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TITLE: Study of relationships between morphological and agronomic traits of cassava (*Manihot esculenta* Crantz)

ADDITIONAL TITLE : Etude des relations entre les caractères morphologiques et agronomiques du manioc (*Manihot esculenta* Crantz)

N'ZUE Boni[1], KOFFI Adjo Christiane[2], N'NAN-ALLA Oulo[2], KOUAKOU Amani Michel[1], DIBI Konan Evrard Brice[1], ESSIS Brice Sidoine[1], NGUETTA Assanvo Simon-Pierre [2]

[1] Centre National de Recherche Agronomique (CNRA), Côte d'Ivoire 01 PO 1740 Abidjan, Phone: (225) 22 48 96 24, Fax. (225) 22 48 96 11, www.cnra.ci,
[2] University Félix Houphouët-Boigny, Côte d'Ivoire, 22 PO 582 Abidjan, Phone: (225) 08 97 08 73,

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Corresponding Author
Dr. NZUE Boni
***E-mail:** nboni1@ yahoo. fr*
***Phone:** (225) 22 48 96 24*

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ABSTRACT

Cassava (*Manihot esculenta* Crantz) is a food and industrial commodity that plays a very important role in food security and the textile industry for the world's population. It ranks second among food crops after yam, with production estimated at 4.24 million tons in Côte d'Ivoire. In order to preserve the genetic diversity of cassava in the CNRA collection, several studies on morphological and agronomic characterization were carried out. However, no study on the relationship between morphological and agronomic traits has yet been conducted. It is in this context that a trial was carried out on the Adiopodoumé site in Abidjan with 261 accessions used as plant material. Work has shown a relationship between apex color, peduncle length, phelloderm color, adult limb color, average plant production, cooking and taste. In addition, the results revealed a correlation between branching habit, flowering, adult leaf shape, virus disease and dry matter content.

Additional non-english abstract

Le manioc (*Manihot esculenta* Crantz) est une denrée alimentaire et industrielle qui joue un rôle très important dans la sécurité alimentaire et l'industrie textile pour la population mondiale. Il occupe le deuxième rang des productions vivrières après l'igname avec une production estimée à 4.24 millions de tonnes en Côte d'Ivoire. Dans l'optique de préserver la diversité génétique du manioc de la collection du CNRA, plusieurs travaux portant sur la caractérisation morphologique et agronomique ont été réalisés. Cependant, aucune étude sur la relation entre les caractères morphologiques et agronomiques n'a encore été réalisée. C'est dans ce contexte qu'un essai a été réalisé sur le site d'Adiopodoumé à Abidjan avec 261 accessions utilisées comme matériel végétal. Les travaux ont montré l'existence d'une relation entre la coloration de l'apex, la longueur du pédoncule, la couleur du phelloderme, la couleur du limbe adulte, la production moyenne par plant, la cuisson et le goût. En outre, les résultats ont révélé une corrélation entre le port, la floraison, la forme des feuilles adultes, les viroses et le taux de matière sèche.

INTRODUCTION

Cassava (*Manihot esculenta* Crantz), native to South America, is a starchy plant and important in the tropics. Its ability to store in the soil two to three years after maturation gives it interesting characteristics such as starch accumulation (Kehinde, 2006). Global production in 2016 was estimated at 277 million tons, of which 57% is from Africa (FAO, 2017). Cassava is used in the textile industry, in the paper industry as an adhesive and in the food industry, as a gelling agent or stabilizer in soups, breads and sauces (Moorthy, 2004). In Côte d'Ivoire, cassava is the second most important food crop after yam, with production estimated at 3.2 million tons in 2015 (FAO, 2017). Cassava provides multiple derived products such as attiéké, placali, foutou, flour, starch and gari (N'Zué, 2007). However, the abandonment of certain traditional varieties by farmers due to factors such as their low yield (less than 15 t / ha), their long production cycle and their susceptibility to diseases (virus diseases, anthracnose, root rot) and pests (mites, scale insects, nematodes), contributes significantly to the loss of cassava genetic resources. Faced with these constraints that cause the erosion of genetic resources, a collection of these resources followed by their characterization was carried out. Work on the characterization of cassava varieties using morphological and enzymatic markers was conducted. They made it possible to group the cassava genetic resources into several classes based on the observed qualitative and quantitative characteristics measured (Fleming and Rogers, 1970, Zoundjihékpon, 1986, N'Zué, 2007). Unfortunately, according to the literature consulted, very little work has been done on the relationship between the morphological characters and the agronomic characteristics of the tuberous roots of cassava. However, the morphological characters of aerial organs such as leaves contribute greatly to the accumulation of carbohydrate reserves in the roots from photosynthesis. In addition, variety selection is often based on agronomic traits related to tuberous roots.

The general objective of this work is to improve the conditions for the selection of cassava varieties. Specifically, it involves identifying morphological characters that can be correlated with agronomic traits

MATERIALS AND METHODS

Trial localization

The study of the relationship between morphological and agronomic characters was conducted at the CNRA research station in Adiopodoumé (5 ° 19 N, 4 ° 07 W and 43 m) in southern Côte d'Ivoire. According to Avenard *et al*. (1971), this region is characterized by a hot and humid sub-equatorial climate (Attiean climate). The rainfall pattern includes two rainy seasons and two dry seasons. A large rainy season from April to July, a short dry season from August to September, a small rainy season from October to November and a long dry season from December to March. This area is dominated by forest vegetation (Caliman 1983). The soils are of ferralitic type strongly desaturated under heavy rainfall (Monnier, 1979), with a sand-clay or sandy texture. Average annual rainfall is about 2000 mm (Ndabalishye, 1995). Temperatures range from 21.5 ° C (minimum) to 32.2 ° C (maximum) under shelter (Anonymous, 2018).

Plant material

The plant material used for the study consists of 261 accessions all belonging to the cultivated species *Manihot esculenta*. These accessions are of various origins, namely, (i) local cultivars, (ii) locally improved varieties, and (iii) foreign introductions in the form of cultivars and improved varieties.

Experimental design

The experiment was conducted according to the Fisher design in August 2003 on the CNRA’s research station in Adiopodoumé. The 261 accessions were planted in strips. Each accession was planted in two rows of 6 plants each, i.e. 12 cuttings per accession with the spacing of 0.80 m between rows and 0.80 m between plants. The accessions were separated by 1.30 m. The strips were 1.50 m apart. Weeding was done on demand.

Observations and measurements

Morphological traits

Observations on the aerial part of the plant were made from the 5th month after planting. Those on the underground part were made at harvest, 12 months after planting. A total of 13 morphological characters with 33 modalities were observed on the 261 accessions (Table 1).

Table 1: Codes and scale scores of qualitative descriptors of cassava (N'Zué, 2007)

Type of descriptors	**Descriptors observed**	**Code**	**Modalities**	**score**
Leaf and stem descriptors (observations at 5 months)	Apical leaf colour	CAPE	purple green	1 2
	Vein leaf colour	CNFE	green other (red, green-red)	1 2
	Petiole colour	CPET	red green bi-colour (red>green) bi-colour (red<green)	1 2 3 4
	Mature leaf colour	CLAD	dark green light green	1 2
	Shape of mature leaf (lobes)	FFAD	narrow large	1 2
	Apical stem colour	CJTA	purple green green-purple	1 2 3
Tuberous roots descriptors (observations at harvesting (12 months))	Peduncle	LPED	sessile, short pedunculate	1 2
	Shape of tuberous roots	FRTU	conical dominant cylindrical dominant	1 2
	Epidermis colour of tuberous roots	CEPI	brown white	1 2
	Phelloderm colour	CPHE	pink white yellowish	1 2 3
	Pulp colour	CCHA	white yellow	1 2
Other descriptors	Flowering	FLOR	presence absence	1 2
	Branching habit at 12 months	PORT	spread semi-spread erect	1 2 3
	External stem colour at 12 months	CTIG	dark grey orange yellowish	1 2 3 4

Agronomic traits

The measurements included five (5) agronomic traits related to tuberous roots during harvest, 12 months after planting. The incidence of viruses (mosaic) on accessions was made on leaves 5 months after planting (Table 2).

Statistical analyses

The XLSTAT software version 2016.02.27444 was used to study the correlations between morphological and agronomic characters. Principal Component Analysis (PCA) was performed to determine correlations between variables and to obtain principal axes that are linear combinations of the input variables.

RESULTS AND DISCUSSION

Results

The principal components analysis (PCA), performed on the quantitative characteristics and qualitative characteristics, allowed to group them in main axes. Only the first 5 main axes (F1, F2, F3 F4 and F5), representing 58.58% of the total variability, were selected (Table 3). Based on the correlations between variables and factors (Table 4), these 5 axes are characterized as follows (Figures 1 and 2):

- Axis 1 (F1), representing 20.11% of the total variability, is characterized by the average production of tuberous roots per plant (Pmoyp), the cooking (cooking), the taste (taste), the coloring of the Apex (CAPE), adult limb staining (CLAD), peduncle length (LPED) and phelloderm staining (CPHE). On this axis, the average production of tuberous roots per plant, the cooking, the taste and the coloration of the phelloderm are positively correlated and are opposed to the color of the apex, the coloring of the adult limbs, the length of the peduncle. These are also positively correlated with each other. These results mean that accessions that have a purple apex, a dark green adult limbus and a short stalk have good average tuberous root production per plant, poor cooking and a bitter taste. Accessions to white or yellowish phelloderm also have a tendency to bad cooking and bad taste.

- Axis 2 (F2), describing 14.54% of the variability, is defined by mosaic (Mosa), dry matter content (Tms), adult leaf shape (FFAD), flowering (FLOR) and the port (PORT). Port, mosaic and flowering are positively correlated with each other. But, they are negatively correlated to the dry matter content and the shape of the adult leaves. These results show that spreading individuals with broad leaves, bloom, are less susceptible to mosaic and have a high dry matter content.
- Axis 3 (F3) constituting 11.04% of the variability is defined by leaf disc staining (CNFE), petiole staining (CPET) and staining of the young apical stem (CJTA).
- Axis 4 (F4) represents 7.12% of the variability. It is characterized by the average weight of tuber roots (Pmoyt), stalk coloration (CTIG) and epidermal staining (CEPI). The average weight of the tuberous roots is negatively correlated with stalk and epidermis staining.
- Axis 5 (F5) describing 5.78% of the total variability is characterized by the form of tuberous roots (FRTU).

Table 2: Agronomic characteristics measured on cassava accessions

Descriptors	Code	Rating / Unit
Incidence of diseases in the rainy season, 5 months later (mosaic)	Mosa	%
Average weight of tuberous roots	Pmoyt	Kg / tuberous roots
Average tuberous root production per plant	Pmoyp	Kg / plant
Dry matter content	TMS	%
Cooking	Cuis	good = 1, medium= 2, bad = 3
Taste after cooking	Gout	sweet = 1, neutral = 2, bitter = 3

Table 3: **Eigen values of the main axes**

Factor	Eigen value	Variability (%)	Cumulative (%)
F1	3.821	20.108	20.108
F2	2.762	14.535	34.644
F3	2.098	11.043	45.686
F4	1.352	7.118	52.804
F5	1.098	5.778	58.582
F6	1.031	5.425	64.007
F7	0.930	4.897	68.903
F8	0.797	4.196	73.099
F9	0.786	4.137	77.236
F10	0.725	3.817	81.053
F11	0.575	3.026	84.079
F12	0.513	2.702	86.780
F13	0.455	2.396	89.177
F14	0.447	2.352	91.529
F15	0.428	2.250	93.779
F16	0.350	1.844	95.623
F17	0.324	1.704	97.327
F18	0.264	1.389	98.716
F19	0.244	1.284	100.000

Table 4: Correlations between variables and factors

Factors	F1	F2	F3	F4	F5
Mosa	-0.500	**0.529**	0.223	-0.139	-0.073
Pmoyt	0.413	-0.301	-0.228	**-0.460**	0.344
Pmoyp	**0.600**	-0.444	-0.230	-0.307	0.053
Tms	-0.452	**-0.470**	-0.285	0.030	-0.117
Cuis	**0.751**	0.034	0.044	0.150	-0.098
Gout	**0.686**	0.290	-0.044	0.018	0.021
CAPE	**-0.676**	-0.106	0.317	0.005	-0.017
CNFE	-0.232	0.534	**-0.660**	-0.005	-0.133
CPET	0.276	-0.472	**0.678**	0.153	0.066
CLAD	**-0.550**	-0.064	-0.516	0.151	-0.071
CJTA	0.245	0.089	**-0.388**	0.290	-0.286
FFAD	-0.357	**-0.687**	0.106	0.192	-0.126
FLOR	-0.079	**0.415**	0.249	0.102	0.258
PORT	-0.191	**0.728**	0.243	-0.024	0.214
CTIG	0.192	-0.140	-0.413	**0.489**	0.174
LPED	**-0.496**	-0.115	-0.115	-0.046	0.473
FRTU	-0.058	-0.060	-0.344	-0.056	**0.596**
CEPI	0.102	0.005	0.103	**0.759**	0.316
CPHE	**0.620**	0.382	-0.010	0.065	-0.020

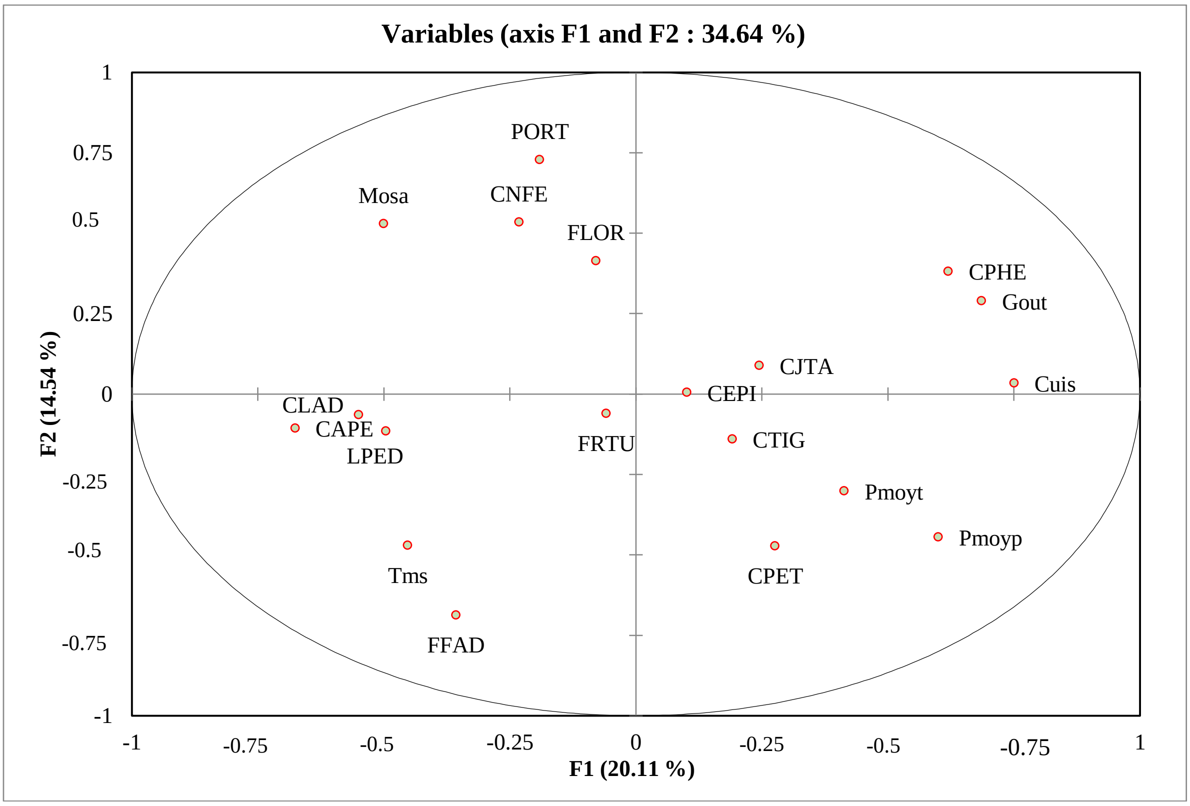

Figure 1: **Representation of variables in the main plan (F1. F2)**

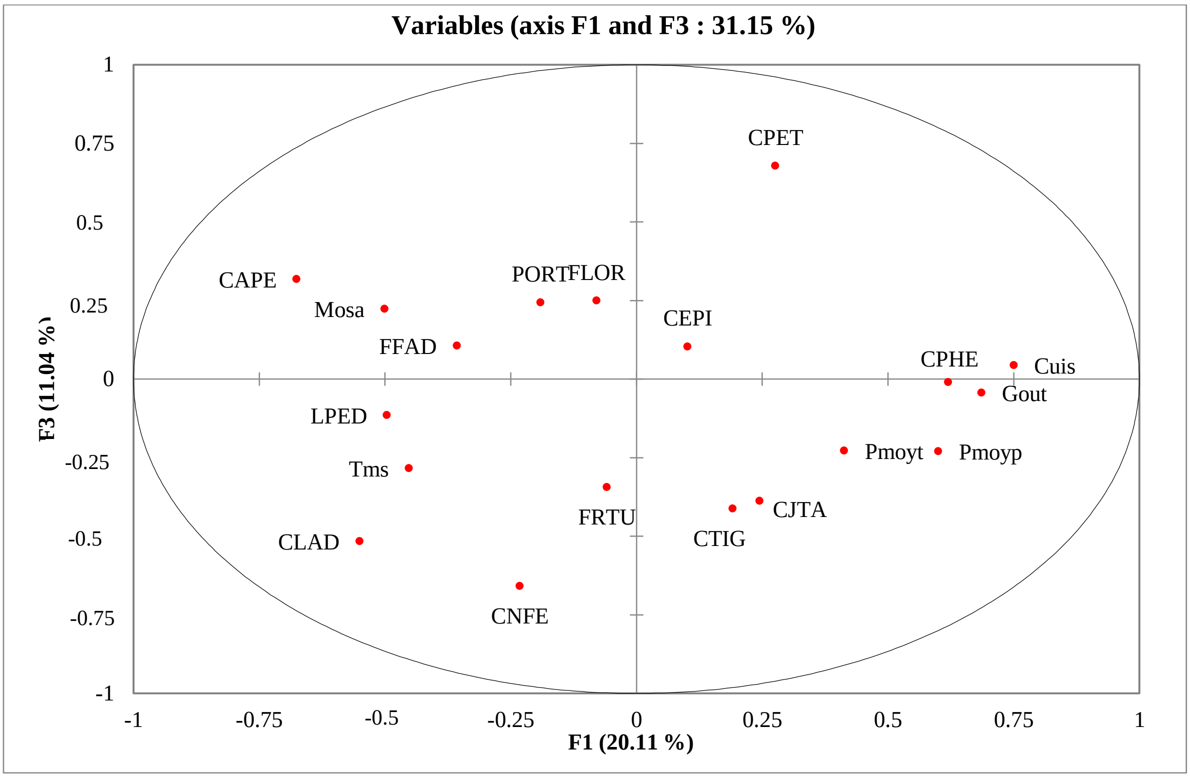

Figure 2: Representation of variables in the main plan (F1. F3)

Discussion

The analysis of the relationships between morphological and agronomic characters made it possible to identify the most discriminating descriptors that contributed to the formation of the main axes. The first five (5) axes representing 58.58% of the total variability related the different morphological and agronomic characteristics of cassava. These axes showed that accessions to white or yellowish phelloderm have poor cooking and bad taste. These results are consistent with the results obtained by Okoma (2014) who made the same observation during his work on morphological and agronomic characterization of cassava. The morphological and agronomic characters used for cassava characterization in this study are the same as those used by Okoma (2014). The author asserts that these varieties are predestined for a transformation that involves a fermentation phase such as attiéké, placali, gari. However, these varieties have a good average production per plant and mostly have purple apices, short peduncles and dark green adult limbs. This good production can be explained by the dark green color of the adult limb containing many chlorophylls, thus predisposed to a strong photosynthetic activity. Photosynthesis is the phenomenon that ensures the storage of starch in tuberous roots. This hypothesis is supported by the work of Zinga *et al*. (2016) who showed that the loss of tuberous root yield is probably due to a chlorophyll deficiency. These authors also indicated that the green color is characteristic of the presence of chlorophyll. The axes have also helped to show that spread accessions are much more resistant to mosaic and have high dry matter content. This can be attributed to the fact that spread accessions are mostly improved varieties. Thus, they had to acquire this resistance when they were created. Hédin's work (1929) confirms this resistance to the mosaic of spread varieties by showing that the Cameroonian peasants fight the mosaic by cultivating the spread varieties. In addition, the majority of these accessions flourish, because flowers are usually born in branching accessions (Eglé, 1992). Broadleaf accessions have higher dry matter content than narrow-leafed accessions. This can also be explained by photosynthesis. Indeed, the larger the leaf, the higher the number of chloroplasts in the cells. Now, photosynthesis takes place in these organelles. It is the basis for the production of carbohydrates that are partly transported to the roots of the tuber to be stored as starch. In 1984, Perez and Villamayor established a strong correlation (R^2 = 0.99) between starch content and dry matter content in cassava. Therefore, a high starch content would also justify a high material content.

CONCLUSION

At the end of the study of 261 cassava accessions, it appears that some morphological characters are good indicators that can be used to predict the agronomic characteristics of the tuberous roots. Dark green adult limbus varieties have good production, whereas those with yellow or white phelloderms have a tendency to produce bitter tuberous roots that are unfit for cooking in water. The broadleaf accessions phenotypes have a tendency to produce tuberous roots with high dry matter content. The present study could guide early selection of agronomic traits based on the observation of morphological characters.

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