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Agromorphological diversity of cassava cultivars (*Manihot esculenta* Crantz) in marginal production zones in Côte d'Ivoire

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Abstract

Cassava (*Manihot esculenta* Crantz) is an important foodstuff for the world's population. In Côte d'Ivoire, it is the second most important food crop after yam. However, production remains low to cover the food needs of the ivorian population. The aim of this study was to carry out an agromorphological evaluation of cassava cultivars, in order to identify suitable candidates for increasing national production in marginal production zones. Twenty (20) cassava cultivars collected in different agroecological production zones of Côte d'Ivoire were characterized on the basis of 8 quantitative variables in a Fisher block design with 3 replications in northern of Côte d'Ivoire, a marginal cassava production zone. Statistical analyses, including ANOVA, Principal Component Analysis (PCA), and Hierarchical Ascending Classification (HAC), revealed significant agromorphological variability among accessions, and also for the traits studied. PCA results confirmed this morphological variability at 73.70%. Hierarchical Ascending Classification (HAC) was used to structure these cultivars into 3 groups of morphological diversity, differentiated by plant height (HPL), height of first branching (HRAM1), tuberous root weight per plant and yield. Group 3 contains the cultivars with the highest yields, with an average of 14.78 ± 7.68. Cultivars in group 3 can be selected as elite varieties, adapted for growing cassava in marginal production zones to increase national production. These cultivars also offer a wide choice of genitors for cassava breeding in Côte d'Ivoire.

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Introduction

Cassava (*Manihot esculenta Crantz*) is a tropical plant cultivated mainly for its starchy tuberous roots. It is used for human and animal consumption. Worldwide production is growing at an average rate of 2% a year, from 252 million tonnes in 2010 to 330 million tonnes in 2022. (Faostat, 2022). It is an excellent source of calories and forms the staple diet of nearly a billion people in tropical regions (Macrae *et al.*, 1993). It is one of the most important food crops in the humid tropics. It was introduced to Côte d'Ivoire by the AKAN immigrant populations from southern Ghana, notably the Aboure and Aladjan. In Côte d'Ivoire, Cassava is the second most important food crop after yam, with production estimated at 5.6 millions tonnes in 2022 (Faostat, 2022), contributing to food and nutritional security and improving the incomes of all actors in the sector. It is produced throughout the country, but mainly in the South, West and Central regions. Its production, the majority of which is located in the southern half of the country, covers around 80% of the national territory. Today, cassava has become an essential part of the Ivorian diet. It is consumed in various forms (Attiéké, gari, foutou, placali, etc.). Despite its socio-economic importance, yields are low (Kouakou *et al.*, 2023). There are several reasons for this, including the use of low-yielding varieties susceptible to pests and diseases (Thiémélé *et al.,* 2024b), the effects of climate change, notably the shortening of rainy periods, which has led to the abandonment of several long-cycle local varieties and varieties sensitive to water stress. In Côte d'Ivoire, cassava is grown in the South, East, West and Center of the country, with little cultivation in the North due to low rainfall. This area is considered as a marginal production zone, despite the fact that cassava is considered to be tolerant to water stress (Koundinya *et al.*, 2024).

Therefore, cassava could be suitably developed in dry areas with low rainfall by identifying potential candidates. Côte d'Ivoire has a great diversity of cassava (Kouakou *et al.*, 2023), which could contain potential candidates adapted to this marginal production zone and cope with the hazards of climate change. The aim of this study is therefore to investigate the agromorphological diversity of cassava cultivars collected in different areas of Côte d'Ivoire under low-rainfall conditions, in the north of the country, with a view to identifying high-performance cassava cultivars for growing cassava in marginal production zones.

Materials and methods

Study site

The study was carried out at the botanical garden of the Peleforo GON COULIBALY University (9°27'28¨N, 5°37¨46 W) in Korhogo, northern Côte d'Ivoire. The site is characterized by a tropical Sudano-Guinean climate, marked by two seasons, a dry season from November to April and a rainy season from May to October, with average annual rainfall ranging from 1100 mm to 1600 mm. The average annual temperature is 27°C and the soils are ferralitic.

Table 1. List of cassava cultivars used and their origin

N°	Cultivars	Origin	N°	Cultivars	Origin
V1	NANTALE	Bonoua	V11	COCO	San Pédro
V2	ESSAPKELE	Dabou	V12	BONOUA B	Bonoua
V3	TRIAGNICLO	Toumodi	V13	AMANIKRO	Daloa
V4	SAMAKE	Dabou	V14	AKAMA	Grand Lahou
V5	WESSE BEH	Danané	V15	BONOUA G	Guiglo
V6	MAHIDIO	Gagnoa	V16	GROS-PIED	Toumodi
V7	POLIMAN	Touba	V17	OLEKANGA	Yamoussoukro
V8	TABOU	Man	V18	KAMAN	Dimbokro
V9	BAHIRE	Bonoua	V19	BABLE	Gagnoa
V10	YACE	Oumé	V20	GOYA 2	Guiglo

Plant material

The plant material consists of 20 cassava cultivars grown in Côte d'Ivoire and collected from farmers in different production zones on the basis of yield (Table 1).

Experimental design

The trial was set up on a 1677 m² plot. The cassava stem cuttings were planted in a Fisher block design with three (3) replications. Each block was divided into 20 elementary plots, with each elementary plot corresponding to one cultivars and comprising 3 lines of 5 plants each, for a total of 15 plants/plot. The planting density was 10,000 plants/ha, with a spacing of 1 m × 1 m between plants and between rows. Plots were separated by paths of 1.5 m and blocks 2 m apart. Cassava stem cuttings were planted obliquely at a depth of less than 10 cm. Tuberous roots were harvested 12 months after planting.

Agromorphological data collection

Data were collected according to the traits defined in the cassava descriptor table (Fukuda *et al.*, 2010). A total of 08 quantitative traits taking into account the stem, the leaves and the tuberized roots were observed at 6 and 12 months after planting (MAP) (Table 2). Data were collected on 10 of the 15 useful plants to avoid border effects per accession. Thus, data were collected on 600 plants in the three blocks.

Table 2. List of characters used for agromorphological characterization of cassava cultivars

Period of data recording	Traits observed	Code	Techniques of measurement
6 months after planting	Number of leaf lobes	NDLO	Counted the leaves per plant with consideration of the predominant number of lobes (5 leaves/plant)
	Length of leaf lobe (cm)	LLOC	Measured from the intersection of all lobes to the end of the middle lobe
	Petiole length (cm)	LPE	Measured on three leaves per plant
12 months after planting	Plant height (cm)	HPL	Measured vertically from the ground to the top of the canopy.
	Height to first branching (cm)	HRAM1	Measured vertically from ground to first primary branch.
	Number of roots per plant	NTP	Number of roots with length greater than 20 cm from three plants
	Weight of fresh root (kg)	PTP	Total root root shaving length greater than 20 cm are weighted
	Yield (t/ha)	RDT	Calculate using the formula : RDT= (Weight of fresh root/plant (kg) / (Plot area (m²)) * (10 000 m² / 1 000)

Data analysis

Data collected was subjected to a descriptive analysis to determine means, minimum and maximum, standard deviation and coefficient of variation. The coefficient of variation was considered high when it exceeded 20%. This showed the variability of certain characteristics in relation to others. An analysis of variance (ANOVA) was performed to assess the degree of discrimination of each of the traits studied, and the means were separated using the Newman-Keul test with a threshold of 5%. PCA (Principal Component Analysis) was used to identify the variables most involved in diversity at cassava cultivar level. These variables were used to perform a Hierarchical Ascending Classification (HAC) to structure the cassava cultivars in groups according to their similarity. An ANOVA was carried out to highlight the characteristics of the classes obtained by HAC, and to show whether there was any difference between them on the basis of the characteristics measured. All these analyses were carried out using XLSTAT version 2019 software.

Results

Variability of agromorphological traits

Descriptive analysis of the measured traits shows that they vary significantly between their minimum and maximum values (Table 3). The height of the first branch (HRAM1) varied considerably, with a coefficient of variation (CV) of 67.01%, ranging from 23 to 327 cm. High variations were also observed with the number of tuberous roots per plant (NTP), tuberous root weight per plant (PTP) and yield (RDT). For the number of tuberous roots per plant (NTP), values vary from 1 to 10, with an average of 5.1 and a coefficient of variation (CV) of 48.36%. For tuberous root weight per plant (TRP), values ranged from 0.1 to 3 kg, with an average of 1.33 kg and a coefficient of variation (CV) of 58.20%. Finally, yield (RDT) varied from 1 to 27 t/ha, with an average of 13.55 t/ha and a coefficient of variation of 55.23%. The number of lobes per leaf (NDLO) and plant height (HPL) show moderate variation, with CVs of 25.13% and 27.36% respectively. Central lobe length (LLOC) and petiole length (LPE) show little variation. Central lobe length varies from 8 to 19 cm, with an average of 13.88 cm and a coefficient of variation (CV) of 17.99%. Finally, petiole length (LPE) ranges from 10 to 25.6 cm, with an average of 17.90 cm and a coefficient of variation (CV) of 16.58%. Table 4 shows the mean values of various traits measured in different cassava cultivars. The results show a significant difference ($P < 0.001$) between accessions for each trait studied. The SAMAKE cultivar stands out for its first branch height, central lobe length, plant height and high yield, with respective values of 325 cm, 18 cm, 342 cm and 25 t/ha.

Table 3. Mean value, standard deviation, minimum, maximum and coefficient of variation (CV) of analyzed characters

Traits	Minimum	Maximum	Average	SD	CV (%)
HRAM1	23,000	327,000	99,150	66,433	67,01
NDLO	3,000	10,000	6,104	1,534	25,13
LLOC	8,000	19,000	13,885	2,498	17,99
LPE	10,000	25,600	17,900	2,968	16,58
HPL	90,000	344,000	225,500	61,689	27,36
NTP	1,000	10,000	5,100	2,466	48,36
PTP	0,100	3,000	1,330	0,774	58,20
RDT	1,000	27,000	13,550	7,484	55,23

LLOC : central lobe length; NDLO: number of lobes per leaf; LPE: petiole length; HPL: plant height; HRAM1: height of first branching; PTP: tuberous root weight per plant; NTP: number of tuberous roots per plant; RDT: yield; CV: coefficient of variation, SD : Standard Deviation

Table 4. Expression of mean values of evaluated traits in cassava cultivars

Cultivars	HRAM1	NDLO	LLOC	LPE	HPL	NTP	PTP	RDT
SAMAKE	325 a	7 c	18 a	20 c	342 a	7 c	2,50 a	25 a
TRIAGNICLO	190 b	8 b	15 cd	25,50 a	235 h	8 b	2,10 bc	21 d
ESSAPKELE	90 g	9 a	16 c	19 c	277 d	9 a	2,20 bc	22 c
NANTALE	100 f	9 a	11 g	17 d	215 k	9 a	2,30 ab	23 b
MAHIDIO	87 h	7 c	12 f	19 c	265 f	7 c	2,30 ab	23 b
TABOU	60 j	6 cd	15 cd	19 c	233 i	6 d	1,50 de	15 g
WESSE BEH	50 k	5 d	14 de	17 d	230 j	7 c	1,66 d	19 f
GROS-PIED	175 c	7 c	13 ef	17 d	195 n	4 f	1,00 g	10 j
OLEKANGA	110 e	5 d	13 ef	16 d	333 b	4 f	1,20 f	12 i
BABLE	50 k	6 cd	17 b	22 b	286 c	1 i	0,10 i	1 n
BAHIRE	30 m	5 d	15 cd	17 d	271 e	5 e	1,50 de	15 g
POLIMAN	88 gh	6 cd	9 h	15 e	180 o	6 d	2,00 c	20 e
AKAMA	90 g	5 d	17 b	22 b	100 r	3 g	0,30 i	3 m
AMANIKRO	89 g	5 d	15 cd	17 d	210 l	2 h	0,60 h	6 l
KAMAN	70 i	5,08 d	15 cd	17 d	263 g	2 h	0,30 i	3 m
GOYA 2	25 n	6 cd	13,20 e	16 d	195 n	6 d	1,40 ef	14 g
COCO	110 e	5 d	13 ef	16,50 d	165 p	5 e	1,30 ef	13 h
YACE	36 l	6 cd	9,50 h	12 f	200 m	6 d	1,40 ef	14 g
BONOUA G	120 d	5 d	14 de	17 d	105 q	2 h	0,30 i	3 m
BONOUA B	88 gh	5 d	13 ef	17 d	210 l	3 g	0,65 h	9 k
P	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001	<0,001
F	15808,782	29,398	65,484	107,002	19136,084	112,180	141,522	686,569

LLOC : central lobe length; NDLO: number of lobes per leaf; LPE: petiole length; HPL: plant height; HRAM1: height of first branching; PTP: tuberous root weight per plant; NTP: number of tuberous roots per plant; RDT:

yield. In the same column, means followed by the same letter are not significantly different according to the Newman-Keuls test at the 5% threshold.

Correlation between agromorphological traits

The correlation coefficients obtained between the characters ranged from -0.253 to 0.995 at the 5% threshold. Table 5 shows a number of significant correlations between traits. Yield (RDT) is strongly and positively correlated with the number of lobes per leaf (NDLO) (0.646), the number of tubers per plant (0.942) and tuber weight per plant (0.995). The number of lobes per leaf (NDLO) correlated strongly with the number of tuberous roots per plant (NTP) (0.733), tuberous root weight per plant (PTP) (0.674) and yield (RDT) (0.646), indicating a strong positive relationship. Central lobe length (LLOC) is positively correlated with petiole length (0.691). Finally, the number of tuberous roots per plant was positively correlated with tuberous root weight per plant (r = 0.941).

Table 5. Correlation matrix between quantitative traits

	HRAM1	NDLO	LLOC	LPE	HPL	NTP	PTP	RDT
HRAM1	1							
NDLO	0,337	1						
LLOC	0,324	-0,045	1					
LPE	0,384	0,310	0,691	1				
HPL	0,246	0,259	0,275	0,137	1			
NTP	0,189	0,733	-0,242	0,051	0,235	1		
PTP	0,336	0,672	-0,246	0,028	0,386	0,941	1	
RDT	0,322	0,646	-0,253	0,017	0,384	0,942	0,995	1

LLOC : central lobe length; NDLO: number of lobes per leaf; LPE: petiole length; HPL: plant height; HRAM1: height of first branching; PTP: tuberous root weight per plant; NTP: number of tuberous roots per plant; RDT: yield.

Table 6. Eigenvalue matrix and correlations between variables and axes in PCA design 1-2

Main components	Axe 1	Axe 2
Eigen value	3,821	2,075
% Variation expressed	47,757	25,939
Cumulative variation expressed (%)	47,757	73,696
Traits	Correlation between traits and factors	
HRAM1	0,186	0,307
NDLO	0,652	0,014
LLOC	0,017	0,834
LPE	0,029	0,714
HPL	0,201	0,111
NTP	0,873	0,042
PTP	0,939	0,025
RDT	0,924	0,029

LLOC : central lobe length; NDLO: number of lobes per leaf; LPE: petiole length; HPL: plant height; HRAM1: height of first branching; PTP: tuberous root weight per plant; NTP: number of tuberous roots per plant, RDT: yield. Values in bold denote highly significant correlations (P<0.001).

Structuring agromorphological variability

The results of the principal component analysis (PCA) in Table 6 reveal that the first two principal axes explain a large proportion of the total variance in the data, accounting for 73.696%. Axis 1, accounting for 47.76% of total variability, is mainly correlated with number of lobes per leaf (NDLO), number of tubers per foot (NTP), tuber weight per foot (PTP) and yield (RDT). The variables on this axis indicate that it is mainly associated with lobe quantity, tuber characteristics and yield. Axis 2 explains 25.94% of the variability and is strongly positively correlated with central lobe length (LLOC) and petiole length (LPE), indicating that this axis is mainly associated with leaf dimensions.

The hierarchical ascending classification (HAC) performed on the basis of the morphological characteristics measured led to the dendrogram showing three (03) cultivar groups with a truncation of 0.97 (Fig. 1). These groups are differentiated by first branch height (HRAM1), plant height (HPL), tuberous root weight per plant (PTP) and yield (RDT), which are the most significant variables within the groups (Table 7).

Table 7. Average characteristics for the three HAC groups

Traits	Group 1	Group 2	Group 3	Pr > F
Number	6	5	9	
HRAM1	168,333±85,95a	38,200±11,45b	86,889±14,71b	< 0,001
NDLO	6,167±1,33a	5,600±0,55a	6,343±1,65a	0,625
LLOC	15,000±2,10a	13,740±2,76a	13,222±2,28a	0,374
NPE	19,667±3,57a	16,800±3,56a	17,333±1,14a	0,195
HPL	190,333±90,67b	236,400±41,04a	242,889±4632a	< 0,001
NPT	4,833±2,32a	5,000±2,35a	5,333±2,74a	0,927
PTP	1,250±0,91b	1,281±0,63b	1,490±0,80a	0,004
RDT	12,500+9,11b	12,600±6,80b	14,778±7,68a	< 0,001

LLOC : central lobe length; NDLO: number of lobes per leaf; LPE: petiole length; HPL: plant height; HRAM1: height of first branching; PTP: tuberous root weight per plant; NTP: number of tuberous roots per plant, RDT: yield. In the same row, means followed by the same letter are not significantly different according to the Newman-Keuls test at the 5% threshold.

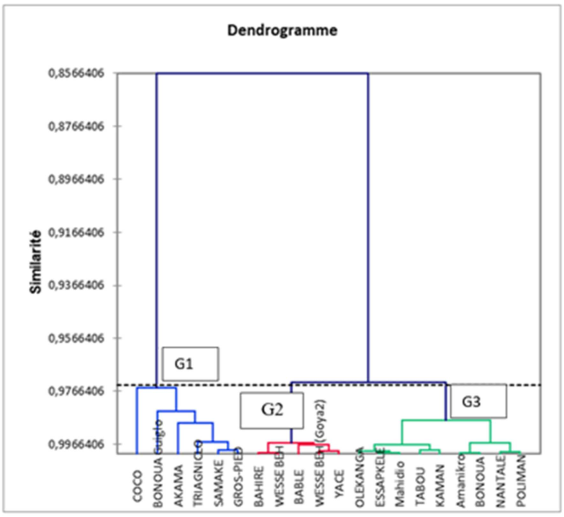

Fig. 1. Agromorphological structuring of cassava cultivars using the HAC method

Group 1 comprises 06 cultivars (SAMAKE, TRIAGNICLO, GROS-PIED, AKAMA, COCO and BONOUA G) and is characterized by small plant size (HPL = 190.33 ± 90.67 cm), greater height of the first branch (HRAM1 = 168.33 ± 85.95 cm) and an average yield of 12,50 ± 9.11 t/ha. Group 2 contains 05 cultivars (WESSE BEH, BABLE, BAHIRE, GOYA 2 and YACE) and is composed of medium-sized plants (HPL = 236,40 ± 41.04 cm), with a small height of the first branch (HRAM1= 38,20 ±11.45 cm), an average tuberous root weight per plant (PTP) of 1,25 ± 0.91 kg and an average yield of 12,60 ± 6.80 t/ha. Group 3 comprises 09 cultivars (ESSAPKELE, NANTALE, MAHIDIO, TABOU, OLEKANGA, POLIMAN, AMANIKRO, KAMAN and BONOUA B). This last group is characterized by high plants (HPL= 242.89 ± 4632 cm), with an average height of the first branch (HRAM1= 86.889±14.71bcm), a high tuberous root weight per foot (PTP) of 1.49 ± 0.80 kg and the highest yield (14.78 ± 7.68 t/ha).

Discussion

Any breeding program begins with morphological variability study (Smith *et al.*, 1991). According to Fraleigh *et al.* (1981), characterization provides breeders with vital information for their work. In this study, multivariate analyses were used to elucidate the nature and degree of divergence of cassava accessions collected in different agro-ecological zones of Côte d'Ivoire. The results of the analysis showed varied coefficients of variation, highlighting variability within cassava cultivars. This agromorphological variability was confirmed by PCA at 73.70%, highlighting significant heterogeneity among cultivars that could be exploited for cassava varietal improvement (Soro *et al.*, 2024). The variability highlighted in our study is in agreement with the work of Thiémélé *et al.* (2024b), who obtained a morphological variability of 81.81% under the same conditions. However, this variability remains high compared with the work of Kouakou *et al.* (2023) and Djaha *et al.* (2017), who obtained variabilities of 37.018% and 63.84% respectively, working on 200 accessions and 44 accessions of cassava collected in Côte d'Ivoire. Several phenomena may explain the increase in variability among cassava accessions from Côte d'Ivoire. Its could be explained by regular introductions of cassava varieties from other countries, natural hybridization and the presence of several cultivars in farmers' fields (Ferguson *et al.*, 2019; Thiémélé *et al.*, 2024b). Hierarchical Ascending Classification (HAC) analysis coupled with ANOVA showed that the cultivars studied fell into three groups, and these groups differed significantly in first branch height (HRAM1), plant height (HPL), tuberous root weight per foot (PTP) and yield (RDT). Our results are similar to those of Kouakou *et al.* (2023), Agre *et al.* (2015) and Gmakouba *et al.* (2018), who highlighted significant agromorphological diversity between cassava accessions in Côte d'Ivoire, Benin and Burkina Faso respectively, using traits such as plant height, height of first branching, number of lobes, number of tuberous roots per foot and tuberous root weight per foot. The three agromorphological diversity groups highlighted in this study are similar to those obtained by N'Zué *et al.* (2014), Kouakou *et al.* (2023) and Thiémélé *et al.* (2024a). Group 3 cultivars also have high yields. These cultivars are better candidates for improving productivity in Côte d'Ivoire and in marginal production zones, especially as their yields are well above the national average of less than 10 t/ha (Perrin, 2015). Cultivars such as SAMANKE (25 t/ha), TRIANICLO (21 t/ha), ASSAPKELE (22 t/ha), NANTALE (23 t/ha), MAHIDJO (23 t/ha) and POLIMAN (20 t/ha) had the highest yields at or above 20 t/ha. These cultivars had yields similar to those of improved varieties developed by research and grown in conventional production zones, and are excellent candidates (Bakayoko *et al.*, 2012 ; N'Zué *et al.*, 2014). These results could be explained, on the one hand, by the genetic and intrinsic potentialities of the cultivars, and on the other hand, by the fact that cassava is considered drought-tolerant (El-sharkawy, 1993).

Conclusion

The agromorphological evaluation of 20 cassava cultivars in marginal production zones on the basis of 8 quantitative traits showed significant variability and enabled us to select potential candidates for cassava cultivation in the north of the country. First branch height, plant height, tuberous root weight per plant and yield were the variables that most discriminated cultivars into 3 genetic groups, with group 3 having high-yielding individuals. Cultivars such as SAMANKE (25 t/ha), TRIANICLO (21 t/ha), ASSAPKELE (22 t/ha), NANTALE (23 t/ha), MAHIDJO (23 t/ha) and POLIMAN (20 t/ha) had yields above 20 t/ha in marginal production zones. These cultivars are potential candidates for cassava cultivation in marginal production zones, with a view to increasing national production. They are also potential breeding stock for high-yielding cassava varieties in Côte d'Ivoire.

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