Original Research Article

Morphological variability of 23 kola (*Cola nitida*) genotypes from Côte d'Ivoire and Nigeria

Abstract

Twenty-three kola genotypes from Côte d'Ivoire and Nigeria were assessed for their morphological traits. The objective of this study was to identify potentially promising genotypes for kola productivity improvement. This study highlighted the significant variations in phenotypic traits between the two origins, except for nuts length. Genotypes from Côte d'Ivoire produced large follicles with more nuts. Those from Nigeria have large leaves, thick cortex, and large but few nuts. Correlation analyses revealed complex relationships among these characteristics, potentially influencing yield. Furthermore, the classification of genotypes into clusters highlighted notable differences in terms of fruit weight and nut size. Cluster 2 (CIV-313, CIV-322, NIG-330, NIG-341, and NIG-352) stands out as the most interesting, showing the highest values for these traits. These findings could be valuable in productivity and quality improvement programs for kola nuts, by incorporating specific characteristics of each genotype to meet agronomic goals.

Keywords: *Cola nitida*, genotypes, morphological traits, variability

Introduction

Kola, *Cola nitida* (Malvaceae), is a tree native to West Africa [1]. It is a diploid species with 2n = 40 chromosomes [2] and grows in African tropical rainforests [3]. Its mature height can reach 24 m [4]. It is important to note that West Africa, especially the Cavally valley, is the center of diversity for the genus *Cola*; but it can be found in Australia, Trinidad, Jamaica, India, Madagascar, and South America [3]. Kola is cultivated for its nuts, which are used for several purposes, for instance, in the manufacture of energy drinks and wines [5,6], for social ceremonies such as weddings, baptisms, and funerals [7–9], and in medicine for the manufacture of medicines and treatment of diseases [10,11]. Thus, kola cultivation contributes greatly to the economic development of producing countries and to household livelihoods in particular [12–15]. Côte d'Ivoire is the world's leading producer and exporter of kola nuts [16]. Production is carried out by farmers who own pure kola plantations. In addition to these pure plantations, part of kola nut production comes from spontaneous trees scattered in coffee or cocoa fields [17,18]. Despite these achievements, kola cultivation in Côte d'Ivoire faces major production challenges, mainly due to aging orchards and insufficient quality planting material [17]. To enhance kola production sustainability, Côte d'Ivoire has focused its research on conserving genetic resources and selecting quality planting material [17,19,20]. Thus, germplasm collections were set up at CNRA (Centre National de Recherche Agronomique) research stations. Trees were collected from different agro-ecological zones of Côte d'Ivoire and Nigeria [17,19–22].

These collections constitute a veritable reservoir of genes for the creation and selection of varieties. Diversity studies among genotypes from Côte d'Ivoire have revealed contrasting morphological traits [17,21]. However, morphological differentiation among these two origins has been partially studied by [19]. Thus, in this article, we present a more complete review, which consists of assessing morphological trait variations among genotypes of the two origins, taking into account other criteria considered in the selection. The objective was to identify kola clones most suitable for use as base materials in the breeding programmes. This is an important step in the implementation of a kola genetic improvement program.

2. Materials and methods

2.1 Plant material

Morphological traits were assessed in 23 genotypes: 13 from Côte d'Ivoire and 10 from Nigeria (Cocoa Research Institute of Nigeria). These 23 genotypes were chosen on the basis of their representativeness in the plot. Only genotypes represented by at least 3 trees were considered. Thus, 3 to 15 trees were considered for each genotype (Table 1). Trees were implanted at Divo (5°50’27.8”N; 5°21’30.1”W) at the CNRA (Centre National de Recherche Agronomique) station in a polycross experimental design (free fertilization between clones randomly distributed on a plot isolated from an external pollen source) [19]. The experiment was conducted from March to October 2020. Trees had an age of 42 years when data were collected.

Table 1. Origins and numbers of trees used for morphological traits measurements

Genotypes	Countries origin	Sampling sites	Trees numbers
CIV-305	Côte d’Ivoire	Bingerville	5
CIV-306	Côte d’Ivoire	Divo	5
CIV-311	Côte d’Ivoire	Divo	5
CIV-313	Côte d’Ivoire	Issia	5
CIV-314	Côte d’Ivoire	Issia	7
CIV-315	Côte d’Ivoire	Issia (Béhibouo)	15
CIV-316	Côte d’Ivoire	Issia (Balahio)	5
CIV-318	Côte d’Ivoire	Issia (Balahio)	5
CIV-321	Côte d’Ivoire	Toumodi (Kimoukro)	8
CIV-322	Côte d’Ivoire	Toumodi (Kimoukro)	5
CIV-323	Côte d’Ivoire	Tiassalé (BOFECAO)	5
CIV-A2	Côte d’Ivoire	Divo	5
CIV-A3	Côte d’Ivoire	Divo	5
NIG-329	Nigeria	CRIN	5
NIG-330	Nigeria	CRIN	3
NIG-331	Nigeria	CRIN	3
NIG-341	Nigeria	CRIN	5
NIG-342	Nigeria	CRIN	4
NIG-352	Nigeria	CRIN	3
NIG-356	Nigeria	CRIN	7
NIG-364	Nigeria	CRIN	3
NIG-366	Nigeria	CRIN	3
NIG-379	Nigeria	CRIN	3
Total			80

2.2 Methods

2.2.1 Data collection

Morphological variability was studied using 15 traits inspired by [23] and [24] works on same species. Leaf traits measured included: length (LoF), width (LaF) and petiole length (LoP). These measurements were recorded on 10 leaves. Leaf area (Surf) was calculated as follows: Surf = LoF x LaF. Follicle traits measured included: length (LoFr), circumference (Circ), weight (PoFr), cortex thickness (Ecor) and number of nuts (NoGr). These measurements were collected on 20 follicles. Follicle length and cortex thickness were measured using a Vernier caliper. The circumference, reflecting the follicles size, was measured with a tape measure in its median part. Fresh weight of follicles was determined using a precision balance shortly after the collection of the follicles. Nuts traits measured included: length (LoGr), width (LaGr), thickness (EpGr) and weight (PoGr) and total nut weight (PoGr/Fr) were measured. Total nut weight (PoGr/Fr) was measured. Nuts size (VoGr), representing a synthetical variable, was calculated as follows: VoGr = LoGr x LaGr x EpGr. These measurements were obtained on 30 nuts per genotype. Length, width and thickness were measured using a Vernier caliper. For weight, nuts were stripped of their husks using a knife before they were weighted.

2.2.2 Statistical analysis

Means and standard deviations were calculated for each origin and for each genotype taken singly using SAS 9.4 software [25]. The Student's t-test at a 5% significance level was used to compare the means of each origin for all traits. Means and standard deviations were presented as histograms. Means of each genotype were then compared by analysis of variance using the GLM procedure. The Newman-Keuls test at the 5% level of significance was used for the comparison. Coefficients of variation (CV), which measure data dispersion around the means, were calculated for each trait. We accept that a CV is low when its value is less than or equal to 20%. Any value above 20% is considered high. The relationship between traits was determined using Pearson correlation test on STATISTICA 7.1 (2005) software. A Hierarchical Ascending Classification (HAC) was done with means of each variable, using the UPGMA method. This HAC leads to a dendrogram, firstly to group the less dissimilar genotypes, and then to illustrate dissimilarity relationships among clusters. The XLSTAT software was used for this analysis.

3 Results

3.1 General traits of the two origins

The results of the Student's t-test show significant differences among the two origins for all traits, except for nut length ($t = 0.49$; $p = 0.62$). For leaf traits, CV values obtained for leaf length and width (CV < 20%) indicate a slight variation among the two origins, despite the differences highlighted by the t-test. On the other hand, petiole length and leaf area showed a stronger variation (CV > 20%). As with leaf dimensions, follicle dimensions had few variations as indicated by the CV values: 9.79% for circumference, 14.95% for length and 18.23% for cortex thickness. Follicles weight and the number of nuts per follicle varied greatly: 29.34% for PoFr and 31.93% for NoGr. Regarding nut traits, length and width had few variations (CV < 20%), while nut thickness, size, and weight varied widely (CV > 20%) (Table 2).

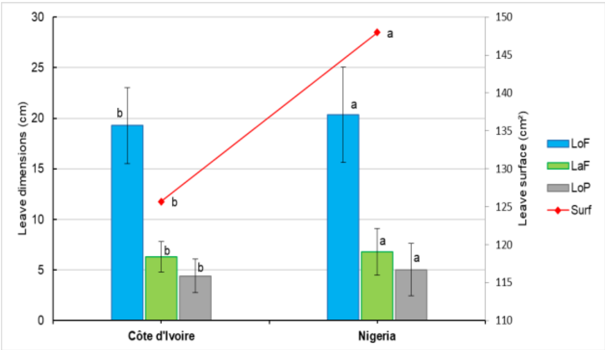
Table 2. Comparison test result of the two origins for all measured traits

Traits	t test value	p	CV (%)
LoF (cm)	-2.99	0.003	12.86
LaF (cm)	-3.15	0.002	16.64
Surf (cm²)	-3.94	< 0.001	30.90
LoP (cm)	-3.43	< 0.001	29.47
Circ (cm)	2.34	0.019	9.79
PoFr (g)	3.93	< 0.001	29.34
LoFr (cm)	-20.14	< 0.001	14.95
Ecor (cm)	-26.21	< 0.001	18.23
NoGr	9.49	< 0.001	31.93
LoGr (cm)	0.49	0.62	10.49
LaGr (cm)	-3.09	0.002	14.32
EpGr (cm)	-11.74	< 0.001	21.38
VoGr (cm3)	-8.46	< 0.001	34.55
PoGr (g)	-2.19	0.028	31.09
PoGr/Fr (g)	5.18	< 0.001	38.79

LoF (Leaf Length), LaF (leaf width), Surf (leaf area), LoP (petiole length), Circ (follicle circumference), PoFr (follicle weight), LoFr (follicle length), Ecor (cortex thickness), NoGr (number of nuts per follicles), LoGr (nut length), LaGr (nut width), EpGr (nut thickness), VoGr (nut size), PoGr (nut weight), PoGr/Fr (total nut weight per follicle)

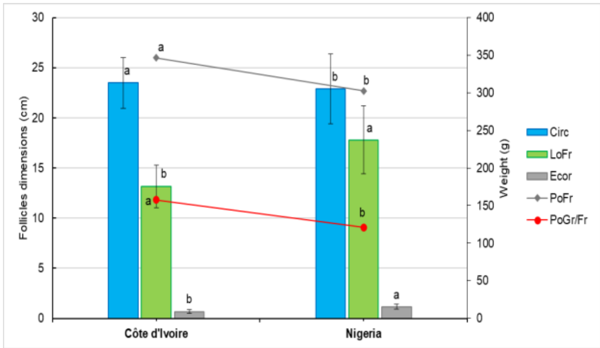
Leaf dimensions differ between the two origins, with genotypes from Côte d'Ivoire having thinner leaves compared to those from Nigeria. This trend also applies to petiole length (Figure 1A). On average, follicles of the genotypes measured 23.47 cm in circumference, 13.17 cm in length, and had a cortex thickness of 0.67 cm. The follicle weight was 346.43 g, with a total nut weight per follicle of 157.72 g. In contrast, Nigerian genotypes showed lower average values for three follicle traits: circumference (22.89 cm), weight (302.45 g), and total nut weight per follicle (120.86 g).

However, cortex thickness (1.16 cm) and follicle length (17.78 cm) were greater than those of the genotypes (Figure 1B). Regarding the nuts, Nigerian genotypes produced the largest nuts (37.26 cm³) with the highest weight (24.86 g), compared to Ivorian genotypes (25.77 cm³ and 22.81 g). The total nut weight per follicle was also higher in the Ivorian genotypes (157.72 g) compared to the Nigerian genotypes (120.86 g). The average number of nuts per follicle was 7.21 for the Ivorian genotypes, compared to 5.08 for the Nigerian genotypes (Figure 1C).



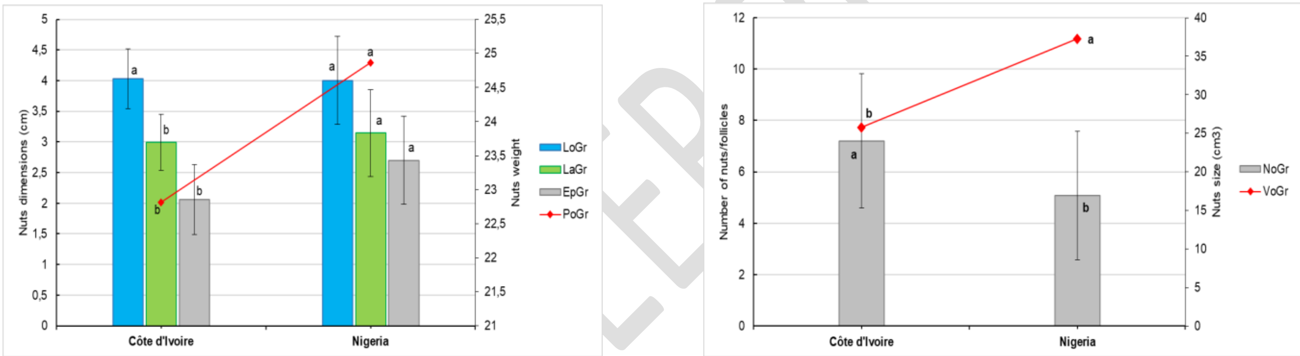
A. Leaf traits

LoF: leaf length, LaF: leaf width, LoP: petiole length, Surf: leaf area



B. Follicle traits

Circ: follicle circumference, LoFr: follicle length, Ecor: cortex thickness; PoGr/Fr: total nut weight per follicle



C. Nut traits

LoGr: nut length, LaGr: nut width, EpGr: nut thickness, PoGr: nut weight
PoFr: follicle weight, NoGr: number of nuts per follicles, VoGr: nut size

Figure 1. Histograms showing mean values of morphological traits for 23 kola genotypes from Côte d'Ivoire and Nigeria.

3.2 Morphological traits of genotypes

3.2.1 Leaf traits

The data indicate significant differences between genotypes from Côte d'Ivoire and Nigeria in terms of leaf dimensions, petiole length, and leaf surface area. Overall, Nigerian genotypes show higher values for leaf length, leaf width, and leaf surface area, with averages reaching 26.59 cm for LoF, 10.34 cm for LaF, and 282.84 cm² for Surf. These values are substantially higher than the averages for the Ivorian genotypes, although CIV-A3 stands out with relatively large leaf dimensions (26.68 cm for LoF and 206.94 cm² for Surf). For petiole length, Nigerian genotypes, particularly NIG-331, also show higher values (8.77 cm), while genotypes from Côte d'Ivoire generally have shorter petioles. Statistical analyses reveal significant differences for all measurements between the two origins ($p < 0.001$).

Table 3. Mean leaf characteristics of 23 kola genotypes from Côte d'Ivoire and Nigeria.

Genotypes	LoF (cm)	LaF (cm)	Surf (cm²)	LoP (cm)
CIV-305	20.98 ± 1.53 cde	8.16 ± 0.82 b	172.06 ± 27.33 cd	5.29 ± 1.35 cde
CIV-306	17.24 ± 2.89 gh	5.57 ± 1.13 f	98.92 ± 36.81 g	4.81 ± 1.39 def
CIV-311	18.23 ± 2.37 g	5.75 ± 0.97 ef	106.84 ± 31.69 g	4.15 ± 1.15 efgh
CIV-313	14.39 ± 1.36 i	4.31 ± 0.52 g	62.45 ± 12.28 h	2.37 ± 0.84 j
CIV-314	16.82 ± 2.25 gh	5.74 ± 1.24 ef	98.89 ± 34.38 g	3.99 ± 1.49 fghi
CIV-315	18.75 ± 1.61 fg	7.42 ± 0.92 bc	139.59 ± 23.35 ef	3.60 ± 0.84 fghi
CIV-316	17.39 ± 2.08 gh	6.03 ± 0.91 ef	106.49 ± 28.21 g	3.37 ± 1.02 ghij
CIV-318	22.03 ± 2.71 bcd	7.09 ± 1.11 cd	158.42 ± 41.25 de	5.76 ± 2.11 cd
CIV-321	17.93 ± 2.52 g	5.52 ± 0.95 f	100.46 ± 29.21 g	3.48 ± 0.85 ghij
CIV-322	22.46 ± 2.19 bc	7.77 ± 1.17 bc	175.91 ± 39.76 cd	5.97 ± 1.36 cd
CIV-323	19.15 ± 2.64 efg	5.30 ± 0.96 f	103.35 ± 31.07 g	3.61 ± 1.05 fghi
CIV-A2	18.69 ± 2.69 fg	5.45 ± 0.92 f	103.43 ± 30.32 g	4.42 ± 0.77 efg
CIV-A3	26.68 ± 2.44 a	7.75 ± 0.71 bc	206.94 ± 26.04 b	6.39 ± 1.26 c
NIG-329	15.62 ± 1.60 hi	3.54 ± 0.49 h	55.88 ± 13.12 h	2.81 ± 0.81 ij
NIG-330	20.90 ± 2.33 cde	6.68 ± 0.61 de	140.86 ± 27.94 ef	5.65 ± 1.47 cd
NIG-331	26.59 ± 4.41 a	10.34 ± 2.09 a	282.84 ± 105.43 a	8.77 ± 2.87 a
NIG-341	23.68 ± 3.33 b	7.94 ± 1.35 b	189.91 ± 52.19 bc	5.31 ± 1.67 cde
NIG-342	17.05 ± 3.39 gh	6.12 ± 1.09 ef	107.55 ± 39.4 g	3.88 ± 1.48 fghi
NIG-352	26.31 ± 3.53 a	9.92 ± 1.81 a	266.10 ± 81.99 a	7.64 ± 2.51 b
NIG-356	20.37 ± 1.98 def	5.84 ± 0.74 ef	120.06 ± 25.43 fg	5.93 ± 1.53 cd
NIG-364	18.16 ± 1.98 g	5.78 ± 0.87 ef	106.04 ± 25.09 g	2.83 ± 1.14 ij
NIG-366	17.48 ± 2.86 gh	5.94 ± 1.29 ef	105.83 ± 34.84 g	4.32 ± 1.51 efg
NIG-379	17.46 ± 2.56 gh	5.86 ± 1.28 ef	104.89 ± 37.32 g	2.92 ± 1.14 hij
Means	19.65 ± 4.13	6.46 ± 1.82	133.24 ± 65.85	4.61 ± 2.04
p	< 0.001	< 0.001	< 0.001	< 0.001

Means with the same letter in a column are statistically equal at the 5% level of significance.
LoF (Leaf Length), LaF (leaf width), Surf (leaf area), LoP (petiole length)

3.2.2 Follicle traits

All genotypes exhibited significant differences in follicle traits ($p < 0.001$). Follicle circumference varies among genotypes, with higher values seen in some Nigerian genotypes, such as NIG-352 and NIG-341 (26.50 cm and 26.41 cm, respectively), which are comparable to certain Ivorian genotypes like CIV-322 (26.68 cm). Regarding follicle weight, Ivorian genotypes, such as CIV-323 (508.23 g) and CIV-322 (501.74 g), stand out with greater weights, surpassing most Nigerian genotypes, except for a few, like NIG-341 (433.07 g). These findings suggest that the Ivorian genotypes tend to produce heavier follicles. For follicle length, Nigerian genotypes, particularly NIG-330 and NIG-356, show longer lengths, with averages of 19.49 cm and 18.96 cm, respectively. Cortex thickness also varies, with significantly higher values in some Nigerian genotypes, such as NIG-352 (14.9 cm), while Ivorian genotypes exhibit comparatively lower average thickness. Ivorian genotypes generally produce more nuts per follicle, with CIV-316 averaging 10.68 nuts, whereas some Nigerian genotypes show lower values, like NIG-330, which has only 3.55 nuts.

3.2.3 Nut traits

All p-values below 0.001 indicate that the differences observed between genotypes for each characteristic are highly significant. The NIG-330 and NIG-341 genotypes are distinguished by superior values for almost all measured traits, including volume (VoGr) and weight (PoGr), suggesting that they could be promising candidates for crop improvement. In contrast, the CIV-316 and NIG-352 genotypes show the lowest values for the majority of traits.

Table 4. Mean values for follicle traits in 23 kola genotypes from Côte d'Ivoire and Nigeria.

Genotypes	Circ (cm)	PoFr (cm)	LoFr (cm)	Ecor (cm)	NoGr
CIV-305	24.10 ± 1.24 bcd	363.56 ± 74.08 bc	13.21 ± 1.19 gh	7.41 ± 1.11 fgh	7.32 ± 1.57 cdefg
CIV-306	23.83 ± 1.89 bcde	328.72 ± 72.02 cd	12.23 ± 1.08 hi	5.17 ± 1.03 jk	6.28 ± 1.74 fgh
CIV-311	21.49 ± 2.92 fg	332.70 ± 49.27 cd	14.53 ± 0.81 fg	8.17 ± 0.79 f	8.08 ± 1.87 bcd
CIV-313	25.10 ± 2.63 abc	436.75 ± 134.87 b	14.31 ± 1.65 fg	4.56 ± 1.15 k	7.64 ± 2.44 bcdef
CIV-314	23.19 ± 1.66 cdef	364.71 ± 79.72 bc	16.10 ± 1.27 def	7.02 ± 1.54 fgh	5.48 ± 2.26 ghi
CIV-315	22.64 ± 1.99 def	289.65 ± 89.87 cde	12.36 ± 1.85 hi	7.06 ± 1.67 fgh	6.24 ± 2.04 fgh
CIV-316	21.86 ± 1.42 efg	300.70 ± 45.03 cde	12.95 ± 0.84 gh	9.32 ± 0.82 e	10.68 ± 2.18 a
CIV-318	21.52 ± 1.88 fg	225.40 ± 71.48 ef	11.67 ± 1.64 hi	6.72 ± 1.83 ghi	5.72 ± 2.62 ghi
CIV-321	22.56 ± 2.81 def	220.70 ± 61.09 ef	10.15 ± 1.17 j	5.78 ± 1.30 ij	4.93 ± 2.45 hij
CIV-322	26.68 ± 2.03 a	501.74 ± 139.87 a	14.74 ± 1.68 efg	8.10 ± 1.68 f	8.93 ± 2.09 b
CIV-323	25.52 ± 1.87 ab	508.23 ± 119.55 a	15.03 ± 1.65 ef	4.54 ± 0.71 k	8.93 ± 1.46 b
CIV-A2	22.66 ± 1.70 def	268.49 ± 72.97 de	10.92 ± 1.29 ij	6.26 ± 0.65 hi	5.60 ± 1.52 ghi
CIV-A3	24.03 ± 1.66 bcd	362.70 ± 74.50 bc	13.11 ± 1.04 gh	7.68 ± 1.09 fg	8.24 ± 2.01 bc
NIG-329	22.45 ± 1.92 def	299.91 ± 71.14 cde	15.92 ± 2.59 def	11.45 ± 1.76 cd	6.50 ± 2.21 defg
NIG-330	24.3 ± 3.48 bcd	323.10 ± 135.93 cd	19.49 ± 3.56 a	11.50 ± 2.42 cd	3.55 ± 1.85 j
NIG-331	22.62 ± 2.67 def	298.67 ± 133.39 cde	17.08 ± 3.39 cd	11.35 ± 1.182 d	4.75 ± 2.02 hij
NIG-341	26.41 ± 3.66 a	433.07 ± 150.42 b	18.54 ± 3.47 abc	10.75 ± 3.32 d	5.45 ± 2.35 ghi
NIG-342	19.50 ± 2.53 h	184.61 ± 98.87 f	16.37 ± 2.86 de	13 ± 1.78 b	3.40 ± 1.81 j
NIG-352	26.50 ± 3.05 a	412.42 ± 137.57 b	17.62 ± 3.05 bcd	14.9 ± 1.39 a	6.35 ± 1.87 efgh
NIG-356	23.46 ± 1.28 cdef	379.02 ± 85.51 bc	18.96 ± 1.96 ab	11.6 ± 1.53 cd	7.95 ± 1.95 bcde
NIG-364	22.66 ± 2.88 def	261.87 ± 111.02 def	18.52 ± 4.55 abc	10.95 ± 2.19 cd	7.30 ± 2.71 cd
NIG-366	20.49 ± 1.39 gh	217.99 ± 35.32 ef	17 ± 2.17 cd	8.05 ± 0.51 f	5.10 ± 1.65 hij
NIG-379	20.50 ± 2.92 gh	213.81 ± 119.01 ef	18.34 ± 4.26 abc	12.15 ± 2.28 bc	4.05 ± 2.39 ij
Means	23.27 ± 2.89	331.52 ± 130.24	14.74 ± 3.41	8.38 ± 3.11	6.48 ± 2.76
p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Means with the same letter in a column are statistically equal at the 5% level of significance.
Circ (follicle circumference), PoFr (follicle weight), LoFr (follicle length), Ecor (cortex thickness), NoGr (number of nuts per follicles)

Table 5. Mean follicle characteristics of 23 kola genotypes from Côte d'Ivoire and Nigeria

Genotypes	LoGr (cm)	LaGr (cm)	EpGr (cm²)	VoGr (cm^3)	PoGr	PoGr/Fr
CIV-305	3.77 ± 0.32 defg	2.91 ± 0.27 fghijk	2.14 ± 0.42 efg	23.87 ± 7.13 fgh	22.56 ± 6.08 efghi	154.58 ± 38.65 cd
CIV-306	4.34 ± 0.23 c	3.11 ± 0.37 defghi	2.38 ± 0.39 cdef	32.16 ± 6.61 def	26.58 ± 7.49 def	154.21 ± 31.36 cd
CIV-311	3.78 ± 0.22 defg	2.77 ± 0.27 hijkl	1.73 ± 0.31 hij	18.21 ± 4.51 hi	17.66 ± 3.66 hijk	139.10 ± 31.27 cde
CIV-313	4.63 ± 0.31 b	3.20 ± 0.42 defg	2.08 ± 0.5 fgh	30.98 ± 9.82 def	31.99 ± 10.55 cd	232.96 ± 83.88 b
CIV-314	4.03 ± 0.47 cd	2.89 ± 0.49 fghijkl	2.05 ± 0.47 fgh	25.01 ± 11.55 fgh	24.68 ± 6.84 efg	129.16 ± 52.47 cdef
CIV-315	4.27 ± 0.38 c	3.22 ± 0.38 defg	2.26 ± 0.32 def	31.37 ± 7.69 def	17.63 ± 5.73 hijk	109.37 ± 47.71 defg
CIV-316	3.53 ± 0.14 fg	2.65 ± 0.24 ijkl	1.41 ± 0.37 j	13.11 ± 2.95 i	10.63 ± 1.41 l	112.59 ± 23.18 defg
CIV-318	3.52 ± 0.40 fg	2.65 ± 0.37 ijkl	1.82 ± 0.49 ghi	17.68 ± 8.51 hi	18.77 ± 10.33 ghij	93.58 ± 45.22 efg
CIV-321	4.06 ± 0.38 cd	3.02 ± 0.65 efghji	2.69 ± 0.51 bc	32.97 ± 10.48 def	21.17 ± 7.86 fghi	88.40 ± 30.11 efg
CIV-322	4.03 ± 0.41 cd	3.16 ± 0.35 defgh	2.46 ± 0.57 cdef	31.62 ± 9.52 def	26.36 ± 7.69 def	232.15 ± 80 b
CIV-323	4.63 ± 0.59 b	3.59 ± 0.50 bc	2.52 ± 0.35 cde	42.09 ± 10.58 c	34.97 ± 7.77 c	308.99 ± 76.48 a
CIV-A2	3.92 ± 0.23 de	2.88 ± 0.30 ghijkl	1.70 ± 0.39 hij	19.17 ± 4.68 hi	22.74 ± 2.70 efghi	127.08 ± 37.44 cdef
CIV-A3	3.85 ± 0.36 def	2.83 ± 0.35 ghijkl	1.53 ± 0.36 ij	16.79 ± 5.43 hi	20.82 ± 3.29 fghi	168.09 ± 41.18 c
NIG-329	3.84 ± 0.21 def	2.79 ± 0.34 hijkl	2.38 ± 0.45 cdef	25.46 ± 5.79 fgh	17.52 ± 2.94 hijk	114.52 ± 42.24 def
NIG-330	4.98 ± 0.37 a	4.17 ± 0.31 a	3.47 ± 0.65 a	71.99 ± 15.73 a	45.32 ± 5.57 a	158.04 ± 77.25 cd
NIG-331	3.78 ± 0.75 defg	3.25 ± 0.57 def	2.75 ± 0.65 bc	36.53 ± 19.44 cde	23.55 ± 12.51 efgh	112.34 ± 68.24 defg
NIG-341	4.83 ± 0.42 ab	3.79 ± 0.51 b	3.42 ± 0.52 a	63.15 ± 15.37 b	40.88 ± 9.54 b	215.93 ± 91.64 b
NIG-342	3.64 ± 0.72 efg	2.83 ± 0.64 ghijkl	2.61 ± 0.53 bcd	28.88 ± 14.31 efg	19.65 ± 9.57 ghij	65.67 ± 40.20 g
NIG-352	3.43 ± 0.44 g	2.49 ± 0.41 l	2.04 ± 0.70 fgh	18.29 ± 8.57 hi	12.09 ± 5.04 kl	78.47 ± 46.34 fg
NIG-356	4.3 ± 0.69 c	3.32 ± 0.59 cde	2.66 ± 0.67 bcd	39.32 ± 16.85 cd	28.2 ± 10.28 de	224.8 ± 100.82 b
NIG-364	4.14 ± 0.44 cd	3.44 ± 0.5 cd	2.94 ± 0.66 b	42.81 ± 14.30 c	30.64 ± 9.47 cd	96.07 ± 51.56 efg
NIG-366	3.46 ± 0.47 g	2.56 ± 0.47 kl	2.23 ± 0.45 def	21.12 ± 9.84 ghi	13.95 ± 6.40 jkl	72.70 ± 43.47 g
NIG-379	3.60 ± 0.33 efg	2.76 ± 0.51 ijkl	2.47 ± 0.48 cdef	25.01 ± 8.95 fgh	16.81 ± 5.29 ijk	70.08 ± 54.51 g
Means	4.02 ± 0.58	3.04 ± 0.57	2.27 ± 0.69	29.66 ± 16.52	23.51 ± 10.78	145.22 ± 83.44
p	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Means with the same letter in a column are statistically equal at the 5% level of significance.
LoGr (nut length), LaGr (nut width), EpGr (nut thickness), VoGr (nut size), PoGr (nut weight), PoGr/Fr (total nut weight per follicle)

3.3 Correlations among characteristics

Table 6 presents correlation coefficients among the measured variables, with statistical significances indicated by asterisks. Leaf length shows a strong positive correlation with width (0.88) and leaf area (0.95), indicating that longer leaves are generally wider and have a greater surface area, which is beneficial for photosynthesis. Petiole length (0.89) and circumference (0.44) also exhibit positive correlations, although less pronounced, suggesting a less direct relationship. Furthermore, the correlations between fruit weight and length (0.29), width (0.17), leaf area (0.23), and petiole length (0.23) indicate that their impact on fruit weight is weak.

Regarding fruit weight, the positive correlations with circumference (0.89), number of nuts per fruit (0.60) and nut weight (0.54), suggest that fruit weight is closely related to circumference and the number of nuts per fruit, which can be a good indicator of yield. The lengths and widths of nuts generally display weak correlations with other variables, indicating that they are not directly influenced by leaf traits.

Concerning bark thickness, the positive correlations with the number of nuts (0.37) and fruit length (0.61) show a link with fruit length and the number of nuts, although some negative correlations, such as with fruit weight, indicate complex relationships. The dimensions of the nuts, particularly length and width, exhibit negative correlations with several variables, suggesting that they are less affected by other measurements. In terms of nut size and weight, the values show high correlations among themselves, indicating that an increase in nut size is associated with an increase in its weight, desirable in agronomic practices.

Finally, the total weight of nuts per fruit shows positive correlations with fruit weight (0.70) and the number of nuts per fruit (0.86), suggesting that an increase in fruit weight is linked to better overall performance of the concerned genotypes. These results underscore the importance of exploring these relationships to optimize yield and quality in crops.

Table 6. Matrix correlations among the 23 kola genotypes traits.

	LoF	LaF	Surf	LoP	Circ	PoFr	LoFr	Ecor	NoGr	LoGr	LaGr	EpGr	VoGr	PoGr
LaF	0.88***													
Surf	0.95***	0.97***												
LoP	0.89***	0.85***	0.90***											
Circ	0.44*	0.32*	0.39*	0.35*										
PoFr	0.29*	0.17	0.23*	0.23*	0.89***									
LoFr	0.15	0.15	0.17	0.17	0.09	0.13								
Ecor	0.32*	0.36*	0.37*	0.32*	-0.11	-0.19	0.73**							
NoGr	0.05	-0.06	-0.01	0.001	0.37*	0.60**	-0.34*	-0.36*						
LoGr	-0.09	-0.20	-0.17	-0.13	0.54*	0.50*	0.20	-0.25*	-0.03					
LaGr	0.10	0.01	0.03	0.04	0.45*	0.37*	0.38*	-0.02	-0.18	0.91***				
EpGr	0.08	0.08	0.08	0.07	0.22*	0.06	0.61**	0.35	-0.56**	0.61**	0.78**			
VoGr	0.11	0.05	0.06	0.07	0.38*	0.25*	0.53**	0.17	-0.36*	0.84***	0.95***	0.91***		
PoGr	0.07	-0.07	-0.03	0.03	0.52**	0.54**	0.35*	-0.12	-0.18	0.91***	0.93***	0.71**	0.89***	
PoGr/Fr	0.08	-0.11	-0.04	0.37*	0.70**	0.86***	0.05	-0.40*	0.56**	0.70**	0.57**	0.17	0.40*	0.65**

LoF (Leaf Length), LaF (leaf width), Surf (leaf area), LoP (petiole length), Circ (follicle circumference), PoFr (follicle weight), LoFr (follicle length), Ecor (cortex thickness), NoGr (number of nuts per follicles), LoGr (nut length), LaGr (nut width), EpGr (nut thickness), VoGr (nut size), PoGr (nut weight), PoGr/Fr (total nut weight per follicle)

*** very strong correlations at 5% level of significance;
** strong correlations at 5% level of significance;
* average correlations at 5% level of significance;
no * weak correlations at 5% level of significance.

Examination of the dendrogram reveals three clusters following the vertical plot at level 20,000 (Figure 2). Clusters are independent of genotype origins. Cluster 1 is predominant, with 13 genotypes, including 8 from Côte d'Ivoire and 5 from Nigeria. Clusters 2 and 3 each include 5 genotypes that are almost equally distributed among each origin.

In addition, the inter-cluster variance accounts for 80.76% of the total variance, indicating that the differences between the clusters are significantly more pronounced than the variations observed within the clusters themselves (19.24%), as shown in Table 7.

Table 7. Decomposition of variance for optimal classification

	Variance	Variance percentage
Intra-cluster	1624,144	19,24%
Inter-cluster	6815,845	80,76%
Total variance	8439,989	100,00%

There is a marked contrast among the three clusters for fruit weight, nut size, and nut weight. Other traits are of almost the same order of significance among clusters. Cluster 2 is the most interesting, with the highest values for follicles and nuts (Figure 3). On the other hand, Cluster 3 obtained values that are half those of Cluster 2 for follicle weight and nut size. Cluster 1 was in an intermediate position for the same traits.

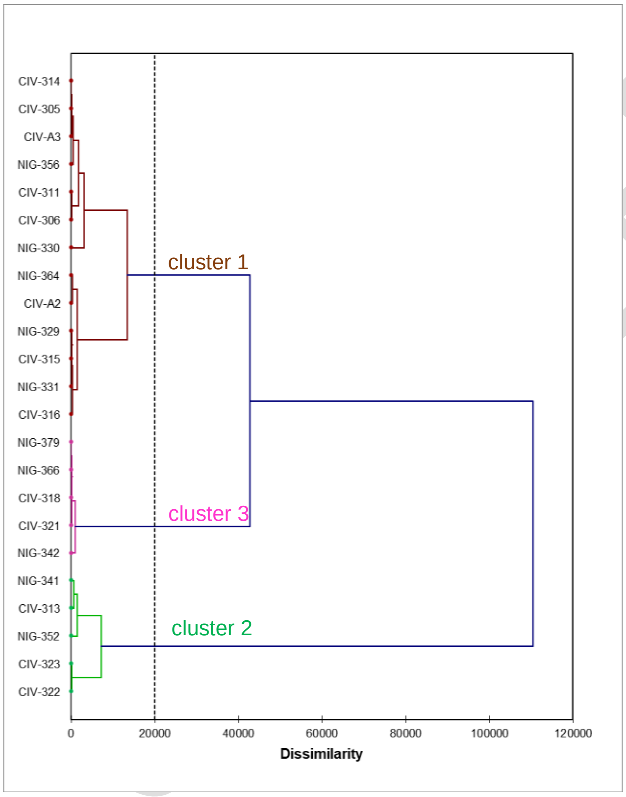


Figure 2. dendrogram showing dissimilarity relationships among clusters obtained with Hierarchical Ascending Classification

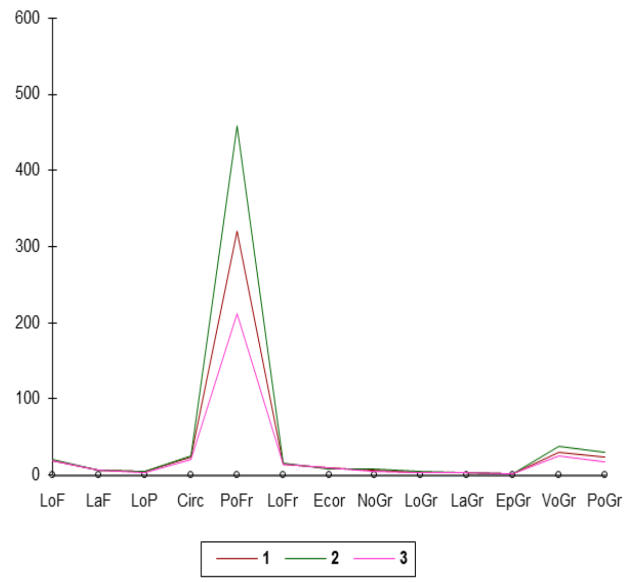


Figure 3. Clusters profiles obtained with Hierarchical Ascending Classification

4 Discussion

Varietal selection is based on species genetic variability. Thus, plant breeding programs must necessarily include morphological variability for all crop species. The morphological variability analysis is therefore an important step in crop plants' germplasm description. In this study based on

23 kola genotypes from Côte d'Ivoire and Nigeria, the variability of all morphological traits among the two origins was shown, except for nut length. Leaf dimensions differ among genotypes from the two origins. The same observation was made by [19] on the same origins but with different genotypes.

Overall, Nigerian genotypes, notably NIG-331 and NIG-352, showed higher values for foliar traits. These values are significantly higher than the averages of the Ivorian genotypes, although CIV-A3 stood out with relatively large dimensions. This trend also applies to petiole length, indicating significant morphological variation. Similar results were obtained by [26] on *C. acuminata* in Cameroon. These variations could reflect distinct genetic potential in leaf traits. Thus, the fact that Nigerian genotypes stand out for their larger leaf dimensions could influence their photosynthetic efficiency.

In terms of follicles, variations were also observed. Ivorian genotypes showed higher averages for follicle circumference and weight, though cortex thickness remained lower. For example, CIV-322 exhibited a follicle circumference comparable to Nigerian genotypes NIG-352 and NIG-341. For follicle weight, CIV-323 and CIV-322 stood out with higher weights, exceeding most Nigerian genotypes except for a few, such as NIG-341. This suggests that Ivorian genotypes tend to produce heavier follicles. Conversely, Nigerian genotypes displayed lower average values for follicle circumference and weight, although cortex thickness was greater than in Ivorian genotypes. Morphological differences in *Cola nitida* follicles were also observed by [27] in Nigeria. These differences could indicate different developmental or resource strategies, possibly influenced by environmental factors or natural selection. Moreover, these differences in follicle characteristics between the genotypes from the two origins suggest that Ivorian genotypes are more productive in terms of weight and nut number per follicle, while Nigerian genotypes stand out for their thicker cortex.

Regarding the nuts, Nigerian genotypes produced larger and heavier nuts compared to Ivorian genotypes. Thus, NIG-330 and NIG-341 stood out with higher values for nut size and average weight, suggesting they could be promising candidates for genetic improvement. In contrast, CIV-316 and NIG-352 show the lowest values for the same traits. However, the total nut weight per follicle was higher in Ivorian genotypes, also reflecting a higher average number of nuts per follicle than in Nigerian genotypes, as seen in CIV-316 (10.68 nuts) and NIG-330 (3.55 nuts). These observations suggest that Ivorian genotypes could be optimized for producing more nuts per follicle, while Nigerian genotypes tend to produce individually larger and heavier nuts. In other species, such as cocoa, [28] observed a variation in the number of beans per pod depending on the genotype. These results offer perspectives for targeted variety selection to improve yield and nut quality. Significant correlations between different pairs of traits highlight interesting relationships that deserve further exploration. Although correlations were less pronounced for some characteristics, they show links between morphological leaf traits and some fruit characteristics, such as circumference. However, the low correlation between nut weight and foliar traits suggests that other factors influence nut weight, indicating that phenotypic variability could also be due to genetic traits.

The observation of positive correlations between fruit weight, circumference, and average nut weight per follicle indicates that these traits could be valuable yield indicators. Similar results were obtained for the same species by [19] and for *C. acuminata* by [29]. This could imply that selecting genotypes with larger circumferences could improve overall yields. However, the weak correlations of nut dimensions with other variables suggest that they are not directly influenced by foliar characteristics, which could be an interesting area of study to understand the determinants of nut size.

Regarding bark thickness, the negative correlation with nut number highlights a relationship where greater bark thickness could be associated with lower nut production. This highlights the existence of a trade-off between the two linked traits. Thus, a reduction in nut thickness would favor an increase in the quantity of nuts produced through resource allocation. This also indicates that, while bark thickness is beneficial for certain characteristics (such as protecting nuts from pests), it could also limit nut production, warranting further investigation.

The examination of the dendrogram reveals the existence of three distinct clusters, regardless of origin. This observation suggests that genotype classification is not based on geographic origin, which could indicate phenotypic similarities between genotypes from different origins [21]. It is also noted that variance between clusters is significantly higher than variance within clusters, highlighting the importance of differences between clusters compared to variations within each cluster. This indicates that genotypes within clusters share similar characteristics, but there are significant differences between the clusters themselves.

Regarding follicle and nut characteristics, particularly nut size and weight, Cluster 2 stands out as the most interesting, displaying the highest values for both follicles and nuts. This could make it a prime target for breeding programs due to its high yield potential. In contrast, Cluster 3 presents values that are about half of those in Cluster 2 for follicle weight and nut size, which could indicate that these genotypes are less productive. Cluster 1, on the other hand, ranks in an intermediate position for these traits, suggesting it may possess beneficial characteristics but does not reach the same performance level as Cluster 2. This observation further emphasizes the importance of continuing to analyze these clusters to identify the specific traits that contribute to their respective performance.

Conclusion

This study highlighted significant morphological variability in the morphological traits of kola tree genotypes from Côte d'Ivoire and Nigeria. Analyses of leaf, follicle, and nut dimensions revealed notable variations, indicating that certain genotypes, particularly those in Cluster 2, possess superior yield potential. Correlations between different variables also emphasized the importance of leaf dimensions on follicle circumference and the total nut weight per follicle. The classification of genotypes into three distinct clusters, regardless of geographic origin, revealed that phenotypic differences are more pronounced between clusters than within them. This observation highlights the genetic diversity among the studied genotypes and underscores the importance of targeted selection for genetic improvement. The genotypes identified as the top performers in Cluster 2 could serve as a foundation for breeding programs aimed at increasing productivity and crop quality. These results provide valuable insights that could be leveraged in genetic selection programs to improve kola nut productivity and quality by incorporating specific traits from each origin to meet diverse agronomic objectives.

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