could be effective [43]. Meena et al. [44] suggested that selection for improvement in a particular trait does not depend only on inherent genetic diversity but also on the extent of heritability.

Both phenotypic coefficient of variation (CV_p) and genotypic coefficient of variation (CV_g) ranged from medium to high. Plant height and storage root length had moderate CV_p (19.14 % and 12.7 % respectively) whilst storage root yield (32%), storage root number (28%), storage root girth (20.1%) storage root length to girth ratio (L:G, 22.1 %) and mean root weight (MRW, 63%) had high CV_p. On the other hand, CVg ranged from low (< 10 %) for storage root length (9.6%), medium (10-20 %) for plant height (14.1 %), root girth (15.9%) and L:G ratio (17.3%) and high (> 20%) for harvest index (44.8 %), MRW (41.4 %), root yield (25.8 %) and root number per plant (20.9 %). The highest (44.8 %) environmental coefficient of variation (CV_e) was recorded for MRW (44.8 %) whilst root length had the lowest (8.1 %). A low genotypic coefficient of variation was recorded for only root length. Khan et al. [28] indicated that traits with moderate to high genotypic coefficient of variation will have high clonal variability therefore direct selection would be effective. However, in the case of mean root weight, an equally high environmental variance coupled with low broad sense heritability indicates a higher environmental influence. The relative coefficient of variation which is the ratio of the genotypic coefficient of variation to the environmental coefficient of variation was greater than 1 for all the traits apart from mean root weight. This indicates that environmental effects were minimal compared to the genetic effect for these traits apart from meant root weight [33, 45]. Though heritability is very useful in predicting future progress in planting breeding, several authors have reported that heritability alone does not give an accurate prediction of the amount of progress that can be made with selection [46, 47, 48]. Therefore, the genetic advance had to be estimated. Genetic advance as a percentage of the mean (GAM) ranged from 11.4 % for storage root length, to 33.7 % for mean root weight. Mean root weight, though had the highest genetic advance as a percentage of the mean also had a low heritability and high environmental coefficient of variation indicating that any selection based on it could be ineffective. For an effective response to selection, the selected traits should combine moderate to high heritability, high relative coefficient of variation and high genetic advance as a percentage of the mean [28, 49, 50].

Table 2. *Mean (±) estimates of variance components, heritability, phenotypic and genotypic coefficient of variation for eight traits from 30 cassava genotypes evaluated for two years at Nyankpala.*

Traits	**Mean (±STD)**	σ^2_g	$\sigma^2_{g\times y}$	σ^2_e	σ^2_p	H^2_b	CV_p (%)	CV_g (%)	CV_e (%)	CV_r (%)	**GA**	**GAM**
Plt_ht (cm)	147.35±20.93	432.18	16.58	346.33	795.10	54.36	19.14	14.11	12.63	1.12	22.83	15.49
Rt_yld (t ha^{-1})	21.03±5.33	29.44	1.00	16.83	47.26	62.28	32.69	25.80	19.51	1.32	6.84	32.53
HI	0.55±0.06	0.06	0.01	0.02	0.09	66.67	54.81	44.75	25.84	1.73	0.08	14.28
Rt_no plt^{-1}	7.78±1.51	2.65	0.37	1.80	4.82	54.94	28.22	20.92	17.25	1.21	1.71	21.95
MRW (g)	348.31±132.45	20748.33	3204.67	24299.33	48252.33	43.00	63.07	41.35	44.75	0.92	117.33	33.68
Rt_girth (cm)	4.66±0.71	0.55	0.04	0.28	0.88	62.49	20.06	15.86	11.44	1.39	0.91	19.58
Rt_lent (cm)	42.62±4.06	17.05	0.54	11.83	29.43	57.95	12.73	9.69	8.07	1.20	4.85	11.38
L:G ratio	9.69±1.64	2.80	0.11	1.67	4.57	61.22	22.06	17.26	13.32	1.30	2.07	21.35

Key: *STD = Standard deviation,* σ^2_g *= genotypic variance,* $\sigma^2_{g\times y}$ *= genotype × year variance,* σ^2_e *= environmental (year) variance,* σ^2_p *= phenotypic variance,* H^2_b*= broad sense heritability,* CV_p *(%) = Phenotypic coefficient of variation,* CV_g *(%) = Genotypic coefficient of variation,* CV_e *(%) = environmental coefficient of variation,* CV_r *(%) = relative coefficient of variation, GA = Genetic advance, GAM = Genetic advance as percentage of mean; Plt_ht (cm) = Plant height (cm), Rt_yld (t* ha^{-1}*) = Storage root yield (t* ha^{-1}*), HI = Harvest index, Rt_no* plt^{-1} *= Number of storage roots per plant, MRW (g) = Mean root weight (g), Rt_girth (cm) = Girth of storage roots, Rt_lent (cm) = Length of storage roots (cm), L:G ratio = Storage root length to girth ratio.*

Principal Component Analysis

Principal component analysis is important in determining the relative contribution of different traits to the total variation [27]. The relative discrimination power of the PC axes depends on the strength of its axes as measured by their eigenvalues [29, 51]. The principal component analysis showed that the first two PC axes cumulatively explained 51.7 % of the total variation captured within the population used (Table 3). The first principal component axis (PC1) which explained 29.9 % of the variability had plant height, root yield, mean root weight, storage root girth, and storage root length to girth ratio as contributing greatly to the variability. Also, the second PC (PC2) which explained 21.8 % of the variation had root number per plant, harvest index, and storage root length as the important traits. These identified traits could be prioritized and targeted for selection to make progress in the breeding programme [29]. In addition to this, some of these traits (as presented in Table 2), especially harvest index (66 %), root yield (62 %), root girth (62 %) and storage root length to girth ratio (61 %) had relatively high broad sense heritability estimates suggesting the possibility of significant progress with selection based on these traits. Earlier studies have indicated that selection based on multiple traits, and their associated genotypes allows the identification of genotypes that can be selected as sources of genes for these traits [36]. Yan and Tinker [52] further suggested the use of genotype × trait biplot for assessing the relative contribution of traits to variability and associated genotypes. Egesi et al. [53] also compared genotypes based on multiple traits using the genotype × trait biplot analysis to identify those that combine several desirable traits and the associations between those traits.

Table 3. *Principal component (PC) analysis of eight traits showing their relative contributions to the total variation among 30 cassava genotypes at Nyankpala for two years.*

Traits	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Plant height (cm)	**0.36**	-0.30	-0.22	0.44	0.43
Root yield (t ha^{-1})	**0.31**	0.47	0.30	0.35	0.25
Root number per plant	-0.25	**0.36**	-0.17	0.63	0.03
Mean root weight (g)	**0.44**	0.01	0.40	-0.32	0.45
Harvest index	-0.17	**0.58**	0.34	-0.15	-0.05
Storage root girth (cm)	**0.54**	0.19	-0.18	0.02	-0.51
Storage root length (cm)	0.23	**-0.30**	0.52	0.33	-0.53
Ratio of root length to girth	**-0.37**	-0.32	0.50	0.22	0.09
Latent roots	2.39	1.75	1.51	1.30	0.58
%variation	29.89	21.84	18.85	16.18	7.22
Cumulative	29.89	51.73	70.58	86.76	93.98

Note: Figures in bold represent the most important traits under the different principal components (PCs).

Biplot Analysis showing the relationship between traits

The PCA biplots indicated varying levels of association between the traits and their association with certain genotypes which could be useful in identifying genotypes with unique attributes [26, 28]. The first two principal component axes accounted for 41.4 % and 20.35 % respectively (Figure 1). The angle between the vectors of traits below 90^{o} indicates a positive association whilst angles above 90^{o} indicate a negative correlation between these traits. For instance, storage root yield was highly correlated with harvest index, root girth, and mean root weight, and were closely associated with genotypes 061A (highest root yield), 026A (2nd highest for root girth), and 175A (highest for mean root weight). This implies that selection for harvest index can indirectly result in yield improvement. Other studies have also reported the importance of harvest index, especially in selection for high root yield in cassava seedling populations [54, 55, 56]. On the other hand, storage root length to girth (L:G) ratio and root length were found to be negatively correlated with root yield and were more pronounced in genotypes 055A, 007A, and 134A, all of which had relatively lower root yields compared to genotypes 061A and 026A. Earlier studies have also found the L:G ratio to be associated with adaptability traits such as high leaf abscisic acid content, low stomatal conductance, and carbon isotope discrimination (especially under stress environments), under moisture-stress conditions than under well-watered conditions [57, 58, 59]. Genotypes with higher L:G ratios tend to partition photosynthates for root extension at the expense of expansion in root girth [3, 60]. Therefore, using the L:G ratio in selecting suitably adapted cassava genotypes for dry areas should be done concurrently with high root yield.

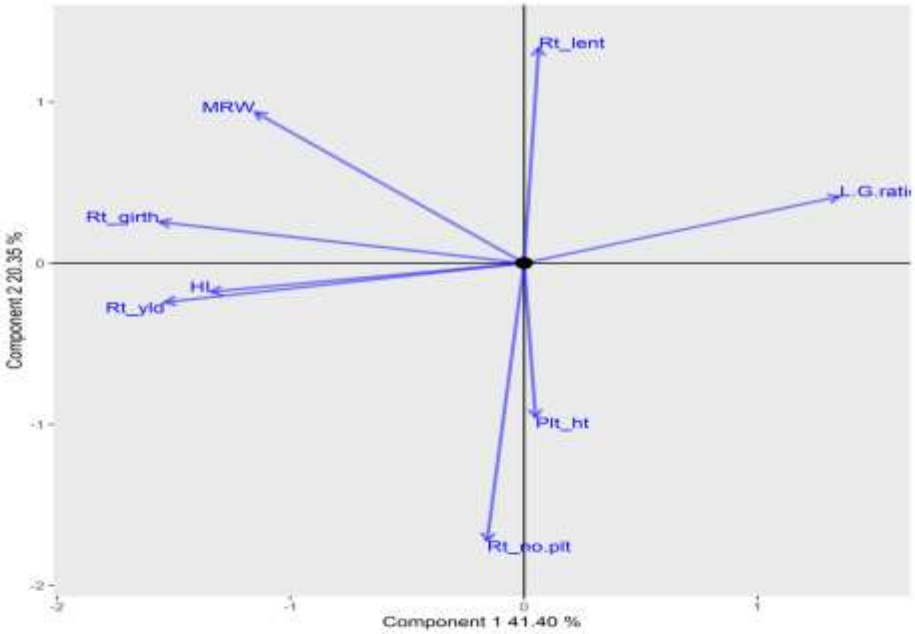

Fig. 1. *PCA biplot showing relationship between growth and yield traits from 30 cassava genotype. Plt_ht (cm) = Plant height (cm), Rt-yld (t ha*$^{-1}$*) = Storage root yield (t ha*$^{-1}$*), HI = Harvest index, Rt_no plt*$^{-1}$ *= Number of storage roots per plant, MRW (g) = Mean root weight (g), Rt_girth (cm) = Girth of storage roots, Rt_lent (cm) = Length of storage roots (cm), L:G ratio = Storage root length to girth ratio.*

Genotype × Trait Association Analysis

The principal component (PC) biplot was further used to illustrate the relationship between the traits and the associated genotypes (Figure 2). Identification of traits associated with specific genotypes facilitates the selection of these genotypes as parents for inclusion in breeding programmes that seek to improve those traits [25, 53]. Moreover, the detection of association between traits allows simultaneous selection of those traits or use such easy-to-measure trait to indirectly select for the one that is more difficult to measure. From the current study, storage root yield, harvest index, and root girth were closely linked and were found to be closely associated with genotype 061A which was the best-performing genotype for these traits. Genotypes 026A and 175A were also linked with high mean root weight. Again, genotypes 010A and 065A were noted for their relatively longer roots compared to most of the other genotypes found at the opposite end of the biplot. Genotypes 055A and 007A had the greatest L:G ratios whereas Pontisange and 100A produced the tallest plants compared to the other genotypes. Other genotypes that were found around the origin of the biplot did not stand out for any of the traits or they had stable performances in all the traits compared to the genotypes at the apex of the vertices that were associated with the respective traits.

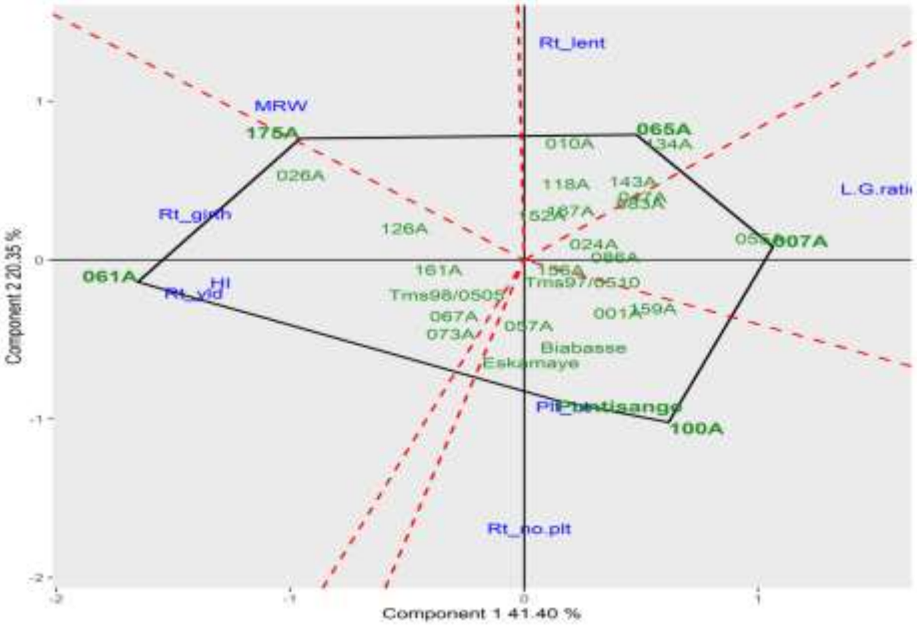

Fig. 2. *PCA biplot showing genotype x trait association with growth and yield traits of 30 cassava genotypes. Plt_ht (cm) = Plant height (cm), Rt-yld (t ha^{-1}) = Storage root yield (t ha^{-1}), HI = Harvest index, Rt_no plt^{-1} = Number of storage roots per plant, MRW (g) = Mean root weight (g), Rt_girth (cm) = Girth of storage roots, Rt_lent (cm) = Length of storage roots (cm), L:G ratio = Storage root length to girth ratio.*

Performance of Genotypes

Genotypic variation was significant for all the agronomic parameters measured. Plant height ranged between 113.7 cm and 230.5 cm for genotypes 083A and Pontisange respectively with a mean of 147.85 cm (Table 4). Plant height is an important attribute that indicates the level of agronomic management and is an indication of growth in a particular environment [61, 62]. It also influences the choice of cassava varieties by farmers especially in intercropping-based cropping systems where most farmers prefer tall late-branching or non-branching genotypes [63, 64] that are suitable for intercropping. It is also crucial when selecting varieties suitable for the rapid multiplication of planting materials [65] as most tall plants yield more planting materials. From this study, none of the progenies was significantly taller than the farmer-preferred variety, Pontisange. However, two progenies, genotypes 075A and 057A, had significantly taller plants than the female parents, TMS98/0505, which was shorter (141.6 cm) than the male parent TMS97/0510 (160.8 cm).

Storage root yield and quality characteristics (food and industrial utilization) are the ultimate aims of most cassava breeding programmes [66, 67, 68]. Significant genotypic variation was observed for storage root yield which varied from 12.09 t ha^{-1} (055A) to 36.55 t ha^{-1} (061A) with a mean of 20.89 t ha^{-1}. Five of the progenies; 061A (36.55 t ha^{-1}), 126A (28.73 t ha^{-1}), 175A (27.65 t ha^{-1}), 067A (26.53 t ha^{-1}) and 026A (26.34 t ha^{-1}) had a significantly greater root yield than the highest yielding check, TMS98/0505 (23.42 t ha^{-1}) which was also the female parent.

These genotypes again had a significantly greater root yield than the released variety, Eskamaye (23.32 t ha^{-1}). The yield ranges of these check varieties are similar to the findings of earlier studies involving the same local check varieties (Eskamaye and Biabasse) in the same environment [3, 69]. The harvest index varied significantly among the genotypes studied. Genotype 055A had the lowest harvest index (0.44) with genotype 026A having the highest of 0.64. Only four of the progenies had a significantly lower harvest index than the average harvest index of 0.55.

Harvest index is an important trait that indicates the partitioning efficiency of dry matter into the economic parts of the cassava plant. It has also been identified to be positively and highly correlated to storage yield and can therefore be used to indirectly select for high storage root yield [54, 55, 56]. In dry ecologies, with limited soil water availability, there is the need to identify and select genotypes that are efficient in partitioning the dry matter into the storage roots. Such genotypes would be ideal candidates for selection. The current findings revealed adequate genotypic variability among the genotypes to warrant selection. Traits such as storage root number per plant, mean root weight, root girth, and root length are very important determinants of root yield in cassava and have been used as surrogate traits in situations where direct selection result is slow or is ineffective [33, 47, 54, 55, 56]. Based on the correlation analysis, storage root yield had a stronger and positive correlation with root girth than root length corroborating the findings of an earlier [69]. Subsequently, the ratio of the storage root length to girth, which was used as an index to determine the pattern of dry matter accumulation; whether for expansion in girth or extension in root length [69, 70, 71]. This index was found to be negatively correlated with storage root yield but positively correlated with survival traits such as abscisic acid content, carbon isotope ratio, and long roots [3, 60]. Lower values of storage root length to girth ratio reflect genotypes that prioritise storage root expansion in girth over extension in length to lower soil depths. It is therefore important to consider multiple traits based on their importance in determining the final root yield.

Table 4. *Mean performance of 25 cassava progenies and five checks evaluated for storage root yield and related traits at Nyankpala for two years (2016 – 2018).*

Genotypes	Plt_ht (cm)	Rt_yld (t ha^{-1})	HI	Rt_no plt^{-1}	MRW (g)	Rt_girth (cm)	Rt_lent (cm)	L:G ratio
Progenies								
001A	132.30	17.72	0.53	8.92	202.70	4.37	39.74	9.46
007A	151.60	15.45	0.46	8.31	206.10	3.72	46.09	13.81
010A	139.30	20.75	0.55	6.54	373.90	4.75	50.18	10.96
024A	130.90	14.92	0.51	5.93	419.70	4.29	33.83	8.49
026A	135.90	26.34	0.64	6.06	447.50	6.44	44.92	7.18
047A	140.90	16.60	0.49	6.08	268.30	4.52	44.03	9.78
055A	133.00	12.09	0.44	6.89	179.70	3.99	41.04	10.55
057A	172.80	22.06	0.53	8.61	381.40	5.01	38.51	9.89
061A	139.00	36.55	0.63	8.96	555.30	6.86	41.42	6.11
065A	147.70	18.23	0.51	5.96	373.50	4.26	50.09	12.12
067A	157.30	26.53	0.53	9.21	430.00	4.97	40.57	8.17
073A	136.00	21.45	0.60	8.83	308.90	5.08	36.96	7.33
083A	113.70	12.97	0.51	5.75	237.20	4.53	39.22	8.80
086A	154.10	21.20	0.53	7.83	345.40	4.05	43.06	10.92
100A	155.30	18.93	0.46	11.57	164.60	3.93	38.63	10.38
118A	139.40	17.73	0.61	6.75	263.10	4.81	48.42	10.45
126A	136.40	28.73	0.61	8.21	410.70	5.21	46.26	8.97
134A	144.50	15.01	0.45	5.38	553.40	3.97	42.14	10.84

143A	123.80	18.61	0.57	7.21	296.40	4.11	47.00	11.64
152A	137.70	24.17	0.59	8.82	398.10	4.36	48.78	11.40
156A	157.70	19.76	0.52	7.15	309.30	4.75	40.89	8.77
159A	156.20	16.05	0.51	8.21	196.50	4.31	40.91	9.64
161A	129.70	25.20	0.63	8.54	472.20	4.54	40.06	9.06
167A	148.40	23.45	0.54	7.75	429.00	4.28	46.26	11.05
175A	161.80	27.35	0.57	5.97	772.00	5.71	46.38	8.18
Checks								
Biabasse	162.40	23.25	0.59	10.13	235.30	4.31	43.53	10.61
Eskamaye	149.80	23.32	0.59	10.04	279.00	4.54	39.61	8.83
Pontisange	230.50	21.19	0.61	8.75	280.20	4.05	41.32	10.72
TMS97/0510	160.80	17.81	0.55	6.74	250.90	5.16	39.12	8.80
TMS98/0505	141.60	23.42	0.59	8.42	402.10	5.08	39.72	7.79
Mean	147.35	20.42	0.55	7.78	348.31	4.66	42.62	9.69
SED	13.23	1.41	0.04	1.22	52.31	0.42	2.11	0.82

Plt_ht (cm) = Plant height (cm), Rt_yld (t ha^{-1}) = Storage root yield (t ha^{-1}), HI = Harvest index, Rt_no plt^{-1} = Number of storage roots per plant, MRW (g) = Mean root weight (g), Rt_girth (cm) = Girth of storage roots, Rt_lent (cm) = Length of storage roots (cm), L:G ratio = Storage root length to girth ratio.

CONCLUSION

The study revealed ample significant genotypic variability among the cassava genotypes for all the traits studied. A greater proportion of the observed phenotypic variability for all the traits, except mean root weight was due to genetic influence. A significant positive correlation was found between storage root yield and some of the traits such as root girth, harvest index, and mean root weight. Root girth and harvest index combined high genetic advance and moderate broad sense heritability making them suitable traits to target for indirect selection for improvement in storage root yield. Compared to the checks, five genotypes (061A, 126A, 175A, 067A, and 026A) had significantly superior storage root yield than the checks which makes them suitable candidates for further testing towards release.

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REFERENCES

[1] Burns, A., Gleadow, R., Cliff, J., Zacarias, A., Cavagnaro, T. (2010): Cassava: the drought, war and famine crop in a changing world. Sustainability 2: 3572-3607.

[2] Jarvis, A., Ramirez-Villegas, J., Campo, B. V. H., Navarro-Racines, C. (2012): Is cassava the answer to African climate change adaptation? Tropical Plant Biology 5(1): 9-29.

[3] Adjebeng-Danquah, J., Asante, I. K., Manu-Aduening, J., Agyare, R. Y., Gracen, V., Offei, S. K. (2020): Genotypic variability in some morpho-physiological traits in different environments and their relationship with cassava (*Manihot esculenta* Crantz) root yield. International Journal of Agronomy 2020: 1-19.

[4] Turner, N. C. (1979): Drought resistance and adaptation to water deficits in crop plants. In: Mussell, H., Staples, R. C. (Eds.). Stress Physiology in Crop Plants. Wiley, New York. pp. 343-372.

[5] Turyagyenda, L. F., Kizito, E. B., Ferguson, M., Baguma, Y., Agaba, M., Harvey, J. J. W., Osiru, D. S. O. (2013): Physiological and molecular characterization of drought responses and identification of candidate tolerance genes in cassava. AoB Plants 5: 1-17.

[6] El-Sharkawy, M. A. (2007): Physiological characteristics of cassava tolerance to prolonged drought in the tropics: Implications for breeding cultivars adapted to seasonally dry and semiarid environments. Brazilian Journal of Plant Physiology 19(4): 257-286.

[7] Okogbenin, E., Ekanayake, I. J., Porto, M. C. M. (2003): Genotypic variability in adaptation responses of cassava to drought stress in the Sudan Savannah zone of Nigeria. Journal Agronomy and Crop Science 189: 376-389.

[8] Adjebeng-Danquah, J., Martey, E., Manu-Aduening, J., Gracen, V., Asante, I. K., Offei, S. K. (2020): Farmers' perception on drought constraints and mitigation strategies in cassava cultivation in Northern Ghana: implications for cassava breeding. Sustainable Futures, 2: 1-14.

[9] Ezenwaka, L., Rabbi, I., Onyeka, J., Kulakow, P., Egesi, C. (2020): Identification of additional/novel QTL associated with resistance to cassava green mite in a biparental mapping population. PLos One 15(4): 1-15

[10] Ezenwaka, L., Dunia Pino Del Carpio, D. P., Jannink, J. L., Rabbi, I., Danquah, E., Asante, I., Danquah, A, Blay, E., Egesi, C. (2018): Genome-wide association study of resistance to cassava green mite pest and related traits in cassava. Crop Science 58: 1907-1918

[11] Parsa, S., Kondo, T., Winotai, A. (2012): The cassava mealybug (*Phenacoccus manihoti*) in Asia: First records, potential distribution, and an identification key. PLoS One 7(10):1-11

[12] Turyagyenda, L. F., Kizito, E. B., Baguma Y., Osiru, D. (2013): Evaluation of Ugandan cassava germplasm for drought tolerance. International Journal of Agriculture and Crop Sciences 5(3): 212-226.

[13] Aina, O. O., Dixon, A. G. O., Akinrinde, E. A. (2007): Effect of soil moisture stress on growth and yield of cassava in Nigeria. Pakistan Journal of Biological Sciences 10(18): 3085-3090.

[14] Oliveira, E. J., Morgante, C. V., Aidar, S. T., Chaves, A. R. M., Antonio, R. P., Cruz, J. L., Filho, M. A. C. (2017): Evaluation of cassava germplasm for drought tolerance under field conditions. Euphytica 213(8): 1-20.

[15] Duque L.O. and Setter T.L. (2013): Cassava response to water deficit in deep pots: root and shoot growth, ABA, and carbohydrate reserves in stems, leaves and storage roots. Tropical Plant Biology, 6: 199-209.

[16] Agyemang, I., Abdul-Korah, R. (2014): Strategies to combat desertification in Northern Region of Ghana: The role of Environmental Protection Agency. Physical Sciences Research International 2(2): 35-43.

[17] Oguz, M. C., Aycan, M., Oguz, E., Poyraz, I., Yildiz, M. (2022): Drought stress tolerance in plants: interplay of molecular, biochemical and physiological responses in important development stages. Physiologia 2: 1-18.

[18] Beebe, S. E., Rao, I. M., Blair, M. W., Acosta-Gallegos, J. A. (2013): Phenotyping common beans for adaptation to drought. Frontiers in Physiology 4(35): 1-20.

[19] Ahmadi, S. H., Plauborg, F., Andersen, M. N., Sepaskhah, A. R., Jensen, C. R., Hansen, S. (2011): Effects of irrigation strategies and soils on field grown potatoes: Root distribution. Agricultural Water Management 98: 1280-1290.

[20] El-Sharkawy, M. A. (2006): International research on cassava photosynthesis, productivity, eco-physiology, and responses to environmental stresses in the tropics. Photosynthetica 44(4): 481-512.

[21] Premachandra, G. S., Hahn, D. T., Axtell, J. D., Joly, R. J. (1994): Epicuticular wax load and water use efficiency in bloomless and sparse bloom mutants of *Sorghum bicolor* L. Environmental and Experimental Botany 34: 293-301.

[22] Sanchez, F. J., Manzanares, M., de Andres, E. F., Tenorio, J. L., Ayerbe, L. (2001): Residual transpiration rate, epicuticular wax load and leaf colour of pea plants in drought conditions: Influence on harvest index and canopy temperature. European Journal of Agronomy 15: 57-70.

[23] Blum, A. (2011): Plant water relations, plant stress and plant production. In: Breeding plants for water-limited environments. Springer, New York, NY. pp. 11-52. https://doi.org/10.1007/978-1-4419-7491-4_2 .

[24] Gurmu, F., Hussein, S., Laing M. (2018): Combining ability, heterosis and heritability of storage root dry matter, beta-carotene, and yield-related traits in sweetpotato. HortScience 53(2): 167-175.

[25] Adjebeng-Danquah, J., Acheremu, K., Chamba, E. B., Abukari, I. A., Sumaila, A., Agyare, R. Y., Amegbor, I. K., Agyapong, F. A., Amoako, O. A., Amagloh, F. C., Kassim, B. Y., Parkes, E. (2023): Genotypic variability and genetic parameters for root yield, dry matter and related traits of cassava in the Guinea Savannah ecological zone of Ghana. Archives of Agriculture and Environmental Science 8(3): 1-9.

[26] Akonor, P. T., Osei Tutu, C., Arthur, W., Adjebeng-Danquah, J., Affrifah, N. S., Budu, A. S., Saalia, F. K. (2023): Granular structure, physicochemical and rheological characteristics of starch from yellow cassava (*Manihot esculenta*) genotypes. International Journal of Food Properties 26(1): 259-273.

[27] Gerrano, A. S., Thungo, Z. G., Mavengahama, S. (2022): Phenotypic description of elite cowpea (*Vigna ungiculata* L. Walp) genotypes grown in drought-prone environments using agronomic traits. Heliyon 8(2): 1-7

[28] Khan, M. M. H., Rafii, M. Y., Ramlee, S. I., Jusoh, M., Oladosu, Y., Al Mamun, M., Khaliqi, A. (2022): Unveiling genetic diversity, characterization, and selection of Bambara groundnut (*Vigna subterranea* L. Verdc) genotypes reflecting yield and yield components in tropical Malaysia. BioMed Research International 2022: 1-23

[29] Akinyosoye, S. T., Adetumbi, J. A., Amusa, O. D., Agbeleye, O. A., Anjorin, F. B., Olowolafe, M. O., Omodele, T. (2017): Bivariate analysis of the genetic variability among some accessions of African yam bean (*Sphenostylis stenocarpa* Hochst Ex A. Rich). Acta Agriculturae Slovenica 109: 493-507

[30] EPA. (2003): National action programme to combat drought and desertification. Final Report. Environmental Protection Agency Accra-Ghana. 160 pp.

[31] R Core Team (2021): R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

[32] Ntawuruhunga, P., Dixon, A. (2010): Quantitative variation and interrelationship between factors influencing cassava yield. Journal of Applied Biosciences 26: 1594-1602

[33] Oliveira, C. R. S., Borel, J. S., Pereira, D. A., Carvalho, B. P., Medrado, E. S., Ishikawa, F. H., Oliveira, E. J. (2021): Genetic parameters and path analysis for root yield of cassava under drought and early harvest. Crop Breeding and Applied Biotechnology 21(3): 1-8.

[34] Payne, R. W., Murray, D. A., Harding, S. A., Baird, D. B., Soutar, D. M. (2009): Genstat for Windows (12th Edition) Introduction. VSN International, Hemel Hempstead

[35] Tiwari, N.D., Tripathi, S.R., Tripathi, M.P., Khatri, N., Bastola, B.R. (2019.): Genetic variability and correlation coefficients of major traits in early maturing rice under rainfed lowland environments of Nepal. Advances in Agriculture 2019: 1-9.

[36] Dagnaw, T., Mulugeta, B., Haileselassie, T., Geleta, M., Tesfaye, K. (2022): Phenotypic variability, heritability and associations of agronomic and quality traits in cultivated Ethiopian durum wheat (*Triticum turgidum* L. ssp. durum, desf.). Agronomy 12: 1-15

[37] Amelework, A. B., Bairu, M. W., Marx, R., Laing, M., Venter, S. L. (2023): Genotype × environment interaction and stability analysis of selected cassava cultivars in South Africa. Plants 12(13): 1-13.

[38] Uchendu, K., Njoku, D. N., Ikeogu, U. N., Dzidzienyo, D., Tongoona, P., Offei, S., Egesi, C. (2022): Genotype-by-environment interaction and stability of root mealiness and other organoleptic properties of boiled cassava roots. Scientific Reports 12: 1-11.

[39] Olivoto, T., Lúcio, A. D., Silva, J. A., Marchioro, V. S., Souza,V. Q., Jost, E. (2019): Mean performance and stability in multi-environment trials I: Combining features of AMMI and BLUP techniques. Agronomy Journal 111: 2949-2960.

[40] Olomitutu, O. E., Abe, A., Oyatomi, O. A., Paliwal, R., Abberton, M. T. (2022): Assessing intraspecific variability and diversity in African yam bean landraces using agronomic traits. Agronomy 12: 1-13.

[41] dos Santos Silva, P. P., Sousa, M. B., Oliveira, E. J., Morgante, C. V., Oliveira, C. R. S., Vieira, S. L., Borel, J. C. (2021): Genome-wide association study of drought tolerance in cassava. Euphytica 217(60): 1-26.

[42] Ceballos, H., Iglesias, C. A., Pérez, J. C., Dixon, A. G. O. (2004): Cassava breeding: opportunities and challenges. Plant Molecular Biology 56: 503-516.

[43] Farshadfar, E., Rahmani, S., Jowkar, M. M., Shabani, A. (2014): Estimation of genetic parameters and chromosomal localization of QTLs controlling agro-physiological indicators of drought tolerance in agropyron using wheat-agropyron disomic addition lines. Australian Journal of Crop Science 8: 133-139.

[44] Meena, M. L., Kumar, N., Meena, J. K., Rai, T. (2016): Genetic variability, heritability and genetic advances in chilli, *Capsicum annuum*. Bioscience Biotechnology Research Communications 9(2): 258-262.

[45] Diniz, R. P., Oliveira, E. J. (2019): Genetic parameters, path analysis and indirect selection of agronomic traits of cassava germplasm. Anais da Academia Brasileira de Ciências 91: 1-11.

[46] Najeeb, S., Rather, A. G., Parray, G. A., Sheikh, F. A., Razvi, S. M. (2009): Studies on genetic variability, genotypic correlation and path coefficient analysis in maize under high altitude temperate ecology of Kashmir. Maize Genetics Cooperation Newsletter 83: 1-8.

[47] Aina, O. O., Dixon, A. G. O., Akinrinde, E. A. (2007): Trait association and path analysis for cassava genotypes in four agroecological zones of Nigeria. Journal of Biological Sciences 7: 759-764.

[48] Ali, Z., Khan, A. S., Asad, M. A. (2002): Salt tolerance in bread wheat: Genetic variation and heritability for growth and ion relation. Asian Journal of Plant Science 1: 420-422.

[49] Faysal, A. S. M., Ali, L., Azam, M. G., Sarker, U., Ercisli, S., Golokhvast, K.S. and Marc, R. A. (2022): Genetic variability, character association and path coefficient analysis in transplant Aman rice genotypes. Plants 11: 1-15.

[50] Khaliqi, A., Rafii, M. Y., Mazlan, N., Jusoh, M., Oladosu, Y. (2021): Genetic analysis and selection criteria in Bambara groundnut accessions based on yield performance. Agronomy 11(1634): 1-13.

[51] Idehen, E. O., Oyelakin, S. A., Onikola, A. O., and Adedapo, V. O. (2016): Numerical and RAPD analysis of eight cowpea genotypes from Nigeria. Nigerian Journal of Biotechnology 31: 59-65.

[52] Yan, W., Tinker, N. A. (2006): Biplot analysis of multi-environment trial data: principles and applications. Canadian Journal of Plant Science 86(3): 623-645.

[53] Egesi, C.N., Illona, P. Ogbe, F.O. Akoroda, M, Dixon, A.G.O. (2007): Genetic variation and genotype × environment interaction for yield and other agronomic traits in cassava in Nigeria. Agronomy Journal 99: 1137-1142.

[54] Adu, M. O., Asare, P. A., Yawson, D. O., Nyarko, M. A., Abdul-Razak, A., Kusi, A. K., Tachie-Menson, J. W., Afutu, E., Andoh, D. A., Ackah, F. K., Vanderpuije, G. C., Taah, K. J., Asare-Bediako, E., Amenorpe, G. (2020): The search for yield predictors for mature field-grown plants from juvenile pot-grown cassava (*Manihot esculenta* Crantz). PLos One 15(5): 1-27.

[55] Asefa, G. (2019): The role of harvest index in improving crop productivity: A review. Journal of Natural Sciences Research 9(6): 24-28.

[56] Ojulong, H. F., Labuschagne, M. T., Herselman, L., Fregene, M. (2010): Yield traits as selection indices in seedling populations of cassava. Crop Breeding and Applied Biotechnology 10: 191-196.

[57] dos Santos, T. B., Ribas, A. F., de Souza, S. G. H., Budzinski, I. G. F., Domingues, D. S. (2022): Physiological responses to drought, salinity, and heat stress in plants: A Review. Stresses, 2: 113-135.

[58] Santanoo, S., Vongcharoen, K., Banterng, P., Vorasoot, N., Jogloy, S., Roytrakul, S., Theerakulpisut, P. (2022): Physiological and proteomic responses of cassava to short-term extreme cool and hot temperature. Plants 11(17): 1-19.

[59] Adjebeng-Danquah, J., Manu-Aduening, J., Gracen, V., Offei, S. K., Asante, I. K. (2016): Genotypic variation in abscisic acid content, carbon isotope ratio and their relationship with cassava growth and yield under moisture stress and irrigation. Journal of Crop Science and Biotechnology 19 (4): 263-273.

[60] El-Sharkawy, M. A., De Tafur, S. M. (2007): Genotypic and within canopy variation in leaf carbon isotope discrimination and its relation to short-term leaf gas exchange characteristics in cassava grown under rain-fed conditions in the tropics. Photosynthetica 45(4): 515-526

[61] León-Pacheco, R. I., Macias, M. P., Campos, F. C., Izquierdo, A. J., Izquierdo, G. A. (2020): Agronomic and physiological evaluation of eight cassava clones under water deficit conditions. Revista Facultad Nacional de Agronomía Medellín 73(1): 9109-9119.

[62] León-Pacheco, R., Pérez, M., Gutiérrez, M., Rodríguez, A., Fuenmayor, F., Marín C. (2014): Ecophysiological characterization of four clones of cassava from genebank at INIA-CENIAP. Agronomía Tropical 64(1-2): 97-105.

[63] Ayoola, O. T., Makinde, E. A. (2008): Influence of cassava population density on the growth and yield performance of cassava - maize intercrop with a relayed cowpea. Tropical and Subtropical Agroecosystems 8: 235-241.

[64] Amanullah, M. M., Somasundaram, E., Vaiyapuri, K., Sathyamoorthi, K. (2007): Intercropping in cassava-a review. Agricultural Reviews 28: 179-187.

[65] Chikwado, E. K. (2012): Cassava stem multiplication technology: A viable option for industry development? National Root Crops Research Institute (NRCRI), Umudike, Nigeria. https://knowledge.cta.int/en/Dossiers/S-T-Issues/Biotechnology/Feature-articles/Cassava-Stem-Multiplication-Technology-a-Viable-Option-for-Industry-Development.html

[66] Ceballos, H., Hershey, C., Iglesias, C. and Zhang, X. (2021): Fifty years of a public cassava breeding program: evolution of breeding objectives, methods, and decision-making processes. Theoretical and Applied Genetics 134: 2335-2353.

[67] Tran, T., Zhang, X., Ceballos, H., Luna, J., Escobar, A., Morante, N., Belalcazar J., Becerra L.A., Dufour, D. (2021): Correlation of cooking time with water absorption and changes in relative density during boiling of cassava roots. International Journal of Food Science and Technology 56: 1193-1205.

[68] Koundinya, A. V. V., Hegde, V., Sheela, M. N., Chandra, C. V. (2018): Evaluation of cassava varieties for tolerance to water deficit stress conditions. Journal of Root Crops 44(1): 70-75.

[69] Adjebeng-Danquah, J., Gracen, V., Offei, S. K., Asante, I. K., Manu-Aduening, J. (2016): Genetic variability in storage root bulking of cassava genotypes under irrigation and no irrigation. Agriculture and Food Security 5(9): 1-12.

[70] Kengkanna, J., Jakaew, P., Amawan, S., Busener, N., Bucksch, A., Saengwilai, P. (2019): Phenotypic variation of cassava root traits and their responses to drought. Applications in Plant Sciences 7(4): 1-14.

[71] Adu, M. O., Asare, P. A., Asare-Bediako, E., Amenorpe, G., Ackah, F. K., Afutu, E., Amoah, M. N., Yawson, D. O. (2018): Characterising shoot and root system trait variability and contribution to genotypic variability in juvenile cassava (*Manihot esculenta* Crantz) plants. Heliyon 4(6): 1-28