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SCREENING CASSAVA (*Manihot esculenta* CRANTZ) GENOTYPES FOR DRY ROOT YIELD AND RELATED AGRONOMIC TRAITS

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ABSTRACT: Cassava is grown for human consumption in Asia, Latin America, and Africa as cheap source of carbohydrate and feed for livestock and is a significant industrial crop in many countries including Nigeria. Recently, cassava has received significant attention by research workers and many varieties have been released. However, little is known of the yield determinants for identifying promising genotypes. The present study aimed to screen cassava germplasm under field conditions at the University of Ibadan for dry storage root yield (DSRY). Genotypes were evaluated across two growing seasons in Ibadan, Nigeria, using randomized complete block design with two replications. Data were collected on cassava mosaic disease (CMD) severity at 1, 3 and 5 months after planting (MAP) on a scale of 1–5. At 12 MAP, data on yield, and related agronomic traits were collected and analyzed using analysis of variance (ANOVA) and correlation analysis. Majority of the genotypes (approximately 79%) showed low CMD severity (resistant), while a small proportion (approximately 21%) exhibited moderate to high severity (susceptible). The genotypes exhibited considerable variation in dry matter content (DMC), harvest index (HI), fresh storage root yield (FSRY), and dry storage root yield (DSRY), indicating substantial genetic diversity. This diversity suggests potential for selecting superior genotypes with desirable yield and quality traits such as resistance to CMD, for breeding and cultivation. There was a strong correlation between DSRY and FSRY (r = 0.94), which suggests that FSRY was more important to DSRY than DMC (0.07) and HI (0.44), therefore breeding programmes should pay premium attention to improving FSRY. Genotypes Karagba, IITA-TMS I090509, and COB-1-103 exhibited superior DSRY and low CMD severity, indicating their potential as promising candidates for further multi-environment evaluation and as parents in breeding programmes aimed at improving cassava dry root yield and CMD resistance.

Keywords: Breeding programmes, cassava mosaic disease, dry matter content, dry storage root yield, harvest index.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial shrub which belongs to the family Euphorbiaceae, also known as the spurge family. The origin of cassava is highly debated, however recent reports indicate that it originated from the northeast Brazil and is now distributed across tropical regions of Africa, Asia and Latin America. In the tropics, it is regarded as the fourth most important source of carbohydrates for humans mention the crops before cassava (Udoka *et al.*, 2016). As a major source of carbohydrates, cassava is a staple food for millions of people in tropical regions and contributes significantly to food security in many developing countries (Immanuel *et al.*, 2024). The annual world production of cassava is currently estimated to be around 334 million tonnes with Africa solely accounting for more than one-third of the production (FAOSTAT, 2023). Nigeria is the largest producer with an estimated production output of 45.2 million tonnes (FAOSTAT, 2023). Other major producers in the top ten are DR Congo, Thailand, Brazil,

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Indonesia, Ghana, Angola, Vietnam, India, and the United Republic of Tanzania (FAOSTAT, 2023).
Cassava crop is widely cultivated due to its ability to thrive well in marginal and degraded soils and still produce satisfactory yields even when grown under unfavourable environmental conditions without the use of improved practices or technology (Cock, 1982). It is also well adapted to soil with a wide range of pH ranging from acidic to alkaline. In contrast to other staple crops such as maize, rice, and wheat, it grows well under marginal conditions and these conditions are common in the tropics (particularly in African and South American countries), thus, it contributes significantly to the economy of most tropical countries.

For propagation, vegetative stem cuttings are utilized while botanical seeds are mainly utilized in breeding programmes to generate new and improved varieties (Olasanmi *et al.*, 2014; Olasanmi, 2010). Cassava is a botanically perennial crop; however, its storage roots can be harvested from 6 to 24 months after planting (MAP) depending on the genotype and the growing conditions (i.e. the environment) (El-Sharkawy, 1993). However, the roots of many varieties can be left in the ground without harvesting for a long period (high in-ground storability) making it a very useful security crop against famine. Cassava is a highly productive crop considering food calories produced per unit land area per day which is approximately 250,000 cal/ha/day when compared to other staple crops like maize (200,000 cal/ha/day), rice (156,000 cal/ha/day), and wheat (110,000 cal/ha/day) (El-Sharkawy, 1993). The most notable characteristic of this crop is its capacity to store starch in its storage roots, which constitute 70 to 90% of the dry matter content (Baguma, 2004). This makes dry matter an important trait for cassava producers since it is a crop grown largely for its carbohydrate content. Dry matter determines the recovery rate of some food products derived from the crop in Nigeria, examples of which are starch, *fufu*, *gari*, *tapioca*, fermented flour, snacks etc.

Dry matter content reflects the extent of starch accumulation in cassava storage roots and serves as a reliable indicator of true biological yield and economic value. It is also referred to as the dry weight, and it is controlled by a polygenic additive factor (IITA, 1985). Dry matter production and partitioning are important determinants of storage root yield in cassava and could be an important selection criterion in breeding programmes for enhanced yield. Total dry matter production is a good estimator of the degree of adaptation of a genotype to the environment in which it is grown (Kamara *et al*., 2003). Differences in total dry matter accumulation in genotypes reflect differences in canopy growth and photosynthesis (Wongnoi *et al.,* 2020). Aside from genotypic variation, several other factors such as the age of the plant, crop season, location, and efficiency of the canopy to trap sunlight also influence the dry matter content of the crop (Yeboah *et al.,* 2023; Lain, 1985). Cassava genotypes that produce high dry matter also produce a high leaf area index and root yield (Phoncharoen *et al.*, 2022).

The constant increase in population growth is simultaneously increasing the importance of cassava to humans in the tropics. In addition, cassava is currently at a stage of great economic importance as it has become an industrial crop. Therefore, continuous research is needed to develop varieties of higher dry root yields to feed the teeming population and meet industrial needs. Dry Storage Root Yield (DSRY), which results from the interaction of Fresh Storage Root Yield (FSRY) and Dry Matter Content (DMC), is a key agronomic trait influencing cassava productivity and its acceptance by growers, researchers, processors, and consumers (Amelework and Bairu, 2022). It is an important to both the breeders (major trait of interest) and the consumers (determines the yield of finished products). Thousands of varieties of this crop have been developed with each variety exhibiting distinct traits. While some cassava varieties are maintained by farmers, hundreds to thousands of additional varieties are conserved in the germplasm collections of research institutions such as the International Institute of Tropical Agriculture (IITA) and the National Root Crops Research Institute (NRCRI), Umudike, Nigeria, among others. Evaluating the DSRY of these genotypes is essential for identifying superior varieties that could be recommended for breeding programs or eventual adoption by farmers. Therefore, the objective of this study was to screen cassava genotypes in the University of Ibadan germplasm collection to identify those with high DSRY and potential for further use in breeding and cultivation.

MATERIALS AND METHODS

The study was conducted at the Department of Crop and Horticultural Sciences, Teaching and Research Farm, Parry Road, University of Ibadan, Oyo State, Nigeria. The site is located at latitude 07°27.8’ N, longitude 03°53.24' E. Eighty-six cassava genotypes (Table 1) were evaluated for cassava mosaic disease (CMD) severity as well as dry matter content (DMC), fresh storage root yield (FSRY), dry storage root yield (DSRY), and harvest index (HI) during two cropping seasons (2021/2022 and 2022/2023). The experimental field was cleared and ridges were made manually, 1 m apart, across the slope to minimize erosion problems. The length of each ridge was 2.5 m and one ridge constituted a plot for each genotype. The field layout was randomized complete block design (RCBD), with two replicates. Stem cuttings 25 cm in length (each having at least four nodes) from healthy plants were planted in a slanting orientation at 0.5 m apart along the ridges (resulting in a population of 20,000 plants ha^{-1}) with five cuttings of each genotype planted per plot. Weeding was done manually at an early stage using a hoe and cutlass and a post-emergence herbicide (glyphosate) was applied at 3 MAP when the plants were well established. No fertilizer was applied to the plants during the experiment.

The cassava genotypes were assessed for resistance to cassava mosaic disease (CMD) at 1, 3, and 5 months after planting (MAP) using a scale of 1 to 5, where 1 represents no symptoms and 5 represents very severe symptoms. CMD incidence was assessed by counting the number of plants exhibiting typical symptoms, and the CMD severity was scored based on the plant exhibiting the highest severity within each plot, for each genotype, following the procedure described by IITA (2000). Furthermore, the highest severity score across the replications was considered for each genotype in the disease response rating as it reflects a genotype's level of resistance to CMD. The scale used for scoring CMD severity in the genotypes is presented below:

1 = no visible symptom (highly resistant);
2 = mild chlorotic patterns (moderately resistant);
3 = mosaic patterns on all leaves and leaf distortion (mildly susceptible);
4 = mosaic pattern on all leaves, leaf distortion, and a general reduction in leaf size (susceptible); and
5 = misshapen and twisted leaves and stunting of the whole plant (highly susceptible).

All the plants in each plot were harvested 12 months after planting. Data were collected on the number of storage roots, above-ground biomass (stump, stem, and leaves), root quality, and storage root weight per plot on the field.

Dry Matter Content Determination

At 12 months after planting (12MAP), freshly harvested cassava roots from each plot were packed in labeled bags immediately after field data collection and transferred to the laboratory for the determination of dry matter content. The sampled roots were washed thoroughly to remove adhering soil particles. Samples were taken from different sections of the roots (head, middle, and tail). The samples were further chopped into smaller pieces to increase the surface area to facilitate oven-drying at 70°C for approximately 48 hours. Approximately 100g of per genotype was oven-dried and the dry weight was measured after 24 hours and subsequently at intervals until a constant weight was attained. A sensitive electronic balance was used in taking the weight measurements. These steps were carried out within 24 hours of harvest to prevent changes due to postharvest physiological deterioration or moisture loss of the roots. Dry matter content (%) was calculated as the ratio of the dry weight to fresh weight of the sample taken, expressed as a percentage.

Dry matter content (DMC, %), fresh storage root yield (FSRY, t/ha), dry storage root yield (DSRY, t/ ha), and harvest index (HI) were determined from the collected data as follows:

$$\textbf{DMC (\%)} = \frac{\text{Dry weight after oven-drying (g)} \times 100\%}{\text{Fresh weight before oven-drying (g)}}$$

$$\textbf{FSRY (t/ha)} = \frac{\text{Fresh root weight (kg)} \times 20{,}000\text{plants/ha}}{\text{Number of plants/plot} \times 1000\text{kg}}$$

$$\textbf{DSRY (t/ha)} = \text{FSRY (t/ha)} \times \text{DMC (\%)}$$

$$\textbf{HI} = \frac{\text{FSRY}}{\text{TB}}$$

Where TB = Total Biomass

$$\text{TB} = \frac{\text{(Above ground biomass + fresh root weight)} \times 20{,}000\text{plants/ha}}{\text{Number of plants/plot} \times 1000\text{kg}}$$

Statistical Analysis

Data collected on CMD were subjected to descriptive statistics, whereas other data were subjected to analysis of variance (ANOVA) and correlation among the variables (DMC, FSRY, DSRY, & HI) was determined using PROC GLM of SAS v. 9.0 (SAS Institute, 2002). Means were separated using Duncan's Multiple Range Test (DMRT) at the $p \leq 0.05$ level of significance.

Table 1: Cassava genotypes evaluated in Ibadan in 2021/2022 and 2022/2023 growing seasons

S/N	Genotype	S/N	Genotype	S/N	Genotype
1	COB-1-103	30	IITA-TMS-I961632	59	COB-5-48
2	IITA-TMS-I071378	31	Isunikankiyan	60	COB-1-139
3	IITA-TMS-I010098	32	COB-5-104	61	COB-4-27
4	IITA-TMS-I070045	33	IITA-TMS-I070134	62	NR8082
5	NR06/0394	34	IITA Agric 2	63	IITA-TMS-I920067
6	IITA-TMS-I980581	35	IITA-TMS-I071393	64	COB-6-19
7	NR05/0067	36	NR05/0100	65	IITA-TMS-I011807
8	IITA-TMS I090521	37	COB-7-180	66	IITA-TMS-I920057
9	IITA-TMS-I010046	38	COB-5-57	67	IITA-TMS-I061635
10	COB-5-36	39	IITA-TMS-I011097	68	NR06/0333
11	COB-4-77	40	IITA-TMS-I070337	69	Tonade
12	COB-5-28	41	IBA141092	70	NR05/0080
13	COB-5-11	42	NR05/0041	71	IITA Agric
14	IITA-TMS-I071313	43	COB-6-1	72	NR05/0052
15	COB-4-75	44	COB-5-53	73	Odongboro
16	IITA-TMS-I011086	45	IITA-TMS-I011368	74	COB-6-31
17	COB-4-79	46	COB-5-86	75	COB-6-4
18	COB-7-197	47	IITA-TMS-B9200068	76	COB-5-61
19	IITA-TMS-I972205	48	NR05/0107	77	IITA-TMS-I070094
20	NR05/0362	49	NR06/0135	78	COB-5-17
21	IITA-TMS I090506	50	COB-5-12	79	Ege Pupa
22	COB-7-25	51	Karagba	80	IITA-TMS I090509
23	COB-4-74	52	NR05/0266	81	COB-6-10
24	Anonymous	53	COB-5-4	82	IBA130896
25	Gbaguda	54	Yomonnuse	83	COB-4-100
26	NR06/0169	55	IITA-TMS-I070004	84	IITA-TMS-I070593
27	IITA-TMS-I011371	56	IITA-TMS-I30572	85	IITA-TMS-I30555
28	IITA-TMS-I010034	57	IITA-TMS-I020452	86	TME3
29	Vit. A fort	58	Oyarugba		

RESULTS AND DISCUSSION

Figure 1 shows the CMD severity score (CMDSS) of the assessed genotypes. Sixty genotypes (approximately 70%) had a CMDSS of 1, while eight genotypes (9%) had a CMDSS of 2 as moderately resistant. This indicates that approximately 79% of the genotypes are resistant to cassava mosaic disease. About 16% (14 genotypes) of the evaluated cassava genotypes had a CMDSS of 5 (highly susceptible). Only one genotypes had a CMDSS of 3 while three genotypes had a CMDSS of 4. Genotypes with a CMDSS of 5 can be used as susceptible checks in CMD screening experiments at different growth stages till 5MAP.

The resistance to CMD observed in the majority of the genotypes indicates that efforts to reduce the menace of CMD is yielding positive results as a substantial number of the genotypes evaluated in this study are cultivated by farmers in Nigeria. Adoption of such resistant genotypes will reduce cassava mosaic virus inoculum pressure, thereby reducing the rate of disease spread by the whitefly (*Bemisia tabaci*) vector. Storage root yield losses due to CMD in sub-Saharan Africa were estimated at 15–24% annually, which is equivalent to 12–23 million tonnes, or an annual loss of USD 1.2–2.3 billion (Calvert and Thresh, 2002). Use of resistant varieties has been suggested as the most effective measure against the viral disease in many African countries (Sheat and Winter, 2023). The potential of these genotypes can therefore be harnessed to minimise yield losses caused by CMD.

Variation among the genotypes for the FSRY, DSRY, DMC and HI was highly significant ($p \leq 0.0001$) (Table 2). These results confirm the presence of genetic variation among the genotypes for the four yield parameters. Therefore, selection decisions can be based on mean trait values across seasons. The season*genotype interaction was significant ($p \leq 0.0001$) for DMC. A significant season*genotype interaction can result from changes in the magnitude of differences among the genotypes across seasons or changes in the relative ranking of the genotypes, or combination of the two phenomena (Fernandez, 1991; Kang, 1997).

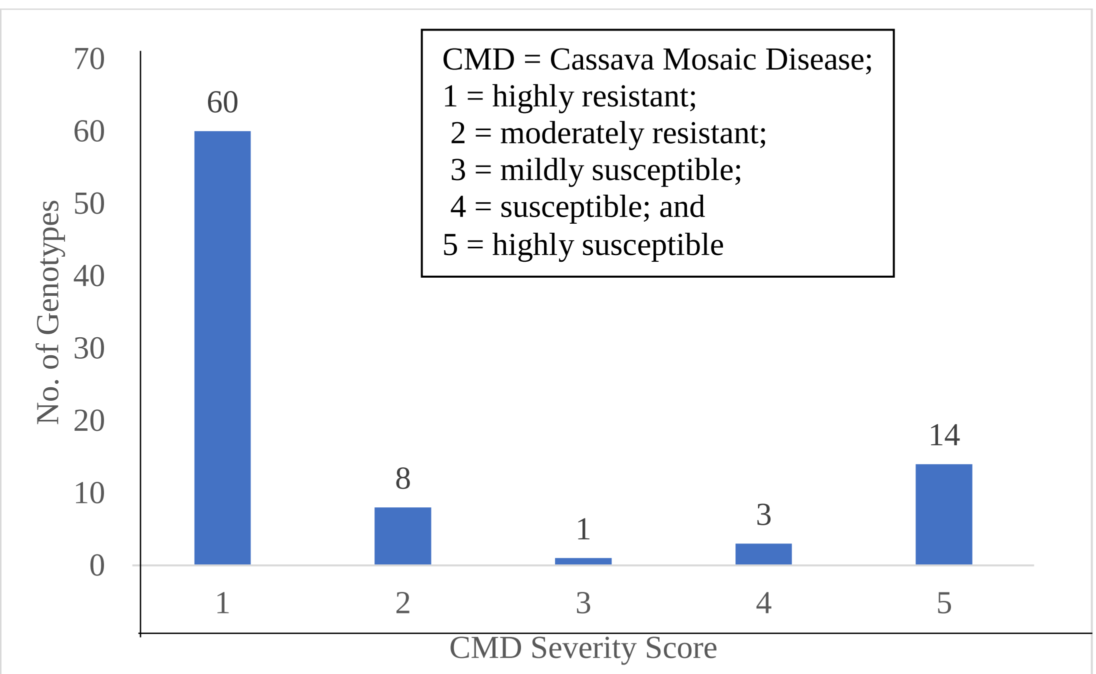

Figure 1: Distribution of CMD severity scores for 86 cassava genotypes evaluated in Ibadan in the 2021/2022 and 2022/2023 seasons

The significant season*genotype interaction observed for DMC in this study resulted from both sources of variation, and hence, there is a need to select genotypes with desired and stable performance for these traits across seasons in future breeding programmes.

There was a highly significant correlation ($p \leq 0.001$) between DSRY and both FSRY and DMC (Table 3) as well as between HI and both DSRY and FSRY. The highly significant correlation observed between DSRY and FSRY (r = 0.94) in this study indicates that a breeder can select with high accuracy for DSRY in cassava using FSRY. The significant correlations observed between DSRY and both DMC and HI among the genotypes also indicate that DMC and HI could be used as selection criteria for DSRY in cassava.

The mean values of the ten best-performing and the five least-performing genotypes for dry storage root yield (DSRY), fresh storage root yield (FSRY), dry matter content (DMC), and harvest index (HI) ranked based on DSRY among the 86 cassava genotypes evaluated in Ibadan during the 2021/2022 and 2022/2023 seasons are presented in Table 4. The level of variation observed among the cassava genotypes for these traits makes it possible to select the outstanding ones among them for further evaluation. The variation observed in DSRY and related yield parameters in this study can be exploited for further improvement of cassava. The ten cassava genotypes (Karagba, IITA Agric 2, IITA-TMS I090509, IITA-TMS-I070004, COB-1-103, NR06/0333, IITA-TMS-I010098, COB-5-12, Gbaguda, and IITA-TMS-B9200068) with significantly higher DSRY and DMC than the others are potential candidates for further evaluation.

Table 2: Mean square estimates from analysis of variance for DSRY, FSRY, DMC, and HI of 86 cassava genotypes evaluated in Ibadan in 2021/2022 and 2022/2023 seasons

Sources of Variation	DF	FSRY (t/ha)	DSRY (t/ha)	DMC (%)	HI
Reps	1	16483.03***	1332.58***	119.86***	0.1411***
Season	1	26378.17***	1783.20***	0***	0.2804***
Genotypes	85	548.58***	39.78***	58.76***	0.02948***
Season*Reps	1	4932.39***	345.29***	0***	0.00006638ns
Reps*Genotypes	85	256.11ns	21.51*	22.44***	0.006743ns
Season*Genotypes	85	161.84ns	11.07ns	0.00***	0.009799ns
Error	85	217.43	13.73	0.00	0.007625

*, *** indicate significances at the 0.05 and 0.001 levels, respectively; ns indicates non-significance. DF = Degree of Freedom; FSRY = Fresh Storage Root Yield; DSRY = Dry Storage Root Yield; DMC = Dry Matter Content; HI = Harvest Index

Table 3: Correlation coefficients (n = 344) of yield and related traits of 86 cassava genotypes evaluated in Ibadan in 2021/2022 and 2022/2023 seasons

Parameters	FSRY (t/ha)	DSRY (t/ha)	DMC (%)
DSRY (t/ha)	0.94a*		
DMC (%)	0.07ns	0.37a	
HI	0.44a	0.43a	0.05ns

a and a* = Significantly different from zero at the 0.01 and 0.001 probability level, respectively; ns = not significant. FSRY = Fresh Storage Root Yield; DSRY = Dry Storage Root Yield; DMC = Dry Matter Content; HI = Harvest Index

Table 4: Variation among the ten best-performing and the five least-performing genotypes for DSRY, FSRY, DMC, and HI ranked based on mean DSRY values of the 86 cassava genotypes evaluated in Ibadan during the 2021/2022 and 2022/2023 seasons

S/N	Genotype	DSRY (t/ha)	FRSY (t/ha)	DMC (%)	HI
1	Karagba	18.15	67.40	25.71	0.52
2	IITA Agric 2	15.48	45.73	34.15	0.57
3	IITA-TMS I090509	15.40	55.94	27.56	0.57
4	IITA-TMS-I070004	14.74	56.50	26.25	0.60
5	COB-1-103	13.91	50.41	28.97	0.49
6	NR06/0333	13.81	46.35	29.08	0.57
7	IITA-TMS-I010098	13.73	52.07	25.43	0.64
8	COB-5-12	13.38	47.23	28.00	0.49
9	Gbaguda	13.32	51.75	25.77	0.62
10	IITA-TMS-B9200068	12.63	42.99	29.06	0.52
11	NR05/0080	4.51	15.35	29.72	0.27
12	Isunikankiyan	3.64	15.97	23.09	0.44
13	COB-5-104	3.31	15.35	21.86	0.45
14	IITA-TMS-I061635	3.09	15.74	19.36	0.36
15	IITA-TMS-I011371	1.63	8.18	19.57	0.38
	Mean	**8.69**	**33.67**	**25.70**	**0.50**
	CV (%)	**36.28**	**34.78**	**14.91**	**17.17**
	SED	**0.34**	**1.26**	**0.41**	**0.01**
	R^2	**0.89**	**0.88**	**1.00**	**0.87**

DSRY = Dry Storage Root Yield; FSRY = Fresh Storage Root Yield; DMC = Dry Matter Content; HI = Harvest Index; CV = Coefficient of Variation; SED = Standard Error of Difference; R^2 = Coefficient of Determination

The genotypes Karagba, IITA Agric 2, IITA-TMS I090509, IITA-TMS-I070004, and COB-1-103 with higher DSRY and FSRY than the other genotypes should be promising candidates for further improvement of cassava dry matter content. As reported by Karama *et al.* (2003), total dry matter output is a good estimator of how well a genotype has adapted to its growing environment. The mean dry matter content (DMC) ranged between 18.9–34.5%. These values are consistent with the findings of Teye *et al.* (2011), who reported that dry matter of cassava varies among cassava varieties to another and ranges between 17% and 47% with the majority lying between 20% and 40%, and values above 30% considered high. This makes dry matter and the dry starch root yield important traits for cassava producers, since it is a crop cultivated largely for its carbohydrate content.

Genotypes IITA-TMS-I070134 and IITA-TMS-I010098 had a significantly higher HI than the other high-yielding genotypes. Therefore, these two genotypes can be deployed in future breeding programmes to improve cassava for root productivity. Moreover, the combination of higher DSRY, FRSY, and HI by IITA-TMS-I010098 compared to other genotypes indicates its strong potential for improvement of cassava for desired traits. However, further improvement of HI in Karagba and IITA-TMS I090509 would enhance their promise as candidates with multiple desirable traits. Similarly, targeted improvement could render COB-6-19, IITA-TMS-I011807, and IITA-TMS-I920057 promising candidates for desirable traits as they exhibited notably moderate dry matter content of 34.50%, 33.88%, and 32.77%, respectively. While genotypes with a high harvest index (HI) are preferred, the availability of sufficient planting material to promote adoption of this asexually propagated crop is equally important. Therefore, this consideration should be incorporated into the final selection of promising genotypes for further evaluation.

CONCLUSION

In this study, 86 cassava genotypes were evaluated at the University of Ibadan to evaluate their dry root yield and other associated traits. Processors and other end-users prefer varieties with higher dry matter content after processing. Cassava storage root yield is influenced by both root volume and dry matter content. Dry root yield can be improved by increasing fresh storage root yield and dry matter content. From the results obtained in this study, considerable variation was observed for DMC, FSRY, DSRY, and HI among the genotypes. Approximately 80% of the genotypes showed resistance to cassava mosaic disease. As previously reported, DSRY determines the market value of a cassava variety because it reflects the quantity of the final products. The observed variation in DSRY enables the selection of outstanding genotypes for further breeding programmes. The genotypes Karagba, IITA-TMS I090509, and COB-1-103 exhibiting higher DSRY, have good potential to enhance storage root productivity for cassava farmers and processors. These genotypes can also serve as parents in breeding programmes to further improve cassava for dry storage root yield.

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