Original article

Agro-morphological characterization of cashew (*Anacardium occidentale* L.) ecotypes from North-Central of Côte d'Ivoire

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Summary

Introduction – **Cashew (*Anacardium occidentale* L.) is one of the main economic crops of Côte d'Ivoire. However, cashew orchards have low yields and populations in which different trees with unknown characteristics coexist. The objective of this study was to characterize the morphological diversity of cashew ecotypes identified in the Poro and Bagoué regions in North-Central Côte d'Ivoire, assuming that the highest genetic diversity might have been found in these regions which are the introduction points of cashew in the country.** *Materials and methods* – **The plant material consisted of 48 potentially high yielding cashew trees. Participatory approaches were used to select those mother trees. Fourteen agro-morphological quantitative traits were used to assess the phenotype diversity. A normed principal component analysis (NPCA) was performed. Following the NPCA, an ascending hierarchical classification was carried. The number of homogeneous groups and a significant difference between groups were determined by performing a multivariate analysis of variance.** *Results and discussion* – **Descriptive analyses have shown significant phenotypic variability among the ecotypes. The ascending hierarchical classification has structured this diversity into three groups. Most yielding trees ascribed to Group 1 could be better described as highest yielding ecotypes at $P<0.05$ significant level. The Group 2 described least yielding ecotypes compared to Group 3 of moderate yielding.** *Conclusion* – **The first and third groups contained high yielding ecotypes that could be multiplied and distributed to producers while continuing their genetic improvement. Molecular analysis using microsatellite markers would help better understand the observed morphological diversity.**

Keywords
Côte d'Ivoire, cashew tree, *Anacardium occidentale*, genetic diversity, morphological traits, nut tree orchard management

Résumé

Caractérisation agro-morphologique des écotypes d'anacardier (*Anacardium occidentale* L.) du Nord-Centre de la Côte d'Ivoire.

Introduction – **La culture de l'anacardier (*Anacardium occidentale* L.) constitue de façon générale l'une des principales activités économiques des zones situées dans la moitié Nord de la Côte d'Ivoire. Cependant, les vergers d'anacardier présentent des rendements faibles et des populations au sein desquelles coexistent des arbres différents et, aux caractéristiques inconnues. L'objectif de la présente étude était de caractériser la diversité morphologique des écotypes d'anacardier identifiés dans les régions du Poro et de la Bagoué, au Centre-Nord de la Côte d'Ivoire, avec comme hypothèse la plus grande diversité génétique proviendrait de ces régions qui sont les points d'introduction de l'anacardier dans le pays.** *Matériel et méthodes* – **Le matériel végétal est constitué de 48 arbres d'anacardier potentiellement hauts producteurs. La sélection participative a été utilisée pour identifier les arbres-mères. Quatorze caractères quantitatifs agro-morphologiques ont servi à évaluer la diversité phénotypique. Une analyse en composantes principales normées (ACPN) a été effectuée. Suite à l'ACPN, une classification hiérarchique ascendante a été réalisée, afin d'identifier des groupes d'individus homogènes. Pour déterminer le nombre de groupes représentant la partition optimale dans l'arbre hiérarchique, une analyse de variance multivariée a été effectuée.** *Résultats et discussion* – **Les analyses descriptives ont montré une variabilité phénotypique importante entre les écotypes**

Significance of this study

What is already known on this subject?
- The morphological diversity of cashew trees was already characterized in Côte d'Ivoire, from the collection of the National Centre of Agronomic Research (CNRA).
- The characterization of cashew trees diversity in rural areas in Côte d'Ivoire was missing.

What are the new findings?
- A great diversity has been observed between cashew tree ecotypes within the study areas.
- This diversity was structured in three groups. The first and third groups contain elite and high yielding trees that present interesting characteristics for the producers. The second group consisted of ecotypes that will enrich the CNRA germplasm collection.

What is the expected impact on horticulture?
- This study provides useful information that should be used in cashew breeding programs in Côte d'Ivoire.

étudiés. La classification ascendante hiérarchique a permis de structurer la diversité morphologique en trois groupes. La plupart des arbres productifs attribués au groupe 1 pourraient être mieux décrits comme des écotypes à plus haut rendement à un niveau significatif de $P<0{,}05$. Le groupe 2 a décrit des écotypes à faible rendement par rapport au groupe 3 qui a renfermé les écotypes à rendement modéré. *Conclusion* – **Les premier et troisième groupes contenaient des écotypes à haut rendement qui pourraient être multipliés et distribués aux producteurs tout en poursuivant leur amélioration. L'analyse moléculaire utilisant des marqueurs microsatellites permettrait de mieux comprendre la diversité morphologique observée.**

Mots-clés
Côte d'Ivoire, anacardier, *Anacardium occidentale*, diversité génétique, caractères morphologiques, gestion de verger de fruits à coque

Introduction

Cashew tree (*Anacardium occidentale* L.), first described by Linné in 1753, is a tropical plant native to the Northeast of Brazil (Trévian *et al.*, 2005). The authors agree that its area of origin extends from Mexico to Northeastern Brazil and Peru (Lautié *et al.*, 2001; Trevian *et al.*, 2005). It is a diploid species of type $2n=42$ (Aliyu and Awopetu, 2007a). It was introduced successively in West Africa in the fifteenth century against soil erosion, and in East Africa and India in the sixteenth century by the Portuguese (Martin *et al.*, 1997). The first introduction of cashew trees in Côte d'Ivoire was around 1951 in the entire Northern and Central area of Côte d'Ivoire. Then, it was only between 1959 and 1960 that cashew tree was extended to the entire Sudano-Guinean savanna zone (Djaha *et al.*, 2014).

Cashew tree is a tree whose cultivation contributes to the socio-economic development of several countries in the world (Martin, 2003). In Côte d'Ivoire, from a forest plant in the beginning, cashew tree has, since 1970, become a fruit cash crop due to the growing commercial interest in cashew nuts. Its production is only risen in view of the increase in the world prices of the nut and the ease of setting up this perennial crop (Dugué *et al.*, 2003). At its maximum yield, an orchard of well-maintained cashew trees, with selected plant material, would yield between 1.5 t and 2 t of nuts per hectare and about 20 t of apples. The wood is used as firewood. The bark is rich in tannins. The gum is an insecticide and is used for bookbinding. The liquid balm extracted from the walls of the shell has many industrial applications: insecticide, fungicide, tar, paint, waterproofing. From another point of view, the production of cashew nut and its processing help fight against rural exodus, without, however, leading to the abandonment of food crops and small backyard flock; ensuring daily subsistence (Djaha *et al.*, 2014).

Côte d'Ivoire is the world's largest cashew nut producer with more than 700,000 t in 2015 (Rabany *et al.*, 2015). The national cashew nut yield of 480,000 t in 2013, over an estimated surface area of 1,071,429 ha (Cashew Handbook, 2014), rises thus to 700,000 t in 2015, that is, an increase of 31% in three years. The corresponding sown areas are about 1,562,500 ha, whereas in 2002, cashew tree cultivation extended over 234,375 ha. This constant increase in cashew nut yield in Côte d'Ivoire is due in large part to the extension of cultivated areas at the expense of natural vegetation and areas devoted to other crops. Ivorian orchard yields remain low, with an average 448 kg nut ha^{-1} (Cashew Handbook, 2014) due to the use of plant material consisting of ordinary nuts and unsuitable rural cropping system such as very high planting densities ranging from 625 to 1,111 plants ha^{-1}. Most of the local cashew trees in farmers' fields today are progenies of the first introduced trees. Thus, cashew orchards are made up of heterogeneous tree populations with unknown characteristics. The allogamous nature of cashew and the use of seeds as planting material instead of grafted plants, are the main causes of this heterogeneity (Djaha *et al.*, 2014).

In order to remove this constraint, a first survey was carried out by the team of the National Center for Agronomic Research (CNRA) with the support of the National Agency for Rural Development Support (ANADER) in 2010 in the ex-Denguélé, Savanes, Bandama Valley and Zanzan regions, so as to identify potentially High Yielding Trees (HYT), characterize them and enrich the CNRA collection. At the end of the survey, 72 HYT had been identified, geo-referenced and characterized at the agro-morphological level. A second survey was carried out after the training on the varietal selection of cashew trees organized by a Tanzanian expert. This second survey took place in February and March 2014 in the Poro (Waraniéné, Karakoro, Koni, Fapaha and Sinématiali) and Bagoué (Boundiali) regions. It helped to identify 48 HYT. The agro-morphological characterization of these HYT and the technological characterization of their nuts are the main objectives.

The general objective of this work was to select among these adapted cashew landraces, the best ones for setting up experimental plots intended to the creation and selection of cashew tree varieties in Côte d'Ivoire. More specifically, it was a question of characterizing at the agro-morphological level the HYT identified from producers in the Poro and Bagoué regions, assuming that the highest genetic diversity might have been found in these regions which are the introduction points of cashew in the country.

Materials and methods

Plant material

The plant material consisted of 48 potentially high yielding cashew trees that have been identified in the Poro and Bagoué regions, in North-Central Côte d'Ivoire. The location of these trees as well as their ages are shown in Table 1.

Study areas

The present study was conducted in the regions of Poro (Korhogo, Karakoro, Koni and Sinématiali) and Bagoué (Boundiali). These regions are located between parallels 8°50' and 10°75' North latitude and 5°10' and 6°93' West longitude, with 300–450 m altitude above sea level (Figure 1). The vegetation of these zones is represented by savannah woodland, wooded savannah and shrub savannah types depending on the level of agricultural pressure. The climate is Sudano-Guinean type with two seasons. The average annual temperature in the locality of Korhogo is 26.5 °C and that of Boundiali is around 26.1 °C. As for the average annual rainfall, Korhogo accumulates 1,286 mm of rain while Boundiali records 1,441 mm. The soils of the study area are ferralitics. However, hydromorphic soils are found (Beaudou and Sayol, 1980).

Table 1. List of the 48 cashew potentially high yielding trees identified in the Poro and Bagoué regions and their location sites.

Cashew ecotypes	Region of origin	Localities	Latitude	Longitude	Altitude (m)	Germplasm expedition year	Age of trees in 2015
Ka1	Poro	Karakoro	9°23'231n	5°29'856w	321	2014	15
Ka2		Karakoro	9°23'238n	5°29'945w	326	2014	15
Ka3		Karakoro	9°23'234n	5°29'949w	315	2014	15
Ka4		Karakoro	9°23'230n	5°29'280w	320	2014	15
Ka5		Karakoro	9°23'246n	5°29'983w	318	2014	15
Ka6		Karakoro	9°23'174n	5°30'029w	323	2014	15
Ka7		Karakoro	9°23'156n	5°30'029w	336	2014	15
Ka8		Karakoro	9°23'144n	5°30'055w	339	2010	15
Ka9		Karakoro	9°23'111n	5°30'056w	335	2014	15
Ka10		Karakoro	9°23'089n	5°30'063w	343	2010	15
Ka11		Karakoro	9°23'172n	5°30'055w	327	2014	15
Ka12		Karakoro	9°23'159n	5°30'069w	353	2014	15
Ka13		Karakoro	9°23'159n	5°30'064w	328	2010	15
Ka14		Karakoro	9°24'288n	5°31'873w	336	2014	13
Ka15		Karakoro	9°24'292n	5°31'887w	338	2014	13
Si1		Sinématiali	9°30'301n	5°27'351w	355	2010	10
Si2		Sinématiali	9°30'303n	5°27'367w	370	2010	10
Si3		Sinématiali	9°30'281n	5°27'480w	375	2014	10
Si4		Sinématiali	9°30'280n	5°27'439w	368	2014	10
Si5		Sinématiali	9°30'318n	5°27'350w	370	2010	10
Fa1		Fapaha	9°28'813n	5°50'367w	362	2010	20
Ko1		Koni	9°36'247n	5°41'392w	348	2010	25
Ko2		Koni	9°36'257n	5°41'381w	355	2014	6
Ko3		Koni	9°36'239n	5°41'285w	355	2010	25
Wa1		Waraniéné	9°26'239n	5°39'576w	405	2014	10
Wa2		Waraniéné	9°26'238n	5°39'575w	406	2014	10
Wa3		Waraniéné	9°26'307n	5°39'602w	385	2014	10
Wa4		Waraniéné	9°26'321n	5°39'584w	397	2014	10
Wa5		Waraniéné	9°26'326n	5°39'570w	396	2014	10
Wa6		Waraniéné	9°26'347n	5°39'570w	400	2014	10
Wa7		Waraniéné	9°26'367n	5°39'573w	398	2014	10
Wa8		Waraniéné	9°26'336n	5°39'602w	413	2014	10
Wa9		Waraniéné	9°26'280n	5°39'644w	397	2014	5
Wa10		Waraniéné	9°26'265n	5°39'665w	400	2014	10
Wa11		Waraniéné	9°26'221n	5°39'664w	394	2014	10
Bo1	Bagoué	Boundiali	9°30'200n	6°27'406w	426	2014	18
Bo2		Boundiali	9°30'123n	6°27'418w	444	2014	18
Bo3		Boundiali	9°30'123n	6°27'434w	437	2014	18
Bo4		Boundiali	9°29'719n	6°26'548w	420	2010	17
Bo5		Boundiali	9°29'733n	6°26'551w	403	2014	17
Bo6		Boundiali	9°29'665n	6°26'566w	400	2010	17
Bo7		Boundiali	9°29'652n	6°26'569w	384	2014	17
Bo8		Boundiali	9°29'637n	6°28'108w	396	2010	17
Bo9		Boundiali	9°29'690n	6°26'592w	402	2010	17
Bo10		Boundiali	9°29'692n	6°26'592w	403	2010	17
Bo11		Boundiali	9°29'638n	6°28'069w	397	2010	17
Bo12		Boundiali	9°29'631n	6°28'103w	411	2010	17
Bo13		Boundiali	9°29'533n	6°28'083w	398	2010	17

Selection of producers and orchards

The HYT which are the subject of this study were surveyed in 2010 and 2014. The survey report took into account the following information: origin of seeds, planting method, planting density, cropping system, weeding, fertilization, pesticide use, pruning, harvest, age of the orchards and labour used. In each locality, the producers were selected according to their experiences and on the recommendation of the agricultural council (ANADER, Cotton and Cashew Council). The number of cashew tree orchards surveyed was nine. One orchard was selected in the following localities: Waraniéné, Fapaha and Sinématiali, two orchards in Karakoro and Koni, and three orchards in Boundiali. Orchard sizes ranged from 1 to 4 ha. Each orchard made up the experimentation site.

The selection of potentially high yielding trees was done in a participative way in the different orchards. It was done in collaboration with the producers. The selection criterion used by the producers was the high nut yield. The latter would firstly state the high yielding trees he had in his orchard. Once this step was completed, the research team used the following additional criteria for identifying the mother trees:

- good tree architecture (tree with an erect-open architecture, dense and compact crown);
- grouped maturity and precocity;
- shape (well-filled nut) and quality of nuts (nut easily detachable from apple);
- nut weight ≥ 7 g (verifiable on the field depending on the size of the nut);
- resistance to inflorescence diseases (no presence of inflorescence diseases);
- yield ≥ 8 kg tree^{-1} year^{-1} (accepted on producer's declaration, but will be verified with assessments over at least two years).

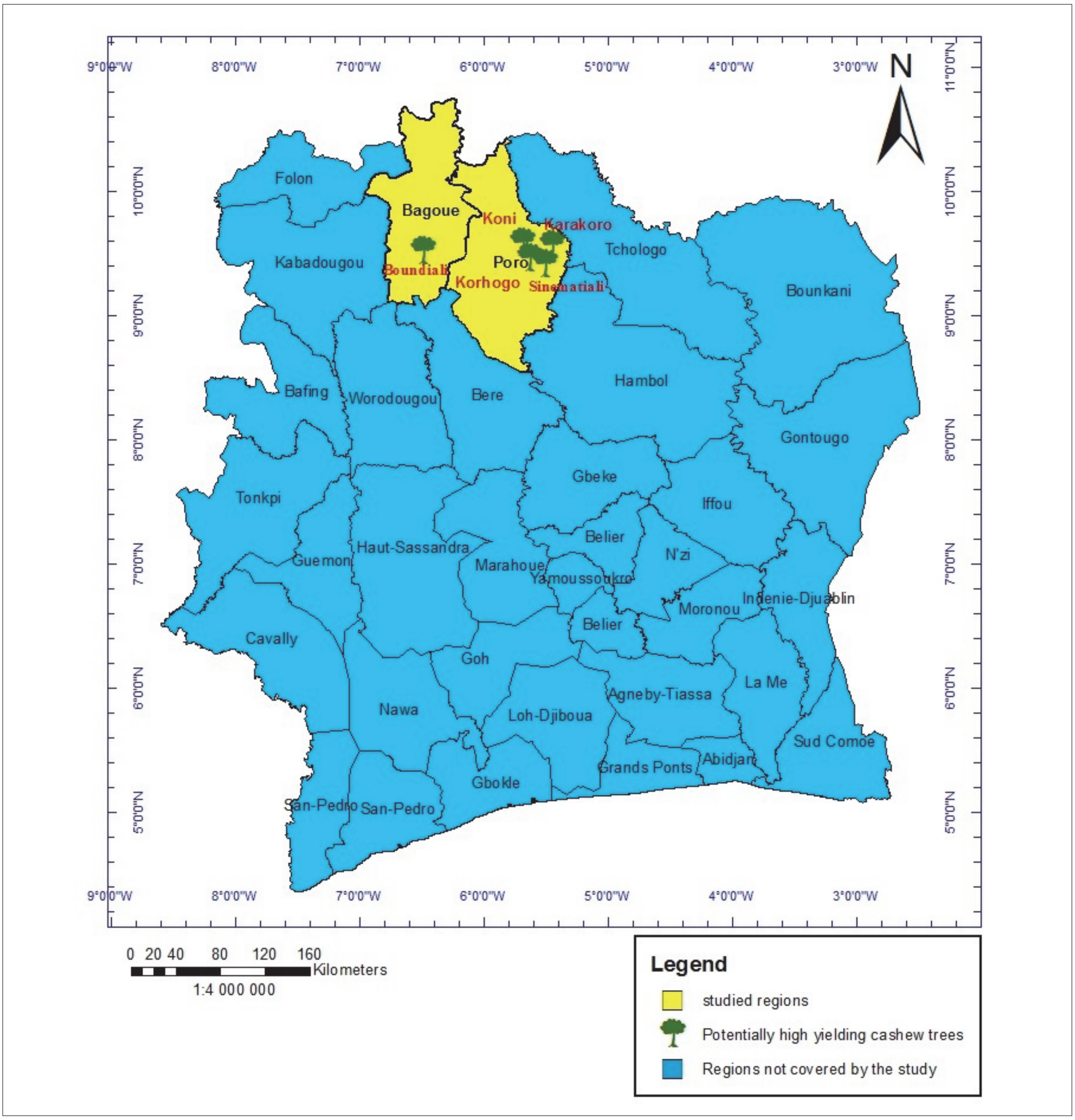

FIGURE 1. Map of the administrative regions of Côte d'Ivoire showing the study areas.

Agro-morphological traits measured

Fourteen agro-morphological features, all quantitative, were used to assess HYT. These measurements included morphological characters relating to tree architecture and reproductive attributes of yield determinants.

Morphological characters (girth at 1 m above ground, tree height, tree spread across East-West, tree spread across North-South, main branch crotch angle, leaf length and width, leaf petiole angle relating to branch) were taken in one time measurement, in the month of January. Tree yield was recorded each two days (harvesting cycle) during the period from 20th February to 15th April 2015. Yield determinants (nut length, width and thickness, nut weight and number of nuts per 1 kg) were collected at the end of the nut harvesting period.

From 48 HYT studied, yield data were obtained on 36 HYT. The measurements were made using the cashew tree description manual (IBPGR, 1986).

Statistical analyses

The collected data were organized in the form of a matrix crossing each observation (ecotypes) with the different parameters measured. This matrix was subjected to a descriptive analysis (average, minimum, maximum, standard deviation, coefficient of variation).

The coefficient of variation was calculated according to the following formula:

$$CV = \frac{s}{\bar{x}} \times 100$$

where CV is the coefficient of variation, S is the standard deviation, and $\bar{x}$ the mean value.

To avoid bias related to scale difference between variables, the data were standardized so that their average is zero and their standard deviation is equal to 1 (Mohammadi and Prasanna, 2003). From the standardized data matrix, a correlation matrix was calculated between the variables (Pearson correlation). This matrix was used to perform a normed principal component analysis (NPCA) with "Varimax rotation" (Iezzoni and Pritts, 1991). Before proceeding, the conditions for applying the method via the Kaiser Meyer Olkin (KMO) Measure of Sampling Adequacy and the Bartlett sphericity test were verified. According to Kaiser (1974), a KMO value ranging between 0.5 and 0.6 is poor, average up to 0.7 and good beyond. In the case of this study to be conserved in the Principal Component Analysis (PCA), a variable must obtain a KMO value exceeding 0.5. Bartlett sphericity test checks whether the correlation matrix is statistically different from an identity matrix (no correlation between variables). It must therefore be significant for the data to be factorable.

Following the NPCA, an ascending hierarchical classification (AHC) (Peeters and Martinelli, 1989) was carried out, in order to identify homogeneous individual groups. The Ward method was selected to aggregate individuals. The square Euclidean distance was used as a measure of similarity between individuals. The quality of the representation of the dendrogram provided with respect to the original data was quantified using the cophenetic correlation coefficient, as described by Rincon *et al.* (1996), and Légendre and Légendre (1998). This coefficient was estimated using the Mantel test (Mantel, 1967). In order to determine the number of groups representing the optimal partition in the hierarchical tree, a multivariate analysis of variance (MANOVA) was performed according to Mohammadi and Prasanna (2003). In order to test the validity and optimize the groups obtained, an analysis of variance (ANOVA) was carried out. When a significant difference was revealed between groups for a given character, the ANOVA was supplemented by the Tukey test which makes it possible to identify the group(s) which differs significantly from others.

A discriminant analysis (step-by-step method) was carried out so as to determine the variables that best differentiate the groups identified in the hierarchical classification. The selection criterion used to estimate this discriminating power was the multivariate Wilks lambda. As a preliminary to this, the normality of the variables and the equality of the variance/covariance matrices of the groups has been verified. The homogeneity of the group variance/covariance matrices was verified using the Box test.

Descriptive analyses, Principal component analysis, hierarchical ascending classification, ANOVA and discriminant factorial analysis were carried out with STATISTICA 7.1 (Statistica, 2005) and SPSS 16.0 software (Statistical Package for Social Science Software, 2007).

Results and discussion

Variation of quantitative traits

The average, minimum, maximum values and the coefficient of variation (CV) of the different traits observed in the 36 cashew tree ecotypes are summarized in Table 2. A large variation between ecotypes (in %) was observed for trunk circumference, tree spread in East-West direction and tree spread in North-South direction North-South (36.99, 30.29 and 31.72, respectively). A very large variation between ecotypes was also observed for nut yield, with a CV of 90.95%. The results showed that there was significant phenotypic diversity among cashew ecotypes cultivated by farmers. These results are consistent with previous studies conducted on this species. From morphological studies of six vegetative traits, Djaha *et al.* (2014) identified high CV concerning trunk diameter (38.42%), plant height (31.13%) and plant spread (28.32%) on 57 cashew tree accessions.

Conversely, CV values (in %) indicated little variation between ecotypes concerning nut thickness, nut length, nut width and leaf length (8.71, 12.51, 12.85 and 13.91%). Nut weight and nuts count showed average variations, with CV of 26.93 and 23.03%. The results would indicate little variation between ecotypes for the traits that are related to the size of nuts. This would show homogeneity between ecotypes concerning the characters related to the size of the nuts. These results corroborate those of Chabi Sika *et al.* (2015), who observed little variations in nut length (14.83%) and nut width (14.99%), in their study conducted on cashew trees in Benin. Overall, the differences between the minimum and maximum values for all the features analyzed showed significant phenotypic variability among the ecotypes in our study. This could be explained by the allogamous nature of cashew tree on the one hand, and the fact that the plant material used by producers came from various geographical origins on the other hand. According to Djaha *et al.* (2014), most cashew tree orchards in Côte d'Ivoire would consist of descendants of the 'Jumbo' variety of Brazilian origin, and seeds introduced from Australia and Benin. Mzena *et al*. (2018) also showed a wide range of CV that ranged from 11.6% plant height to 42.7% yield and 46.5% number of nuts, in their study on agro-morphological characterization of two hundred genetically diverse F_2 progenies of cashew. These authors mentioned that the significant variability found in the

Table 2. Minimum, maximum, average values and coefficient of variation of the 14 quantitative traits studied.

Variables	Minimum	Maximum	Average	Standard deviation	% Coefficient of variation
Trunk circumference (m)	0.35	2.92	1.38	0.51	36.99
Tree height (m)	3.50	9.50	6.23	1.45	23.25
Tree spread in East-West direction (m)	3.34	19.90	11.77	3.57	30.29
Tree spread in North-South direction (m)	4.00	20.20	11.71	3.71	31.72
Crotch angle of main branch (°)	50.00	190.00	110.69	32.32	29.20
Leaf length (cm)	12.70	23.00	15.65	2.18	13.91
Leaf width (cm)	6.03	13.00	9.14	1.57	17.17
Angle of leaf petiole relative to stem (°)	10.00	15.00	12.67	2.43	19.15
Nut length (cm)	2.90	4.80	3.43	0.43	12.51
Nut width (cm)	2.20	3.40	2.69	0.35	12.85
Nut thickness (cm)	1.50	2.30	1.86	0.16	8.71
Nut yield (kg of nut tree^{-1})	0.50	48.50	13.66	12.42	90.95
Nut count	73.00	190.00	128.53	29.60	23.03
Nut weight (g)	5.90	13.10	8.04	2.16	26.93

population, confirmed that agro morphological traits can be used to discriminate genotypes to different groups. This high variability is attributed to segregation nature of cashew which is characterized by high genetic recombination.

Agro-morphological diversity structuration

The application of the Kaiser criterion led to selecting four dimensions: those with an eigenvalue greater than a unit (Table 3). These first four axes alone accounted for 82.21% of the total variance. The first axis restored 33.98% of the variance, the second axis 26.50%, the third axis 13.94% and the fourth axis 7.79%. The review of factor scores (Table 4) showed that axis 1 was characterized on the positive side by the nut weight (0.967), nut width (0.933) and nut thickness variables (0.747) and on the negative side by nut count (-0.960) variable. This axis can be interpreted as the yield component axis. Axis 2 was explained by tree spread in North-South direction (0.924), tree spread in East-West direction (0.922), trunk circumference (0.856), tree height (0.835) and nut yield (0.734). All these variables were positively correlated to the axis. This axis mainly described plant vegetative development and the yield. Two variables contributed to the formation of the third axis: leaf length (0.906) and leaf width (0.876). This axis provided additional information to axis 2. The following variables contributed to the formation of axis 4: angle of leaf petiole relative to stem (0.786) and crotch angle of main branch (0.709). This axis also provided additional information to axis 2.

The projection of individuals and variables (Figure 2) in the principal plane (plane 1–2), showed the individuals that weighed the most in the emergence of components. Axis 1 indicated ecotypes which yielded large and less numerous nuts (Bo13, Wa8, Ka7, Ka10, Ka8, Ka6, Ka11, Ka15, and Bo10, against ecotypes which yielded small and numerous nuts (Ko1, Ko3, Ka1, Ka4, Ka14, Ka5, Bo12 while Axis 2 distinguished ecotypes which were small in size, which had less significant spread and which were low yielding (Wa9, Wa5, and Wa11) from ecotypes which were large in size, which had more significant spread and which were high yielding (Ka9).

The results highlighted the relationship existing between the vegetative development, the yield and yield components of the ecotypes. For instance, the small-sized nut ecotypes would yield a lot and the large-sized nut ecotypes would yield little. This relationship between size and number of nuts was also reported by Aliyu and Awopetu (2011) in their works on 33 cashew tree accessions in Nigeria.

A hierarchical classification was carried out for grouping ecotypes according to their morphological similarity. In order to obtain the best possible classification, several analyses were tried with different aggregation methods namely: UPGMA, Complete linkage, Single linkage, Ward. As a result, the method of aggregation with the best result was the Ward method. This method provided the phenetic tree (Figure 3). The multivariate analysis of variance enabled to determine the number of optimal classes. The split into three groups gave the highest value of ($F=9.37$, $P<0.05$). The partition into three classes appeared optimal. It was therefore selected. The average values of the different groups are summarized in Table 5. Three of the 14 traits (crotch angle of main branch, Leaf length and Leaf width) did not show a significant difference between the groups ($P>0.05$). The other traits allowed a partial distinction of the groups. The first group consisted of 12 ecotypes (33.33%) which were large in size (7.33 m), whose spread (tree spread in East-West direction = 14.32 m) and girth (trunk circumference = 1.75 m) were significant. The ecotypes in this group yielded many nuts (nut count = 150.92), with relatively small nut size (nut weight = 6.79 g, nut thickness = 1.76 cm). This group contained the most yielding ecotypes with average yields of 20.17 kg nuts tree^{-1}. These ecotypes come mainly from the locality of Karakoro in the department of Korhogo (Poro region). The second group consisted of 14 ecotypes (38.88%).

Table 3. Eigen vectors and percentage of variation expressed by the first four axes of the principal components analysis.

Principal components	Axis 1	Axis 2	Axis 3	Axis 4
Eigen variance	4.758	3.710	1.952	1.091
% Total variance	33.984	26.500	13.942	7.791
% Cumulative total variance	33.984	60.484	74.426	82.217

TABLE 4. Correlation between variables and components.

Variables	Axis 1	Axis 2	Axis 3	Axis 4
Trunk circumference	-0.091	**0.856***	0.139	-0.178
Tree height	0.045	**0.835***	-0.001	-0.318
Tree spread in East-West direction	0.073	**0.922***	-0.051	0.089
Crotch angle of main branch	0.177	**0.924***	-0.056	0.017
Crotch angle of main branch	0.169	0.318	-0.198	**0.709***
Leaf length	0.202	-0.003	**0.906***	0.074
Leaf width	0.131	0.102	**0.876***	-0.256
Angle of leaf petiole relative to stem	-0.035	-0.387	-0.007	**0.786***
Nut length	**0.878***	0.134	0.004	0.175
Nut width	**0.933***	0.148	0.009	0.002
Nut thickness	**0.747***	-0.125	0.383	-0.199
Nut yield	0.029	**0.734***	0.071	0.247
Nut count	**-0.960***	0.073	-0.143	-0.077
Nut weight	**0.967***	0.113	0.131	0.032

* = significant correlation.

The ecotypes in this group were small tree size (tree height = 5.04 m) and had less significant spread (tree spread in East-West direction = 8.54 m). This group was represented by the least yielding ecotypes (nut yield = 5.22 kg nuts tree^{-1}) with relatively small nut (nut weight = 6.91 g, nut thickness = 1.83 cm) and numerous nuts (nut count = 136.57). The ecotypes of this group were mainly located in Waraniéné in the department of Korhogo (Poro). The third group consisted of 10 ecotypes, that is, 27.77% of the total population. The ecotypes in this group were medium tree size (tree height = 6.60 m) and had significant spread (tree spread in East-West direction = 13.24 m). This group contained ecotypes yielding big nuts (nut thickness = 2.03 cm, nut weight = 11.12 g), with less numerous nuts (nut count = 90.40). The ecotypes of this group 3 (17.68 kg nuts tree^{-1}) and those of group 1 (20.17 kg nuts tree^{-1}) had average nut yields. They were mainly located in Karakoro. Ecotypes coming from Boundiali (Bagoué region) were distributed throughout these three groups.

The ascending hierarchical classification made it possible to structure the diversity into three groups. Whatever their regions of origin (Poro and Bagoué regions), the ecotypes were distributed throughout the three groups formed. Indeed, the two regions from which the studied ecotypes originated belong to the same agro-ecological zone, namely the sub-Sudanian Savannah area. Thus, a structuring of the morphological diversity according to the agro-ecological zones cannot be highlighted in this study. In contrast, the observation of morphological diversity of cashew tree accessions in Malawi by Chipojola *et al.* (2009) was attributed to geographic and ecological origin factors. However, the morphological diversity of the ecotypes in this study was structured in localities within the same region, particularly the Poro region. The low yielding ecotypes were located in Waraniéné while the high yielding ones were located in Karakoro. In Boundiali, the studied ecotypes ranged from low to high yielding. These ecotypes belonged to different orchards located in the same locality (Municipality of Boundiali). These results would reveal a high heterogeneity between orchards of the same locality and the same region. These observations are in accordance with those of Djaha *et al.* (2014) who in-

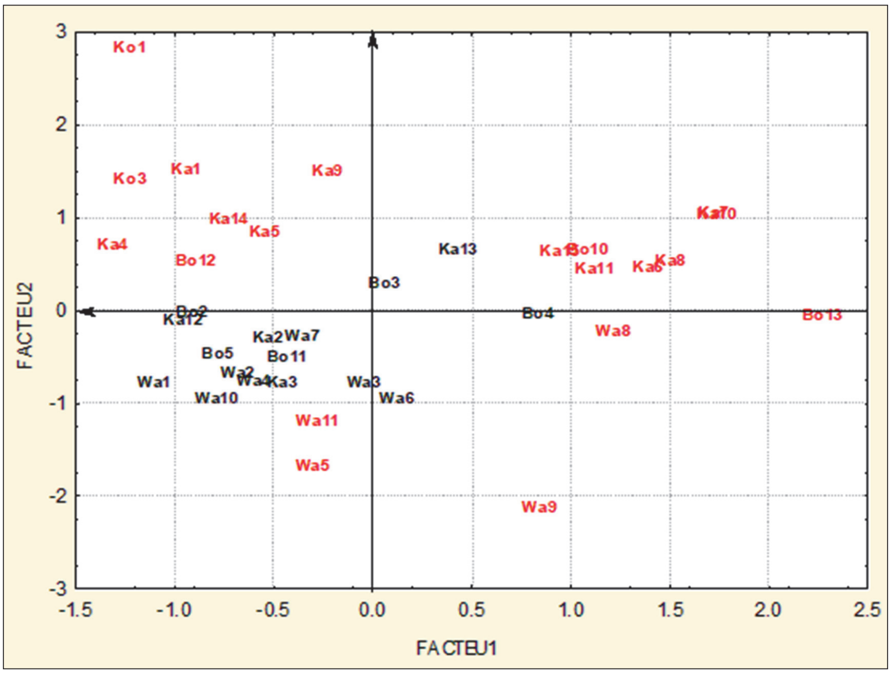

FIGURE 2. Distribution of ecotypes along axes 1 and 2 of the Principal Component Analysis. Red = individuals well represented in the 1–2 plane and interpretable; Black = poorly represented individuals in the 1–2 plane.

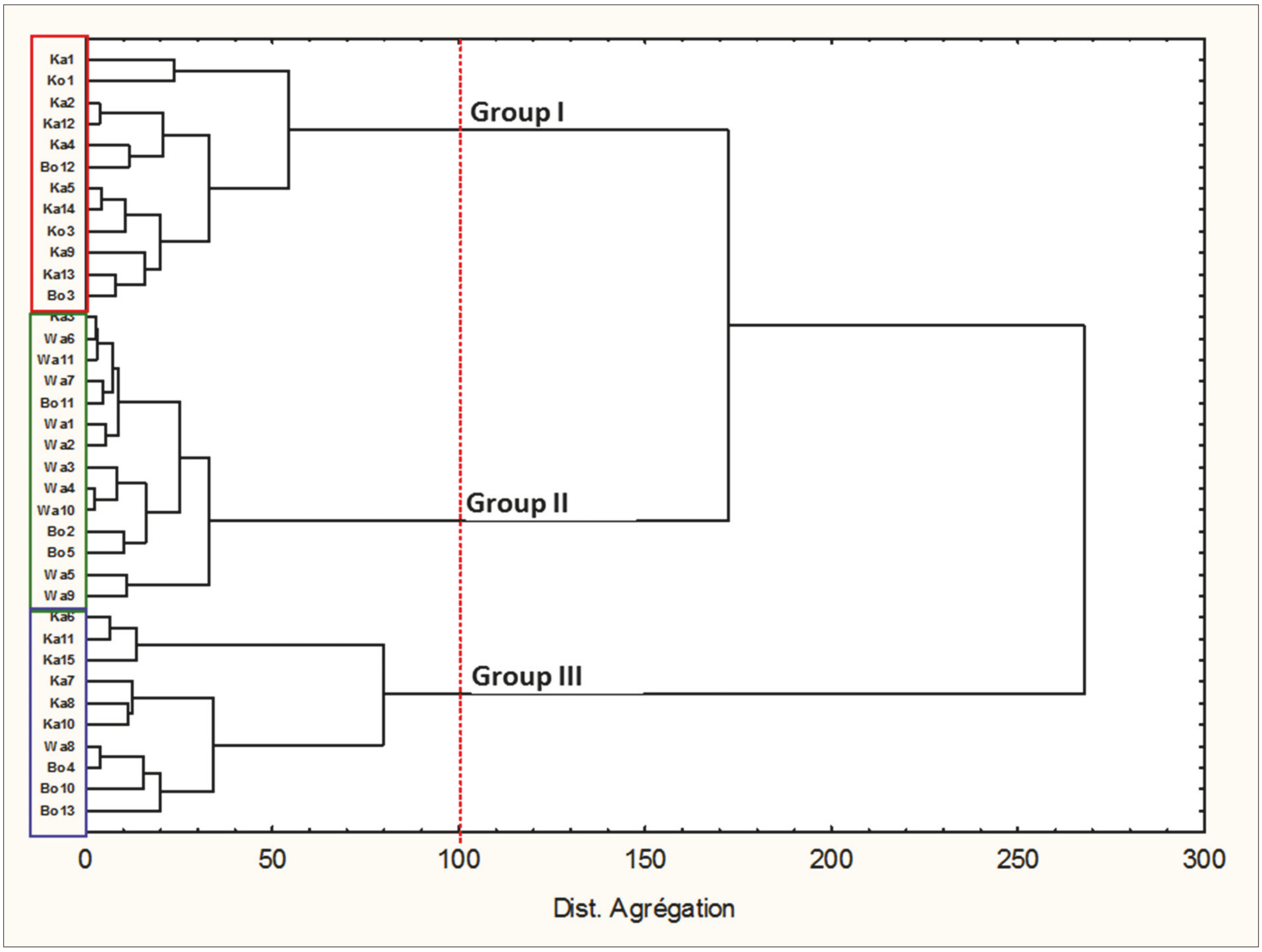

FIGURE 3. Ascending Hierarchical Classification (AHC) of 36 cashew tree ecotypes from the Poro and Bagoué Regions, using the Ward Aggregation Method.

dicated that the majority of Ivorian cashew tree orchards are made up of populations in which different trees coexist. The mentioned results are helpful for our cashew varietal improvement program. According to Smith *et al.* (1991), any breeding program is necessarily based on morpho-phenological variability.

TABLE 5. Average values of the different groups formed by the hierarchical classification.

Variables	Classes			F	P
	Group 1	Group 2	Group 3		
Trunk circumference	1.745^{a}	0.990^{b}	1.478^{a}	11.974	<0.001
Tree height	7.325^{a}	5.035^{b}	6.600^{a}	15.588	<0.001
Tree spread in East-West direction	14.318^{a}	8.537^{b}	13.240^{a}	20.370	<0.001
Tree spread in North-South direction	14.044^{a}	8.117^{b}	13.941^{a}	26.092	<0.001
Crotch angle of main branch	105.833^{a}	103.928^{a}	126.000^{a}	1.619	0.214
Leaf length	14.793^{a}	15.608^{a}	16.727^{a}	2.323	0.114
Leaf width	9.105^{a}	8.779^{a}	9.689^{a}	0.984	0.384
Angle of leaf petiole relative to stem	11.250^{a}	14.000^{b}	12.500^{ab}	5.184	<0.001
Nut length	3.258^{a}	3.178^{a}	3.980^{b}	32.437	<0.001
Nut width	2.467^{a}	2.535^{a}	3.170^{b}	56.809	<0.001
Nut thickness	1.758^{a}	1.835^{a}	2.030^{b}	13.821	<0.001
Nut yield	20.167^{a}	5.215^{b}	17.680^{a}	7.369	<0.001
Nut count	150.916^{a}	136.571^{a}	90.400^{b}	38.415	<0.001
Nut weight	6.791^{a}	6.907^{a}	11.120^{b}	66.748	<0.001
Effectifs	12	14	10		
	33.33 %	38.88%	27.77%		

Means followed by the same letter across rows were not statistically different.

The implication of the results for the breeder is as follows. Group 3 would have relatively high nut yielding ecotypes (1,768 t nuts ha^{-1}) and yielding large nuts, 11.12 g (nut weight greater than 7 g). These ecotypes could be multiplied and proposed to producers in order to improve the yield of Ivorian orchards, which is of the order of 0.35 to 0.50 ton per hectare, as well as the quality of their nuts. Group 1, although containing ecotypes with small nuts, 6.79 g (less than 7 g), contained three elite trees based on the combination of yield and age features of the tree. These elite trees were ecotypes 'Ko1' (25 years old with a yield of 48.5 kg nuts tree^{-1} year^{-1}, that is equivalent to 4.85 t nuts ha^{-1}), 'Ka1' (15 years old with a yield of 45 kg nuts tree^{-1} year^{-1}, equivalent to 4.5 t nuts ha^{-1}), and 'Ka9' (15 years with a yield of 34 kg nuts tree^{-1} year^{-1}, equivalent to 3.4 t nuts ha^{-1}). The size of the nuts of these elite trees could be improved by crossing these ecotypes with those of group 3 which yielded large nuts. In contrast, the nut yield of group 3 ecotypes could be improved by crossing the ecotypes of this group to elite group 1 trees.

Traits that best discriminate the three groups

The Discriminant Factor Analysis was performed so as to determine the variables that best discriminate the three groups. The results of the average equality test of groups (Table 6) showed that 11 variables make it possible to discriminate the three groups ($P<0.05$). Nut weight, nut width, nut count, nut length were the variables that better explain the difference between the groups. They were followed by tree spread in North-South and East-West directions, tree height, nut thickness and trunk circumference. Angle of leaf petiole relative to stem and nut yield seemed to be the least explanatory variables (lambda is closer to 1 and the value of F is lower). Crotch angle of main branch, leaf length and leaf width variables do not enable to discriminate groups.

The characteristics of the discriminant functions (Table 7) indicated that the first function had an eigenvalue of 9.262 and accounts for 67% of the intergroup variance. The second discriminant function, orthogonal to the first one, had an eigenvalue equal to 4.567 and only accounts for 33% of the intergroup variance. The values of the canonical correlation coefficients of the first and second functions were respectively 0.950 and 0.906. This means that the variables properly account for the structure of the groups. Wilks' lambdas of the first and second functions were low (0.018 and 0.180, respectively). These low values reflect little intra-group variations and therefore, high inter-group variability. The Bartlett KHI-2 was 107.204 for the first function and 45.499 for the second ($P<0.05$). Although the two discriminant functions obtained maximize the separation between the three groups, the power is more important for the first function.

Discriminant analysis showed that nut weight, nut width, number of nuts and nut length were the variables that better explain the difference between groups. All these traits were the components of nut yield of the studied ecotypes. Similar results were obtained by Aliyu and Awopetu (2007b) by analyzing 59 cashew tree accessions grown in Nigeria. The results could show the existence of a phenotypic selection practiced by cashew tree producers in Côte d'Ivoire. This rural selection would mainly take into account nut characteristics. The reason is that cashew trees are grown mainly for its nuts. In fact, Ivorian farmers select nuts from high yielding trees that have nuts which are of good quality so as to meet the needs of the export market or for sale to local processors. According to Masawe *et al.* (2015), processing factories accept nut count of equal or less than 200. This is due to the fact that nut count below 200 will not be easily processed due to its small size. This study highlighted some descriptors (nut

Table 6. Average equality test of groups.

Variables	Wilks' Lambda	F	ddl 1	ddl 2	Significance
Zscore: trunk circumference	0.579	11.974	2	33	0.000
Zscore: tree height	0.514	15.588	2	33	0.000
Zscore: tree spread in East-West direction	0.448	20.370	2	33	0.000
Zscore: tree spread in North-South direction	0.387	26.092	2	33	0.000
Zscore: crotch angle of main branch	**0.911**	**1.619**	**2**	**33**	**0.213**
Zscore: leaf length	**0.877**	**2.323**	**2**	**33**	**0.114**
Zscore: leaf width	**0.944**	**0.984**	**2**	**33**	**0.385**
Zscore: angle of leaf petiole relative to stem	0.761	5.184	2	33	0.011
Zscore: nut length	0.337	32.437	2	33	0.000
Zscore: nut width	0.225	56.809	2	33	0.000
Zscore: nut thickness	0.544	13.821	2	33	0.000
Zscore: nut yield	0.691	7.370	2	33	0.002
Zscore: nut count	0.300	38.415	2	33	0.000
Zscore: nut weight	0.198	66.748	2	33	0.000

ddl : degree of freedom.

Table 7. Eigenvalues associated to canonical discriminant functions.

Axis	Eigenvalues	% of Variance	Canonical correlation	Wilks' Lambda	Khi-2	ddl	p-value
1	9.262[a]	67.0	0.950	0.018	107.204	28	0.000
2	4.567[a]	33.0	0.906	0.180	45.499	13	0.000

[a] The first 2 canonical discriminant functions were used for analysis.

weight, nut width, number of nuts per kg and nut length) as the most relevant for applied breeding purposes. These descriptors are suggested for further study of cashew tree morphological diversity in Côte d'Ivoire.

Conclusion

Cashew varietal improvement in Côte d'Ivoire is recent. This study provides useful information that should be used in Ivorian cashew breeding program. It highlights the agro-morphological variability that exists between cashew ecotypes, and confirms the hypothesis of a high genetic diversity of cashew ecotypes in the Poro and Bagoué regions. Since the important step to identifying genetic variability through morphological characterization has been done, it now opens the way to the selection and creation of improved cashew varieties in Côte d'Ivoire.

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