

Full Length Research Paper

Diversity and agromorphological patterns of cassava (*Manihot esculenta* Crantz) accessions cultivated in Gabon's northern and northeastern regions

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Received 21 October, 2025; Accepted 19 December, 2025

Describing the agromorphological traits of cassava varieties helps to identify high-yielding types or those best suited to specific farming systems and is essential for making informed varietal selection decisions. This study assessed the agromorphological diversity of cassava accessions from the Woleu-Ntem and Ogooué-Ivindo provinces of Gabon. Agronomic characterization of 212 accessions was carried out using 12 descriptors in a completely randomized design. Data analysis revealed high heterogeneity and substantial phenotypic variation. Hierarchical classification grouped the accessions into three distinct clusters, with an agglomeration coefficient of 0.995, indicating strong dissimilarity among the groups. Accessions in Group G1 allocated more biomass to aerial organs, whereas those in Group G3 favored root biomass, resulting in higher root yields. Group G2 exhibited an intermediate biomass allocation strategy. These contrasts in morpho-physiological traits suggest underlying genetic and environmental differences. This diversity is valuable for selecting cassava varieties with high yield potential or adaptation to specific cropping systems.

Key words: Accessions, cassava, sustainable agriculture, varietal diversity, Africa.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz), a staple crop native to South America, plays a crucial role in sub-Saharan Africa. It is the main source of carbohydrates for more than 200 million people (Nassar and Ortiz, 2010; Food and Agriculture Organisation (FAO), 2022). Farmers typically cultivate cassava for its starchy tuberous roots and protein-rich leaves, which also contain essential vitamins and minerals (Ceballos and de la Cruz, 2012; Álvares et al., 2013). In Central Africa, cassava contributes significantly to food security, rural livelihoods, and climate resilience, as it thrives across diverse environments and tolerates drought and poor soil conditions (Alene et al., 2018).

Despite its high socio-economic importance and considerable potential as a staple crop, cassava productivity remains constrained by several biotic and abiotic stressors, including pests, diseases, and unfavorable environmental conditions, which collectively reduce yields (Kosh-Komba et al., 2021). Yield variability is further exacerbated by differences among cassava varieties, many of which remain poorly characterized. Consequently, cassava production often fails to meet market demand in several African regions. These challenges also threaten the crop's genetic diversity, placing some cultivars at risk of extinction (Singer et al., 2021).

Although farmers frequently cultivate local landraces selected through experiential knowledge (Mouketou et al., 2022), these varieties are rarely supported by scientific data regarding their agronomic performance, stress tolerance, or technological attributes.

From a conservation and varietal improvement perspective aimed at enhancing productivity across the continent, agronomic characterization studies of cassava cultivars have been conducted in several Central African countries, including Congo (Kombo et al., 2012), the Central African Republic (Kosh-Komba et al., 2014), Chad (Nadjiam et al., 2016), the Democratic Republic of Congo (Otobo et al., 2016), and Cameroon (Temegne et al., 2016). In Gabon, however, research on the diversity of local cassava cultivars remains limited.

Notable exceptions include studies by Delêtre et al. (2011) and Abessolo (2013), which employed interdisciplinary approaches encompassing historical, socio-logical, ethnobotanical, and molecular genetic analyses to reveal substantial genetic variation among cassava populations. Building on these foundational findings, the present study aims to evaluate the agromorphological diversity of cassava accessions cultivated in the agricultural basins of the Woleu-Ntem and Ogooué-Ivindo regions of Gabon.

MATERIALS AND METHODS

Site description

The experiment was conducted at WAVE's experimental field located in Ntoun (geographical coordinates 0.39132° N latitude and 9.75887° E longitude), in the Estuaire Province, on the northwestern coastal plain of Gabon, within the Komo-Mondah Department. Ntoun experiences a humid equatorial climate, with annual temperatures ranging from 21 to 31°C (Moussavou, 2019). The soils in this area consist mainly of fine-textured ferrallitic soils, with hydromorphic features manifested as small rust-colored spots, particularly in the surface horizons (Delhumeau, 1969).

Plant

The plant material consisted of 212 cassava accessions collected during field surveys conducted between 2021 and 2022 in major agricultural production areas of the Woleu-Ntem and Ogooué-Ivindo provinces, located in the northern and northeastern regions of Gabon. A total of 65 accessions were collected from plantations in Woleu-Ntem, while 147 accessions were collected from Ogooué-Ivindo. The plantations sampled were 3 to 6 months old and spaced approximately 10 km apart (Figure 1). Cassava accessions were collected as stem cuttings and individually labeled in situ with their local names and corresponding identification codes.

Experimental design

An augmented randomized complete block design, as described by Nokoe (2001), was used in this study. The accessions collected from each province were randomly arranged into eight blocks, separated by 2 m walkways. Each sub-block consisted of 26 elementary plots, except the last sub-block, which contained 30 plots. Each elementary plot consisted of two rows of five plants, with a planting density of 1 plant per m².

Trial time frame and cutting preparation

The trial was conducted from September 2023 to July 2024. Cassava cuttings were treated for 20 min with a diluted solution (90 mL in 15 L of water) containing an insecticide (lambda-cyhalothrin, 50 g L⁻¹) and a fungicide (thiophanate-methyl, 450 g L⁻¹), in accordance with the manufacturers' recommendations. After treatment, the cuttings were air-dried at room temperature and then planted on ridges. Weeding and hoeing were carried out manually at 1, 3, and 6 months after planting. The trial was conducted without fertilizer application, and no phytosanitary treatments were applied after planting.

Data collection

A total of twelve agronomic descriptors were evaluated following the trait description methods proposed by Fukuda et al. (2010). Observations were recorded at different stages of plant development. The parameters assessed included: number of leaf

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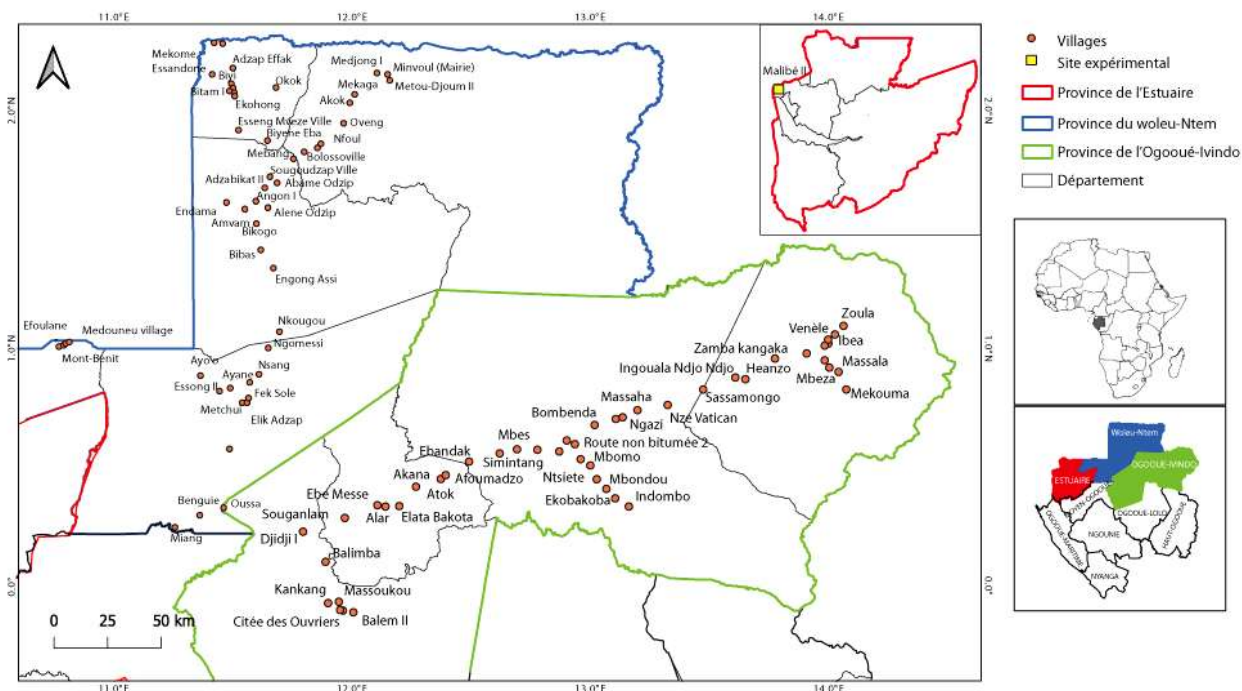


Figure 1. Distribution map of sampled areas (site for collecting accessions of cassava cultivated in the agricultural basins of northeastern Gabon). Source Design: Geomatics Laboratory, National School of Water and Forestry of Gabon (WAVE Hub Gabon Program).

Table 1. Descriptive analysis of agronomic traits.

Variable	Mean	Std dev.	CV
NL	6.95	0.73	0.10
LP	24.84	5.68	0.22
LLo	16.08	2.62	0.16
ILo	3.82	0.72	0.19
Llo_ILo	4.34	1.24	0.28
LT	290.86	61.82	0.21
T1B	75.81	77.15	1.01
ABr	50.57	43.36	0.85
NRT_P	4.38	2.70	0.61
NRMC	2.13	2.19	1.02
PdsR	1555.91	1116.55	0.71
NRa	1.32	1.42	1.07

Std dev.: standard deviation, CV: coefficient of variation.

(ILo, cm), lobe length-to-width ratio (LLo/ILo), stem length (LT, cm), height of the first branching point (T1B), angle of the first branch (ABr,°), number of tuberous roots per plant (NRT_P), number of marketable roots (NRMC), root weight (PdsR, g), and number of branches (NRa).

Statistical analysis

Descriptive statistical analyses were first performed, followed by variability analyses to assess the relative dispersion of data around the means. Normalized principal component analysis (PCA) and

ascending hierarchical clustering (AHC) were then conducted to classify the accessions into heterogeneous groups using Ward's method and Euclidean distance as the similarity index. The twelve morphometric variables were subjected to statistical analysis to compare the three study groups (G1, G2, and G3). For each quantitative variable, descriptive statistics were calculated, including the mean, standard deviation ($\pm$ SD), minimum and maximum values, and the median.

As the morphometric data did not meet the assumptions of normality and homogeneity of variance, comparisons among the three groups were performed using the Kruskal-Wallis test (with results expressed as a Chi-squared statistic). The threshold for statistical significance was set at $p < 0.05$. Only variables showing significantly different results between the three groups are presented.

Discriminant factor analysis (DFA) was subsequently performed to determine the variables that most effectively discriminated among the groups and to visualize group separation on a factorial plane. The selected morphometric parameters were further described and used to establish a comparison matrix of group mean vectors using Wilks' Lambda test. All multivariate analyses were performed using the ade4, MASS, stats, dendextend, vegan, and cluster packages in R software version 4.4.3 (R Core Team, 2024).

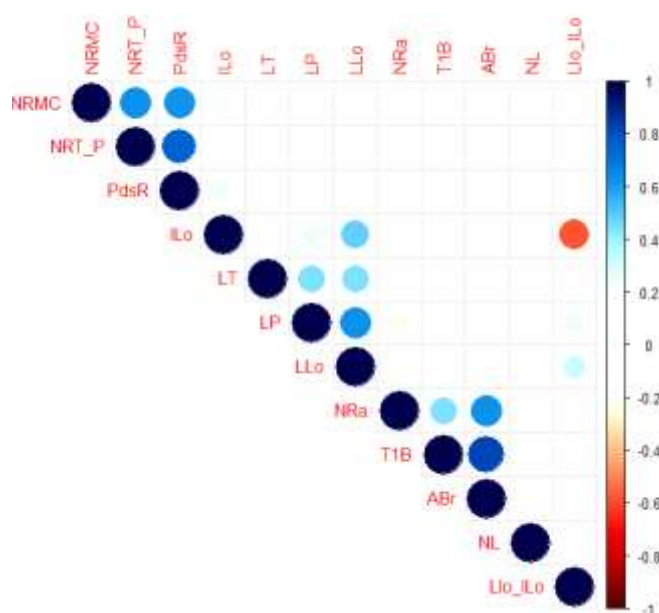
RESULTS

Descriptive and variability analysis

Table 1 presents the results of the descriptive statistical analyses, highlighting the variability observed among the evaluated agronomic traits. The coefficients of variation (CVs) provided insight into the relative dispersion of the

Table 2. Matrix of eigenvalues from normalized PCA.

Factor axis	Axis 1	Axis 2
Eigenvalue	2.44	2.14
Cumulative total variance (%)	10.48%	18.74%
Morphometric variable		
ABr	23.58*	15.51
NRa	19.86*	6.66
LP	17.57*	13.27
T1B	11.88	24.01*
LLo	11.29	19.29*
LT	10.46	11.92*
Llo_ILo	4.26	5.82
NL	1.08	1.18
NRMC	0.02	2.35

**Figure 2.** Correlogram illustrating linear relationships between quantitative variables.

data around the means of the studied variables. The CVs ranged from 0.106 (10.6%) for the number of NL to 1.076 (107.6%) for the NRa. Descriptive analysis of the data (Table 1) showed that the LLo/ILo varied from 2.52 to 15.49, with a mean value of 4.34 ± 1.24 . The average LT of the collection was 290.86 ± 61.83 cm. With respect to yield components per plant, the mean NRT_P was 4.38, with approximately 50% of these roots being marketable (2.13 out of 4.38). The weight of harvested roots per plant ranged from 40 to 7.660 g.

Correlation analysis

Figure 2 presents the correlation matrix among the studied

variables. The correlation coefficients ranged from -0.04 to 0.28 and were significant at the 5% probability level. Positive correlations are represented in blue, while negative correlations are shown in red. The intensity of the color and the size of the circles are proportional to the magnitude of the correlation coefficients. The scale of correlation coefficients is displayed on the right side of the figure. The analysis revealed several strong positive correlations among certain variables, indicating close relationships between them. Two main groups of positively correlated variables emerged. The first group comprised the number of marketable roots (NRMC), NRT_P, root weight (PdsR), LLo, LT, LP, and ILo. The second group included the NRa, height of the first branching point (T1B), angle of the ABr, and NL. For instance, a strong positive correlation was observed between NRMC and NRT_P ($r = 0.50$), as well as between NRT_P and PdsR ($r = 0.70$). In contrast, a strong negative correlation ($r = -0.50$) was observed between LLo and the LLo/ILo.

Classification of cassava varieties

Principal component analysis (PCA)

Variability among accessions was assessed using PCA based on agromorphological traits. The first two principal components (Table 2) had eigenvalues greater than 1, in accordance with the Kaiser criterion, which is based on the principle of maximum variance (minimum inertia). The data presented in Table 2 indicate that the angle of the first branch (ABr; 23.58%), number of branches (NRa; 19.86%), and petiole length (LP; 17.57%) contributed most strongly to the first principal axis, which therefore represents the main direction of variation among the accessions. In contrast, the height of the first branching point (T1B; 24.01%), lobe length (LLo; 19.29%), and stem length (LT; 11.92%) contributed most significantly to the formation of the second axis. The variables lobe width (ILo), number of leaf lobes (NL), and number of marketable roots (NRMC) played only a minor role, contributing weakly to the construction of the axes, and thus appear to be less decisive in explaining the overall structure of variability.

Ascending hierarchical classification (AHC) and discriminant factor analysis (DFA)

Figure 3 presents the dendrogram obtained from the ascending hierarchical classification (AHC) of the accessions under study, based on the mean values of the measured variables. Clustering was performed using Euclidean distance and Ward's method as the aggregation criterion. Evaluation of the loss of homogeneity between clusters at the tree level yielded an agglomeration coefficient of 0.995, indicating strong dissimilarity among the identified groups. The dendrogram presented in Figure 3 revealed three distinct clusters. Group 1 (G1) comprised

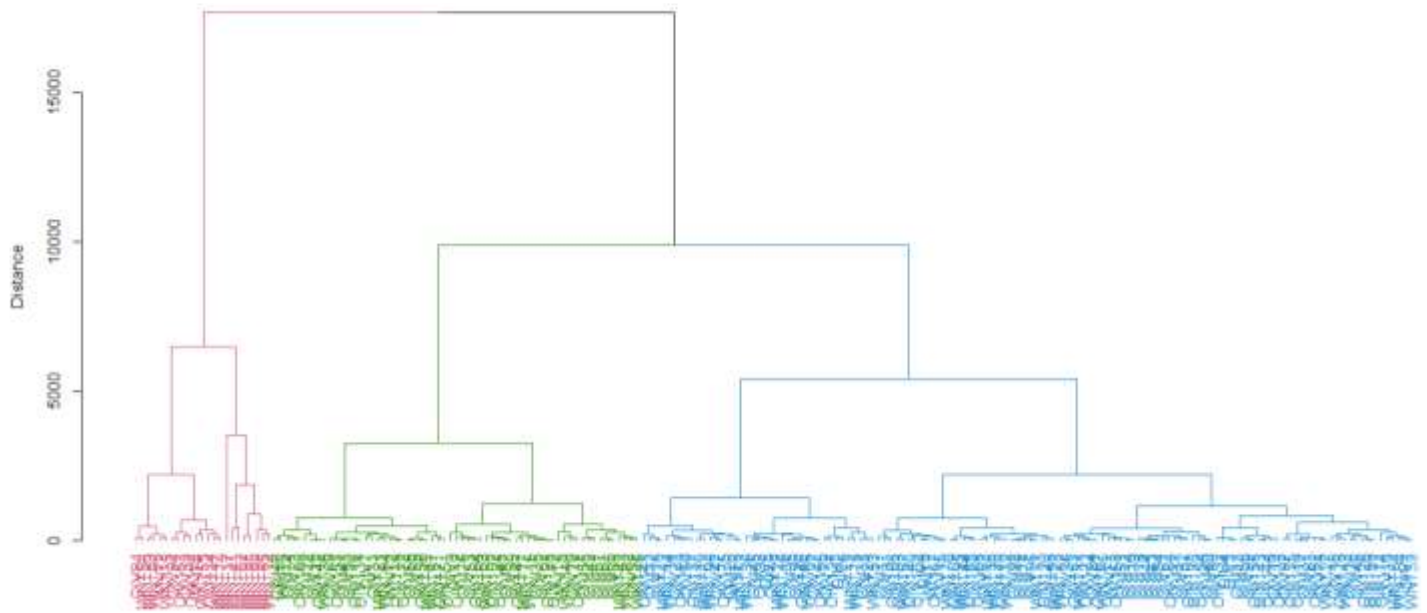


Figure 3. Dendrogram derived from AHC.

56 accessions, including 48 from Ogooué-Ivindo and 8 from Woleu-Ntem. Group 2 (G2) consisted of 76 accessions, of which 65 originated from Ogooué-Ivindo and 11 from Woleu-Ntem. Group 3 (G3) included 80 accessions, with 34 from Ogooué-Ivindo and 46 from Woleu-Ntem. Table 3 presents a comparative analysis of quantitative variables among the three groups (G1, G2, and G3), using Chi-square (χ^2) tests and their corresponding p-values.

The results of the Kruskal-Wallis test indicated that almost all variables LLo, LP, LT, NRa, NRM, T1B, ABr, and ILo significantly discriminated among the groups ($p < 0.001$). The only exception was the NL, which showed a moderate but still significant difference among groups ($p < 0.01$). Overall, Group G1 was characterized by low branching (NRa) and very LT. In contrast, Group G2 exhibited the highest values for T1B and ABr, along with the LLo. Group G3 was characterized by relatively LP and LT and occupied an intermediate position for other morphological traits, including LLo, T1B, and ABr.

DISCUSSION

Descriptive analysis and data variability

The analysis of the coefficients of variation of cassava accessions grown in the production hubs of northern (Woleu-Ntem) and northeastern (Ogooué-Ivindo) Gabon revealed high heterogeneity for most variables ($CV > 30\%$). Similar findings were reported by Ndiade et al. (2025) in a study of cassava accessions cultivated in the agricultural basins of southwestern Gabon. This observation indicates that these traits are highly discriminating and may be useful for varietal selection or classification.

Furthermore, the traits T1B, ABr, NRT_P, NRM, PdsR, and NRa exhibited very high coefficients of variation ($CV > 50\%$) in the present study. Such variability may reflect underlying genetic heterogeneity but could also result from strong genotype $\times$ environment interactions, as suggested by Aremu (2012) and Tokatlidis (2023).

The wide variation observed in the lobe length-to-width ratio (LLo/ILo), ranging from 2.52 to 15.49, suggests substantial genetic differentiation among accessions. This morphological trait is commonly used in cassava characterization studies to discriminate between genotypes (Fukuda et al., 2010). The average stem length of approximately 3 m indicates that the collection is dominated by medium- to tall-growing genotypes. According to El-Sharkawy (2012), stem length influences planting density and can facilitate harvesting operations. Indeed, accessions with long stems and large lobes may be valuable for the production of cuttings or for developing varieties with enhanced photosynthetic capacity, productivity, and disease resistance (Bolamba et al., 2024).

The average number of tuberous roots per plant (between 4 and 5) falls within the range commonly reported for cassava. However, the fact that only about 50% of these roots were marketable (2.13 out of 4.38) indicates a limited effective yield, highlighting the need for targeted selection to improve root marketability. Similar results were reported by Kamanda et al. (2020), who emphasized that the proportion of marketable roots is a key criterion in the evaluation of cassava accessions. Overall, the observed variation in the evaluated traits reflects substantial heterogeneity among accessions, which may be influenced by environmental factors such as soil fertility, rainfall, and cultivation practices. This

Table 3. Descriptive analysis of morphometric variables and results of the Kruskal–Wallis test comparing median values among the three groups.

Variable	Indice	G1	G2	G3	Chi-squared	P-value
LLo	Min	11	9	9.32	11.376	***
	Max	22.32	22.20	20.72		
	Mean $\pm$ Std dev.	16.77 $\pm$ 2.29	6.41 $\pm$ 2.73	15.28 $\pm$ 2.58		
	Median	17.00	16.57	15.48		
LP	Min	19.72	12.54	0.00	46.077	***
	Max	40.50	37.60	35.44		
	Mean $\pm$ std dev.	27.78 $\pm$ 4.77	26.14 $\pm$ 5.01	21.54 $\pm$ 5.32		
	Median	27.45	26.00	21.88		
LT	Min	206.80	177.00	34.00	33.351	***
	Max	496.00	450.20	369.25		
	Mean $\pm$ std dev.	319.85 $\pm$ 60.59	304.91 $\pm$ 56.04	259.32 $\pm$ 55.17		
	Median	319.50	305.50	270.00		
NL	Min	5	5	3	9.855	**
	Max	9	9	9		
	Mean $\pm$ std dev.	7.00 $\pm$ 0.38	7.13 $\pm$ 0.68	6.75 $\pm$ 0.92		
	Median	7	7	7		
NRa	Min	0	0	0	67.455	***
	Max	2	4	5		
	Mean $\pm$ std dev.	0.07 $\pm$ 0.7	1.61 $\pm$ 1.31	1.91 $\pm$ 1.45		
	Median	0	2	1		
NRMC	Min	0	0	0	80.13	***
	Max	5.40	6.00	12.00		
	Mean $\pm$ std dev.	1.99 $\pm$ 1.45	1.97 $\pm$ 1.39	2.40 $\pm$ 3.08		
	Median	1.80	2.00	2.00		
T1B	Min	0	0	0	90.39	***
	Max	149.00	293.80	234.00		
	Mean $\pm$ std dev.	5.75 $\pm$ 23.76	129.46 $\pm$ 74.74	73.89 $\pm$ 63.45		
	Median	0.00	131.70	72.80		
ABr	Min	0	0	0	80.133	***
	Max	80.00	107.80	130.00		
	Mean $\pm$ std dev.	3.35 $\pm$ 13.72	73.20 $\pm$ 32.94	62.13 $\pm$ 40.95		
	Median	0.00	86.80	84.50		
Llo	Min	3.11	2.89	2.52	20.237	***
	Max	5.88	15.49	7.95		
	Mean $\pm$ std dev.	4.37 $\pm$ 0.57	4.67 $\pm$ 1.83	4.01 $\pm$ 0.72		
	Median	4.31	4.29	3.93		

Minimum, maximum, mean $\pm$ standard deviation and median of the 9 quantitative variables, with Kruskal-Wallis test results showing Chi-squared and p-value. **: $p < 0.01$; ***: $p < 0.001$.

underscores the importance of integrating genotype $\times$ environment interactions into agronomic characterization studies (Egesi et al., 2007). According to Akinwale et al.

(2011), such diversity in cassava populations represents a major asset for varietal improvement programs, as it enables the identification of accessions with high yield

potential or adaptation to specific cropping systems.

Correlation analysis

The correlation analysis identified two main groups of associated traits. The first group included traits related to root production and leaf morphology. The strong positive correlation observed between the NRMCI and the NRT_P suggests that accessions producing more tuberous roots also tend to produce a higher number of marketable roots. This relationship can be explained by the fact that an increase in the total number of tuberous roots increases the likelihood that a substantial proportion will reach sufficient size and biomass to be considered marketable; reflecting more efficient allocation of assimilates to storage organs. These findings are consistent with those of Wilhelm et al. (2022) and Onyenali et al. (2025), who reported that commercial cassava root yield is strongly influenced by the total number of tuberized roots. Similarly, the strong positive correlation between NRT_P and root weight (PdsR; $r = 0.70$) suggests that accessions producing more tuberous roots also tend to have higher root biomass. Comparable relationships have been reported in cassava by Kumba (2012) in Ghana and Gmakouba et al. (2018) in Burkina Faso, who emphasized that root yield is directly related to both the number and size of tuberized roots. The consistency of these results across different agroecological contexts supports the hypothesis that the number of tuberous roots is a major and relatively stable determinant of root yield in cassava.

The second group comprised traits associated with plant architecture and vegetative development. The positive correlations observed among the NRa, T1B, ABr, and number of NL indicate that accessions with greater branching tend to have increased leaf production. This relationship can be explained by the fact that enhanced branching increases the number of leaf-bearing axes, thereby improving the plant's overall photosynthetic capacity and vegetative growth potential. These findings are in agreement with those of Moreno-Cadena et al. (2021) and Phoncharoen et al. (2022), who demonstrated that vegetative architecture plays a key role in determining leaf production and branching intensity in cassava.

Classification of cassava varieties

Axis 1 of the PCA was primarily defined by the ABr, NRa, and LP. These variables reflect dynamics related to aerial architecture and leaf expansion. Thus, strong branching development combined with long petioles characterizes a major architectural gradient. Axis 2, structured mainly by the T1B, LLo, and LT, contrasts leaf dimensions and longitudinal vegetative organs (stems and lobes), reflecting a second gradient of variation centered on leaf morphology and overall vegetative vigor. These results

highlight two major axes of morphological differentiation in cassava, which have previously been described as adaptive responses to environmental conditions such as planting density, competition for light, and agroecological constraints (Jennings and Iglesias, 2001; Ceballos et al., 2020).

Ascending hierarchical classification identified three distinct morphological groups (G1, G2, and G3). The high agglomeration coefficient (0.995) indicates a very clear hierarchical structure, confirming that the clusters are internally homogeneous and well differentiated from one another. Analysis of the data presented in Table 3 revealed that Group G1 preferentially allocates biomass to aerial organs, characterized by longer leaves and lower root development. This strategy may be advantageous in environments where efficient light capture is critical; however, it may limit water and nutrient uptake from the soil. Such trade-offs between aboveground biomass allocation and access to edaphic resources is well documented in the literature. For example, Poorter et al. (2012) demonstrated that genotypes with high investment in aerial biomass often exhibit increased sensitivity to water and nutrient stress.

Group G2 exhibited a more balanced biomass allocation strategy, investing in both aboveground and belowground organs. This strategy may enhance the acquisition of soil resources while maintaining competitive aerial growth, thereby improving overall plant resilience. This observation is consistent with the findings of Qi et al. (2019), who suggested that balanced allocation between roots and shoots can enhance plant adaptability to environmental variability. In contrast, Group G3 showed a biomass allocation pattern strongly oriented toward root development, accompanied by reduced leaf area. This strategy may be advantageous in environments where access to underground resources is critical; however, it may constrain photosynthetic capacity at the whole-plant level, as reported by Poorter et al. (2012).

Taken together, these results reveal the existence of contrasting morpho-physiological profiles among the three groups, reflecting underlying genetic differences and/or environmental influences.

Conclusion

This study focused on the agromorphological characterization of cassava accessions cultivated in the major agricultural production hubs of Woleu-Ntem and Ogooué-Ivindo in Gabon. Growth- and yield-related parameters were used to assess diversity among 212 cassava accessions. The results revealed high heterogeneity within the collection for ten of the twelve evaluated traits, suggesting substantial genetic diversity and, to some extent, strong genotype $\times$ environment interactions. Hierarchical classification identified three distinct groups with contrasting structural and functional

characteristics, underscoring the discriminating power of the evaluated parameters. Accessions in Group G1 tended to allocate biomass preferentially to aerial organs, whereas those in Group G3 showed a strong tendency toward root biomass allocation, with implications for yield performance. Group G2 displayed an intermediate allocation strategy between these two extremes. This diversity represents a valuable resource for cassava improvement programs, as it enables the identification of accessions with high yield potential or those adapted to specific cropping systems and agroecological conditions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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