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Research Article

Phenotypic Characterisation of Selected Cultivars of *Manihot esculenta* Crantz (Cassava)

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Abstract— Various accessions of *Manihot esculenta* Crantz (cassava) exhibit notable morphological similarities in their stems, leaves, and root systems. The genetic enhancement of cassava relies heavily on the crop's diversity and variability. This study focused on the characterisation of eleven cassava cultivars through morphological methods. The experiment, structured in a complete randomised design each with three replicates, underwent detailed statistical analysis using SAS version 2010. Analysis of variance (ANOVA) showed significant differences in the performance of the cultivars across all traits at $p \leq 0.05$. Among the cultivars, Agric (White), Nwator, Allimeme (Brown), and Vitamin A (Brown) demonstrated superior growth characteristics. The trait with the highest heritability was the number of branches per plant, with an estimate of 99.79%, while the number of leaf lobes per plant showed the lowest heritability at 95.04%. At 327.37 and 327.71, respectively, the highest values of the Phenotypic Coefficient of Variation (PCV) and Genotypic Coefficient of Variation (GCV) were found for the number of branches per plant. Conversely, the number of leaf lobes per plant accounted for the lowest GCV (9.24) and PCV (9.48). The most significant genetic advance was noted in the number of branches per plant (674.68), whereas the least was in the number of leaf lobes per plant (18.58). Plant height displayed a strong positive correlation with leaf area ($r = 0.69$) and a moderate positive correlation with stem girth ($r = 0.51$). Principal Component Analysis (PCA) indicated that Prin. 1 accounted for the largest proportion of variance, contributing 32.02% with an eigenvalue of 7.36. Consequently, Agric (White), Nwator, Allimeme (Brown), and Vitamin A (Brown) are promising cassava cultivars that merit documentation, hybridisation and conservation for the improvement of cassava germplasm.

Keywords— Genetic variability, *Manihot esculenta*, Variance components, Heritability, Conservation

1. Introduction

Manihot esculenta Crantz, popularly referred to as Cassava, is a shrub belonging to the Euphorbiaceae family, one of the largest groups of dicotyledonous plants, primarily propagated through vegetative means using its stem. This plant produces storage roots, which can be harvested between six months to three years post-planting. The Euphorbiaceae family encompasses approximately 334 genera and 8,910 species, predominantly found in tropical and subtropical regions worldwide [1-3]. Nigeria stands as one of the world's leading cassava producers, with an annual output exceeding 38.7 million tonnes. Cassava serves various purposes, including food, feed and industrial raw materials [4, 5]. Various cassava accessions exhibit morphological similarities, especially in their stems and leaves [6].

Cassava is not commonly employed in herbal medicine; yet, indigenous tribes utilise it for numerous therapeutic uses. The leaves serve as a styptic, while a mixture of starch and rum is applied to treat skin issues, particularly in children [7]. The leaves are used to treat rheumatism, fever, headaches, diarrhoea, and appetite loss because of its anti-inflammatory, anti-haemorrhoid, analgesic, and antibacterial qualities. [8, 9]. Methanolic extracts of cassava have shown potent anthelmintic activity [10]. Additionally, cassava leaf extract possesses antioxidant properties and nutraceutical potential for addressing malnutrition [11].

Genetic improvement of cassava relies heavily on its genetic diversity. Detecting variability is crucial as it allows for the selection of desirable traits for improvement and potential hybridisation [12]. Heritability represents the proportion of phenotypic variation passed from parent to progeny. Higher heritable variation increases the likelihood of character fixation through selection [13]. In genetically heterogeneous populations, phenotypic and genotypic coefficients of variation are useful parameters for evaluating the correlations between agronomic traits, facilitating crop improvement progress [14]. Likewise, genetic advance is important as it shows how much a trait has improved from a single selection cycle [15].

Principal Component Analysis (PCA) helps to identify traits contributing significantly, minimally, *or* not at all to the variation among treatments [16]. Cassava is generally propagated vegetatively from stem cuttings, and breeders often face challenges in selecting the best variety due to morphological similarities. Given these similarities among cassava accessions, assessing variations based on phenotypic characters is essential. This study evaluated the morphological characteristics of eleven cassava cultivars.

2. Related Work

Cassava breeding programs leverage genetic variability and correlation studies to improve yield and resilience traits. Research has shown that the phenotypic coefficient of variation (PCV) generally exceeds the genotypic coefficient of variation (GCV), indicating environmental influences on trait expression. For example, studies report high heritability and genetic advance (GA) for traits like tuber yield, starch content, and dry matter content, suggesting these are controlled by additive gene actions and respond well to selection. In one study, tuber yield per plant exhibited strong positive correlations with plant height, number of tubers per plant, and starch content, identifying these as indirect selection targets for yield improvement [17]. Additionally, PCA revealed that traits such as root size and disease resistance are major contributors to variability, aiding breeders in prioritising traits [18].

Advanced genetic studies, such as genome-wide association studies (GWAS), have further identified quantitative trait loci (QTL) related to disease resistance and yield traits. For example, loci associated with cassava mosaic disease resistance and root yield have been identified on chromosomes 9 and 11, respectively [19]. Correlation studies have also highlighted key inter-trait relationships, with root yield positively linked to starch content, tuber weight, and dry matter, reinforcing the importance of these traits in selection programs [17]. Furthermore, heritability estimates suggest significant genetic control for traits such as root number, height, and CMD resistance, facilitating targeted breeding for high-yield and disease-resistant cassava varieties. This multi-pronged approach demonstrates the value of integrating phenotypic, genotypic, and molecular data in optimising cassava breeding strategies.

3. Materials and Method

3.1 Source of Planting Materials

The stem cuttings of eleven cassava cultivars evaluated in this study were collected from five farms in Otupko, Benue State.

3.2 Study Location, Experimental Design and Treatments

This field research was carried out in Ibadan, Nigeria, at the Nursery Farm of the Botany Department of the University of Ibadan. Situated at an elevation of 150m within a valley at 275m above sea level, the location has an annual rainfall of 1,205mm and is located between 7° 02’ 49″ and 7° 43′ 21″ N latitude and 3° 31′ 58″ and 4° 08′ 20″ E longitude [20]. Three replicates of each of the eleven cassava cultivars were set up in a fully randomised design.

3.3 Land Preparation, Lining, and Pegging

Prior to planting, the land was prepared by slashing and burning the weeds to manage weed emergence and promote better crop establishment. Ridges were manually constructed using a hoe, each with a height of 23cm, a breadth of 85cm, and a length of 320cm. Pegs were used for pegging, marking the planting spots for each cassava stem to distinguish each cultivar.

3.4 Planting

Cassava stem cuttings, each 25cm in length, were planted at a spacing of 0.5m x 0.5m. Each cultivar had three replications. The cuttings were inserted into the soil at a 45° angle, leaving one-third of each cutting above the ground.

3.5 Watering and Weed Control

Before the rainy season started, the department's tap water was used every day to water the plants. Each replicate of every cultivar received 2000mL of water per plant, applied in the early morning hours and discontinued once the rainy season was fully established. After planting, weeds were routinely pulled to keep them from competing with the crops for space, light, water, and nutrients.

3.6 Data Collection

Data on establishment (sprouting) was collected weekly for the first three months post-planting. The number of sprouted nodes per replicate for each cultivar was counted, and the number of sprouted nodes that survived three weeks after sprouting was also recorded. Measurements included counting the actual surviving population in each plot. Data on growth parameters for the cultivars began two weeks after sowing (WAS) and continued weekly for ten weeks. Parameters measured included plant height (PH), stem length (SL), stem girth (SG), internode length (IDL), apical leaf colour (CAL), apical leaf pubescence (PAL), leaf colour (LC), petiole colour (PC), petiole length (PL), petiole orientation (PO), lobe length (LOTH), lobe width (LOWTH), lobe margins (LM), number of lobes (NBLO), number of stems per stand (NBS), colour of stem (SC), number of branches (NBB), disease severity (DS), number of leaves (NBL), leaf vein colour (CLV), branching habit (BH), and shape of the central leaf lobe (SCL). All morphological features were described following standards [21].

3.6.1 Leaf Size

The length and width of the central lobe were accessed to ascertain the size of the leaf, and lobe length (LL) was measured from the intersection of the lobes to the apex of the middle lobe, while leaf width (LW) was recorded at the widest point of the middle lobe. Both the fourth and fifth completely developed leaves were used for these measurements.

3.6.2 Plant Height

The height of the plant was recorded weekly for a duration of ten weeks following the time of establishment. Using a metre

rule, measurements were made in centimetres from each tagged plant's soil level to its terminal end.

3.6.3 Stem Diameter and Leaf Area

Stem diameter was measured using vernier callipers weekly for ten weeks post-planting. The leaf area (LA) per cultivar was calculated using the formula:

$L \times W \times b$ [22].

Where: L = Length of leaf lobe
W = leaf lobe width
b = constant = 0.7

3.6.4 Disease Severity

A scale from 1 to 5 was used to assess the severity of the disease following described standards [23]. A score of 1 on this scale denotes the absence of any outward signs of Cassava Mosaic Disease (CMD), whereas a score of 2 suggests a mild chlorotic pattern and a small deformation of the base of the leaves. A mosaic pattern with leaf deformation on every leaf is indicated with a score of 3. A score of 4 indicates a general decrease in leaf size along with distortion and a mosaic pattern, while a score of 5 indicates very twisted leaves and stunted plant growth.

3.7 Data Analysis

The collected morphological data was subjected to an analysis of variance (ANOVA) in order to evaluate variations in each trait. The analysis was performed using the Statistical Analysis System (SAS) software, version 2010. After confirming that the assumptions of the ANOVA were met, mean differences were assessed at a 95% confidence level ($p < 0.05$) using Duncan's Multiple Range Test (DMRT) (SAS, 2010). To determine the correlations between quantitative and qualitative traits, Pearson correlation coefficients and PCA were employed. Additionally calculated were heritability, GCV, GA, PCV, and genetic advance as a percentage of the mean (GAM). Additionally, the standard error, mean, and range were determined.

3.7.1 Estimates of Variance Components

In order to evaluate population variability, the mean, phenotypic variance (PV), genotypic variance (GV), and their corresponding coefficients of variation were determined. To compute them, the following formulae were used [24]:

$$\sigma^2_g = \frac{MSg - MSe}{r} \ldots\ldots\ldots\ldots\ldots [16, 21]$$

$$\sigma^2_p = \sigma^2_g + \sigma^2_e \ldots\ldots\ldots\ldots\ldots [16, 21]$$

$$\sigma^2_e = MS_e \ldots\ldots\ldots\ldots\ldots [16, 21]$$

The variables $\sigma^2 g$, $\sigma^2 p$, and $\sigma^2 e$ represent genotypic, phenotypic, and environmental variance (error mean square based on the analysis of variance), respectively; R is the number of replications, and MSe is the error mean square and MS_g for the mean square of genotypes/cultivars.

$$GCV = \frac{\sqrt{\sigma^2 g}}{\bar{x}} \times 100 \ldots\ldots\ldots\ldots [24]$$

$$PCV = \frac{\sqrt{\sigma^2 p}}{\bar{x}} \times 100 \ldots\ldots\ldots\ldots [24]$$

where the genotypic variance is denoted by $\sigma^2 g$, the phenotypic variance by $\sigma^2 p$, and the grand mean of a character by $\bar{X}$. Three categories of GCV and PCV levels were created: high (20% and above), intermediate (10–20%), and low (0–10%). [25].

3.7.2 Assessment of Heritability in Broad Sense

The heritability in a broad sense (h^2_{bs}) for all traits was calculated as follows [23]:

$$h^2_{bs} = \frac{\sigma 2g}{\sigma 2p} \times 100 \ldots\ldots\ldots\ldots [23]$$

The following notations are used: Heritability in the broad sense is represented by h^2_{bs}, genotypic variance by σ^2_g, and phenotypic variance by σ^2_p. Heritability percentages were divided into three groups: high (≥60%), moderate (30–60%), and low (0–30%) [26].

3.7.3 Assessment of Genetic Advance

The formula below was used to measure genetic advance (GA) [26]:

$$GA = K \times \sqrt{\sigma^2 p} \times h^2_{bs} \ldots\ldots\ldots\ldots [26]$$

where: $\sqrt{\sigma^2 p}$ denotes the character's phenotypic standard deviation, K represents the selection differential (K = 2.06 at 5% selection intensity), and h^2_{bs} signifies heritability in the broad sense.

To calculate the genetic advance as a percentage of the mean (GAM), the following calculation was applied:

$$GAM\ (\%) = \frac{GA}{\bar{x}} \times 100 \text{ ---------- } [26]$$

where GA is the genetic advance, GAM is the genetic advance expressed as a percentage of the mean, and $\bar{X}$ is the grand mean of the traits. The resultant genetic gain (%), which is equal to GA × 100, was classified as high (20% or greater), moderate (10–20%) or low (0–10%).

4. Results

4.1 Qualitative Traits in Cassava Cultivars

The qualitative traits of cassava cultivars listed in Table 1 were characterised based on the descriptors which provided the criteria for the observations [21]. The colour of apical leaves ranged from Light green in Cham (brown), Cham (white), Nwator, TME 419 and Wonono to purple-green in Agric (brown), Agric (white), Allimeme (brown), Allimeme (white), Vitamin A (brown), and Vitamin (white). The presence or absence of hair-like structures (pubescence) on the upper surfaces of leaves at the tips of the stems (apical leaves) was recorded for all cultivars with its presence seen in Agric (brown), Allimeme (white), Cham (white) and Vitamin A (white). Colour of the leaf ranged between dark green in Cham (brown), Nwator, TME 419, Wonono, Agric (brown), Agric (white), Allimeme (brown), Allimeme (white) and Vitamin A (brown), to light green in Cham (white) and Vitamin A (white); Petiole colour between green in Agric (brown) and Agric (white), yellowish-green in Vitamin A

(brown) and Vitamin A (white), reddish-green in Allimeme (brown), Allimeme (white) Nwator and TME 419, red in Cham (brown) and Cham (white) and purple in Wonono. Colour of leaf vein ranged between green in Agric (brown), Agric (white), Allimeme (brown), Allimeme (white), Nwator, TME 419, Vitamin A (brown) and Vitamin A (white); reddish-green to less than half of the lobe in Cham (brown), reddish-green to more than half of the lobe in Cham (white) and Wonono. Stem colour ranged between orange in Allimeme (white), Cham (white), Vitamin A (Brown) and Vitamin A (white); greenly-yellowish in Cham (brown), golden in Allimeme (brown) and Nwator; light brown in Agric (white), dark brown in Agric (brown) and Wonono to silver colour in TME 419. Petiole orientation ranged between being Horizontal, inclined upwards to irregular orientation while the branching habit for the cultivars ranged between being erect in Agric (brown), Cham (brown), Cham (white), Nwator, TME 419 and Wonono; erect/dichotomous in Agric (white) and Allimeme (brown) to erect/dichotomous/trichotomous patterns in Allimeme (white), Vitamin A (Brown) and Vitamin A (white). The lobe margin for different genotypes ranged between being smooth or winding while the shape of the central leaf ranges between ovoid in Agric (white), Cham (brown), Nwator and Vitamin A (white); oblong-lanceolate in Allimeme (brown), obovate-lanceolate in Vitamin A (Brown), elliptic-lanceolate in Cham (white), to lanceolate in Agric (white), Allimeme (brown), TME 419 and Wonono.

Table 1: Qualitative Traits of Cassava Cultivars

Cultivars	CAL	PAL	LC	PC	CLV	LM	PO	BH	SCL	SC
Agric (Brown)	Purple Green	Present	Dark Green	Green	Green	Smooth	Horizontal/Irregular	Erect	Lanceolate	Dark Brown
Agric (White)	Purple Green	Absent	Dark Green	Green	Green	Smooth	Horizontal	Erect/Dichotomous	Ovoid	Light Brown
Allimeme (Brown)	Purple Green	Absent	Dark Green	Reddish Green	Green	Smooth	Horizontal	Erect/Dichotomous	Oblong-lanceolate	Golden
Allimeme (White)	Purple Green	Present	Dark Green	Reddish Green	Green	Smooth	Horizontal	Erect/Dichotomous/Trichotomous	Lanceolate	Orange
Cham (Brown)	Light Green	Absent	Dark Green	Red	Reddish Green < half of lobe	Winding	Inclined Upwards/Irregular	Erect	Ovoid	Greenly-Yellowish
Cham (White)	Light Green	Present	Light Green	Red	Reddish Green > half of lobe	Winding	Horizontal/Irregular	Erect	Elliptic-lanceolate	Orange
Nwator	Light Green	Absent	Dark Green	Reddish Green	Green	Smooth	Inclined Upwards/Irregular	Erect	Ovoid	Golden
TME 419	Light Green	Absent	Dark Green	Reddish Green	Green	Smooth	Inclined Upwards	Erect	Lanceolate	Silver
Vitamin A (Brown)	Purple Green	Absent	Dark Green	Yellowish Green	Green	Smooth	Inclined Upwards/Horizontal	Erect/Dichotomous/Trichotomous	Obovate-Lanceolate	Orange
Vitamin A (White)	Purple Green	Present	Light Green	Yellowish Green	Green	Smooth	Inclined Upwards	Erect/Dichotomous/Trichotomous	Ovoid	Orange
Wonono	Light Green	Absent	Dark Green	Purple	Reddish Green > half of lobe	Smooth	Inclined Upwards	Erect	Lanceolate	Dark Brown

CAL = Colour of Apical Leaves; **PAL** = Pubescence on Apical Leaves; **LC** = Leaf Colour; **PC** = Petiole Colour; **CLV** = Colour of Leaf Vein; **LM** = Lobe Margin; **PO** = Petiole Orientation; **BH** = Branching Habit; **SCL** = Shape of Central Leaf; **SC** = Stem Colour.

4.2 Mean Square Variance of Quantitative Traits in Cassava

The results in Table 2 present the mean square variance for quantitative traits in cassava. According to the findings of this study, most traits—such as number of branches per plant, lobe width, number of leaves, stem length, plant height, internode length, leaf area, number of stems per stand, stem girth, lobe length, number of lobes per plant, and petiole length —exhibited highly significant effects ($p < 0.001$) due to cultivars, treatment, weeks, replicates, and interaction effects like cultivars × treatment and cultivars × weeks. The number of leaves, lobe length, and internode length were significant ($p < 0.01$) for replicates, whereas treatments showed significant differences in number of stems per plant ($p < 0.05$). However, the number of stems per stand was not significantly influenced by weeks, cultivars × weeks, or replicates, and replicates did not significantly affect the number of branches per plant.

Table 2: Mean Square Variance of Cassava Cultivars

Source Variation	ofdf (n-1)	LOGTH (cm)	LOWTH (cm)	PL (cm)	SL (cm)	PH (cm)	SG (cm)	IDL (cm)	LA (cm)	NBS	NBL	NBB	NBLO
Cultivars	10	791.47***	61.44***	1258.31***	72.11***	58.93***	2.38***	5.45***	148.98***	8.41***	115.46***	14.58***	1.17***
Treatments	3	231.68***	13.89***	180.46***	7.97***	5.86***	1.17***	3.01***	38.58***	0.21*	66.35***	4.76***	0.63***
Weeks	9	1424.02***	71.83***	5745.81***	371.58***	333.39***	13.40***	40.51***	229.75***	0.05NS	670.27***	0.40***	2.48***
Cultivars ×Treatments	×30	65.96***	8.13***	155.20***	20.29***	17.66***	0.58***	2.62***	13.79***	0.50***	57.42***	4.37***	0.53***
Cultivars × Weeks	90	17.82***	1.73***	37.31***	2.19***	1.81***	0.02***	0.13***	3.29***	0.08NS	5.76***	0.09***	0.05***
Replicates	2	11.59**	1.76***	73.54***	3.20***	2.65***	0.20***	0.18**	3.21***	0.04NS	7.37**	0.00NS	0.31***
Error	1175	1.73	0.21	6.06	0.3	0.29	0.01	0.03	0.32	0.07	1.15	0.01	0.02
Corrected Total	1319												

* = Significant at p<0.05, ** = Highly significant at p<0.01, *** = Highly significant at p<0.001, df =Degree of freedom; **LOGTH** = Lobe Length; **LOWTH** = Lobe Width; **PL** = Petiole Length; **SL** = Stem Length; **PH** = Plant Height; **SG** = Stem Girth; **IDL** = Internode Length; **LA** = Leaf Area; **NBS** = Number of Stem Per Stand; **NBL** = Number of Leaves**; NBB** = Number of Branches Per Plant; **NBLO** = Number of Lobes Per Plant.

4.3 Mean Performance of Quantitative Traits of Cassava

From the mean performance analysis for quantitative traits, cassava is significantly impacted ($P < 0.05$). When compared to other cultivars as presented in Table 3, Agric (white) had considerably greater lobe lengths (16.10 cm), lobe widths (5.04 cm), petiole lengths (22.46 cm), stem girths (5.05 cm), leaf areas (57.03 cm), and the number of lobes per plant (7.64 cm) and was statistically significant. Nwator was significantly higher for stem length (56.46cm), plant height (57.50cm) and internode length (1.75cm), but, not statistically different from Agric (white) (56.25cm) for plant height compared to other cultivars. Also, the number of stems (4.68) and the number of leaves (91.69) produced a significant effect from Allimeme (Brown). The number of branches (1.94) was significantly higher for Vitamin A (Brown) compared to other cultivars.

Table 3: Mean Performance of Quantitative Traits in Cassava

Cultivars	LOGTH (cm)	LOWTH (cm)	PL (cm)	SL (cm)	PH (cm)	SG (cm)	IDL (cm)	LA (cm)	NBS	NBL	NBB	NBLO
Agric (Brown)	10.88^{f}	3.31^{c}	18.01^{d}	30.76^{f}	34.36^{ef}	3.95^{cd}	1.50^{jk}	25.27^{c}	2.24cd	38.05^{gh}	0.25^{f}	6.68^{ed}
Agric (White)	16.10^{a}	5.04^{a}	22.46^{a}	53.09^{b}	56.25^{a}	5.05^{a}	1.71^{ba}	57.03^{a}	1.66e	52.37^{c}	0.49^{c}	7.64^{a}
Allimeme (Brown)	12.35^{c}	3.00^{f}	20.64^{b}	28.59^{g}	32.28^{gh}	3.94^{d}	1.66^{bc}	26.18^{c}	4.68^{a}	91.69^{a}	0.59^{d}	6.69^{c}
Allimeme (White)	10.76^{f}	3.72^{d}	17.21^{e}	35.77^{d}	39.15^{c}	4.26^{b}	1.09^{jk}	28.24^{d}	2.17^{kl}	70.60^{b}	1.17^{c}	7.15^{b}
Cham (Brown)	5.63^{h}	2.28^{g}	11.13^{gh}	27.66^{g}	31.52^{h}	3.25^{gh}	1.14^{gh}	8.82^{gh}	2.63^{c}	49.09^{e}	0.25^{f}	5.92^{c}
Cham (White)	10.77^{f}	3.91^{c}	17.67^{ed}	45.28^{c}	47.39^{b}	3.34^{gf}	1.46^{f}	29.55^{cd}	2.63^{c}	74.38^{b}	0.25^{f}	6.65^{d}
Nwator	11.68^{e}	3.89^{c}	20.85^{b}	56.46^{a}	57.50^{a}	4.02^{dc}	1.75^{a}	31.60^{c}	2.27^{kl}	58.04^{d}	0.25^{f}	6.68^{ed}
TME 419	12.22^{ed}	4.04^{b}	17.56^{ed}	36.71^{d}	38.52^{c}	3.41^{f}	1.65^{c}	35.15^{b}	1.55^{c}	43.55^{f}	0.25^{f}	5.80^{c}
Vitamin A (Brown)	11.94^{dc}	3.74^{d}	18.78^{c}	31.69^{fe}	35.79^{ed}	3.62^{e}	1.49^{fe}	31.42^{c}	3.17^{b}	59.10^{d}	1.94^{a}	6.75^{c}
Vitamin A (White)	9.20^{g}	3.02^{f}	13.57^{f}	32.52^{e}	36.15^{d}	3.11^{h}	1.52^{e}	19.71^{f}	3.35^{b}	69.66^{b}	1.72^{b}	6.93^{c}
Wonono	13.07^{b}	3.92^{c}	19.27^{c}	31.38^{fe}	33.69^{gf}	4.13^{c}	1.58^{d}	36.10^{b}	3.27^{b}	64.51^{c}	0.25^{f}	6.82^{c}

The Duncan Multiple Range Test (DMRT) indicates that means with the same letter in the same column are not statistically different at p≥0.05; **LOGTH** = Lobe Length; **LOWTH** = Lobe Width; **PL** = Petiole Length; **SL** = Stem Length; **PH** = Plant Height; **SG** = Stem Girth; **IDL** = Internode Length; **LA** = Leaf Area; **NBS** = Number of Stem Per Stand; **NBB** = Number of Branches Per Plant; **NBLO** = Number of Lobes Per Plant; **NBL** = Number of Leaves.

4.4 Mean, Genotypic and Phenotypic Variance, Genetic Component Variance, Phenotypic Component Variance, Heritability in Broad Sense (h^2_{bs}), Genetic Advance and Genetic Advance as Percentage of the Mean of Qualitative Traits of Selected Cultivars of Cassava

Results in Table 4 present the variance components for qualitative traits in cassava cultivars, encompassing genetic advance, heritability, genotypic variance (σ^2_g), phenotypic and genotypic coefficients of variation, phenotypic variance (σ^2_p), and genetic advance as a percentage of the mean. Notably, σ^2_p exceeded σ^2_g across all evaluated characters. Stem colour (209.21 and 209.07 respectively) showed the highest σ^2_p and σ^2_g, while leaf colour showed the lowest values, at 4.06 and 4.03. Except for pubescence on apical leaves, where both GCV and PCV were equal, the majority of growth-related traits had higher PCV than GCV. Pubescence on apical leaves showed the highest GCV (758.83%) and PCV (758.83%), while leaf colour had the lowest GCV (110.27%) and PCV (110.68%). Heritability estimates were high for all growth-related characters, with pubescence on apical leaves showing the highest (100%) and leaf colour and branching habit showing the lowest (99.26%). The highest genetic advance was observed for stem colour (29.82), while leaf colour showed the lowest (4.13). Furthermore, pubescence on apical leaves showed the highest GAM (1565.46%), while leaf colour showed the lowest (226.65%).

Table 4: Mean, Genotypic and Phenotypic Variance, Genetic Component Variance, Phenotypic Component Variance, Heritability, Genetic Advance and Genetic Advance as Percentage of the Mean of Qualitative Traits of Selected Cultivars of Cassava

Characters	MEAN	σ^2g	σ^2p	GCV (%)	PCV (%)	h^2_{bs} (%)	GA	GAM (%)
DS	1.68	37.40	37.50	363.78	364.26	99.73	12.60	749.47
CAL	2.10	46.00	46.01	322.72	322.76	99.98	13.99	665.71
PAL	0.41	9.64	9.64	758.83	758.83	100.00	6.40	1565.46
LC	1.82	4.03	4.06	110.27	110.68	99.26	4.13	226.65
PC	3.19	108.62	108.69	326.86	326.96	99.94	21.49	674.09
CLV	1.38	19.53	19.56	319.44	319.68	99.85	9.11	658.50
LM	1.23	4.09	4.12	164.58	165.19	99.27	4.16	338.30
PO	1.98	26.11	26.21	257.92	258.41	99.62	10.52	531.06
BH	1.24	6.69	6.74	207.93	208.70	99.26	5.32	427.36
SCL	2.96	129.92	130.06	384.80	385.00	99.89	23.50	793.41
SC	3.14	209.07	209.21	459.91	460.06	99.93	29.82	948.47

DS = Disease Severity; **CAL** = Colour of Apical Leaves; **PAL** = Pubescence on Apical Leaves; **LC** = Leaf Colour; **PC** = Petiole Colour; **CLV** = Colour of Leaf Vein; **LM** = Lobe Margin; **PO** = Petiole Orientation; **BH** = Branching Habit; **SCL** = Shape of Central Leaf; **SC** = Stem Colour; **σ^2g** = genotypic variance; **σ^2p** = phenotypic variance; **GCV** = Genotypic coefficient of variation; **PCV** = Phenotypic coefficient of variation; **h^2_{bs}** = broad sense heritability; **GA** = Genetic advance; **GAM** = Genetic advance as percentage of the mean.

4.5 Mean, Genotypic and Phenotypic Variance, Genetic Component Variance, Phenotypic Component Variance, Heritability, Genetic Advance and Genetic Advance as Percentage of the Mean of Quantitative Traits of Selected Cultivars of Cassava

Table 5 presents the variance components for quantitative traits in cassava cultivars, encompassing GA, heritability, σ^2_g, PCV and GCV, σ^2_p, and GAM. It was observed that a consistent pattern emerged, with σ^2_p exceeding σ^2_g across all evaluated growth-related characters. The greatest σ^2_g and σ^2_p were found in leaf lobe length, at 263.25 and 264.98, respectively, whereas the number of leaf lobes per plant showed the lowest values, at 0.40 and 0.38. Similarly, the PCV surpassed the GCV for all growth-related traits. Number of branches per plant exhibited the highest GCV (327.37%) and PCV (327.71%), while number of leaf lobes per plant showed the lowest GCV (9.24%) and PCV (9.48%). Heritability estimates were high for all growth-related characters, with the NBB displaying the highest (99.79%) and the NBLO showing the lowest (95.04%). PL demonstrated the highest GA (41.85), while NBLO showed the lowest (1.25). Additionally, with respect to GAM, NBB showed the largest GA (674.68%), while NBLO showed the lowest (18.58%).

Table 5: Mean, Genotypic and Phenotypic Variance, Genetic Component Variance, Phenotypic Component Variance, Heritability, Genetic Advance and Genetic Advance as Percentage of the Mean of Quantitative Traits of Selected Cultivars of Cassava

Characters	MEAN	σ^2g	σ^2p	GCV (%)	PCV (%)	h^2_{bs} (%)	GA	GAM (%)
LOGTH	11.33	263.25	264.98	143.24	143.71	99.35	33.36	294.54
LOWTH	3.62	20.41	20.62	124.68	125.32	98.98	9.27	255.91
PL	17.92	417.42	423.48	114.00	114.82	98.57	41.85	233.49
SL	37.26	23.94	24.24	13.13	13.21	98.76	10.03	26.92
PH	40.23	19.55	19.84	10.99	11.07	98.54	9.05	22.50
SG	3.82	0.79	0.80	23.24	23.39	98.75	1.82	47.65
IDL	1.50	1.81	1.84	89.39	90.13	98.37	2.75	182.90
LA	29.92	49.55	49.87	23.53	23.61	99.36	14.48	48.39
NBS	2.69	2.78	2.85	61.95	62.73	97.54	3.40	126.23
NBL	61.00	38.10	39.25	10.12	10.27	97.07	12.55	20.57
NBB	0.67	4.86	4.87	327.37	327.71	99.79	4.54	674.68
NBLO	6.70	0.38	0.40	9.24	9.48	95.04	1.25	18.58

σ^2g = genotypic variance; **σ^2p** = phenotypic variance; **GCV** = Genotypic coefficient of variation; **PCV** = Phenotypic coefficient of variation; **h^2_{bs}** = broad sense heritability; **GA** = Genetic advance; **GAM** = Genetic advance as percentage of the mean; **LOGTH** = Lobe Length; **LOWTH** = Lobe Width; **PL** = Petiole Length; **SL** = Stem Length; **PH** = Plant Height; **SG** = Stem Girth; **IDL** = Internode Length; **LA** = Leaf Area; **NBS** = Number of Stem Per Stand; **NBL** = Number of Leaves; **NBB** = Number of Branches Per Plant; **NBLO** = Number of Lobes Per Plant.

4.6 Principal Component Analysis (PCA) of Growth-Related Characters of Cassava Cultivars

The results in Table 6 categorised the cultivars into ten principal component axes: Prin. 1 through Prin. 10. Prin. 1 accounted for the largest proportion and eigenvalue (32.02% and 7.36, respectively), whereas Prin. 10 had the smallest proportion (0.74%) and eigenvalue (0.17). Notably, leaf area and leaf lobe length showed the highest eigenvector (0.35) for Prin. 1, while Disease Severity exhibited the lowest (-0.21). Prin. 2 displayed the highest eigenvector (0.31) for the Petiole colour, with the least influence being shown in the number of branches per plant (-0.40). Prin. 3 highlighted the highest eigenvector (0.30) for pubescence on apical leaves, contrasting with stem colour which had the lowest impact (-0.41). Prin. 4 emphasised the highest eigenvector (0.46) for the lobe margin, whereas apical leaf pubescence showed the lowest impact (-0.28). While leaf colour had the least impact (-0.44), Prin. 5 demonstrated the largest eigenvector (0.40) for the number of leaves. For petiole orientation, Prin. 6 had the largest eigenvector (0.41), but internode length exhibited the smallest impact (-0.41). While petiole colour showed the smallest influence (-0.33), Prin. 7 exhibited the greatest eigenvector (0.47) for internode length. Prin. 8 displayed the greatest eigenvector (0.40) for the number of lobes per plant, while the shape of the central leaf had the lowest impact (-0.45). Prin. 9 showed the biggest eigenvector (0.48) for the colour of the leaf vein, with the NBL having the smallest impact (-0.35). Lastly, Prin. 10 highlighted the highest eigenvector (0.38) for PL, whereas the leaf area had the least impact (-0.39).

Table 6: Principal Component Analysis of Growth-Related Characters in Cassava

Characters	Prin1	Prin2	Prin3	Prin4	Prin5	Prin6	Prin7	Prin8	Prin9	Prin10
LOGTH	0.35	0.02	-0.07	0.13	0.16	-0.06	-0.02	0.02	0.20	-0.10
LOWTH	0.33	0.11	0.11	-0.05	0.13	-0.10	-0.19	0.03	0.18	-0.02
PL	0.31	0.07	-0.08	0.25	0.12	0.04	0.05	-0.25	0.29	0.38
SH	0.23	0.24	0.27	0.07	-0.10	-0.07	-0.01	-0.17	-0.23	0.13
PH	0.24	0.23	0.29	0.07	-0.11	-0.04	0.00	-0.16	-0.19	0.08
SG	0.30	0.07	-0.08	0.09	0.01	0.41	-0.20	0.13	-0.12	-0.09
IDL	0.23	0.07	-0.10	0.25	-0.06	-0.41	0.47	0.00	-0.01	0.11
LA	0.35	0.07	0.03	0.01	0.06	-0.06	-0.11	0.15	0.12	-0.39
NBS	-0.16	-0.17	-0.15	0.44	0.20	-0.06	0.14	0.19	0.08	0.11
NBB	0.00	-0.40	0.19	0.06	-0.06	-0.07	-0.30	0.01	0.08	0.23
NBLO	0.27	-0.12	0.19	0.12	0.16	0.28	-0.02	0.40	-0.15	0.15
NBL	-0.10	-0.13	0.05	0.45	0.40	-0.01	-0.08	-0.17	-0.35	-0.04
DS	-0.21	0.30	0.17	0.08	-0.17	0.06	0.03	0.19	0.02	0.33
CAL	0.11	-0.35	0.05	0.06	-0.05	0.38	0.24	-0.01	0.19	-0.20
PAL	0.01	-0.12	0.30	-0.28	0.28	0.31	0.45	0.01	-0.20	0.12
LC	0.09	-0.02	-0.37	0.11	-0.44	0.20	-0.21	0.16	-0.01	0.12
PC	-0.13	0.31	-0.13	0.01	0.33	0.06	-0.33	0.21	-0.21	0.21
CLV	-0.18	0.25	0.15	-0.04	0.36	-0.09	-0.01	0.29	0.48	-0.13
LM	-0.19	0.15	-0.11	0.46	-0.07	0.19	0.11	-0.08	-0.04	-0.31
PO	-0.15	0.24	0.20	0.16	-0.13	0.41	0.07	-0.19	0.42	0.17
BH	-0.01	-0.38	0.20	0.09	-0.11	-0.20	-0.10	0.24	0.14	0.29
SCL	0.05	-0.10	-0.38	-0.23	0.33	0.12	-0.11	-0.45	0.11	0.26
SC	0.14	0.13	-0.41	-0.17	0.02	0.04	0.36	0.35	-0.07	0.21
Eigenvalue	**7.36**	**5.00**	**3.21**	**2.39**	**1.85**	**1.41**	**0.77**	**0.49**	**0.35**	**0.17**
Proportion (%)	**32.02**	**21.73**	**13.96**	**10.41**	**8.05**	**6.13**	**3.33**	**2.11**	**1.52**	**0.74**

LOGTH = Lobe Length; **LOWTH** = Lobe Width; **PL** = Petiole Length; **SH** = Stem Height; **PH** = Plant Height; **SG** = Stem Girth; **IDL** = Internode Length; **LA** = Leaf Area; **NBS** = Number of Stem Per Stand; **NBB** = Number of Branches Per Plant; **NBLO** = Number of Lobes Per Plant; **NBL** = Number of Leaves; **DS** = Disease Severity; **CAL** = Colour of Apical Leaves; **PAL** = Pubescence on Apical Leaves; **LC** = Leaf Colour; **PC** = Petiole Colour; **CLV** = Colour of Leaf Vein; **LM** = Lobe Margin; **PO** = Petiole Orientation; **BH** = Branching Habit; **SCL** = Shape of Central Leaf; **SC** = Stem Colour

4.7 Correlation Coefficient Among the Growth-Related Traits of Cassava

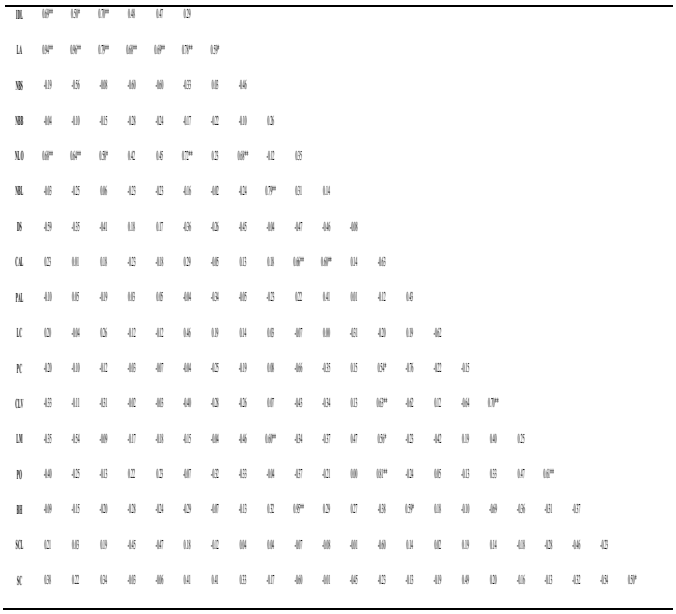
Table 7 presents correlation coefficients between different morphological traits. The results showed that PH (r = 0.53) and stem height (r = 0.53) were positively and statistically significantly correlated with lobe length, while petiole length (r = 0.92), lobe width (r = 0.87), SG (r = 0.77), IDL (r = 0.69), leaf area (r = 0.94), and NBLO (r = 0.68) were strongly positively correlated with lobe length. Lobe width also showed strong positive correlations with PL (r = 0.75), stem height (r = 0.76), PH (r = 0.76), SG (r = 0.70), LA (r = 0.96), and NBLO (r = 0.64). Lobe width also showed a positive correlation with IDL (r = 0.50). The PL also showed strong positive correlations with SG (r = 0.76), ISL (r = 0.70), and leaf area (r = 0.79), along with positive correlations with stem height (r = 0.56), PH (r = 0.56), and NBLO (r = 0.58).

Stem height was shown to be strongly positively correlated with both SG (r = 0.50) and LA (r = 0.68). Both LA (r = 0.69), and SG (r = 0.51) were positively correlated with PH. There was a substantial positive correlation between SG and NBLO (r = 0.72) and LA (r = 0.78). The IDL and leaf size were positively correlated (r = 0.59), while NBLO and LA was strongly positively correlated (r = 0.68). Additionally, the NBL (r = 0.79) and the LM (r = 0.60) were strongly correlated with NBS. While NBLO was positively correlated with the CAL (r = 0.60), NBB exhibited strong positive relationships with both branching habit (r = 0.95) and apical leaf colour (r = 0.66).

With regards to disease traits, there was a strong positive relationship between disease severity and lobe margin (r = 0.56), petiole colour (r = 0.54), petiole orientation (r = 0.81), and leaf vein colour (r = 0.63). Branching habit and apical leaf colour were positively correlated (r = 0.59). Similarly, the lobe margin showed a significant positive relationship with petiole orientation (r = 0.61) and a strong correlation between petiole colour and leaf vein colour (r = 0.70). There was a positive correlation between stem colour and the middle leaf shape (r = 0.50).

Table 7: Correlation Coefficient Among the Growth-Related Traits of Selected Cultivars of Cassava

	LOLB (cm)	LOWB (cm)	PL (cm)	SH (cm)	PH (cm)	SG (cm)	IDL (cm)	LA (cm)	NBS	NBB	NLO	NBL	DS	CAL	PAL	LC	PC	CLV	LM	PO	BH	SCL	SC
LOLB																							
LOWB	0.87**																						
PL	0.92**	0.75**																					
SH	0.52*	0.76**	0.59*																				
PH	0.52*	0.76**	0.59*	1.00**																			
SG	0.77**	0.70**	0.76**	0.50*	0.53*																		



** = significant at p < 0.01; * = significant at p < 0.05; LOLH = Lobe Length; LOWH = Lobe Width; PL = Petiole Length; SH = Stem Height; PH = Plant Height; SG = Stem Girth; IDL = Internode Length; LA = Leaf Area; NBS = Number of Stem Per Stand; NBB = Number of Branches Per Plant; NLO = Number of Lobes Per Plant; NBL = Number of Leaves; DS = Disease Severity; CAL = Colour of Apical Leaves; PAL = Pubescence on Apical Leaves; LC = Leaf Colour; PC = Petiole Colour; CLV = Colour of Leaf Vein; LM = Lobe Margin; PO = Petiole Orientation; BH = Branching Habit; SCL = Shape of Central Leaf; SC = Stem Colour.

4.8 Dendrogram Based on Morphological Characters

Results in Figure 1 show the dendrogram illustrating the relationships among various Cassava cultivars. The dendrogram reveals three primary clusters, which are further divided into four distinct groups. Notably, the Agric (brown) and Allimeme (white) cultivars exhibited close relatedness, distinguishing them from the TME 419 and Wonono cultivars, which showed a higher degree of similarity to each other. Also, Vitamin A (brown) and Vitamin A (white) cultivars are closely related compared to Allimeme (brown) cultivars. Again, Agric (white) and Nwator are closely related as also observed in Cham (brown) and Cham (white) cultivars.

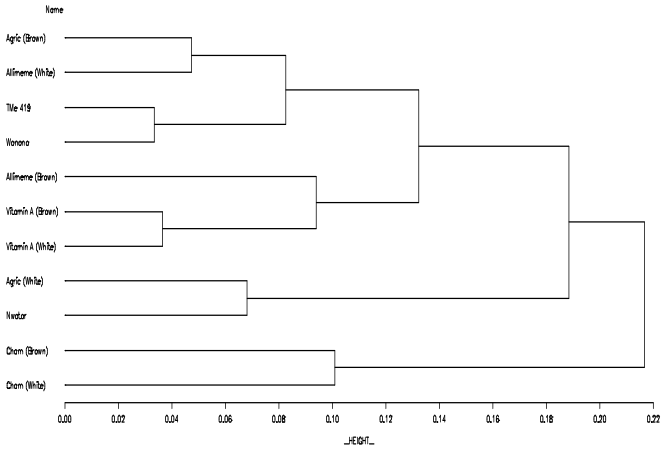


Figure 1. Dendrogram Showing Relationships Among Different Cultivars of Cassava using both Qualitative and Quantitative Characters

4.9 Principal Component Analysis Biplot Clusters

The biplot of PCA depicted in Figure 2 illustrates distinct clustering patterns. Specifically, the Agric cultivar (white) stands apart from the other cultivars, distinguished by traits such as lobe length, lobe width, petiole length, stem girth, the number of lobes per plant, leaf area, and internode length. In contrast, the Nwator group is distinguished by traits like stem height and plant height. Similarly, TME 419 was separated based on stem colour, while Cham (brown and white) were both separated on the basis of lobe margin, colour of leaf vein, disease severity, petiole orientation and petiole colour. The number of stems and leaves were the key traits distinguishing Allimeme (Brown). In contrast, the separation of Allimeme (White) and Agric (Brown) was influenced by the shape of the central leaf, the pubescence on apical leaves and leaf colour. Furthermore, the number of branches, branching habits, and the colour of apical leaves were critical traits for differentiating Vitamin A (Brown) and Vitamin A (White) from the other cultivars.

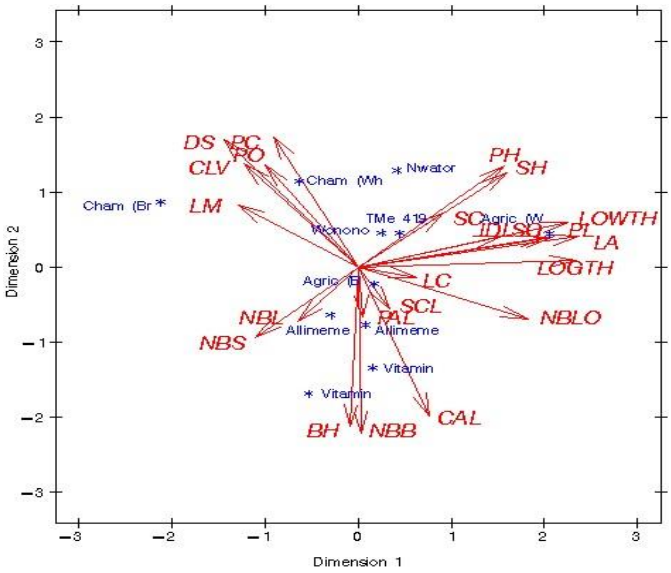


Figure 2. Cluster Analysis of Characters of Selected Cultivars of Cassava

LOGTH = Lobe Length; **LOWTH** = Lobe Width; **PL** = Petiole Length; **SH** = Stem Height; **PH** = Plant Height; **SG** = Stem Girth; **IDL** = Internode Length; **LA** = Leaf Area; **NBS** = Number of Stem Per Stand; **NBB** = Number of Branches Per Plant; **NLO** = Number of Lobes Per Plant; **NBL** = Number of Leaves; **DS** = Disease Severity; **CAL** = Colour of Apical Leaves; **PAL** = Pubescence on Apical Leaves; **LC** = Leaf Colour; **PC** = Petiole Colour; **CLV** = Colour of Leaf Vein; **LM** = Lobe Margin; **PO** = Petiole Orientation; **BH** = Branching Habit; **SCL** = Shape of Central Leaf; **SC** = Stem Colour

5. Discussion

The study's findings revealed substantial variations in the qualitative traits associated with growth among the different cassava cultivars. These morphological variations align with reports of [21, 27, 28], who also observed greater variation within groups compared to between groups. This result

suggests that careful observation is needed to distinguish one cultivar of cassava from another due to the high level of phenotypic similarities among cassava cultivars. The findings are further supported by [29], who documented inter- and intraspecific variations in Garcinia, and [30], who noted differences in both qualitative and quantitative traits of *Garcinia kola*.

Analysis of variance indicated notable differences in the growth traits among the cassava cultivars, highlighting the potential for these variations to be utilised in future breeding programs. The results are corroborated by findings from [12, 13, 20], who emphasised the importance of genetic variability in crop breeding. The substantial genotypic effects found in this study suggest that the trait variations are likely due to high genetic diversity, differences in growth types, and varying adaptation strategies.

The best-performing cultivars in terms of growth traits were Agric (White), Allimeme (Brown), Nwator, and Vitamin A (Brown), likely due to genetic variation. Selecting these cultivars based on their growth traits and inherent genetic diversity could significantly enhance productivity. The results of [31, 32], underscoring the critical role of genetic variability in crop breeding further support this finding. The performances observed in cassava suggest that hybridisation breeding procedures could improve desired traits in the parent lines.

In this study, the observed high phenotypic variance relative to genotypic variance across growth-related traits indicates considerable variability suitable for genetic improvement by selection, when the values of the GCV are lower than those of the PCV. However, the observed close range of values suggests that environmental factors had a minimal impact on trait expression, emphasising the importance of genetic trait-based selection due to the unpredictability of environmental fluctuations. The GCV and PCV values are deemed high if they are greater than 20%, low if they are less than 10%, and medium if they are between 10% and 20% [25].

High PCV and GCV values suggest substantial variation, enhancing the scope for early-stage improvement through selection. These findings align with [13] for total leaf area and [27] for lobe length, width, and stem girth. However, the moderate plant height GCV and PCV values in this study contrast with [12, 30], who reported low values.

Heritability values are crucial for predicting progress through selection. Together with a genetic coefficient of variation, heritability estimates offer an accurate gauge of expected genetic advances [12]. The study found high broad-sense heritability for the characters, likely as a result of additive gene action. These results corroborate the works of reports from [13, 12] for cassava characters and [34] for okra plant height. However, they differ from [31], who reported moderate h^2_{bs} (%) for cassava stem length, and [30], who found low h^2_{bs} (%) and GAM values for *Garcinia kola* traits. According to [26], heritability alone is insufficient to accurately predict genetic advancement; combining high heritability estimates with genetic gains and GCV values—reliable indicators of additive gene action—is essential. [33].

The results of PCA revealed that Prin.1 explained the most variance between the characters, aligning with reports of [33]. This implies that PCA may efficiently measure how various variables contribute to each principal component depending on the eigenvector.

Correlation coefficient findings showed mostly positive relationships among characters, consistent with reports from [31] but higher than findings from [35]. Traits can have a positive or negative correlation because of mutual relationships that might be genetic, phenotypic, or environmental [36]. Positive correlations imply that selection for one quantitative trait may enhance others, which is crucial for yield improvement since yield is influenced by multiple traits [37]. Understanding these correlations helps improve selection efficiency by combining desirable traits [38].

6. Conclusion and Future Scope

The study demonstrated significant morphological and genetic variability among cassava cultivars, highlighting the potential for targeted selection in breeding programs. The Principal Component Analysis (PCA) identified stem girth, lobe width, leaf area, stem length, plant height, lobe length, internode length, petiole length, and number of lobes per plant as the key morphological traits contributing to the observed variations among cassava cultivars. These traits can serve as primary identifiers for cassava genotypes. The study concludes that these traits, showing high genotypic coefficient of variation and heritability estimates, are suitable for selection in cassava crop improvement. Among the cultivars, Agric (White), Allimeme (Brown), Nwator, and Vitamin A (Brown) showed promising potential for future breeding and improvement programs. Their high heritability for traits like number of branches, leaf area, and lobe length suggests they are excellent candidates for cassava improvement, supporting better documentation and conservation of cassava germplasm. Correlation analyses further underscored the relationships between growth traits and yield, emphasising the importance of an integrated approach to selection.

However, the study acknowledges limitations, such as the environmental factors influencing phenotypic traits and the reliance on morphological methods, which may not fully capture genetic diversity. Future research should incorporate molecular tools, such as genome-wide association studies, to validate findings and identify quantitative trait loci linked to key traits. Applications of this research include improving cassava yields, enhancing food security, and developing cultivars resistant to biotic and abiotic stressors. Breeders are encouraged to utilise high-performing cultivars and adopt practices that integrate both traditional and modern breeding methods. Expanding the scope of this study to include larger populations and diverse agroecological zones will enhance the generalizability of the findings. Future efforts should also explore cassava's potential in climate-resilient agriculture,

leveraging its genetic diversity to address global food challenges.

Data Availability
Data is available on request from the corresponding author.

Study Limitations: None

Conflict of Interest
The authors declare that they do not have any conflict of interest.

Funding Source
None

Authors' Contributions
The original draft of the paper was written by the corresponding author, and all other authors modified and evaluated it before approving the final draft.

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