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VARIATION AMONG SOME CASSAVA (*MANIHOT ESCULENTA* CRANTZ) GENOTYPES FOR DRY ROOT YIELD

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Abstract
Cassava is grown largely for its dry storage root yield (DSRY) because it determines the recovery rate of food products derived from it. However, dry matter content varies among cassava genotypes ranging from 17-47% of the fresh root yield. Hence, the need to determine dry root yield of existing varieties to enhance breeding for improved varieties. Therefore, the objective of this study was to screen cassava genotypes in the germplasm at the University of Ibadan for DSRY. The genotypes were evaluated in two 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. The plants were harvested 12 MAP and data were collected on fresh root weight and total biomass. Harvest index (HI) and fresh storage root yield (FSRY) were estimated using the field data while the dry matter content (DMC) was determined for each genotype in the laboratory. The FSRY and DMC were used to estimate DSRY of each genotype. The data were subjected to descriptive statistics, analysis of variance (ANOVA) and correlation analysis.
Among the genotypes, 68 (about 79%) had CMD Severity Score (CMDSS) of 1 to 2 while 15% has CMDSS of 5. Only one of the cassava genotypes had a CMDSS of 3 while the remaining three had a CMDSS of 4. The DMC and HI ranged from 18.9% (IBA141092) to 34.50% (COB-6-19) and 0.27 (NR 05/0080) to 0.69 (IITA-TMS-I071393), respectively among the genotypes. The FSRY and DSRY of the genotypes ranged from 8.18t/ha (IITA-TMS-I011371) to 67.4t/ha (Karagba) and 1.63t/ha (IITA-TMS-I011371) to 18.15t/ha (Karagba), respectively. Genotype had significant effect on DMC and HI, FSRY and DSRY. There was significant correlation between DSRY and each of FSRY (r = 0.94) and DMC (r = 0.37), likewise between HI and each of DSRY (r = 0.43) and FSRY (r = 0.44). Karagba was the best genotype over the two seasons. Genotypes Karagba, IITA Agric 2, IITA-TMS I090509, IITA-TMS-I070004, and COB-1-103 were identified as good candidates for release to farmers and can also be deployed as parents in breeding programmes for further improvement of cassava for dry root yield.

Keywords: Dry matter content; dry storage root yield; harvest index; cassava mosaic disease; breeding programmes.

Introduction
Cassava (*Manihot esculenta* Crantz) is a perennial shrub which belongs to the family Euphorbiaceae also known as the spurge family. It originated in northeast Brazil and is now widely grown throughout the world's tropical regions (Africa, Asia, and Latin America). In the tropics, it is regarded as the fourth most important source of carbohydrates for humans (Udoka *et al.*, 2016). The annual world production of cassava is currently estimated to be around 315 million tonnes with Africa solely accounting for more than one-third of the production. The crop is the most important staple food grown in Africa where it plays a major role in the effort to alleviate the food crisis (Hahn and Keyser, 1985). Nigeria is the largest producer with an estimated production output of 54.9 million tonnes (FAOSTAT, 2023). Other major producers in the top ten are DR Congo, Thailand, Brazil, Indonesia, Ghana, Angola, Vietnam, India, and the United Republic of Tanzania (FAOSTAT, 2022).

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, 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. Cassava is a very important root crop worldwide and provides food for about one billion people (Nuwamanya *et al.*, 2009).

For production, vegetative stem cuttings are utilized while botanical seeds are mainly utilized in breeding programmes to generate new and improved varieties (Olasanmi *et al.*, 2010; 2014). Cassava is a perennial crop but the 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 *et al.*, 1993). The most notable characteristic of this crop is its capacity to store starch in its storage roots, which constitute 70 to 90% (i.e. 700–900 gkg^{-1}) 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 is the chemical potential of cassava which also reflects the true biological yield, and therefore the economic value of its products by the farmers and industries. 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 photosynthetic production (Kamprath *et al*., 1982). 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 (Lian, 1985). Cassava genotypes that produce high dry matter also produce a high leaf area index and root yield (Akparobi *et al*., 1999).

The constant increase in population growth is simultaneously increasing the importance of cassava to humans in the tropics. Also, 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), a function of Fresh Storage Root Yield (FSRY) and Dry Matter Content (DMC), is an important trait for the acceptance of cassava by growers, researchers, and consumers. 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 of the varieties are with farmers, hundreds to thousands of them are kept in the germplasm of different research centers all over the world. The need for adequate knowledge of the DSRY of these varieties cannot be overemphasized. Therefore, the objective of this study was to screen cassava genotypes in the germplasm at the University of Ibadan for dry storage root yield.

Materials and Methods

Eighty-six cassava genotypes (Table 1) were evaluated for cassava mosaic disease (CMD) severity, dry matter content (DMC), fresh storage root yield (FSRY), dry storage root yield (DSRY), and harvest index (HI) in Ibadan, Nigeria, in two growing 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 was used as a plot per genotype. The field layout was randomized complete block design (RCBD), with 2 replicates. Stem cuttings of 25 cm in length (each having at least 4 nodes) from healthy plants were planted in a slanting manner at 0.5 m apart along the ridges (resulting in a population of 20,000 plants/ha) and 5 cuttings of each genotype were planted per plot. Weeding was done manually at an early stage using hoe and cutlass and post-emergence herbicide (glyphosate) was applied from 3 MAP when the plants were well established. No fertilizer was applied to the plants in the course of this experiment.

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

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)

Table 1: List of the eighty-six cassava genotypes evaluated in Ibadan in 2021/2022 and 2022/2023 seasons

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

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 roots of cassava in each plot were packed in labeled bags immediately after collecting field data and transferred to the laboratory for dry matter content determination. The sampled roots were washed thoroughly with water to remove remnants of soil attached to them. A sample size was obtained from the various sections of the roots (head, middle, and tail). It was further chopped into smaller sizes to increase the surface area thus facilitating oven-drying at 70°C for about 48 hours. A sample of about 100 g per genotype was oven-dired and the dry weight was taken after 24 hours and subsequently at intervals till constant weight was attained. A sensitive weighing scale was used in taking the weight measurements. These steps were carried out within 24 hours after harvest to avoid changes through postharvest physiological deterioration or moisture loss of the roots. Percentage dry matter content was obtained by expressing the dry weight as a percentage of the fresh weight of the sample taken.

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.

Results and Discussion

Sixty genotypes (approximately 70%) had CMD Severity Score (CMDSS) of 1 (Figure 1), while 8 genotypes (9%) had CMDSS of 2 - moderately resistant. This, therefore, indicates that about 79% of the genotypes are resistant to cassava mosaic disease. About 16% (14 genotypes) of the cassava genotypes had a CMDSS of 5 (highly susceptible). Only one of the cassava genotypes had a CMDSS of 3 while the remaining three had a CMDSS of 4. Those genotypes with a severity score of 5 can be reliably used as a susceptible check in CMD screening experiments at any growth stage till 5MAP.

The resistance to CMD observed for majority of the genotypes indicates that efforts to reduce menace of CMD is yielding positivie results because a good number of the genotypes screened in this study are being cultivated by farmers in Nigeria. Adoption of such resistant genotypes will lower the population of cassava mosaic virus, thereby reducing the rate of spread of the disease by whitefly (*Bemisia tabacci*). Storage root yield losses due to CMD across 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 virus disease in many African countries (Mahungu, *et al.,* 1994). The potentials of these genotypes can therefore be harnessed to minimise yield loss caused by CMD.

Variation among the genotypes for the FSRY, DSRY, DMC and HI were highly significant ($p \leq 0.0001$) (Table 2). These results indicate the existence of variation among the genotypes for the four yield parameters. Therefore, selection decisions can be made using their mean values across seasons. The season*genotype interaction was significant ($p \leq 0.0001$) for DMC. 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 1998). The significant season*genotype interaction observed for DMC in this study resulted from both changes, and hence, there is need to select genotypes with desired and stable (those with insignificant GEI) performance for this trait across seasons in future breeding programmes.

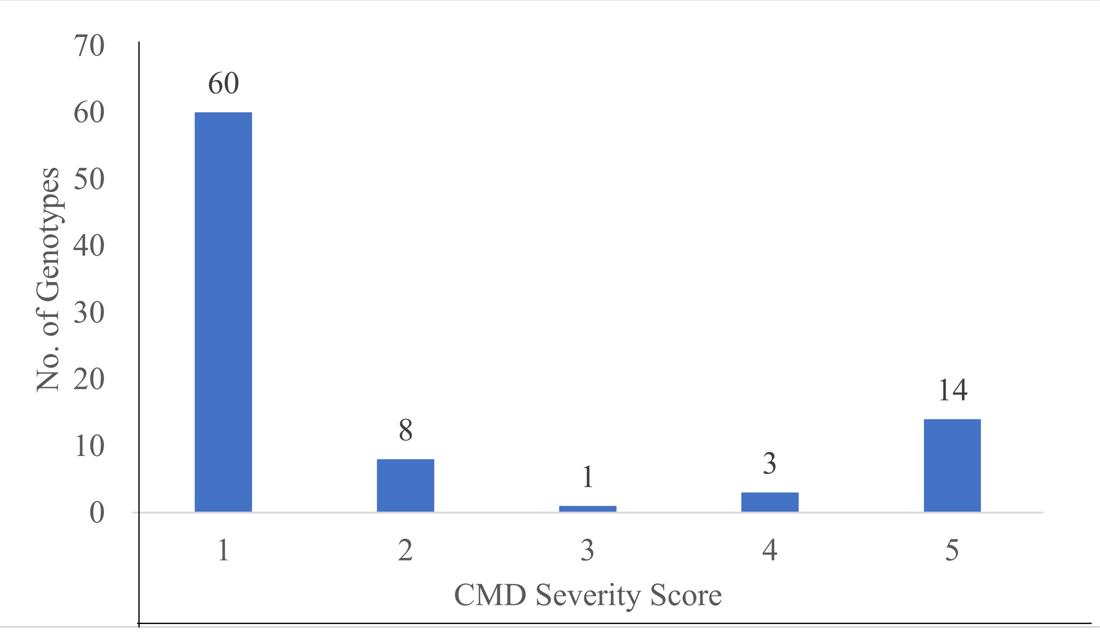

Figure 1: Distribution of eighty-six cassava genotypes evaluated in Ibadan in the 2021/2022 and 2022/2023 seasons based on CMD severity

CMD = Cassava Mosaic Disease; 1 = highly resistant; 2 = moderately resistant; 3 = mildly susceptible; 4 = susceptible; and 5 = highly susceptible

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

The mean values of the best ten and the least five genotypes for dry storage root yield (DSRY), fresh storage root yield (FSRY), dry matter content (DMC), and harvest index (HI) ranked using DSRY of the eighty-six cassava genotypes evaluated in Ibadan in 2021/2022 and 2022/2023 seasons are presented in Table 4. The level of variation observed among the cassava genotypes for the traits makes it possible to select the outstanding ones among them for further evaluation for the traits. The variation observed for DSRY and related yield parameters in this study can be exploited to improve cassava further for the traits. 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 high DSRY and DMC than others are potential candidates for further evaluation.

Table 2: Mean squares for DSRY, FSRY, DMC, and HI of eighty-six 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***	0.009799ns
Error	85	217.43	13.73	0	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 eighty-six 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*		
DM (%)	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 best ten and the least five genotypes for DSRY, FSRY, DMC, and HI ranked using DSRY mean values of the eighty-six cassava genotypes evaluated in Ibadan in 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

Genotypes Karagba, IITA Agric 2, IITA-TMS I090509, IITA-TMS-I070004, and COB-1-103 with higher DSRY and FSRY than others should be good candidates for release to farmers and further improvement of cassava for 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 value obtained for dry matter content (DMC) ranged between 18.9 - 34.5%. These values conform to the findings of Barima (2000) which stated that dry matter of cassava varies from one variety of cassava to another and ranged between 17% and 47% with the majority lying between 20% and 40%, and values above 30% are considered high. This makes dry matter and of course, the dry starch root yield pertinent traits for cassava producers, since it is a crop grown largely for its carbohydrate content.

Genotypes IITA-TMS-I070134 and IITA-TMS-I010098 had significantly higher HI than all other high-yielding genotypes. Therefore, the two genotypes can be deployed in future breeding programmes to improve cassava for root productivity. Also, a combination of significantly higher DSRY, FRSY, and significantly high HI by IITA-TMS-I010098 than other genotypes in most cases indicates that the genotype has great potential for improvement of cassava for desired traits. However, further improvement of Karagba and IITA-TMS I090509 for HI would make them more promising candidates with many desirable genes stacked in a genotype. Similarly, improvement can make COB-6-19, IITA-TMS-I011807, and IITA-TMS-I920057 promising candidates for desirable traits as they had a notably moderate dry matter content of 34.50%, 33.88%, and 32.77% respectively. While genotypes with high harvest index (HI) are highly desired, the need for sufficient planting materials to promote the adoption of asexually propagated species is equally important. Therefore, this should be taken into account in the final selection of promising genotypes for further evaluation.

Conclusion

In this study, 86 cassava genotypes were evaluated at the University of Ibadan to assess them for dry root yield and other associated traits. Processors and other end-users would prefer varieties with higher dry matter content after processing. The yield of cassava storage roots is related to the root volume and dry matter content. Dry root yield of cassava can be improved by increasing its dry matter content and fresh storage root yield. From the results obtained in this study, considerable variations were observed for DMC, FSRY, DSRY, and HI among the genotypes. More than 80% of the genotypes were resistant to cassava mosaic disease. As earlier reported, DSRY determines the market value of any cassava variety as it translates to the final products. The observed variation in the study for DSRY can enable the selection of outstanding genotypes for further evaluation. Genotypes Karagba, IITA Agric 2, IITA-TMS I090509, IITA-TMS-I070004, and COB-1-103 with higher DSRY have good potential to boost storage root productivity for cassava farmers and processors. These genotypes can also be deployed as parents in breeding programmes to further improve cassava for dry storage root yield.

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