Morpho-Diversity Assessment of Coffea canephora Accessions in Nigeria: Trait-Based Characterization for Genetic Improvement

Olaitan P. Babatunde
babatundepaul55@gmail.com

Cocoa Research Institute of Nigeria

Oyeyemi A. Dada
University of Ibadan

Chinyere F. Anagbogu
Cocoa Research Institute of Nigeria

Mohammed Baba Nitsa
University of Abuja

Ibrahim O. Sobowale
Cocoa Research Institute of Nigeria

Morufat O. Balogun
University of Ibadan

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Abstract

Background

Coffea species (Coffee) is one of the most economically important agricultural commodities universally. In Nigeria, *Coffea canephora* is the dominant species, accounting for about 95% of coffee exports, yet its morphological diversity remains poorly documented. Understanding phenotypic variability is vital to developing novel breeding programmes for crop improvement. This study therefore assessed the morpho-diversity of *C. canephora* accessions collected from three agroecological zones in Nigeria.

Results

Forty-three accessions of *C. canephora* comprising six canephora classes: Gold Coast, Java Robusta, Java ex-Gamba, Kouillou, Niaouli, and Uganda Robusta were characterised, using thirteen morphological traits (four quantitative and nine qualitative) following International Plant Genetic Resources Institute descriptors. Plant height ranged from 10.84 cm to 47.89 cm, while leaf width varied from 5.93 cm to 13.20 cm. Leaf length and leaf width were strongly correlated ($r = 0.617$, $p < 0.001$). The first four principal components explained 100% of total variance, with plant height contributing 65% and leaf length 21%. Cluster analysis grouped the accessions into three distinct classes, with 40 accessions expressing broad genetic variation, one genetically distinct accession, and two closely related accessions separating from the main population. Qualitative traits revealed meaningful variation in plant habit, branching pattern, leaf shape, and berry characteristics.

Conclusions

Substantial morphological diversity exists among *C. canephora* accessions in Nigeria, with plant height and leaf length identified as the principal phenotypic traits for discriminating accessions. These findings provide a foundational trait-based framework for selecting superior accessions and designing targeted genetic improvement programmes for Nigerian robusta coffee.

INTRODUCTION

Coffe (*Coffea* species) is one of the most valued agricultural commodities globally, that plays a vital role in shaping economies and cultural values across diverse regions. Coffee was introduced to Nigeria in the early 20th century, though historical evidence suggests production and trade may have predated formal documentation. Initially, efforts by the Federal Department of Agriculture (FDA) focused on indigenous species like *Coffea liberica* and *Coffea abeokutae* [1, 2]. Within the *Coffea* genus, over 130 species have been documented, but only two: *Coffea arabica* (Arabica) and *Coffea canephora* (Robusta) [3] hold substantial economic significance. While *C. arabica* is renowned for its mild flavor, *C. canephora* is distinguished by its robustness, particularly its resistance to environmental stressors, making it wellsuited for cultivation in diverse conditions [2]. In Nigeria, *C. canephora* dominates coffee production zones due to its adaptability to local climates, contributing significantly to rural livelihoods and the agricultural economy.

However, as global demand grew, *C. canephora* became the predominant species, accounting for approximately 95% of Nigeria's coffee exports, with *C. arabica* making up the remaining 5% [4]. This transition established Nigeria as a significant producer of Robusta coffee, supporting rural economies. Regardless of its economic benefits, the coffee industry has faced significant challenges, including global price volatility, and environmental constraints, leading to fluctuations in production [5]. Globally, coffee is cultivated in over 80 countries, with more than 50 nations exporting substantial quantities, particularly from Africa, Asia, and Central and South America [5]. As the second most consumed beverage worldwide after water, with an estimated 3.5 million cups consumed daily [6], the global coffee industry generates over US$10 billion annually, providing livelihoods for millions, particularly rural smallholder farmers [7]. In the East and Central Africa, coffee farming plays a prominent role in alleviating rural poverty and driving economic growth [8].

Currently, *Coffea canephora* is cultivated across 14 states in Nigeria, spanning over 5,000 hectares. The major production regions include the lowland areas of Ogun, Ondo, Osun, and Edo states, where warm temperatures and high humidity provide optimal growing conditions for the species [2]. In contrast, *C. arabica* is primarily cultivated in the cooler, high-altitude regions of Taraba and Plateau states, highlighting ecological differentiation between the two species. The resilience of *C. canephora* to pests and diseases has enabled it to thrive in Nigeria's southern regions, making it a reliable and economically viable crop [2]. However, in the last five decades, coffee production in Nigeria has significantly nosedived by 72.1% in spite of its economic potential, [9]. Factors such as population growth, urbanization, and limited access to quality planting materials have exacerbated this decline.

The rising global demand for coffee presents an opportunity for Nigeria to revitalize its coffee industry, increasing foreign exchange earnings and promote rural employment. In recent years, there has been a growing recognition of coffee's economic and health benefits. For instance, the antioxidant properties of coffee have been associated with reduced risks of neurodegenerative diseases and enhanced cognitive function, further highlighting its broader societal value [10]. Unfortunately, there is high level of inconsistency in the characterization of numerous coffee species in Nigeria. Appropriate phenotypic and genotypic characterization of any plant germplasm are fundamental to optimizing its potentials and further its improvement.

Phenotypic characterization of *Coffea canephora* plays a crucial role in understanding its genetic diversity and adaptability, serving as a foundation for breeding and genetic improvement programs. Morphological traits, such as canopy structure, leaf size, branching pattern, and fruit characteristics, are cost-effective tools for germplasm evaluation and the identification of elite genotypes [11, 12]. Studies on vegetative traits, including shoot height, number of branches, and leaf area, provide insights into the ecological adaptation and productivity potential of individual genotypes, aiding in the selection of high-performing varieties [13].

The morphological diversity observed in *Coffea canephora* offers breeders valuable resources for selecting traits such as yield potential, pest resistance, and environmental tolerance [14]. For example, variations in stem circumference, branch number, and leaf size can serve as selection indices for growth vigor and productivity. Effective management of coffee germplasm allows for the development of cultivars tailored to diverse tropical agroecological zones, ensuring sustainable improvement and consistent yield performance across varying conditions [15]. It becomes necessary to characterize the different accessions of *C. canephora* and identify certain unique morphological traits as a marker for further coffee breeding program.

This study, therefore, aimed at assessing the phenotypic diversity of *Coffea canephora* accessions in the tropical rainforest region of Nigeria using trait-based analysis. The specific objectives were to (i) characterize the morphological traits of selected accessions, and (ii) provide insights into the utilization of phenotypic markers for coffee improvement in Nigeria.

MATERIALS AND METHODS

Plant Materials

The study was conducted across three major coffee-growing regions in Nigeria comprisng Cocoa Research Institute of Nigeria (CRIN) germplasm repository in Ibadan, Oyo State; the CRIN Ajassor substation in Cross River State; and farmers' fields in Kogi and Ekiti States, which are prominent coffee-producing regions. These locations were selected to capture the geographic and genetic diversity of *Coffea canephora* in Nigeria. A total of 43 *Coffea canephora* accessions were used for this study. The accessions and their classifications are presented in Table 1.

Thirty-five accessions were sampled from the CRIN Ibadan germplasm repository (7°12′ N, 3°51′ E, 122 m asl.) using a stratified purposive sampling approach. This method ensured representation across six distinct *Coffea canephora* classes: Gold Coast, Java Robusta, Java ex-Gamba, Kouilou, Niaouli, and Uganda Robusta. The accessions were selected based on their availability within these classes, with 2 to 6 samples allocated proportionally to the distribution of available accessions to ensure comprehensive coverage.

Three accessions were purposively sampled from the CRIN Ajassor substation in Cross River State (5°52′ N, 8°48′ E, 493 m asl) to represent the geographic diversity of the CRIN collections. The Ajassor substation is a significant repository for coffee germplasm with specific regional traits.

Also, five accessions were randomly sampled from farmers' fields in coffee-producing regions: three samples from Kogi State (7°47′ N, 5°48′ E, 493 m asl) and two from Ekiti State (7°46′ N, 5°33′ E, 460 m asl) as shown in Fig. 1. Random sampling was employed to ensure an unbiased representation of farmer-maintained *Coffea canephora* accessions. This approach aligns with the findings of Anagbogu *et al.* (2019), which documented the homogeneity among farmer-maintained accessions in these regions.

Table 1
List of the accession of *Coffea canephora* assessed

1	**Accessions**	**Location**	**Class**
	A81	**CRIN Ibadan**	**Gold Coast**
2	A116	CRIN Ibadan	Gold Coast
3	E1	CRIN Ibadan	Java Robusta
4	E92	CRIN Ibadan	Java Robusta
5	E106a	CRIN Ibadan	Java Robusta
6	E106b	CRIN Ibadan	Java Robusta
7	E130	CRIN Ibadan	Java Robusta
8	T24	CRIN Ibadan	Java ex-Gamba
9	T45	CRIN Ibadan	Java ex-Gamba
10	T116	CRIN Ibadan	Java ex-Gamba
11	T164	CRIN Ibadan	Java ex-Gamba
12	T169	CRIN Ibadan	Java ex-Gamba
13	T188	CRIN Ibadan	Java ex-Gamba
14	T204	CRIN Ibadan	Java ex-Gamba
15	T444	CRIN Ibadan	Java ex-Gamba
16	T797	CRIN Ibadan	Java ex-Gamba
17	T921a	CRIN Ibadan	Java ex-Gamba
18	T921b	CRIN Ibadan	Java ex-Gamba
19	T1049	CRIN Ibadan	Java ex-Gamba
20	C36	CRIN Ibadan	Kouillou
21	C90	CRIN Ibadan	Kouillou
22	C96	CRIN Ibadan	Kouillou
23	C105	CRIN Ibadan	Kouillou
24	C107	CRIN Ibadan	Kouillou
25	C108	CRIN Ibadan	Kouillou
26	C111	CRIN Ibadan	Kouillou
27	M10a	CRIN Ibadan	Niaouli

1	Accessions	Location	Class
	A81	**CRIN Ibadan**	**Gold Coast**
28	M10b	CRIN Ibadan	Niaouli
29	M31	CRIN Ibadan	Niaouli
30	M36	CRIN Ibadan	Niaouli
31	M53	CRIN Ibadan	Niaouli
32	Togolese	CRIN Ibadan	Java Robusta
33	G37	CRIN Ibadan	Uganda Robusta
34	G87	CRIN Ibadan	Uganda Robusta
35	G129	CRIN Ibadan	Uganda Robusta
36	Okondi	CRIN Ajassor substation	Java Robusta
37	Station Gate	CRIN Ajassor substation	Java ex-Gamba
38	Camp II	CRIN Ajassor substation	Java ex-Gamba
39	Iyamoye – 1	Farmers' field (Ekiti)	Java ex-Gamba
40	Iyamoye – 5	Farmers' field (Ekiti)	Java ex-Gamba
41	Omou- 2	Farmers' field (Kogi)	Java ex-Gamba
42	Oranre-1	Farmers' field (Kogi)	Java ex-Gamba
43	Oranre-2	Farmers' field (Kogi)	Java ex-Gamba

Data Collection and Statistical Analysis

Morphological and phenotypic traits were collected following the International Plant Genetic Resources Institute [16] descriptors for coffee as shown in Table 2, focusing on key vegetative, leaf, and berry characteristics. Plant height from the soil level to the first branching, was measured in centimeters, while stem diameter, also in centimeters, was taken at 15 cm above ground using an electronic caliper. Branching habit and density were assessed visually, along with young leaf color, indicating the color of emerging leaves, and leaf shape, which was noted by general outline (e.g., ovate, elliptic). Leaf apex shape was also visually assessed, providing insights into the tip's contour, while leaf length and width were measured with a ruler in centimeters from base to tip and at the broadest point, respectively. Colour of young shoot was visually observed and characterized, whereas mature leaf color described the fully developed leaves. Berry traits included berry shape and berry colour were assessed by visual examination as described by IPGRI (1996). Both represent key indicators of phenotypic diversity.

Table 2
Description of method and instrument used for morphological data collection according to IPGRI (1996)

1	Character	Description	Data type	Instrument
	Plant height (cm)	**Ground to the first branching**	**Quantitative**	**Measuring tape**
2	Stem diameter (cm)	Ground base	Quantitative	Electronic caliper/Measuring tape
3	Plant habit	a. Tree b. Shrub	Qualitative	Visual
4	Branching habit	Type and density of branches	Qualitative	Visual
5	Young leaf colour	Colour of young leaves	Qualitative	Visual
6	Leaf shape	General shape (e.g., ovate, Elliptic, obovate, Lanceolate)	Qualitative	Visual
7	Leaf apex shape	The Shape of the leaf tip (Round, Obtuse, Acute, Acuminate, Apiculate, Spatulate)	Qualitative	Visual
8	Leaf length (cm)	Length of the leaf from base to tip	Quantitative	Ruler
9	Leaf width (cm)	Width of the leaf at the widest point	Quantitative	Ruler
10	Young shoot colour	Colour of young shoots	Qualitative	Visual
11	Mature leaf colour	Colour of fully developed leaves	Qualitative	Visual
12	Berry shape	Shape of the berries (Roundish, Obovate, Ovate, Elliptic, Oblong)	Qualitative	Visual
13	Berry colour	Colour of berries (Yellow, Purple, Yellow-orange, Purple-violet, Orange, Violet, Orange-red, Black)	Qualitative	Visual

Statistical Analysis

Data were analyzed using R version 4.6.0 [17]. Pearson correlation coefficients were computed to assess relationships among quantitative morphological traits. Analysis of variance (ANOVA) was used to test for significant differences among accessions, and means were separated using Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$. Descriptive statistics were used to summarize variation in qualitative traits. Principal Component Analysis (PCA) was applied to determine the traits contributing most to phenotypic variation among accessions. For cluster analysis, the Gower distance metric was used to accommodate both quantitative and qualitative traits simultaneously. This makes it more appropriate than Euclidean distance-based methods, which handle only quantitative data. The Gower distance matrix was computed using the *cluster* package in R, and hierarchical clustering was performed using the Unweighted Pair-Group Method with Arithmetic Mean (UPGMA). The resulting dendrogram was used to identify distinct morphological groups among the accessions.

RESULTS

Pearson correlation coefficients among the four quantitative morphological traits measured in the 43 *C. canephora* accessions is presented in Table 3. Plant height showed a weak but significant positive correlation with stem diameter ($r = 0.189$, $p < 0.05$), suggesting that taller plants tend to have slightly thicker stems. Stem diameter was also positively and significantly correlated with leaf length ($r = 0.232$, $p < 0.01$), indicating that accessions with broader stems tend to produce longer leaves. The strongest correlation was between leaf length and leaf width ($r = 0.617$, $p < 0.001$), showing that as leaf length increases, leaf width increases proportionally. Stem diameter showed a weak positive correlation with leaf width ($r = 0.181$, $p < 0.05$). The correlation between plant height and leaf length ($r = 0.050$) and between plant height and leaf width ($r = 0.050$) were both non-significant, suggesting that taller plants do not necessarily produce larger leaves.

Table 3
Pearson correlation coefficients among quantitative morphological traits of *C. canephora* accessions

Variable	Stem diameter	Leaf length	Leaf width
Plant height	0.18856*	0.05009ns	0.04987ns
Stem diameter	-	0.23175**	0.18147*
Leaf length		-	0.61668***
Leaf width			-
*, **, *** significant p < 0.05; p < 0.01and p < 0.001, respectively; ns = not significant			

Significant ($p < 0.05$) differences were observed among the accessions for all traits as shown in Table 4. Accession M36 was tallest (47.89 cm), followed by Togolese (36.41 cm), while C90 was the shortest accession (10.84 cm) but not significantly ($p > 0.05$) taller than accession G129 (12.21 cm). Accession T24 had the largest stem diameter (22.67 mm), which was not significantly wider than Togolese and Iyamoye-5. Also, G129 had the smallest stem diameter (7.40 mm), but not significantly smaller than G87 (8.74 mm). Okondi produced the longest leaves (27.67 cm), which was statistically similar to M10a, M10b, E130, and Oranre-1 but significantly longer than G129, E1, C90 and T188, Omou-2 had significantly wider leaves than other accessions with narrowest leave observed in M36. These results highlight the wide range of morphological variation present among the accessions, providing valuable diversity for breeding programs.

Distribution of qualitative traits across the 43 *Coffea canephora* accessions is presented in Fig. 2. The majority of accessions (81.4%) were classified as shrubs or small trees, with 16.3% as bushes and only 2.3% as trees. In terms of branching habit, 64.7% of the accessions had many primary branches with few secondary branches, while 35.3% showed a robust branching pattern with many primary and secondary branches. All the 43 accessions recorded green young shoot colour, indicating complete uniformity for this character across the entire collection (Fig. 2). Young leaf colour varied, with greenish leaves being the most common (58.1%), followed by brownish (27.9%) and reddish-brown (9.3%). Elliptic leaf shape was predominant (53.5%), and apiculate leaf apex was the most frequent apex type (60.5%). Mature leaf colour was nearly evenly distributed between green (53.5%) and greenish (46.5%). Roundish berry shape dominated (81.4%), and berry colour showed the most variability among qualitative traits, with orange-red (30.2%) and red-purple (25.6%) being the most frequent categories.

Table 4
Variations in morphological traits of different *Coffea canephora* accessions

Accessions	Plant height	Stem diameter	Leaf length	Leaf width
M36	47.89^{a}	15.96^{e-h}	17.50^{de}	6.067^{x}
TOGOLESE	36.41^{b}	21.54^{ba}	23.17^{a-e}	11.167^{e}
M53	26.77^{bc}	18.97^{a-f}	18.17^{cde}	8.160^{r}
T24	25.17^{bcd}	22.67^{a}	22.27^{b-e}	8.067^{r}
T1049	25.15^{bcd}	18.25^{a-g}	18.80^{cde}	10.67^{i}
E130	24.28^{bcd}	20.22^{bdac}	25.77^{ab}	10.90^{h}
IYAMOYE 5	24.11^{b-e}	21.46^{ba}	23.67^{a-e}	10.967^{g}
T188	24.10^{b-e}	18.14^{a-g}	15.03^{e}	11.60^{d}
T921a	23.88^{b-e}	19.94^{a-dac}	14.30^{e}	6.80^{v}
A81	23.84^{b-e}	19.92^{a-c}	22.33^{b-e}	8.43^{q}
T797	23.84^{b-e}	15.94^{b-h}	18.77^{cde}	9.33^{n}
OKONDI	23.80^{b-e}	18.27^{a-g}	27.67^{a}	12.20^{b}
T921b	23.77^{b-e}	18.63^{a-g}	20.87^{cde}	10.37^{k}
T116	23.49^{cde}	20.87^{bac}	21.83^{b-e}	10.43^{j}
T444	23.41^{cde}	16.76^{a-f}	18.07^{cde}	8.60^{p}
T45	22.90^{cde}	20.13^{a-d}	18.63^{cde}	10.50^{j}
T164	22.90^{cde}	17.93^{a-g}	18.77^{cde}	9.50^{m}
T169	22.75^{cde}	18.13^{a-g}	19.27^{cde}	11.10^{f}
T204	22.63^{cde}	18.43^{a-g}	18.13^{cde}	6.49^{w}
M10a	22.61^{cde}	18.05^{a-g}	26.010^{ab}	9.8133^{l}
E92	22.49^{cde}	13.15^{f-j}	21.20^{cde}	10.93^{g}
C96	22.45^{cde}	14.52^{e-j}	18.10^{cde}	8.13r
E106a	22.23^{cde}	12.58^{g-j}	18.10^{cde}	11.00^{f}

Accessions	Plant height	Stem diameter	Leaf length	Leaf width
C111	22.14 ^{cde}	13.78$^{f\text{-}j}$	23.53$^{a\text{-}e}$	10.73^{i}
M10b	21.98 ^{cde}	15.80$^{c\text{-}i}$	26.03^{ab}	12.17^{b}
Oranre-2	21.88 ^{cde}	18.40$^{a\text{-}f}$	23.33$^{a\text{-}e}$	9.87^{l}
E106b	21.85 ^{cde}	14.21$^{e\text{-}i}$	18.267^{cde}	11.80^{c}
E1	21.55 ^{cde}	14.55$^{e\text{-}i}$	16.52^{e}	7.0433^{u}
C105	20.10 ^{cde}	15.88$^{e\text{-}h}$	18.47^{cde}	7.80^{s}
Oranre-1	19.47 ^{cde}	16.01$^{b\text{-}h}$	25.33^{abc}	11.33^{e}
Station G	18.86 ^{cde}	11.78$^{h\text{-}k}$	24.50$^{a\text{-}d}$	11.00^{f}
M31	18.72 ^{cde}	13.78$^{f\text{-}j}$	17.27^{de}	7.57^{s}
OMOU-2	17.94 ^{cde}	14.04$^{e\text{-}i}$	23.00$^{a\text{-}e}$	13.20^{a}
C107	17.80 ^{cde}	16.15$^{b\text{-}h}$	17.33^{de}	7.20^{u}
A116	17.52 ^{cde}	16.24$^{b\text{-}h}$	17.97^{cde}	7.367^{t}
C108	16.57 ^{cde}	14.19$^{d\text{-}j}$	21.08^{cde}	7.367^{t}
CAMP II	15.20 ^{cde}	14.17$^{d\text{-}j}$	20.33^{cde}	8.67^{p}
G87	14.52 ^{cde}	8.74^{jk}	18.67^{cde}	8.70^{p}
G37	14.30 ^{cde}	9.96ji^{k}	19.50^{cde}	9.367^{n}
C36	14.19 ^{cde}	15.19$^{b\text{-}i}$	19.27^{cde}	9.17^{o}
IYAMOYE 1	13.86 ^{de}	14.75$^{d\text{-}i}$	22.33$^{b\text{-}e}$	8.87^{p}
G129	12.21 ^{e}	7.40^{k}	13.63^{e}	5.93^{y}
C90	10.84 ^{e}	15.95$^{b\text{-}h}$	16.33^{e}	6.90^{v}

Means followed by the same letter(s) are not significantly different according to DMRT ($P < 0.05$)

The distribution of four quantitative traits across the six genetic classes of *C. canephora* were shown in Fig. 3. The boxplots reveal that Niaouli class had the widest range in plant height, including the tallest accession (M36). Uganda Robusta accessions (G37, G87, G129) had smaller stem diameters and shorter plant heights compared to most other classes. Java ex-Gamba accessions showed the widest range in leaf length, and Niaouli accessions showed the widest spread in leaf width, with the narrowest individual leaf (M36). These patterns support the within-class and between-class variation captured by the statistical analyses.

The eigenvalues and factor loadings for the first four principal components derived from the quantitative morphological traits. Together, the four components explained 100% of the total variance among the 43 accessions, with the first three components alone accounted for 97.1%. (Table 5). PC1 accounted for 65.4% of the total variance and was strongly associated with plant height (0.935), making it the dominant trait separating the accessions. Stem diameter contributed moderately to PC1 (0.337). PC2 explained 21.0% of the variance and was driven primarily by leaf length (0.856), with a moderate contribution from leaf width (0.351). This suggests that leaf morphology is the second most important dimension of phenotypic variation among the accessions. PC3 accounted for 10.7% of the variance and was dominated by stem diameter (0.889), highlighting that stem girth represents an independent dimension of variation not fully captured by PC1. PC4 explained only 2.9% of the variance and was strongly associated with leaf width alone (0.920). These results showed that plant height and stem diameter largely define PC1 and PC3, while PC2 and PC4 reflect the dimensions of leaf variation. The biplot, showed how individual accessions are distributed across these components and identifies accessions that separate clearly from the main group (Fig. 4).

Table 5
Eigenvalues and factor scores for the first four principal components

Traits	PC 1	PC 2	PC 3	PC 4
Plant height	0.93519	-0.21937	-0.27778	-0.011853
Stem diameter	0.33682	0.30838	0.88913	0.030077
Length of leaf	0.10035	0.85647	-0.32185	-0.3909
Width of leaf	0.043684	0.35105	-0.16942	0.91987
Eigenvalue	41.6343	13.3773	6.80914	1.82435
% Variance	65.416	21.019	10.699	2.8664

Figure 4 shows the PCA biplot of the 43 *C. canephora* accessions. Accessions such as M36 and Togolese are clearly separated along PC1 due to their exceptionally tall plant height, while Okondi and M10a/M10b are positioned distinctly along PC2 due to their long leaves. C90 falls in a separate region of the biplot, consistent with its unique morphological profile. The clustering of most Java ex-Gamba and Kouillou accessions in the central region of the biplot indicates moderate phenotypic similarity within these classes. On the other hand, G128 and M36 accessions from Uganda robusta and Niaouli, respectively vary from other accession and are not discriminated by leaf width, leaf length, stem diameter and plant height (Fig. 4).

The dendrogram produced from hierarchical clustering using Gower distance and UPGMA linkage is presented in Fig. 5. Unlike Euclidean distance, which describe only quantitative traits, the Gower distance metric accommodates both quantitative and qualitative traits simultaneously. This makes it a more comprehensive and appropriate measure for characterizing accessions that differ in both measured and visually assessed traits. The 43 *C. canephora* accessions grouped into three distinct classes.

Class I was the largest group, containing 40 accessions with broad genetic variation, joining the rest of the dendrogram at a Gower distance coefficient of about 0.59. Within this class, several tight sub-clusters of closely related accessions were observed, for example, T169 and T45, and T116 and T921B, which joined at distance values below 0.05, indicating very high similarity. Other accessions, such as CAMP II and STATION G, joined at slightly larger distances, around 0.16, reflecting a moderate level of relatedness. The presence of farmer-field accessions alongside CRIN germplasm accessions within the same broad class suggests a degree of genetic relatedness that crosses collection site boundaries. The wide internal spread of Class I, from near-identical pairs to more loosely related accessions, provides multiple opportunities for genetic improvement by combining complementary accessions in crossing programs.

Class II consisted solely of C90, which separated from the rest of the accessions at a high distance value, making it a genetically distinct accession in the collection. C90 also recorded the shortest plant height (10.84 cm) and had a distinct morphological profile across multiple traits. Its wide divergence from all other accessions suggests that it harbors unique traits, making it a potentially valuable genetic resource for introducing novel variation into breeding programs.

Class III comprised ORANRE 1 and ORANRE 2, which paired closely together, joining at a very small distance, close to 0.05 but separated from the rest of the collection as their own distinct class. Their tight pairing indicates these two accessions are highly similar to each other, while their separation from Classes I and II indicates they carry a trait combination not well represented elsewhere in the collection. This pairing could represent a duplicate-origin pair or a closely related group worth conserving and studying further for traits that distinguish them from the main population.

Figure 5. Dendrogram based on UPGMA clustering using Gower distance, showing morphological similarity among 43 *Coffea canephora* accessions

Figure 6 shows the concordance between PCA grouping and UPGMA cluster membership across the 43 accessions. The agreement between the two methods strengthens the reliability of the clustering outcome and confirms the three-group structure of genetic variation in the collection.

DISCUSSION

Morphological characterization remains a practical and accessible first step in assessing genetic diversity and identifying useful accessions for breeding [11]. The weak but significant positive correlation between plant height and stem diameter observed in this study is consistent with findings by [18], who reported that taller plants tend to have slightly thicker stems as a structural requirement for support. The strong correlation between leaf length and leaf width agrees with observations by [19], who linked proportional leaf growth with plant adaptability and photosynthetic efficiency. These trait relationships are important for breeding programs targeting yield improvement and stress tolerance, as selecting for one trait may indirectly influence the other.

The significant variability across accessions for all four quantitative traits in *C. canephora* was established in this study. Plant height showed the greatest range, from between C90 which was the shortest to M36 which was the tallest. Similarly, wide variation was established in stem diameter of G129 and T24. These extremes reflected in the PCA results, where PC1 dominated by plant height explained 65.4% of total variance, and PC3 dominated by stem diameter explained an additional 10.7%. Accessions such as M36 and T24, which were at the extreme ends of these traits, stand out as genetically distinctive and may serve as useful parent lines in breeding programs targeting plant vigor. Leaf dimensions were the primary drivers of PC2 with leaf length showing the strongest significance Accessions like Okondi and Omou-2 are particularly notable for their contributions to variability in leaf morphology. [20] reported that leaf size is linked to adaptability under varying climatic conditions, suggesting that these accessions may carry traits useful for developing climate-resilient coffee varieties. The placement of Okondi within the broad and diverse Class I cluster further supports its distinctiveness within the collection.

The qualitative trait data showed that all 43 accessions had green young shoot colour, indicating complete uniformity for this trait. This is consistent with the dominance of one ecotype in the collection and suggests that young shoot colour alone is not a useful discriminating character in this germplasm set. In contrast, berry colour and young leaf colour showed considerable variation, reinforcing their value as phenotypic markers for distinguishing accessions. Elliptic leaf shape and apiculate leaf apex being the dominant forms, reflected the overall genetic background of the *C. canephora* germplasm held at CRIN.

The use of Gower distance for cluster analysis in this study is a significant methodological improvement over Euclidean distance-based approaches. Euclidean distance operates only on quantitative data, and applying it to a mixed data set of quantitative and qualitative traits is statistically inappropriate. Gower distance, by contrast, computes a weighted average of dissimilarities for each trait type and scales each variable to the unit interval, making it suitable for mixed data types [21]. The resulting dendrogram therefore gives a more accurate picture of overall morphological similarity than would be obtained using quantitative traits alone. This approach has been applied successfully in other diversity studies in tropical tree crops [12].

The cluster analysis identified three morphological groups among the 43 accessions, broadly consistent with the findings of Anagbogu *et al*. [4], who reported similar groupings using genotyping-by-sequencing and SNP data. Class I was the largest and most heterogeneous group, comprising 40 accessions with a wide range of trait combinations, from tightly related pairs such as T169 and T45 to more loosely related accessions such as CAMP II and STATION G. The grouping of farmer-field accessions from Ekiti and Kogi alongside CRIN accessions within this broad cluster suggests gene flow or a common origin for part of the Nigerian coffee germplasm. This internal diversity within Class I provides the raw material needed for hybridization and selection.

Class II consisted solely of C90, whose marked separation from all other accessions and distinct morphological profile, including the shortest plant height in the collection confirms its genetic uniqueness. C90 may carry traits that are rare or absent in the rest of the germplasm, making it a candidate for conservation and for use as a parent in crosses aimed at widening genetic diversity. Class III comprised ORANRE 1 and ORANRE 2, which paired closely together but separated from the rest of the collection as a distinct class. Their tight pairing suggests these two accessions share a close relationship, possibly a common origin, while their separation from the main population indicates they carry a trait combination not well represented elsewhere in the germplasm. This pairing represents another useful target for further morphological and molecular investigation. These findings mirror observations by Nasar *et al.* (2022), who demonstrated the utility of integrating morphological and statistical analysis for germplasm classification.

The concordance between PCA and cluster analysis groupings, adds confidence to the interpretation of the three-class structure. When two independent multivariate methods agree, the groupings are more likely to reflect true biological differences rather than statistical artifacts. This integration of analysis of variance, principal component analysis, and Gower distance-based clustering provides a solid, multidimensional framework for understanding morphological diversity in *C. canephora*, and supports the selection of parent lines with complementary traits for future breeding work.

CONCLUSION

This study characterized the morphological diversity of 43 *Coffea canephora* accessions from three locations in Nigeria using both quantitative and qualitative traits. Significant variation was found among the accessions for all four quantitative traits. The integration of morphological and molecular data in future work will further strengthen breeding decisions and support the sustainable conservation and improvement of *Coffea canephora* genetic resources in Nigeria.

Declarations

CONSENT FOR PUBLICATION

Not applicable

AVAILABLITY OF DATA AND MATERIALS

The datasets generated and analysed during the current study are derived from the author's original research and are available from the corresponding author on reasonable request.

COMPETING INTERESTS

The authors declare that they have no competing interests.

FUNDING STATEMENT

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Author Contribution

O.P.B. conceptualized the study, conducted formal analysis, and led the writing of the original draft. O.A.D. co-supervised the work, provided critical review, and contributed to manuscript revision and editing. C.F.A. co-supervised the work and contributed to study design, methodology, and overall research direction. M.B.N. contributed to data collection and fieldwork (investigation). I.O.S. contributed to data analysis (formal analysis). M.O.B. supervised the overall research, and contributed to manuscript review and editing. All authors read and approved the final manuscript.

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Data Availability

The datasets generated and analysed during the current study are derived from the author's original research and are available from the corresponding author on reasonable request.

ETHICS APPROVAL

Not applicable. This study did not involve human participants, human data, human tissue, or animal subjects. All data used were derived from the author's original thesis research.

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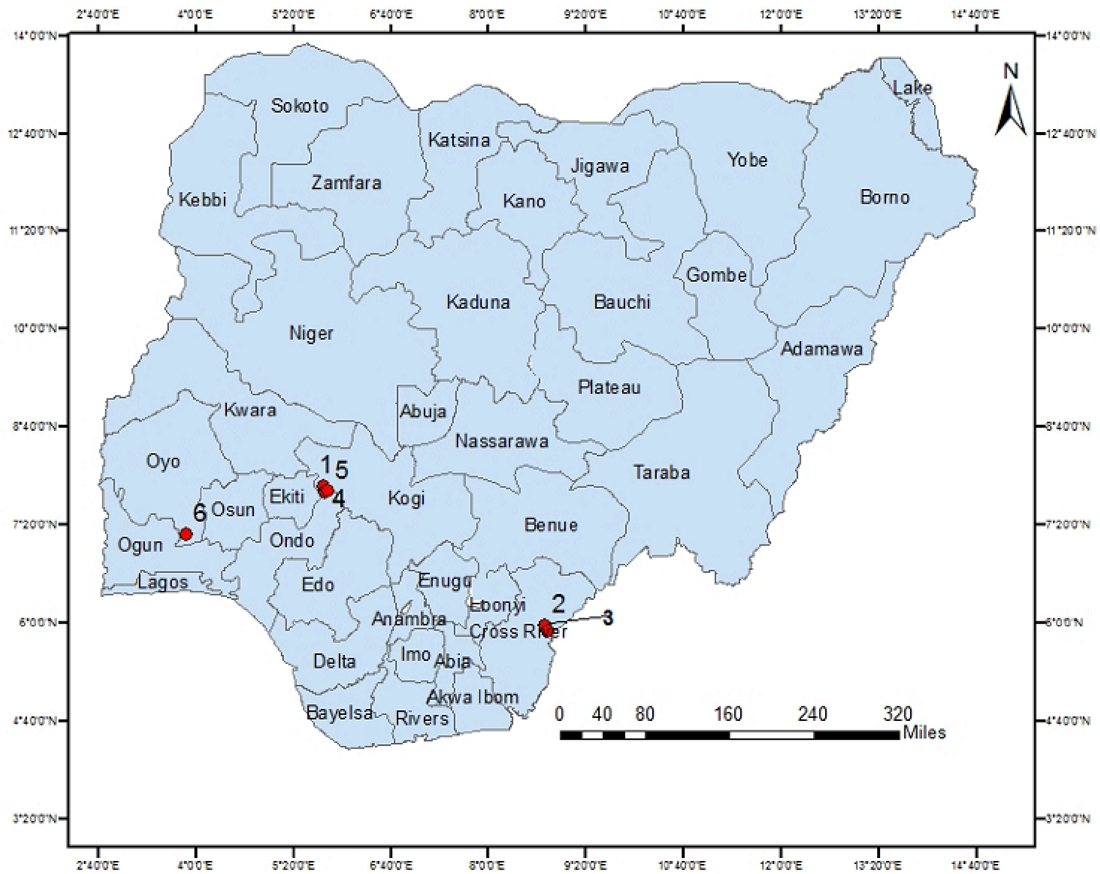
Figures



Locations

sn	N	E
1	7.8634	5.74112
2	5.96118	8.77028
3	5.87446	8.80908
4	7.77586	5.77326
5	7.79257	5.80625
6	7.20363	3.86472

Figure 1

Sampling locations of *Coffea canephora*accessions used in the study

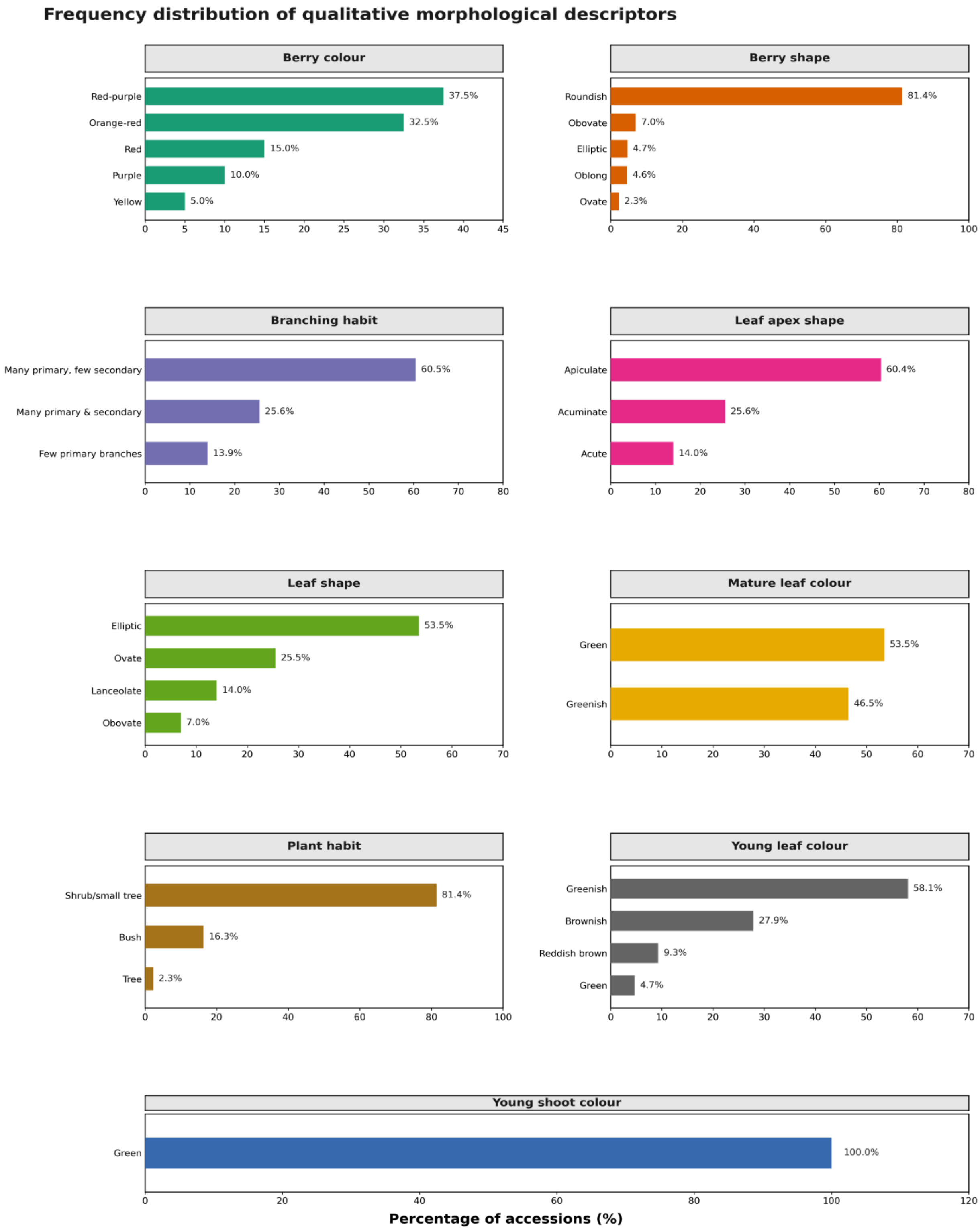


Figure 2

Frequency distribution of qualitative morphological traits in 43 accessions of *C. canephora*

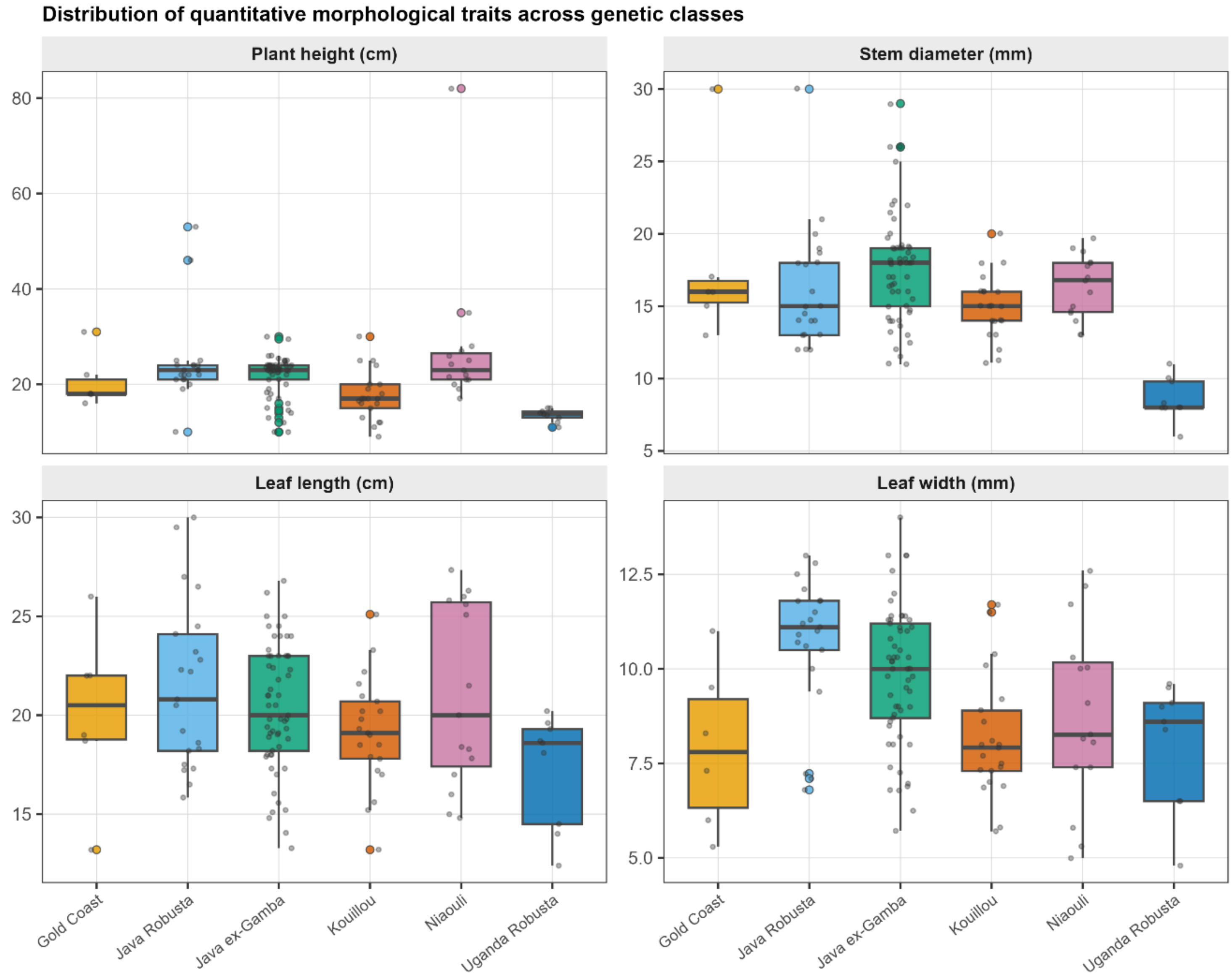


Figure 3

Distribution of quantitative morphological traits across genetic classes in 43 accessions of *C. canephora*

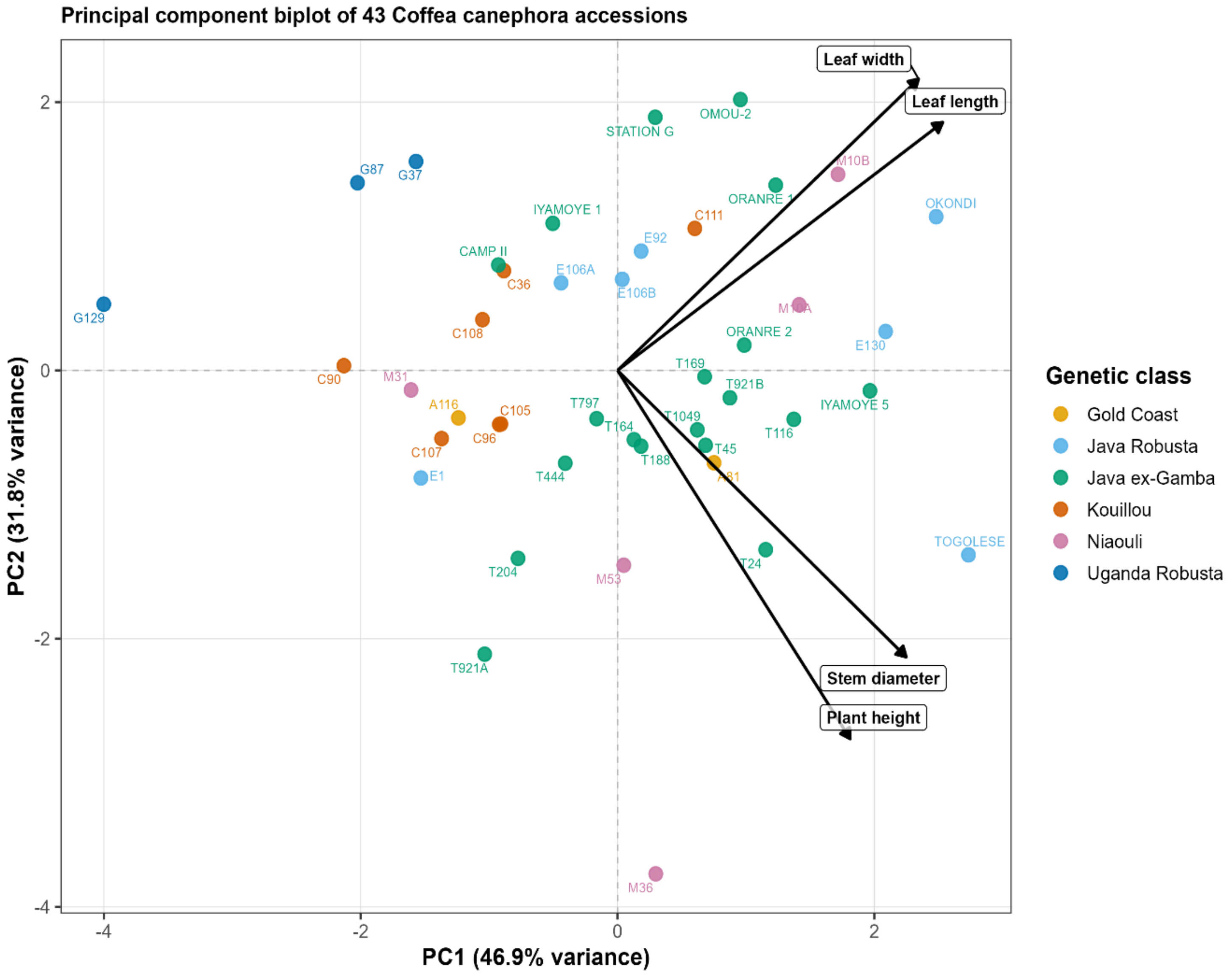


Figure 4

The biplot of 43 *Coffea canephora* accessions based on quantitative traits Gower Distance-Based Cluster Analysis

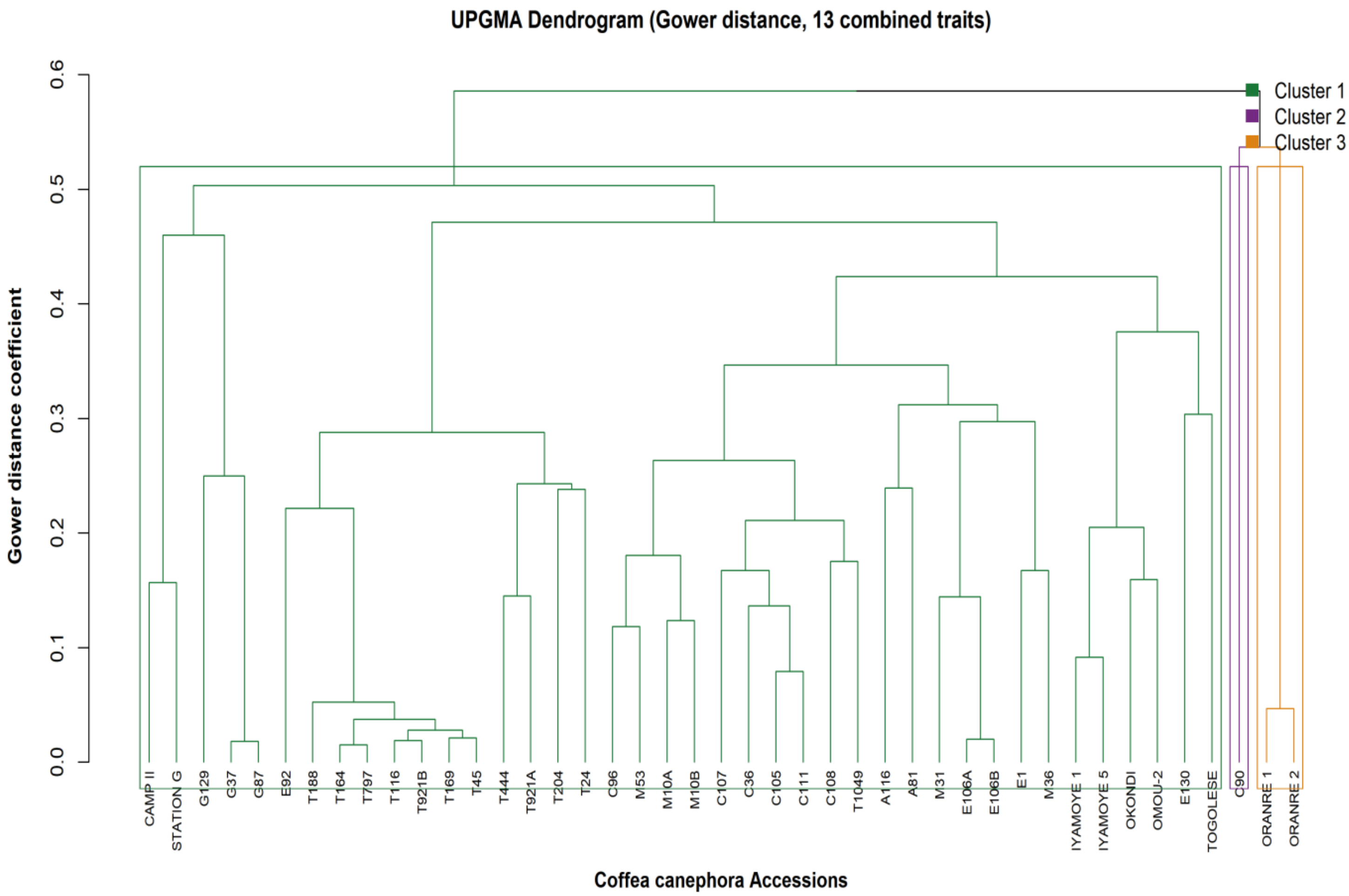


Figure 5

Dendrogram based on UPGMA clustering using Gower distance, showing morphological similarity among 43 *Coffea canephora* accessions

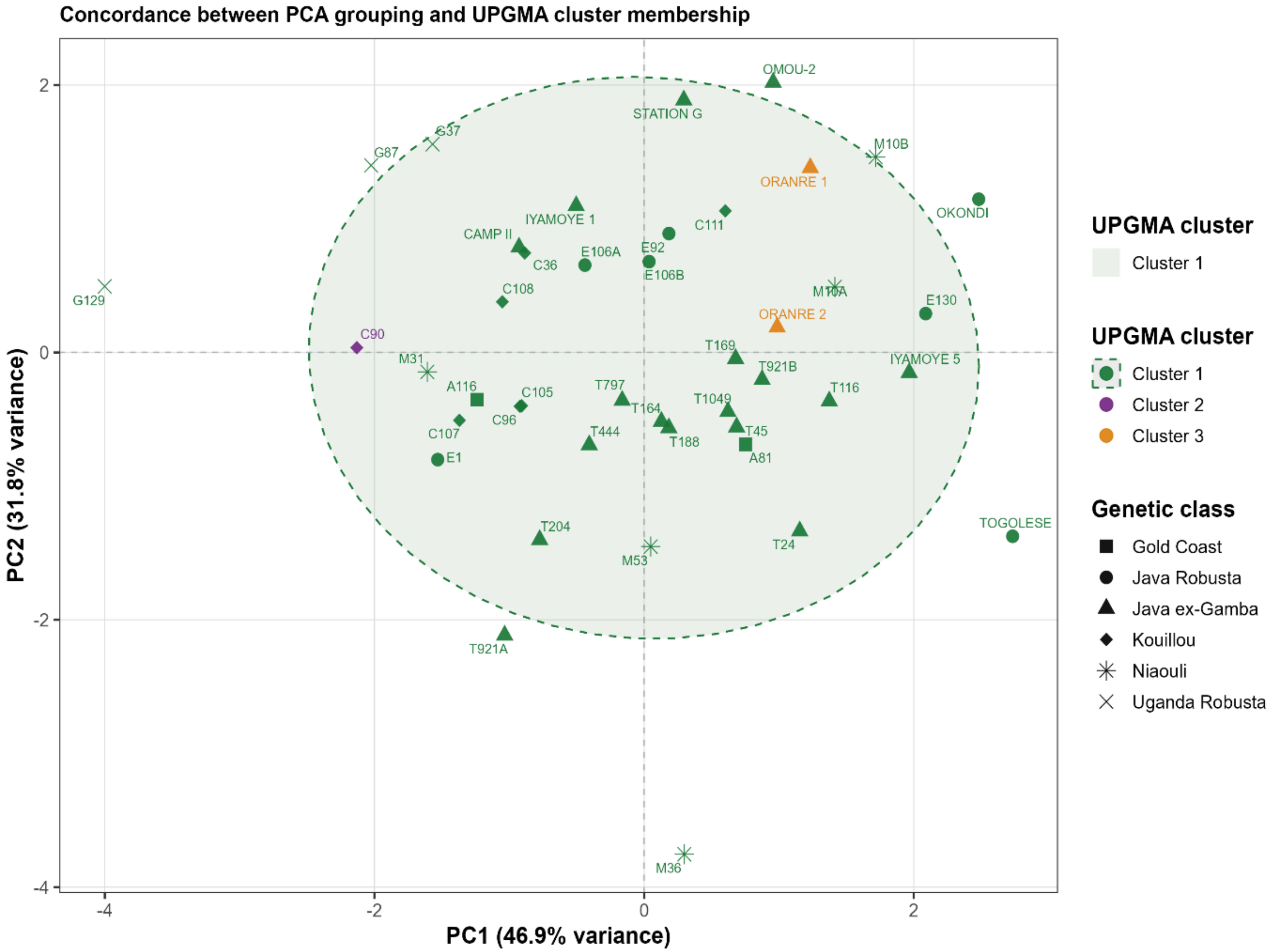


Figure 6

Concordance between PCA grouping and UPGMA cluster membership among the 43 *Coffea canephora* accessions