World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Phenotypic characterization of some Nigerian *Coffea* species using morphological characters

Tope Emmanuel Ebunola [1, 2, *], Odunayo Joseph Olawuyi [2], Chinyere Florence Odey [1], Hamidu Muhammed Askira [1] and Terkula Felix Nyamkume [1]

[1] *Crop Improvement Division, Cocoa Research Institute of Nigeria, P.M.B. 5244, Ibadan, Oyo State, Nigeria.*
[2] *Genetics and Molecular Biology Unit, Department of Botany, University of Ibadan, Nigeria.*

World Journal of Advanced Research and Reviews, 2026, 29(03), 367-380

Publication history: Received on 18 January 2026; revised on 03 March 2026; accepted on 05 March 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.29.3.0475

Abstract

Accurate assessment of phenotypic diversity is essential for the effective conservation and genetic improvement of *Coffea* spp. and so far little work has been done on it in Nigeria. We studied the morphological characterization of 48 coffee accessions comprising one each of *C. arabica*, *C. abeokutae*, *C. liberica* and *C. stenophyla*; 14 accessions of *C. canephora* from the Cocoa Research Institute of Nigeria; and 30 landraces collected from Ekiti and Kogi states in Nigeria. The agro-morphological traits used were classified into quantitative (plant height, stem diameter, leaf length, and leaf width) and qualitative (plant habit, branching habit, leaf shape, leaf apex shape, young leaf colour, mature leaf colour, berry shape and berry colour) traits. Significant variation was observed across all quantitative traits ($p < 0.001$), with notable divergence in plant height, stem diameter, leaf length, and leaf width. Principal Component Analysis (PCA) revealed that the first three components explained 94.4% of total variation, with leaf and stem traits contributing mostly to the variance. Cluster analysis of the quantitative traits grouped the accessions into three distinct clusters and one outlier, indicating the presence of phenotypic diversity among the accessions, while their correlation analysis highlighted strong associations between key growth traits, notably between leaf length and width ($r = 0.69$, $p < 0.01$). Multiple Correspondence Analysis (MCA) of qualitative traits revealed clear associations between accessions and trait categories. Landraces clustered around bushy growth habit, elliptic leaves, and red berries, whereas distinct species such as *Coffea stenophylla* and *Coffea liberica* were separated by tree habit, lanceolate leaves, and sparse branching patterns. A few accessions appeared as outliers due to rare trait expressions, including obovate leaf shape and purple berry colour, which contributed strongly to their discrimination in the MCA space. Qualitative trait distribution was dominated by elliptic leaf shape (87.5%), apiculate apex (81.25%), and red berry colour (41.67%). Overall, these findings indicate a moderate level of phenotypic diversity among Nigerian coffee germplasm, highlighting the need to broaden the genetic base and strengthen improvement efforts in *Coffea canephora*. The considerable variability observed in qualitative traits further suggests that molecular-level investigations would be valuable for elucidating their genetic basis and potential application in coffee breeding programs.

Keywords: Phenotypic diversity; PCA; *Coffea* species; *C. canephora*; Landraces; Nigeria

1. Introduction

Coffea spp. (Coffee) is one of the major tropical cash crops that contribute significantly to rural livelihoods and foreign exchange earnings (Abafita and Tadese, 2021). Despite its potential, coffee productivity in Nigeria remains low, in part due to limited exploitation of available genetic resources. Genetic diversity refers to the total range of genetic characteristics present within a species or population (Bhandari *et al.*, 2017) which serves as a critical determinant of its adaptability, resilience, and long-term survival. Diverisy in a given population is a source of genetic foundation for

* Corresponding author: Ebunola T. E

breeding programs, enabling the selection and development of superior cultivars with enhanced agronomic traits (Bhandari *et al.*, 2017).

The genus *Coffea*, is a diverse crop with over 124 species whereas *C. arabica* Linnaeus and *C. canephora* Pierre ex A. Froehner (Zamir, 2014) are the most cultivated, some of the species are *C, abeokutae*, *C. liberica*, *C. stenophylla* and *C. eugeniodes* and *C. excelsa*.. High genetic diversity enhances the likelihood of identification of genotypes with desirable traits such as high yield, disease resistance, and tolerance to environmental stressors (Swarup *et al.*, 2021). It also plays a pivotal role in breeding efforts aimed at improving beverage quality, productivity, and resistance to major diseases like coffee leaf rust (*Hemileia vastatrix*) and coffee berry disease (*Colletotrichum kahawae*). Morphological characterization remains a foundational approach for assessing phenotypic variation in plant populations and offers critical insights into selecting superior genotypes for breeding.

Morphological traits, such as plant height, stem diameter, leaf size, and fruit characteristics, reflect underlying genetic variation and are essential for variety identification, classification, and improvement. However, such traits are also influenced by environmental factors, making it important to examine patterns of trait association and variation across diverse germplasm. Morphological markers have been extensively utilized in coffee breeding programs for the classification, identification, and selection of superior coffee genotypes due to their ease of observation and minimal technological requirements (Baba Nitsa *et al.*, 2020).

This study evaluates the phenotypic diversity of 48 Nigerian coffee accessions collected from farmers' fields in Ekiti and Kogi states, as well as from the coffee gremplasm of Cocoa Research Institute of Nigeria (CRIN). This research seeks to deepen our understanding of morphological variation present in Nigerian coffee resources and provide valuable insights for breeding and conservation programs. Specifically, the objectives are: firstly, to assess the extent of phenotypic diversity among the accessions based on quantitative and qualitative morphological traits, secondly to identify significant associations among agronomic traits that could inform selection criteria for crop improvement, and thirdly, to analyse the population structure of the accessions using multivariate techniques such as principal component analysis (PCA), multiple correspondence analysis (MCA) and cluster analysis.

Using statistical methods including Analysis of Variance (ANOVA), correlation analysis, principal component analysis (PCA), and hierarchical clustering, the study assessed the extent of morphological diversity, identified key traits contributing to variability, and highlighted the accessions with potential value for breeding programs. Multiple correspondence analysis (MCA) was used to analyse the qualitative traits in order to determine the associations among trait categories and to visualize patterns of variation among the coffee accessions.

2. Materials and Methods

2.1. Plant Material

Forty-eight (48) coffee accessions were assessed (Table 1), comprising 15 landraces from Ekiti and 15 landrace from Kogi States; and 18 accessions from Cocoa Research Institute of Nigeria comprising one accession each of *C. stenophylla*, *C. arabica*, *C, liberica* and *C abeokutea*; and 14 accessions of *C. canephora*.

Table 1 The accessions used for the study

Samples	Code	Accessions	Species	Origin
1–5	Can_1 - Can_5	Landrace	*Canephora*	Omuo Ekiti - 1
6–10	Can_6 - Can_10	Landrace	*Canephora*	Omuo Ekiti - 2
11–15	Can_11 - Can_15	Landrace	*Canephora*	Omuo Ekiti - 3
16–20	Can_16 - Can_20	Landrace	*Canephora*	Iyamoye Kogi - 1
21–25	Can_21 - Can_25	Landrace	*Canephora*	Iyamoye Kogi - 2
26–30	Can_26 - Can_30	Landrace	*Canephora*	Iyamoye Kogi - 3
31-33	C90, C111, C36	Kouilou	*Canephora*	DRCongo
34-35	A116, A81	Gold Coast	*Canephora*	Ghana

36-37	E106, E77	Java Robusta	*Canephora*	Indonesia
38-39	M10, M36	Niaouli	*Canephora*	Benin
40-41	G129, G37	Ugandan	*Canephora*	Uganda
42-44	T1049, T921, T797	Java Robusta ex-Gambia	*Canephora*	Zaire
45	Ste_02		*Stenophylla*	
46	Ara_02		*Arabica*	
47	H139		*Liberica*	Central Africa
48	W104		*Abeokutae*	West Africa

Anagbogu *et al.* 2019

2.2. Morphological Data Collection

Morphological characterization was conducted following the standardized descriptors for coffee outlined by International Plant Genetic Resources Institute (IPGRI, 1996) for quantitative and qualitative traits. Quantitative traits including plant height (cm), stem diameter (cm), leaf length (cm), and leaf width (cm) were measured using a calibrated measuring tape and digital calipers for accuracy on the coffee germplasm in CRIN and farmers' farms in Ekiti and Kogi states of Nigeria. Qualitative traits which included plant habit, branching habit, young leaf color, leaf shape, leaf apex shape, mature leaf color, berry shape, and berry color were recorded based on visual assessment. These descriptors were scored according to IPGRI categorical scales to ensure consistency and comparability across accessions.

2.3. Data Analysis

Statistical analysis was conducted using R software (v4.4.2) for Analysis of Variance at $p < 0.001$, and Duncan's Multiple Range Test (DMRT) to differentiate phenotypic variations among the accessions; while Pearson correlation analysis assessed the traits' associations. Both Principal Component Analysis (PCA) and Hierarchical Analysis (HA) disclosed phenotypic diversity among the accessions. Frequency distributions of qualitative traits were summarized as percentages. Qualitative traits were analyzed using multiple correspondence analysis (MCA) to determine the associations among trait categories and to visualize patterns of variation among the coffee accessions.

3. Results and Discussion

3.1. Phenotypic traits differentiating the 48 accessions

The use of ANOVA had significantly ($p < 0.001$) differentiated the accessions along these traits: plant height, stem diameter, leaf length, and leaf width (Table 2) and indicated a broad phenotypic base within the collection.

Plant height. The accessions were greatly differentiated with plant height. From this study, accession W104 which was classified as *C. abeakutae* had the highest plant height (Table 3). Among *C. canephora* accessions, M36 had the highest plant height (Table 3). Interestingly, plant height has shown to serve as a good parameter in differentiating *Coffea* speices, as was in the case here, *C. abeakutae* had the highest plant height followed by *C. canephora*, while *C. arabica* had the lowest plant height (Table 3). The accessions that exhibited similar low plant height were Ste-02 (*C. stenophylla* accession), G129 (*C. canephora* var. Ugandan accession), H139 (*C .liberica* accession) and C90 (*C. canephora* var. Kouilou accession).

Leaf width and length. The plant leaf characters, width and length both exhibited strong attribute in differentiating the accessions. There was wide range (13.53cm-5.93cm) between the highest and lowest leaf width with T921 (*C. canephora* var. Java ex Gamba accession) having the highest leaf width and G129 (*C. canephora* var. Ugandan accession). Other *coffea* species (*C. arabica, C. stenophylla* and *C .liberica*) except *C. abeokutae* exhibited low leaf width, There was also wide range (29.67cm-513.63cm) between the highest and the lowest leaf length with Can29 (*C. canephora* var. Landrace) having the highest leaf length and G129 (*C. canephora* var. Ugandan accession) having the lowest.

Stem diameter. The accessions showed significant variation in stem diameter, which served as a distinguishing morphological feature among the *Coffea* accessions (Table 3). The widest stem diameter was recorded in Can_29 (26.17cm), a *C. canephora* accession, followed closely by Can_25 (24.17cm) and Can_23 (23.20cm), all classified under *C. canephora* (Table 3). These accessions showed statistically similar (non-significant) groupings, indicating robustness in stem thickness among these landraces. On the other hand, the narrowest stem diameters were observed in Ara_02 (*C. arabica*, 5.57cm), G129 (*C. canephora var. Ugandan*, 7.33cm), and Ste_02 (*C. stenophylla*, 9.57cm), all of which were significantly different from other accessions. Interestingly, *C. abeokutae* (W104) had a stem diameter of 11.77cm, which was significantly lower than most *C. canephora* accessions but higher than *C. arabica* and *C. stenophylla*.

The large accession mean squares relative to residual error further suggest that the observed variation is predominantly genetic rather than purely environmental. In mean separation (Table 3), whereas Can_29 ranked among the top statistical group for multiple growth traits (leaf length, leaf width, and stem diameter), highlighting both as promising donor parents for ideotype development. By contrast, Ara_02 (*C. arabica)* consistently fell into the lower performance group across several vegetative traits, making it a potential source for compact growth or as a contrasting parent in diallel or heterosis studies. This finding is not surprising since this genotype is from a highly different genome as well as Coffee species. Similar significant phenotypic variability among *C. canephora* accessions found in this study has been reported by Gokavi *et al.* (2023) and Baba Nitsa *et al.* (2020), and this emphasized the reliability of morphological traits in distinguishing genotypes within *Coffea canephora*.

Table 2 Mean square variance of the 48 coffee accessions

Source of Variation	Df	Plant Height	Stem Diameter	Leaf Length	Leaf Width
Accession	47	370.08***	55.79***	46.02***	15.57***
Replicate	2	26.02	8.99	22.16***	2.13
Residuals	94	21.39	6.39	2.53	1.23

Significance codes: '***' = very highly significant

Table 3 Quantitative growth traits of the 48 coffee accessions

Accessions	Plant Height (cm)	Stem Diameter (cm)	Leaf Length (cm)	Leaf Width (cm)
W104	82.3^{a}	11.77^{lmnop}	27.20^{abcdef}	12.70^{abcde}
M36	47.67^{b}	15.90^{ghijkl}	17.50^{lm}	7.57^{lmno}
Can_29	30.17^{c}	26.17^{a}	29.67^{a}	13.27^{ab}
Can_25	28.17^{cd}	24.17^{abc}	27.67^{abcde}	12.27^{abcdef}
Can_23	27.17^{ce}	23.2^{abcd}	26.67^{bcdefg}	$11.77^{abcdefg}$
Can_21	26.17^{cdef}	22.47^{abcde}	$25.67^{cdefghij}$	$11.53^{abcdefgh}$
Can_19	25.17^{cdefg}	21.93^{abcde}	$24.67^{efghijk}$	$11.23^{bcdefghi}$
T1049	25.0^{cdefg}	18^{efghij}	18.80^{lm}	10.67^{efghij}
Can_17	24.0^{cdefgh}	21.43^{bcdef}	23.67^{ghijk}	$10.97^{defghij}$
T797	23.77^{cdefgh}	15.80^{ghijkl}	18.77^{lm}	9.33^{ijkl}
A81	$23.67^{cdefghi}$	19.67^{cdefgh}	22.33^{k}	8.43^{klmn}
T921	$23.67^{cdefghi}$	19.8^{cdefg}	14.30^{n}	6.83^{no}
M10	$22.4^{cdefghij}$	17.93^{efghij}	$26.01^{cdefghi}$	9.83^{ghijk}
C111	$22.0^{cdefghij}$	13.70^{jklmno}	23.53^{hijk}	10.73^{efghij}
E106	$22.0^{cdefghij}$	12.33^{klmno}	18.10^{lm}	$11.00^{cdefghij}$
Can_30	$19.9^{defghijk}$	19.9^{cdefg}	29.33^{ab}	$11.67^{abcdefg}$

Can_28	18.9^{efghijk}	18.9^{defghi}	28.33^{abcd}	11.23^{bcdefghi}
Can_2	18.6^{efghijk}	14.73^{hijklmn}	24.67^{efghijk}	13.47^{a}
Can_11	18.13^{efghijk}	14.33^{ijklmno}	25.67^{cdefghij}	13.10^{abcd}
Can_15	18.13^{efghijk}	13.93^{ijklmno}	23.00^{ijk}	13.20^{abc}
Can_4	18.13^{efghijk}	14.33^{ijklmno}	25.67^{cdefghij}	13.10^{abcd}
Can_13	18.07^{efghijk}	14.17^{ijklmno}	24.33^{fghijk}	12.97^{abcd}
Can_6	18.07^{efghijk}	14.17^{ijklmno}	24.33^{fghijk}	12.97^{abcd}
Can_7	18.03^{efghijk}	14.03^{ijklmno}	23.00^{ijk}	13.27^{ab}
Can_9	17.93^{efghijk}	14.07^{ijklmno}	24.00^{ghijk}	13.17^{abc}
Can_14	17.9^{efghijk}	13.93^{ijklmno}	23.00^{ijk}	13.20^{abc}
Can_26	17.9^{efghijk}	17.9^{efghij}	27.33^{abcdef}	10.77^{efghij}
Can_12	17.83^{efghijk}	14.03^{ijklmno}	22.67^{jk}	13.53^{a}
Can_5	17.83^{efghijk}	14.03^{ijklmno}	22.67^{jk}	13.53^{a}
Can_10	17.8^{fghijk}	13.87^{ijklmno}	23.33^{hijk}	13.33^{ab}
Can_3	17.8^{fghijk}	13.87^{ijklmno}	23.33^{hijk}	13.33^{ab}
Can_1	17.77^{fghijk}	13.93^{ijklmno}	23.00^{ijk}	13.20^{abc}
Can_8	17.77^{fghijk}	13.93^{ijklmno}	23.00^{ijk}	13.20^{abc}
A116	17.33^{fghijk}	16.00^{ghijkl}	17.97^{lm}	7.37^{lmno}
Can_24	16.83^{fghijk}	16.9^{fghijkl}	26.33^{cdefgh}	10.33^{fghijk}
Can_22	16.0^{ghijkl}	16.07^{ghijkl}	25.33^{defghijk}	9.90^{ghijk}
Ste_02	15.47^{hijkl}	9.57^{opq}	19.60^{l}	6.97^{no}
Can_20	14.83^{hijkl}	15.60^{ghijkl}	24.33^{fghijk}	9.50^{hijkl}
E77	14.33^{ijkl}	10^{mnopq}	19.37^{l}	9.37^{ijkl}
G37	14.17^{jkl}	9.67^{nopq}	19.50^{l}	9.37^{ijkl}
Can_18	14.13^{jkl}	14.93^{ghijklm}	23.33^{hijk}	9.07^{ijklm}
C36	14.0^{jkl}	15.00^{ghijklm}	19.27^{lm}	9.17^{ijkl}
Can_16	13.83^{jkl}	14.73^{hijklmn}	22.33^{k}	8.87^{jklmn}
G129	12.0^{kl}	7.33^{pq}	13.63^{n}	5.93^{o}
H139	10.87^{kl}	17.07^{fghijk}	16.33^{mn}	7.03^{mno}
C90	10.67^{kl}	15.67^{ghijkl}	16.33^{mn}	6.90^{no}
Ara_02	7.23^{l}	5.57^{q}	17.87^{lm}	8.47^{klmn}

Means with the same letters along the column are not significantly different using DMRT at p-value = 0.05 level of probability; different colours denote different species

3.2. Phenotypic traits association

Pearson correlations analysis on quantitative traits revealed a strong, highly positive association ($r = 0.69$, $p < 0.01$) between leaf length and leaf width and a moderate correlation ($r = 0.52$) between stem diameter and leaf length (Table 4). These relationships imply that selection for broader leaves may indirectly enhance leaf length and stem robustness, traits associated with vegetative vigor and photosynthetic capacity. Such positive associations are valuable in coffee breeding, as improvement in one trait can simultaneously enhance others due to shared genetic control or pleiotropy (Getachew, 2019: Adepoju *et al.*, 2020). Conversely, plant height showed weak and non-significant correlations with other traits, suggesting it can be improved independently of leaf and stem dimensions; a strategy exemplified by the dwarf and semi-dwarf varieties developed during the Green Revolution, which conferred lodging resistance and higher harvest index in dense plantings (Bhujbal *et al.*, 2025).

Similar patterns of inter-trait association have been observed in perennial crop improvement studies. Akpertey *et al.* (2020) reported significant genetic correlation between canopy architecture traits (such as number of laterals and span) and yield in *Coffea canephora*, indicating that early selection for structural traits can improve productivity. Likewise, Adepoju *et al.* (2020) also found strong positive correlation between yield and vegetative traits like leaf length, leaf width, and plant height in Nigerian *C. canephora* accessions. The findings from this study can serve as indirect selection indices for yield improvement and in reinforcing early-stage vegetative traits evaluation strategies breeding decisions for perennial crops like coffee.

Table 4 Pearson coefficient of quantitative traits correlation

	Stem Diameter	**Leaf Length**	**Leaf Width**
Plant Height	0.24^{ns}	0.27^{ns}	0.18^{ns}
Stem Diameter		0.52*	0.18^{ns}
Leaf Length			0.69**

Signif. codes: ** = Highly significant, * = Significant, ^{ns} = Not significant

3.3. Accessions classification based on the quantitative traits variations

The first three principal components PC1: 52.4%, PC2: 22.6% and PC3: 19.4% accounted for 94.4% of the total phenotypic variance observed in this study (Fig. 1). The main traits constituting this variance were 'leaf length', 'leaf width', and 'stem diameter' (Fig. 2). The plant height was moderately contributed to the variation observed (Fig. 2), from this analysis W102 which is an accession from a different *Coffea* species (*C. abeakutae*) was seen as the tallest coffee plant. The Arabica genotype (ara 02) has low height architecture while Stenophylla and Liberica accessions were seen to have similar pattern of height with those of *C. canephora* accessions (Fig. 2). The leaf length and stem diameter clearly differentiate the accessions of *C. canephora* , most of the accessions had low stem diameter and leaf length but accessions from farmers field (Landraces and M10) had higher leaf length and stem diameter (Fig. 2).

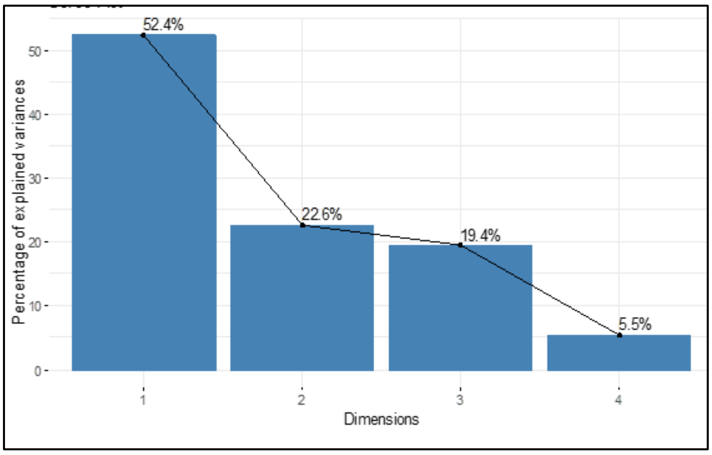

Figure 1 Scree plot of coffee accessions under study

Comparable PCA structures as seen here has proved vegetative traits like plant height, leaf length and stem diameter as primary discriminators for coffee germplasm characterization. These findings in corroboration to Tounekti *et al.* (2017) and Muvunyi *et al.* (2017) having similar observation in leaf and stem characters in explaining a substantial proportion of morphological variation.

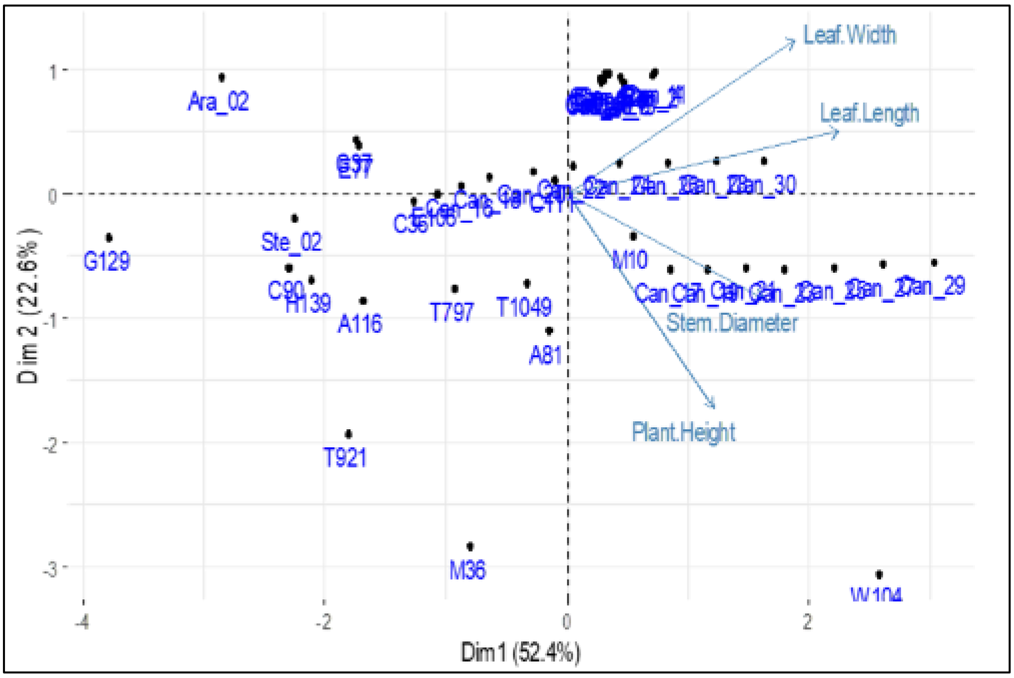

Figure 2 PCA biplot of the 48 accessions

3.4. Phylogenetic characterization of the 48 accessions

Hierarchical clustering based on quantitative traits resolved the 48 coffee accessions into three clusters (I, II and III) and a high divergent distinct outlier represented by accession W104 (Fig. 3). The outlier status of W104 (*C. abeokutea*) is consistent with its extreme values in the multivariate comparisons and its distant position in the PCA scatter, suggesting unique allelic combinations or a distinct adaptation history the warrant. Sub-cluster patterns showed partial grouping by geographic origin (e.g., Ekiti vs. Kogi), yet substantial intermixing with CRIN-derived materials occurred across clusters which is an evidence of historical germplasm exchange, farmer movement of planting material, or convergent selection under similar management pressures. Such mosaics of local adaptation and introduced diversity are common in smallholder perennial crop systems and when deliberatly captured in breeding populations, can generate useful recombination for trait improvement (Ngure and Watanabe, 2024; Andini *et al.*, 2025).

This clustering pattern (Fig. 3) aligns with Adepoju *et al.* (2023), who reported pronounced morphological divergence within CRIN coffee collections attributable to multiple introduction sources and subsequent selection pressures in farmers' fields and research nurseries. The agreement between studies underscores the need to sample across and not within phenotypic clusters when assembling parental panels for population improvement or association mapping in *Coffea* breeding. The diversity at the phenotypic (Fig. 3) and the genotypic (Fig 4) levels were found to be similar with only three diversity structure among *C. canephora* which is the major *Coffea* species with highest number of accessions conserved and cultivated in Nigeria.

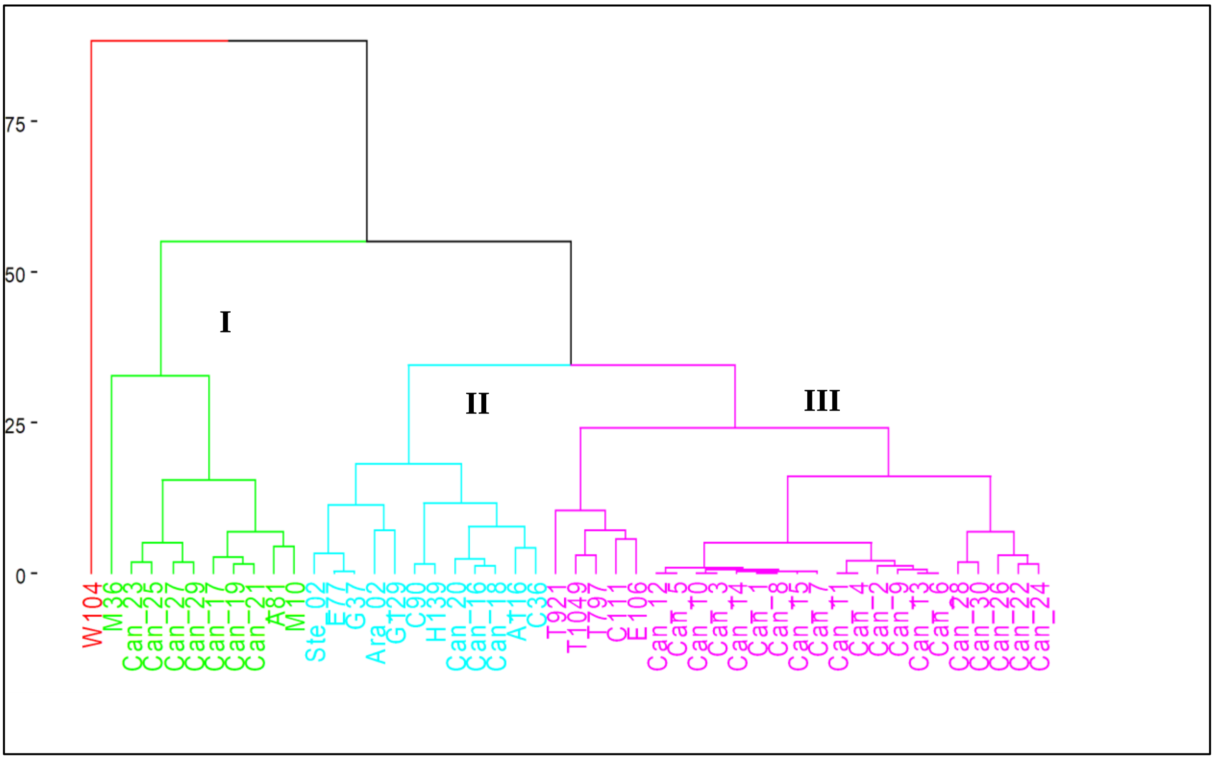

Figure 3 Quantitative traits characterization of *C. canephora* accessions in CRIN germplasm and landraces

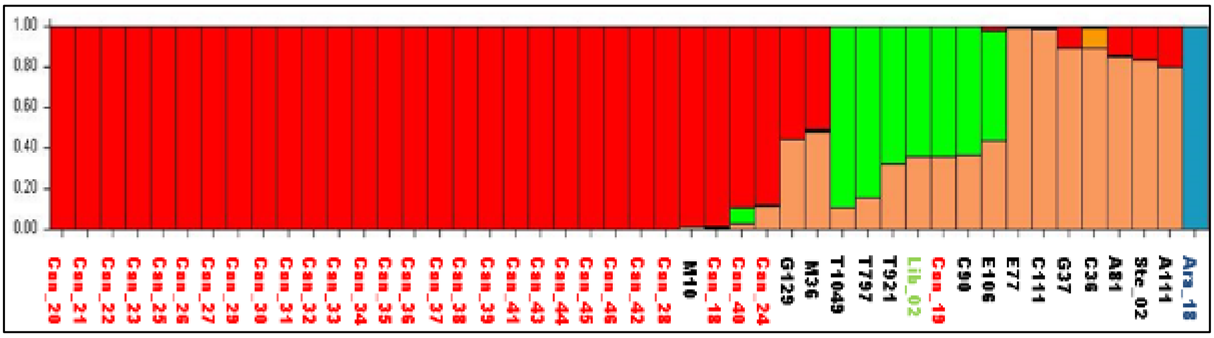

Figure 4 The SNP characterization of *C. canephora* accessions in CRIN germplasm and landraces (Anagbogu *et al.* 2019)

3.5. Characterization of the qualitative traits of 48 accessions

Variation in qualitative traits like berry colour, berry shape, leaf shape, plant habits and branching habits are useful in germplasm characterization (Degefa, 2021). In this study, morphological characters such as plant habit, branching habit, leaf, and berry colour and shape revealed distinct patterns that assisted in distinguishing accessions within the germplasm (Table 5).

Plant Habit. The *Coffea* species exhibited distinct differences in plant habit, a trait that aids in the classification and adaptability of species (Lahai *et al*., 2025). The bush-type growth habit was observed in Can_1 to Can_30 and Ara_02. In contrast, accessions such as C90, H139, and W104 displayed a tree-type growth habit also former genetic characterization by Anagbogu *et al.* (2019) confirmed that these accessions were related. Meanwhile, accessions like C111, C36, A116, A81, E106, E77, M10, M36, G129, G37, T1049, T921, T797, and Ste_02 exhibited an intermediate shrub or small tree form (Table 5), There is a high percentage of accessions with shrub characteristics indicating that this growth habit is common with majority of *Coffea* species.

Branching Habit: There was significant variation in branching patterns across the accessions studied. Very few primary branches were observed in C90, A81, Ara_02, H139, and W104. Conversely, most *C. canephora* landraces (Can_1 to Can_30),and accessions like E106, E77, M36, G129, G37, T921, T797, as well as *C. stenophylla* (Ste_02) exhibited many primary branches with few secondary branches, while accessions such as C111, C36, A116, M10, and T1049 demonstrated many primary and many secondary branches (Table 5). This characteristic of high yielding accessions, since accessions here with high number of both primary and secondary branches were *C. canephora*, and *C. canephora* has high yielding potential than other *Coffea* species (Adepoju *et al*. 2020).

Young leaf colour: Young leaf colour was a visible and variable trait among the accessions, potentially influenced by pigment concentration notably anthocyanins and chlorophylls (Cadot *et al*., 2020). Brownish young leaves were the most prevalent among the landraces and and some of the conserved accessions (A116, C36, M10, and M36). Greenish hues were observed in C90, C111, A81, E106, E77, T1049, T921, T797, and H139, indicating moderate pigment expression typical of intermediate or hybrid forms. A clear green colouration was found in Ste_02, Ara_02, and W104. Reddish-brown pigmentation was seen in G129 and G37 which is the least prevalent young leaf colour among the accessions (Table 5).

Leaf Shape*:* Elliptic leaf shape was the most widespread among accessions, encompassing all Can_1 to Can_30 as well as C111, C36, A116, A81, E106, E77, M10, M36. G129, G37, T921 and W104. In contrast, lanceolate leaves were found in C90, Ste_02, Ara_02, and H139. Accessions such as T1049 (obovate) and T797 (ovate) have unique leaf shapes, thereby exhibiting morphologically distinct characteristic. Regarding leaf apex shape, the apiculate form dominated the 48 coffee accessions and was found in all Can_1 to Can_30 as well as C111, C36, A116, A81, E106, E77, M10, M36 and T1049, while acuminate apices were common in C90, G129, G37, T921, Ste_02, Ara_02, and H139 The acute apex observed in T797 and W104 (Table 5).

Mature Leaf Colour: Variation in mature leaf colour was another distinguishing feature. Greenish mature leaves were commonly observed in Can_1 to Can_30, A81, A116, E106, E77, M10, M36, G129, and G37. Green mature leaves, on the other hand, were recorded in C90, C111, C36, T1049, T921, T797, Ste_02, Ara_02, H139, and W104 (Table 5).

Berry Shape: Berry shape varied across accessions and was closely linked with species and cultivar identity. Obovate berries were typical of Can_1 to Can_15. Roundish berry shape was observed in Can_16 to Can_30, and in several others like C90, C111, C36, A81, A116, E106, E77, M10, M36, G37, T1049, T921, T797, Ste_02, H139 and W104, which was the most prevalent among the accessions (Table 5). Interestingly, G129 and Ara_02 had oblong berries, a less common form which may signal unique developmental genetics.

Berry Colour*.* Berry colour provided striking differences among the accessions. Orange-red berries were observed in Can_1 to Can_15, G37, and T797 Red berries, the standard commercial colour was the most prevalent among the accessions. Red berries were recorded in Can_16 to Can_30, A81, A116, T921, Ara_02, and W104. Red-purple and purple berries were seen in C90, C111, C36, M36, T1049, Ste_02, H139, E106, E77, M10, and G129 (Table 5).

Qualitative descriptor scoring revealed non-uniform frequency distribution among trait classes (Fig. 5). Elliptic leaf shape dominated the collection (87.5%), while an apiculate leaf apex was recorded in 81.25% of accessions. Similarly, roundish berry shape was the most prevalent form (64.58%) (Fig.4). Berry color exhibited broader segregation, although red (41.67%) and orange-red (35.42%) together represented over three-quarters of the accessions, suggesting historical preference or selective retention for market-preferred fruit types. The predominance of bushy plant habit and brownish young leaf coloration indicates adaptive syndromes common under Nigerian low- to mid-elevation growing environments.

While the stability of certain descriptors supports their use for rapid field identification, the high frequency of some states (e.g., elliptic leaves) limits their discriminatory power, reinforcing the need to complement qualitative scoring with quantitative and molecular markers in germplasm characterization. The consistency of certain qualitative traits across accessions observed in this study aligns with findings by Yirga (2021), who reported significant genetic variability in *Coffea arabica* germplasm based on descriptors such as leaf tip color, stipule shape, and fruit color. These parallels underscore the enduring relevance of morphological descriptors, particularly when integrated with molecular markers, for coffee diversity assessment and breeding program design.

The Multiple Correspondence Analysis (MCA) biplot (Fig. 6) revealed clear structure in the qualitative trait space. Farmer-derived accessions Can_1–30 formed a compact cluster characterized by bushy growth, elliptic leaves, greenish mature foliage, and orange-red berry colour, indicating phenotypic homogeneity for the IPGRI coffee descriptors used here. In contrast, C90, H139, and W104 separated on the opposite side of Dimension 1 and aligned with tree habit, lanceolate leaves, and very few primary branches, consistent with a distinct architectural ideotype. Notable outliers included G129 and G37, associated with reddish-brown young leaves and purple berries, and T1049, distinguished by obovate leaf shape; these accessions carry rare category levels that strongly contribute to discrimination in MCA space.

These patterns agree with reports that a small number of qualitative descriptors (growth habit, leaf form/apex, berry colour/shape) are highly informative for structuring coffee germplasm and for rapid field discrimination (IPGRI, 1996; Akpertey *et al*., 2022). The bushy/elliptic/orange-red complex dominating the Can_ group echoes findings that many farmer or landrace materials share compact stature and common fruit/leaf categories, while taller, tree-habit accessions with lanceolate leaves are morphologically distinct and often appear as separate groups in germplasm panels (Paredes-Espinosa *et al*., 2023). Recent agro-morphological surveys of coffee collections also reported clustering by architecture and fruit traits, reinforcing the utility of these descriptors for preliminary grouping prior to quantitative evaluation (Ndikumana, 2022).

From a breeding standpoint, the biplot suggests two major morphological groups; a "bushy/elliptic" cluster and a "tree/lanceolate/sparse-branching" cluster plus rare-trait outliers. Outliers such as G129/G37 (purple berries, reddish-brown young leaves) and T1049 (obovate leaf) are promising donors of unique alleles and should be prioritized for conservation and targeted crossing to broaden trait diversity. This complements molecular evidence that *C. canephora* diversity is structured and that tapping divergent sources improves the effective gene pool (Vanden Abeele *et al*., 2021).

Comparable findings were reported from southern Ethiopian coffee germplasm, where 104 accessions were evaluated using 13 qualitative traits. Substantial variability was observed, with the highest diversity index for growth habit, leaf shape, leaf apex, and fruit colour, traits that also strongly contributed to clustering in the MCA biplot. The accessions were grouped into five distinct clusters, highlighting the potential of divergent parents for generating hybrid vigor (Degefa, 2021). Together, these results underscore that growth habit, leaf morphology, and fruit descriptors are consistently the most discriminatory traits across *Coffea arabica* germplasm, reinforcing their value for both conservation and breeding programs.

Table 5 Differentiation of accessions based on qualitative traits

Trait	**Accessions**
Plant Habit	
Bush	Can_1 to Can_30, Ara_02
Shrub or Small Tree	C111, C36, A116, A81, E106, E77, M10, M36, G129, G37, T1049, T921, T797, Ste_02
Tree	C90, H139, W104
Branching habit	
Very Few Primary Branches	C90, A81, Ara_02, H139, W104
Many Primary with Few Secondary Branches	Can_1 to Can_30, E106, E77, M36, G129, G37, T921, T797, Ste_02
Many Primary with Many Secondary Branches	C111, C36, A116, M10, T1049
Young Leaf Colour	
Brownish	Can_1 to Can_30, A116, C36, M36, M10
Greenish	C90, C111, A81, E106, E77, T1049, T921, T797, H139
Green	Ste_02, Ara_02, W104
Reddish brown	G129, G37
Leaf Shape	
Elliptic	Can_1 to Can_30, C36, C111, A81, A116, E106, E77, M10, M36, G129, G37, T921, W104
Lanceolate	C90, Ste_02, Ara_02, H139
Obovate	T1049
Ovate	T797
Leaf Apex Shape	

Apiculate	Can_1 to Can_30, C111, C36, A81, A116, E106, E77, M10, M36, T1049
Acuminate	C90, G129, G37, T921, Ste_02, Ara_02, H139
Acute	T797, W104
Mature Leaf Colour	
Greenish	Can_1 to Can_30, A81, A116, E106, E77, M10, M36, G129, G37
Green	C90, C111, C36, T1049, T921, T797, Ste_02, Ara_02, H139, W104
Berry Shape	
Obovate	Can_1 to Can_15
Roundish	Can_16 to Can_30, C90, C111, C36, A81, A116, E106, E77, M10, M36, G37, T1049, T921, T797, Ste_02, H139, W104
Oblong	G129, Ara_02
Berry Colour	
Orange-Red	Can_1 to Can_15, G37, T797
Red	Can_16 to Can_30, A81, A116, T921, Ara_02, W104
Red-purple	C90, C111, C36, M36, T1049, Ste_02, H139
Purple	E106, E77, M10, G129

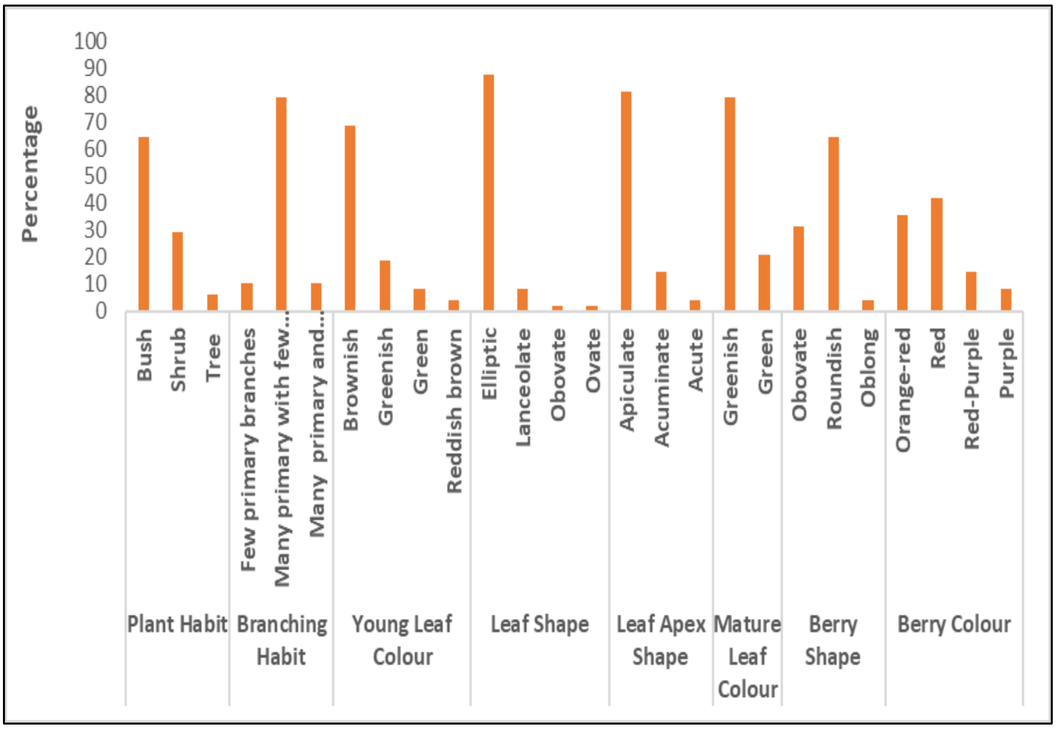

Figure 5 Frequency distribution of qualitative trait in coffee accessions

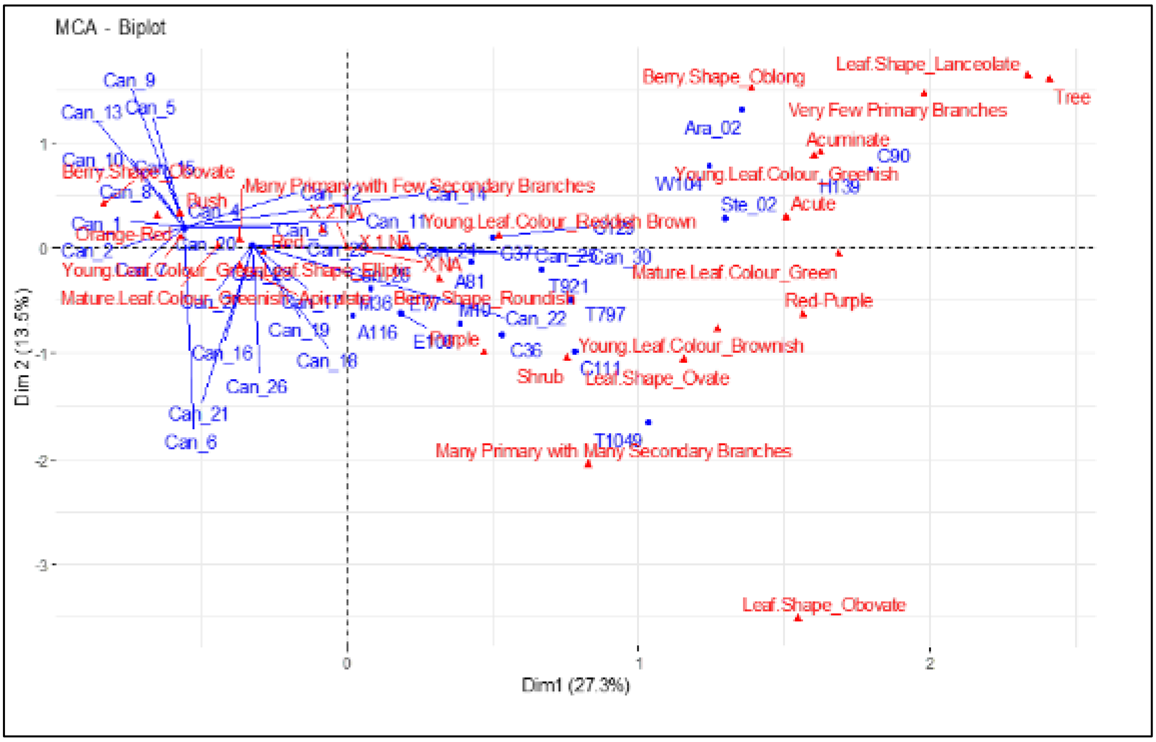

Figure 6 Multiple Correspondence Analysis Biplot of qualitative traits in 48 coffee accessions

3.6. Breeding and Conservation Implications

Taken together, the strong quantitative differentiation, informative trait correlations, and clear multivariate structure indicate that the Nigerian coffee materials evaluated harbor exploitable diversity for plant stature, canopy architecture, and reproductive features. Accessions at phenotypic extremes like W104; tall vs. compact forms; large-leaf vs. narrow-leaf characters can anchor parental pools for generating segregating populations aimed at ideotype refinement. Moderate correlations among key vegetative traits permit tandem selection where vigor is desired, while the weak association of plant height with leaf and stem traits makes it feasible to develop shorter, high-leaf-area cultivars for intensification. The clustering pattern further suggests that targeted sampling across the three major phenotypic groups rather than within-cluster redundancy will maximize allelic capture for pre-breeding.

These findings are essential for the effective conservation and genetic improvement of coffee species. The study demonstrated substantial morphological diversity among Nigerian coffee accessions, highlighting the importance of phenotypic characterization for germplasm conservation, classification, and trait-based selection. Cluster analysis of the quantitative traits grouped the accessions into three distinct clusters and one outlier, indicating the presence of phenotypic diversity among the evaluated germplasm. Stem diameter, leaf dimensions, and plant architecture were critical traits for differentiating accessions, suggesting a useful genetic base that can be exploited in breeding programs. Multivariate analyses revealed clear grouping patterns and identified promising genotypes as potential parental lines, while trait associations suggest synergistic relationships that can inform ideotype development.

4. Conclusion

Moderate phenotypic diversity was observed among Nigerian coffee accessions, with quantitative traits grouping the accessions into three phenotypic clusters and one outlier. These findings highlight the importance of morphological characterization for germplasm conservation, classification, and trait-based selection. Despite the observed variation, the results underscore the need to broaden the genetic base of *Coffea canephora* to strengthen breeding and improvement programs in Nigeria. Furthermore, the high variability in qualitative traits suggests that further molecular-level investigations are needed to elucidate their genetic basis and potential applications in coffee improvement.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed

References

[1] Abafita, J. and Tadese, T. 2021. Determinants of global coffee trade: Do RTAs matter? Gravity Model Analysis. *Cogent Economics and Finance* 9, 1.

[2] Adepoju, A. F., Sobowale, I. O., and Adenuga, O. O. 2023. Genetic Diversity of Coffee Genotypes Using Simple Sequence Repeat (SSR) Markers. *European Journal of Medicinal Plants* 34,8:14-20

[3] Adepoju, A. F., Adenuga, O. O., Dada, K. E., Odey, C. F., Balogun, S. T., & BabaNitsa, M. (2020). Association and interrelationship of yield and agronomic characters in coffee (*Coffea* sp L). *Journal of Plant Breeding and Crop Science*, *12*(4), 299-309.

[4] Akpertey, A., Anim-Kwapong, E., Adu-Gyamfi, P. K. K., & Ofori, A. (2022). Genetic variability for vigor and yield of robusta coffee (*Coffea canephora*) clones in Ghana. *Heliyon*, *8*(8).

[5] Andini, R., Zaelani, A., Sulaiman, M.I., Sembiring, E.R., Jaya, R., Gusain, M., Bhanot, D., Morghade, R.S., Gaafar, A.R.Z., Azis, A. and Widayat, H.P., 2025. Genetic diversity of cultivated Gayo Arabica Coffee (*Coffea arabica* L.) based on morphological and microsatellite markers. *BMC Plant Biology*, *25*(1), p.990.

[6] Baba Nitsa, M. B., Odiyi, A. C., Akinyele, B. O., Aiyelari, O. P., Dada, K. E., Fayeun, L. S., Anagbogu, C. F., Idrisu, M., and Ugioro, O. 2020. Phenotypic Diversity Studies of Coffee (*Coffea arabica* Pierre ex. Froehn) Landrace Accessions and an Accession from Germplasm Using Morphological Markers. *International Journal of Plant Breeding and Genetics* 7, 10: 1–7.

[7] Bhandari, H. R., Bhanu, A. N., Srivastava, K., Singh, M. N., and Shreya, H. A. 2017. Assessment of Genetic Diversity in Crop Plants—An Overview. *Advances in Plants and Agriculture Research* 7, 3: 279–286.

[8] Bhujbal, S.K., Rai, A.N. and Joshi-Saha, A. 2025. Dwarfs standing tall: breeding towards the 'Yellow revolution' through insights into plant height regulation. *Plant Mol Biol* **115**, 34. https://doi.org/10.1007/s11103-025-01565-x

[9] Degefa, M., 2021. Phenotypic Classification of Coffee (*Coffea arabica* L.) Germplasm in Southern Ethiopia. *American Journal of Agriculture and Forestry*, *9*(6), pp.358-365.

[10] Getachew W (2019). Character Association and Path Coefficient Analysis for Yield and Its Related Traits in Ethiopian Coffee (*Coffea arabica* L.) accessions. International Journal of Research Studies in Agricultural Sciences 5(3):19-29.

[11] Gokavi, N., P. M. Gangadharappa, D. Satish, S. Nishani, J. S. Hiremath, and S. Koulagi. 2023. Phenotypic and Genotypic Variability among Exotic Arabica Coffee Genotypes Using Morphological and Molecular Markers (SRAP)." *Ecological Genetics and Genomics* 29:100214.

[12] International Plant Genetic Resources Institute. (1996). *Descriptors for Coffee (Coffea spp. and Psilanthus spp.)*. Bioversity International.

[13] Lahai, P. M., Aikpokpodion, P. O., Bah, A. M., Lahai, M. T., Lim, S., Ahn, E., & Park, S. (2025). Genetic basis of phenotypic diversity in *Coffea stenophylla*: a stepping stone for climate-adapted coffee cultivar development. *Frontiers in Genetics*, 16. https://doi.org/10.3389/fgene.2025.1554029

[14] Muvunyi, B., P. Sallah, L. Dusengemungu, and J. Zhang. 2017. Assessment of Genetic Diversity of Coffee Accessions in Rwanda and Its Implication for Coffee Breeding. *American Journal of Plant Sciences* 8:2461–2473.

[15] Ndikumana, J., 2022. *Agro-morphological characterization of Arabica coffee cultivars in Burundi* (Doctoral dissertation, JKUAT-CoANRE).

[16] Ngure, G.M. and Watanabe, K.N., 2024. Coffee sustainability: leveraging collaborative breeding for variety improvement. *Frontiers in Sustainable Food Systems*, *8*, p.1431849.

[17] Paredes-Espinosa, R., Gutiérrez-Reynoso, D. L., Atoche-Garay, D., Mansilla-Córdova, P. J., Abad-Romaní, Y., Girón-Aguilar, C., Flores-Torres, I., Montañez-Artica, A. G., Arbizu, C. I., Guerra, C. A. and Quintana, J. L. M. 2023. Agro-

morphological characterization and diversity analysis of *Coffea arabica* germplasm collection from INIA, Peru. *Crop science*, *63*(5), pp.2877-2893.

[18] Swarup, S., E. J. Cargill, K. Crosby, L. Flagel, J. Kniskern, and K. C. Glenn. 2021. Genetic Diversity Is Indispensable for Plant Breeding to Improve Crops. *Crop Science* 61, 2:839–852.

[19] Tounekti, T., M. Mahdhi, T. Al-Turki, and H. Khemira. 2017. Genetic Diversity Analysis of Coffee (*Coffea arabica* L.) Germplasm Accessions Growing in the Southwestern Saudi Arabia Using Quantitative Traits." *Natural Resources* 8:321–336.

[20] Vanden Abeele, S., Janssens, S.B., Asimonyio Anio, J., Bawin, Y., Depecker, J., Kambale, B., Mwanga Mwanga, I., Ebele, T., Ntore, S., Stoffelen, P. and Vandelook, F., 2021. Genetic diversity of wild and cultivated *Coffea canephora* in northeastern DR Congo and the implications for conservation. *American Journal of Botany*, *108*(12), pp.2425-2434.

[21] Yirga, M. 2021. Phenotypic Characterization of Coffee (*Coffea arabica* L.) Germplasm in Ethiopia." *American Journal of BioScience* 9, 2:34–41.

[22] Zamir D (2014) A wake-up call with coffee. Science 345(6201):1124–1124. https://doi.org/10.1126/science.1258941