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Full Length Research Paper

Agro morphological characterization of taro (*Colocasia esculenta*) and yautia (*Xanthosoma mafaffa*) in Togo, West Africa

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Taro and yautia are two edible aroids grown in the humid tropics of Asia, Africa and Latin America and used as staple food crops by millions of people in developing countries. They are mainly propagated vegetatively. Selection and improvement of these crops require characterization using desirable morphological traits for various end-uses. An agro morphological characterization study was conducted at the experimental site of Centre de Recherche Agronomique du Littoral (CRAL) of Institut Togolais de Recherche Agronomique (ITRA) in Togo. The aim of the study was to evaluate the morphological variation within taro and yautia accessions. A total of 127 accessions (26 accessions of taro and 101 accessions of yautia) were grown in a randomized complete block design with three replications from October 2016 to November 2017. Thirty-eight (38) characters were studied for taro and twenty-eight (28) for yautia. Data was analyzed using ANOVA, factorial and clustering analyses. Findings of ANOVA show high positive correlations between vegetative traits such as plant height, plant span with corm and cormels weight. The factorial analysis and dendrogram of the HCA, based on the agro morphological traits, showed four major groups for taro accessions and three groups for yautia accessions. The results demonstrated morphological variation among taro and yautia grown in Togo. Findings from this study are an important data base for conservation and use of these crops in Togo. However, the results suggest also the existence of duplicate in the collection. Ploidy analysis and molecular studies are required to complement and confirm the current agro morphological variation.

Key words: Colocasia, Xanthosoma, Araceae, morphology, diversity, Togo.

INTRODUCTION

Taro, *Colocasia esculenta* (L.) Schott, and yautia, *Xanthosoma sagittifolium* Schott, are perennial herbaceous aroids commonly grown in the humid tropics of Asia, Africa and Latin America. Most of the global production of these two crops is provided by smallholder production systems and mainly in developing

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countries (Singh et al., 2012).

Taro and yautia are the main crops of socio-economic importance in the family Araceae (Quero-Garcia et al., 2010). Globally, they rank fifth among the starchy root and tuber crops after cassava, potato, sweet potato and yam, have diverse traditional roles, and are prepared for eating in many different ways (Bamidele et al., 2014; Igbabul et al., 2014). Corms, cormels, and cut corm tops are generally used for propagation. The young leaves of taro (petioles and blades) are widely consumed (Matthews, 2014), and the young leaves of yautia are also consumed as a vegetable and they are an important source of proteins and vitamins (Garnier, 2004). The corms of yautia are eaten boiled, roasted and fried. Some varieties are used for the preparation of pounded fufu, a traditional dish often eaten in West Africa (Owuamanam et al., 2010).

Taro is an ancient crop of uncertain geographical and genetic origins in Southeast Asia (Matthews, 2014) and may have reached sub-Saharan Africa via the Nile or Madagascar (Quero-Garcia et al., 2010; Grimaldi 2016). Taro corms are an excellent source of carbohydrates (Rao et al., 2010; Darkwa and Darkwa, 2013). Young leaves are important source of protein, vitamins and minerals (Amagloh and Nyarko, 2012). The leaves and corms of *Colocasia esculenta* are very polymorphic. While many different morphologies are known, two botanical forms are commonly recognised and cultivated: *Colocasia esculenta* (L.) Schott var. esculenta or 'dasheen' form with large central corm, and *Colocasia esculenta* (L.) Schott var. antiquorum or the 'eddoe' form with a relatively small corm and many cormels (Quero-Garcia et al., 2010). The crop is known as aborbé in the South of Togo (designating dasheen type) and as kpèkèou in the North, designating the eddoe type.

The taxonomy of cultivated *Xanthosoma* species has only recently been reviewed. Three species of this South American genus are cultivated for their starchy corms: *X. maffafa*, *X. sagittifolium* and *X. violaceum* (Gonçalves, 2011, Croat and Delannay 2017; Croat et al., 2017). The presence of all three species in Africa has not been reported. Most agricultural writers in Africa and elsewhere have assumed that all cultivars of *Xanthosoma* sp. are *X. sagittifolium*, but *X. mafaffa* has been widely misidentified as *X. sagittifolium*, and the latter species may have a distribution that is limited to South America. In Togo, *X. mafaffa* is locally known as mancani (or bancani).

For crop selection and breeding programs, and the conservation of crop genetic resources, the morphological traits of existing cultivars need to be analysed in relation to taxonomy, agronomy (cultivation), storage and distribution, and end uses (e.g. culinary traits). Morphological analysis can also help to identify clones and reduce duplication in cultivar collections maintained for conservation and breeding purposes. Although several studies have reported diversity within taro and yautia (Lebot et al., 2010; Traore, 2013; Norman et al., 2015), the character sets recorded are generally not standardised, making comparison difficult across different reports. Here, we employ standard descriptor lists that have been recommended for *Colocasia esculenta* (IPGRI, 1999) and *Xanthosoma* (IBPGR, 1989).

In Togo, *C. esculenta* and *X. mafaffa* were described by Brunel et al. (1984) as introduced, cultivated, and more or less naturalized, and similar observations have been reported in neighbouring Benin (Hetterscheid and van der Maesen, 2006), where *X. mafaffa* is noted as having varied purplish pigmentation, as we have found in Togo. According to Akpavi et al. (2012) both are neglected and underutilized species that require promotion. Production records for *Xanthosoma* (20,165 tonnes, 20,407 tonnes and 11,337 tonnes respectively in 2011, 2012 and 2013) (DSID, 2014) show that the production is decreasing. This appears to be due to rainfall irregularity and soil poverty, and is the subject of ongoing research. Morphological characterization of both species is a prerequisite for the conservation, management and effective promotion and use of these species in Togo. Here, we describe the morphological diversity of *X. mafaffa* and *C. esculenta* in Togo, based on plants grown in a national collection.

MATERIALS AND METHODS

The plant material consists of 134 accessions collected from various locations of the country and implemented on farm.

Experimental site

The experiment/trial was implemented at the Centre de Recherche Agronomique du Littoral (CRAL) experimental station of Institut Togolais de Recherche Agronomique (ITRA) located at Davié and the following coordinates N 6° 23.355 'E 1° 12.255' with 88 m of altitude.

Experimental design and planting

The randomized complete block design (RCBD) with three replications, was used. Each block consisted of four (4) sub-blocks 11 m long and 2.25 m wide. Sub-blocks were spaced 2 m. The corms were planted in pockets 10 - 15 cm deep, following lines spaced 1 × 0.5 m (1 m between two lines and 0.5 m between two pockets). The area of the total experimental plot was 600 m^2 (25 × 24 m). The farm was implemented from the 29th October, 2016 to 10 November, 2017. No fertilizer was applied. As the experiment started at the end of the rainy season, to avoid rot of many propagules, a watering system was installed to water when needed. Regular weeding on the hoe was the main maintenance practice of the farm.

Data collection and analysis

The agro morphological characterization consisted of description of morphological and agronomic characters of accessions. It was carried out 6 months after planting for the aboveground traits and at harvest for the underground traits (corms and cormel). Both qualitative and quantitative characters were described. Thirty-eight

characters selected in the descriptor of International Plant Genetic Resources Institute (IPGRI) (1999) were studied for *C. esculenta* and 28 characters selected in the descriptor of International Board for Plant Genetic Resources (IBPGR) (1989) were studied for *X. mafaffa* (Table 1).

i) Qualitative characters: twenty-one (21) qualitative characters were described for *C. esculenta*, including eleven (11) on the aboveground part and ten (10) on the underground part. For *X. mafaffa*, sixteen (16) characters were described including eleven (11) on the aboveground part and five on the underground part.

ii) Quantitative characters: Seventeen (17) characters were described for *C. esculenta*, including 13 for the aboveground part and 4 for the underground part. Twelve (12) quantitative characters were noted for *X. mafaffa*, nine (9) on the aboveground part and three on the underground part.

For all data, accessions with no data on at least three of the five plants per replicate were discarded from the analysis. Thereafter, the quantitative data were subjected to a normality test before the one-way analysis of variance. Characters that did not have a normal distribution (Plant span (PS), plant height (PH), Number of stolon (NSt), distance of stolon (DSt), petiole length (LP), were transformed by the square root (PS_sqr; PH_sqr; NSt_sqr). Transformed values were used for multivariate analyses using IBM SPSS statistics 20 software.

Qualitative variables were recorded in presence (1) absences (0) matrix. For the petiole basal-ring colour (PBRC) for example, the modalities were coded as follows: PBRC1: White; PBRC2: Yellow; PBRC3: Orange; PBRC4: Pink; PBRC5: Violet. For an accession, if the petiole basal ring colour is pink, the score 1 is recorded for the PBRC4 and the score 0 for the others. Some quantitative variables related to yield were recoded into qualitative variables for hierarchical clustering. The structuring of variability was evaluated with a hierarchical ascending classification (HCA) using UPGMA (Unweighted pair group method with arithmetic mean). The distribution of the variability of the constituted groups was characterized by the discriminant factor analysis (FA). The DARwin6 Software was used for these analyses.

RESULTS

Variation of qualitative characteristics

All *C. esculenta* accessions had peltate leaves, undulate leaf blade margin, white petiole basal-ring, purple colour for basal third of petiole and white buds. Accessions of *X. mafaffa* showed unpelted leaves, undulate leaf blade margin, cup-shaped leaf blade and green colour for upper third of petiole. Flowering was not observed (*C. esculenta* and *X. mafaffa*) under the conditions of our trial.

Most accessions of *C. esculenta* had drooping leaves (PPLLS5 72.73%), green colour for leaf sheath and main vein (LSC3 77.23% and LMVC4 72.73% respectively), a light green to violet green colour for the middle third of the petiole (PCMT4 50% and PCMT7 18.18%) and a light green colour for the basal third of petiole (PCBT4 81.82%). Petiole junction for nearly 50% of the accessions had a yellow or purple colour (PJC1 45.45%, PJC4 50%). Few accessions showed purple for the middle and lower third of the petiole (PCBT3 31.82 and PCBT7 18.2%). For qualitative characteristics observed on the underground part, the accessions presented a brown cortex and a very fibrous character. The main corm shapes were cylindrical, elliptical and dumb-bell (CS3 31.82%, CS5 31.82% and CS4 36.36%), while for cormels, the elongated form was predominant (SC5 40.91%). The corm and cormels showed mostly uniform white flesh.

Relative to *X. mafaffa*, most of the accessions showed hasted leaves (FF2 85.86%), a purple-red leaf blade margin (LBMC 85.86%), a dark green upper leaf surface (CULS3 85.86%) and a pink petiole ring base (PBRC4 71.72%). For the underground traits most of accessions had pink buds (BC 70.72%) and cormels flesh (FCC4 70.72%). Most of cormels were elliptical (SC4 64%).

Variation in quantitative characteristics

C. esculenta accessions had a mean span (transformed values) of 7.69 ± 1.04 cm and a coefficient of variation of 13.55%. Plant height (transformed values) ranged from 4.58 to 8.43 cm with an average of 06.75 ± 0.95 cm, a coefficient of variation of 14.08%. Mean value of leaf length (LL) was 27 ± 6.72 cm and 19 ± 4.66 cm for leaf width (LW) with a coefficient of variation of about 25%. Mean leaf sheath (SL) and petiole (PL_sqr) lengths were 22.6 ± 6.72 cm and 06.18 ± 0.89 cm, respectively. Their coefficients of variation were 29.75 and 14.40%. The calculated ratios presented the lowest coefficients of variation. The mean value of leaf lamina length/width ratio (LLLWR) was 1.45 ± 0.18 with a coefficient of variation of 12.19%. The average ratio of sheath length /total petiole length (RSLTPL) was 0.6 ± 0.09 with a coefficient of variation of 14.92%.

For *X. mafaffa*, leaf lamina length/width ratio had the lowest coefficient of variation (12.55%). Plant height (PHT_sqr) ranged from 4.69 to 10.10 with an average of 7.41 ± 1.11 cm and a coefficient of variation of 14.91%. The circumference of the cormels ranged from 5 to 34 cm with an average of 15.33 ± 5.62 and a coefficient of variation of 36.67%. The dimensions of the lamina were in average 26.64 ± 7.48 cm for the length and 19.09 ± 5.35 cm width and coefficients of variation respectively 25.24 and 28%. Each accession had about 10 tubers with an average weight of 20.08 ± 5.98 g (transformed values per square root). Their respective coefficients of variation are 46.94 and 29.78%.

Relationships between the studied characters

Analysis of the relationships between the studied quantitative characteristics shows significant correlations between several quantitative characters. In fact, for *C. esculenta*, there is a positive and significant correlation between plant span, the height of the plant, lamina length and width, petiole length and sheath length. A positive

Table 1. Morphological traits measured in 127 taro and yautia accessions. The traits and measurement methods were based on the IBPGR (1989) and IPGRI (1999)

Character	Species	Trait acronym	Score code
Growth habit	*Xanthosoma*	PH	1= Acaulescent; 2=Erect aboveground stem; 3=Reclining aboveground stem
Plant span	*Colocasia*	PS	1=narrow (<50 cm); 2=medium (50-100 cm); 3=wide (>100 cm)
Circumference	*Xanthosoma*	CIR	
Plant height	Both	PHT	1=dwarf (<50 cm); 2=medium (50-100 cm); 3=tall (>100 cm)
Number of stolons (side shoots)	*Colocasia*	NSS	0=none; 1=1 to 5; 2= 6 to 10; 3=11 to 20; 4= >20
Stolon length	*Colocasia*	SL	1= Short (<15 cm); 2= Long (≥15 cm)
Number of suckers (direct shoots)	Both	NDS	0=none; 1=1 to 5; 2= 6 to 10; 3=11 to 20; 4= >20
Leaf base shape	Both	LBS	1–peltate; 99 Other (e.g. sagittate; hastate)
Predominant position (shape) of leaf lamina surface	Both	PPLLS	1=drooping; 2=horizontal; 3=cup-shaped; 4=erect - apex up; 5=erect - apex down
Leaf blade margin	Both	LBM	1-entire; 2-undulate; 3-sinuate
Colour upper leaf surface	Both	CULS	1–light green; 2–medium green; 3-dark green; 4–reddish/purplish green; 5–other (specify)
Colour lower leaf surface	Both	CLLS	1–light green; 2–medium green; 3-dark green; 4–reddish/purplish green; 5–other (specify)
Leaf blade colour	Both	LBC	1-whitish; 2-yellow or yellow green; 3-green; 4-dark green; 5-pink; 6- red; 7-purple; 8-blackish (violet-blue)
Leaf blade colour variegation	Both	LBCV	0–absent; 1=present
Leaf blade margin colour	Both	LBMC	1 = Whitish; 2= Yellow; 3 = Orange; 4 = Green; 5 = Pink; 6 = Red; 7= Purple
Leaf lamina length/width ratio	Both	LLLWR	Recorded at maximum length and width of leaf excluding petiole
Petiole junction pattern	*Colocasia*	PJP	0=absent; 1=small; 2=medium; 3=large
Petiole junction colour	*Colocasia*	PJC	0–absent; 1–light green; 2–dark green; 3–purple; 4–purple green
Leaf main vein colour	Both	LMVC	1=whitish; 2=yellow; 3=orange; 4=green; 5=pink; 6=red; 7=brownish; 8=purple
Vein pattern	Both	VP	1=V pattern ('V' space); 2=I pattern ('I' space); 3=Y pattern ('Y' space); 4=Y pattern and extending to secondary veins
Petiole/lamina length ratio	*Colocasia*	PLLR	Ratio of direct measurements
Petiole colour of top third	Both	PCTT	1=whitish; 2=yellow; 3=orange; 4=light green; 5=green; 6=red; 7=brown; 8=purple
Petiole colour of middle third	Both	PCMT	1=whitish; 2=yellow; 3=orange; 4=light green; 5=green; 6=red; 7=brown; 8=purple
Petiole colour of basal third	Both	PCBT	1=whitish; 2=yellow; 3=orange; 4=light green; 5=green; 6=red; 7=brown; 8=purple
Petiole basal-ring colour	Both	PBRC	1 = White; 2 = Green (yellow green); 3= Pink; 4 = Red; 5 = Purple
Leaf sheath length	Both	LSL	
Ratio of sheath length /total petiole length	*Colocasia*	RSLTPL	
Leaf sheath colour	*Colocasia*	LSC	1=whitish; 2=yellow; 3=light green; 4=red purple; 5=brownish
Leaf sheath edge colour	Both	LSEC	1=dark brown (continuous); 2=dark brown (not continuous)
Flower formation	Both	FLOWER	0=no flower; 1=rarely flowering (< 10% of plants flowering); 2=flowering (> 10% of plants flowering)
Corm length (measured on fully mature plants)	*Xanthosoma*	CLEN	3=short (8 cm); 5=intermediate (12 cm); 7=long (18 cm)
Corm shape	*Colocasia*	CS	1=conical; 2=round; 3=cylindrical; 4=elliptical; 5=dumb-bell; 6=elongated; 7=flat and multi-faced; 8=clustered; 9=hammer shaped
Corm weight	Both	CW	1=<0.25 kg; 2=0.25-0.50 kg; 3=0.51-1.0 kg; 4=1.1-1.5; 5=1.6-2.0 kg; 6=2.1-2.5 kg; 7=>2.5 kg
Cormel circumference	*Xanthosoma*	CCIR	
Corm cortex colour	*Colocasia*	CCC	1=white; 2=yellow or yellow-orange; 3=red; 4=pink; 5=brown; 6=purple; 7=blackish; 8=purple-yellow; 9=cream

Table 1. Contd.

Corm flesh colour of central part	*Colocasia*	CFCCP	1=white; 2=light yellow; 3=yellow-orange; 4=pink; 5=red; 6=red-purple; 7=purple; 8=purple-yellow; 9=cream
Corm flesh fibre colour of central part	*Colocasia*	CFFCCP	1=white; 2=light yellow; 3=yellow-orange; 4=red, 5=brown; 6=purple; 99=others (specify)
Bud colour	Both	BC	1=white; 2=yellow-green; 3=pink or red; 4=purple; 99=others (specify)
Number of cormels	Both	NC	1=less than 5; 2=5-10; 3=>10
Weight of cormels	Both	WCL	1=<100 g; 2=100-200 g; 3=201-300 g; 4=301-400 g; 5=401-500; 6=501-600; 7=>600
Shape of cormels	Both	SC	1=conical; 2=round; 3=cylindrical; 4=elliptical; 5=elongated; 6= elongated and curved; 99=others (specify)
Flesh colour of cormels	Both	FCC	1=white; 2=yellow; 3=orange; 4=pink; 5=red; 6=red-purple; 7=purple; 8=colour not uniform (lighter blotches or darker pigmentation)

Table 2. Pearson's correlation coefficients obtained among taro accessions.

	PS	PHT	NSS	SL	NDS	LL	LW	LLLWR	PL	PLLR	LSL	RSLTPL	CLEN	NC	CW	WCL
PS	1															
PHT	0.869**	1														
NSS	0.585**	0.665**	1													
SL	0.624**	0.517**	0.683**	1												
NDS	0.305*	0.196	0.073	0.058	1											
LL	0.805**	0.929**	0.564**	0.460**	0.069	1										
LW	0.748**	0.927**	0.563**	0.383**	0.092	0.945**	1									
LLLWR	0.303*	0.125	0.111	0.335**	-0.102	0.259*	-0.043	1								
PL	0.908**	0.969**	0.607**	0.553**	0.266*	0.906**	0.887**	0.177	1							
PLLR	0.474**	0.351**	0.201	0.318**	0.436**	0.083	0.125	-0.019	0.477**	1						
LSL	0.870**	0.920**	.668**	0.550**	0.161	.886**	.844**	0.222	0.926**	0.332**	1					
RSLTPL	0.000	0.043	0.293*	0.095	-0.159	0.063	0.047	0.000	-0.062	-0.375**	0.265*	1				
CLEN	0.037	0.041	-0.145	-0.139	-0.045	0.133	0.131	-0.086	0.080	-0.136	0.155	0.116	1			
NC	-0.011	-0.101	0.089	0.100	-0.047	-0.111	-0.118	-0.068	-0.092	-0.112	0.082	0.451**	.151	1		
CW	0.206	0.281*	0.035	-0.014	0.041	0.376**	0.392**	-0.107	0.290*	-0.154	0.333**	0.099	0.828**	0.091	1	
WCL	0.174	0.256*	0.182	0.106	-0.056	0.244*	0.250*	-0.098	0.265*	0.015	0.303*	0.158	0.221	0.628**	0.241	1

**. The correlation is significant at the 0.01 level (bilateral).
*. The correlation is significant at the 0.05 level (bilateral).

and significant correlation was observed between plant height and corm and cormels weight (Table 2).

For *X. mafaffa*, significant positive correlations are observed in plant height and cormels circumference (CCIR), lamina dimensions (LL and LW), petiole length, sheath length, corm length (CLEN), number of cormels and weight of cormels (Table 3).

The factorial analysis of *C. esculenta* qualitative traits distinguish four groups according to axes 1 and 2 with total inertia of 61.38%. Axis 1 (40.47% of inertia) separate eddoe-type accessions in the upper part. These accessions are grouped into two subgroups: a subgroup characterized by the presence of a small petiole junction pattern and violet petiole at middle third (PCMT8), the second subgroup is characterized by the absence petiole

Table 3. Pearson's correlation coefficients obtained among yautia accessions.

	PTH	CIR	NDS	LL	LW	LLLWR	PL	LSL	CLEN	NC	WCL
PTH	1										
CIR	0.930**	1									
NDS	0.121	0.130	1								
LL	0.914**	0.923**	0.211*	1							
LW	0.926**	0.909**	0.081	0.933**	1						
LLLWR	-0.378**	-0.321**	0.170	-0.228*	-0.533**	1					
PL	0.984**	0.921**	0.086	0.910**	0.935**	-0.399**	1				
LSL	0.971**	0.939**	0.130	0.928**	0.905**	-0.295**	0.969**	1			
CLEN	0.432**	0.455**	0.037	0.464**	0.496**	-0.279**	0.441**	0.443**	1		
NC	.517**	0.525**	0.142	0.547**	0.512**	-0.108	0.528**	0.548**	0.292**	1	
WCL	0.649**	0.666**	0.022	0.642**	0.644**	-0.228*	0.669**	0.674**	0.523**	0.817**	1

**. The correlation is significant at the 0.01 level (bilateral).
*. The correlation is significant at the 0.05 level (bilateral).

junction pattern and the light green petiole at middle third.

Axis 2 (20.91% inertia) associates accessions according to the purple colour for the main vein, the leaf margin, the petiole junction pattern and middle third of petiole (PCMT8), cup shaped leaf lamina surface, dark green leaf blade (LBC4), the presence of petiole junction pattern, and corm or cormels slice uniformity (CFCCP99 and FCC99) (Figure 1).

For *X. mafaffa*, axis 1 of inertia 51.17% groups the accessions into two, according to the petiole basal ring colour, the bud colour and flesh colour of cormels. Between the two extreme groups is an intermediate group having above-ground trait of the first group (CULS3, PCBT4) and underground traits of the second group (PBRC1, BC1, FCC1) (Figure 2).

Clustering analysis

The radial dendrogram cluster *C. esculenta* accessions into four groups of morphotypes (Figure 3) and *X. mafaffa* accessions into three (Figure 4). For both species, the accessions are not grouped following ecological zones except for eddoe-type accessions of *C. esculenta* accessions that were almost collected in ecological zone II. For *C. esculenta* accessions, Group 1 consists of six dasheen-type accessions from ecological zones III and IV; Group 2 also six dasheen-type accessions collected in ecological zones I (one accession), III (one accession) and IV (four accessions); Group 3 of five eddoe-type accessions and Group 4 of 4 eddoe-type accessions. For accessions of *X. mafaffa*, Group 1 consists of 14 accessions; Group 2 of 15 accessions and Group 3 of 70 accessions.

Agro morphological characteristics of morphotypes

For *C. esculenta* accessions (Figures 3 and 5), Group 1 consists of dasheen-type accessions that were collected in swampy or flooded environment. These morphotypes are founded wild along the rivers. As specific morphological features, these accessions have cup-shaped leaf surface, violet main vein and very often produce a large number of stolons.

Group 2, also consisting of dasheen-type accessions, collected in wet to flooded environment. As characteristics, they have drooping leaves, a green main vein, a large main corm with white uniform flesh or not uniform flesh.

Group 3 has eddoe-type accessions characterized by a few number of suckers, a green petiole, a yellow petiole junction pattern, and droopy leaves.

Group 4 is composed of eddoe-type accessions with many suckers, a small and purple petiole junction pattern, a purple petiole at the upper third and brown in the middle and basal third.

Groups of *X. mafaffa* accessions are characterized as follows (Figures 4 and 6):

Group 1: consists of accessions with a green

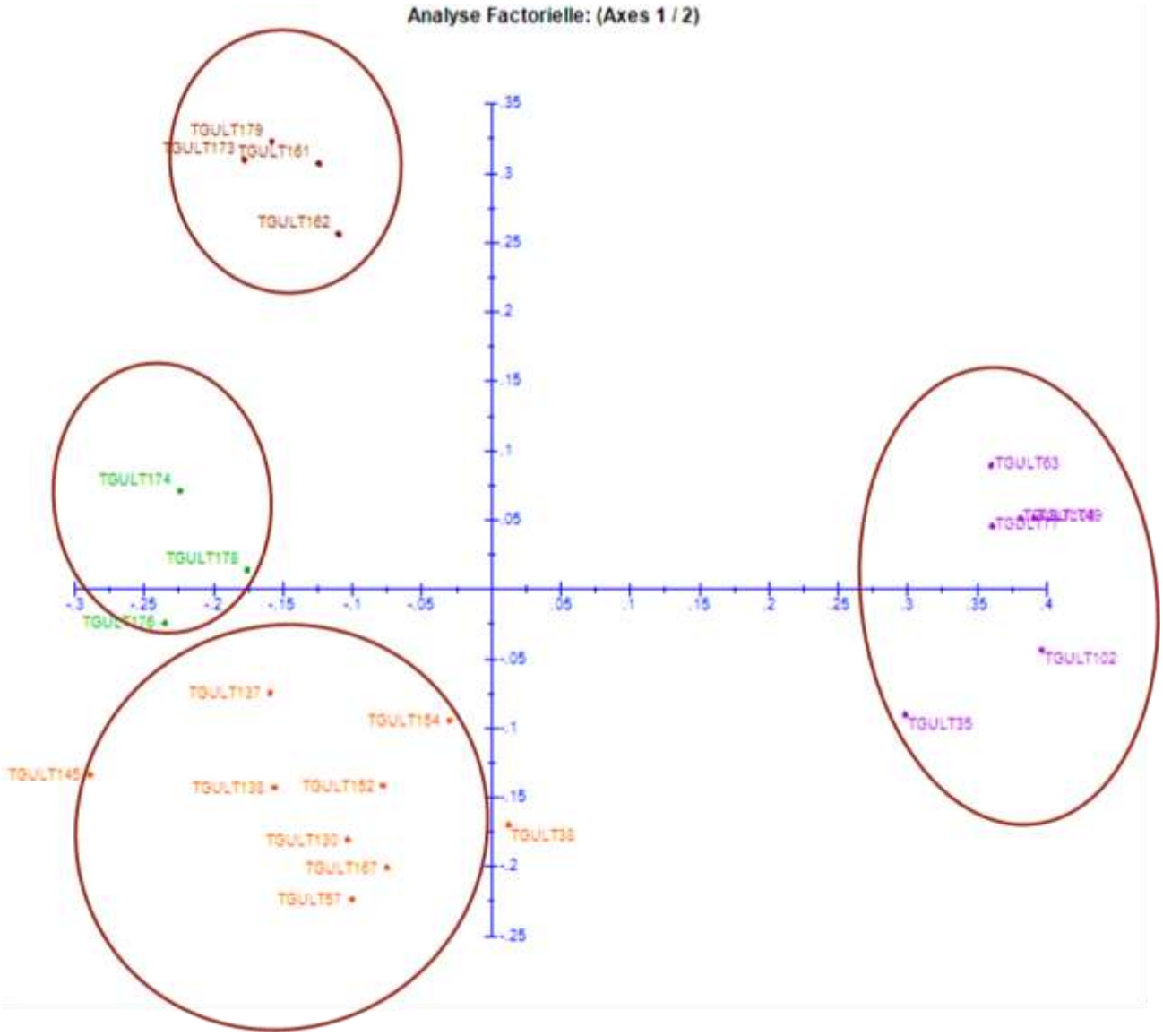

Figure 1. Factorial analysis of the qualitative characteristics of *C. esculenta*

vegetative system. The petiole basal ring is white as well as the bud and the flesh of cormels.

Group 2: an intermediate group between group 1 and group 3. It includes accessions with a dark green blade, a green petiole at the upper third and green striped violet to the lower third but a petiole basal ring the bud and the flesh of cormels are white.

Group 3: These accessions are the most abundant in the collection and the most cultivated. They are characterized by a dark green blade, a green petiole at the upper third and green striped with violet at the lower third, a petiole basal ring pink as well as the bud and the flesh of cormels.

DISCUSSION

Agro morphological variability is based on the colour of the leaf, the corms and cormels flesh colour and the shape of corms and cormels. Several authors have reported similar results for both *C. esculenta* and *X. mafaffa*. According to Lebot et al. (2004), the leaf lamina colour of taro is variable according to the genotype from yellowish to dark purple. In this study, the accessions showed yellow-green to dark green leaves. Similar results on taro were reported by Traore (2013) in Burkina Faso and by Norman et al. (2015) on yautia in Sierra Leone.

Findings of correlation analysis revealed, for both species, strong positive correlation between plant height,

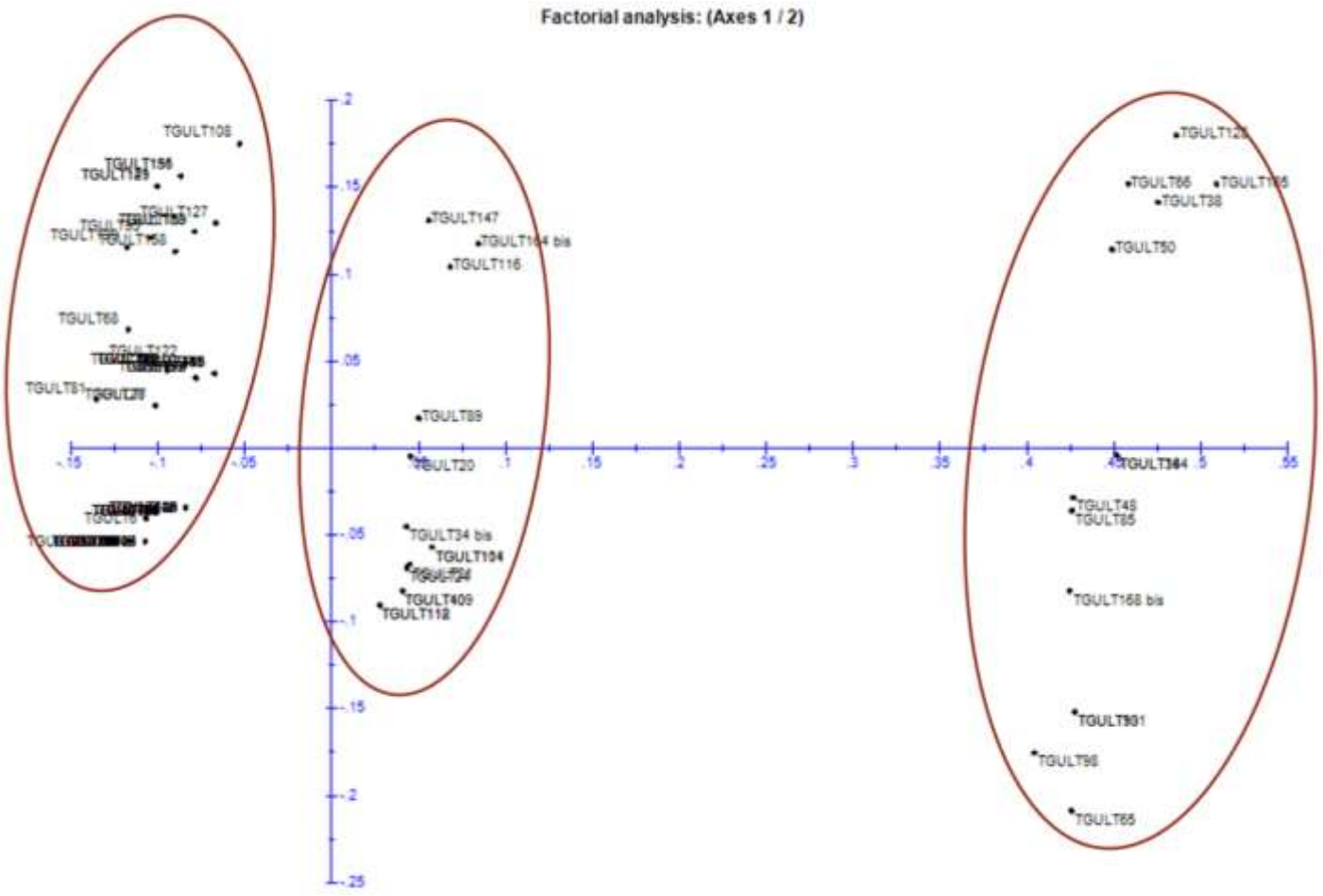

Figure 2. Factorial analysis of the qualitative characteristics of *X. mafaffa*

lamina length and width, petiole length, cormel and cormel weight. This indicates that increasing plant height increases weight of corms and cormels. The strong positive correlations observed between the quantitative traits shows a great agronomic potential of these accessions. Based on similar characters, other authors reported the interdependence between genetic variables and yield. Paul and Bari (2012), Fantaw et al. (2014) and Norman et al. (2015) reported that the number of suckers per plant, the number of cormels per plant, the weight of the cormels, the corm weight and the total yield per plant have a high heritability. According to Quero-Garcia et al. (2004), these characters can be used in the breeding program and production of these species.

The clustering analysis grouped *C. esculenta* accessions into four groups: two groups of dasheen-type accessions and two eddoe-type. The accessions were grouped based on morphological characters such as: blade colour, leaf blade margin colour, petiole junction pattern, petiole colour, leaf main vein colour. These morphological groups are similar to those described by Traore (2013) in Burkina Faso. Accessions of group 1, dasheen type, were collected in a flooded environment, most often along the rivers. This morphotype is locally named *aborbed* or *mancani kokoo*. The second group, also consisting of dasheen type accession, were also collected in wetlands. However, the two groups of eddoe morphotypes were all collected in ecological zone II, which has less annual rainfall than Ecological III and IV. This corroborates the results of Traore (2013) and Lebot et al. (2004) who report that most of the taro morphotypes adapted to flooded or irrigated conditions generally belong to the dasheen varieties and morphotypes adapted to rainfed conditions most often belonging to the eddoe varieties.

For *X. mafaffa*, three groups were identified as distinctive traits: the petiole basal ring colour, the colour of basal third of the petiole, and the colour cormels flesh and bud. According to Opoku-Agyeman et al. (2004), bud colour is the main distinguishing trait of *X. mafaffa* accessions collected in Ghana. In our study, in addition to these traits, the colour of the cormels flesh, the petiole basal ring colour and the colour of basal third of the petiole significantly contribute to the discrimination of

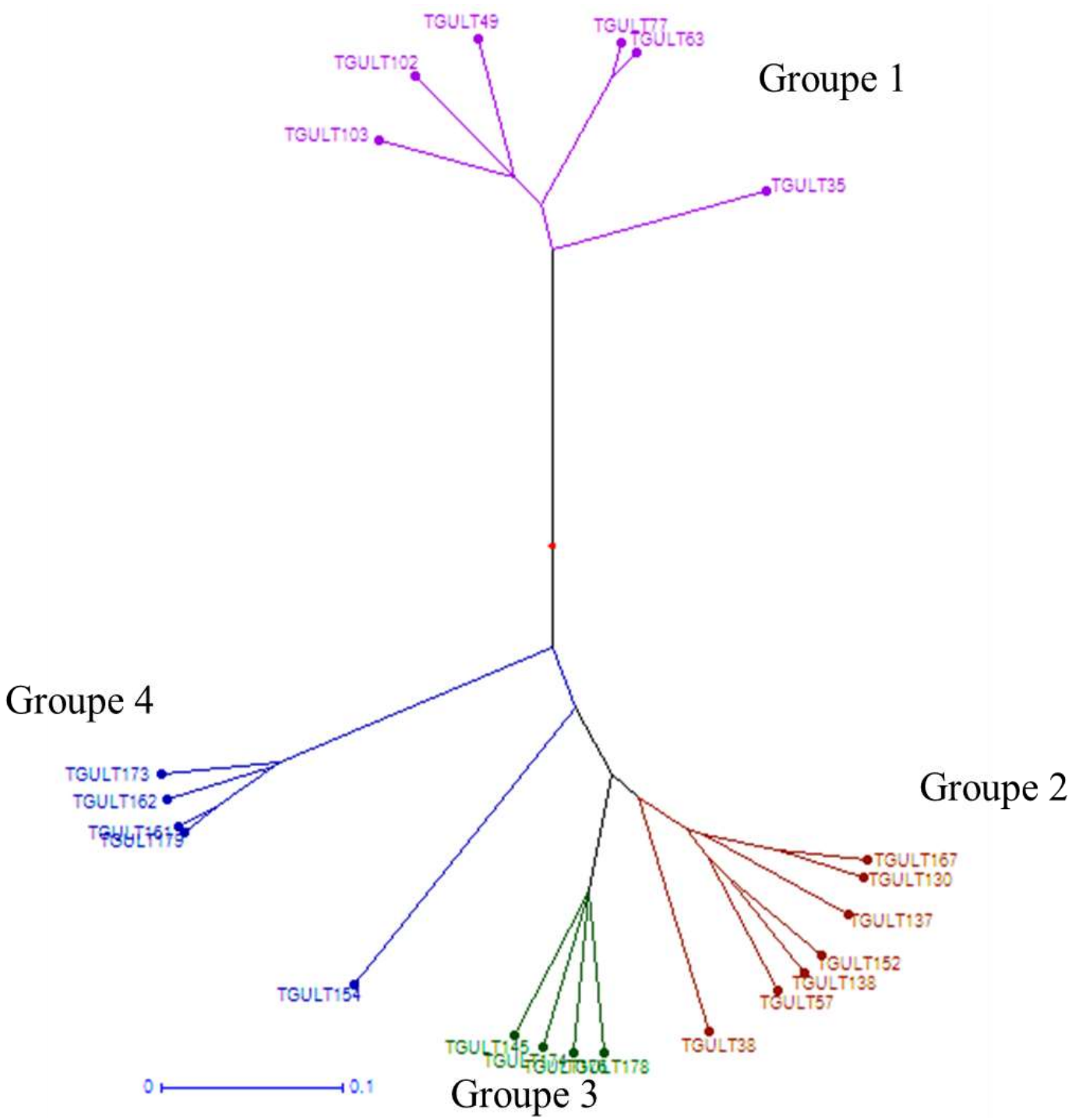

Figure 3. Dendrogram based on UPGMA analysis generated using the Euclidean coefficient representing the morphological relationships among taro accession of Togo

groups. On this basis, groups 1 and 3 are completely distinct while group 2 is an intermediate group between the two main groups. In fact, this group has morphological traits of group 3 for the above-ground part (leaf, petiole) and morphological trait of group 1 in the underground part (petiole basal ring, bud and cormels flesh). The diversity among each species is narrow compared to the diversity reported for Pacific, India or China (Mandal et al., 2013; Chaïr et al., 2016). Other studies in West Africa (Traoré, 2013; Norman et al.,

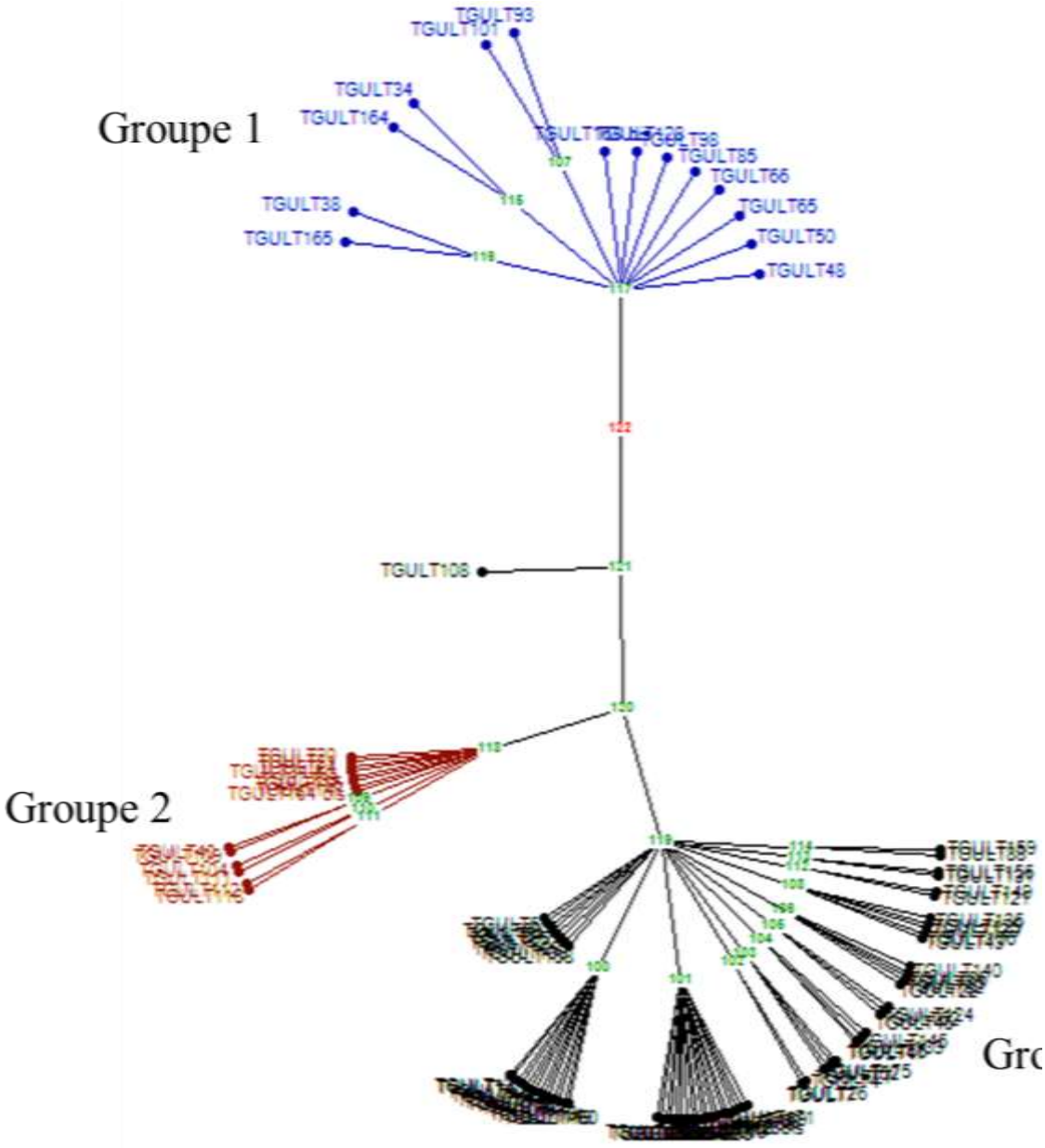

Figure 4. Dendrogram based on UPGMA analysis generated using the Euclidean coefficient representing the morphological relationships among yautia accession of Togo

2015) report a narrow genetic diversity based on morphological and/or molecular tools. The low diversity is explained by the low sexual propagation since these crops are clonally propagated.

Conclusion

Agro morphological variability is observed in taro and yautia accessions in Togo. Taro accessions are distinguished by the colour of the petiole, the leaf main vein colour, the leaf blade colour and the corm and cormels flesh colour. Based on these characters, four groups or morphotypes are distinguished. Two morphotypes of the dasheen type, most found in wet and swampy areas and two eddoe morphotypes more cultivated in the north and adapted to relatively low rainfall conditions. Although flowering was observed during the collecting survey, no accession flourished under the conditions of the trial. For yautia, three morphotypes are distinguished mainly by the colour of the petiole, leaf blade colour, petiole basal ring colour, bud and cormels flesh colour. The disproportionality of groups in accession numbers suggests a selection by

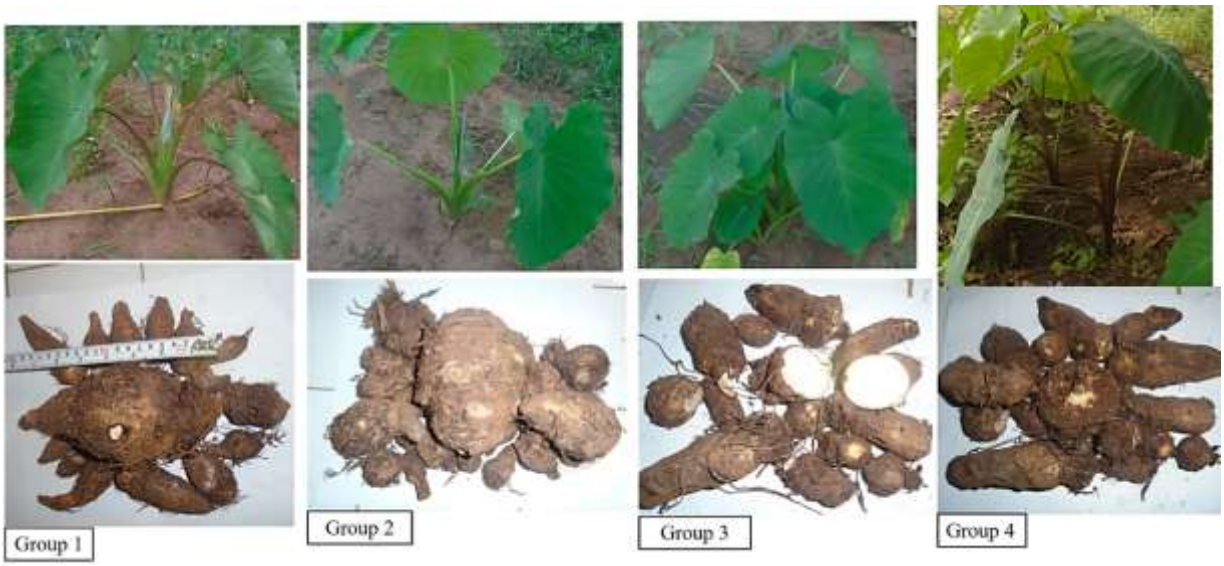

Figure 5. Accessions groups of *Colocasia esculenta*

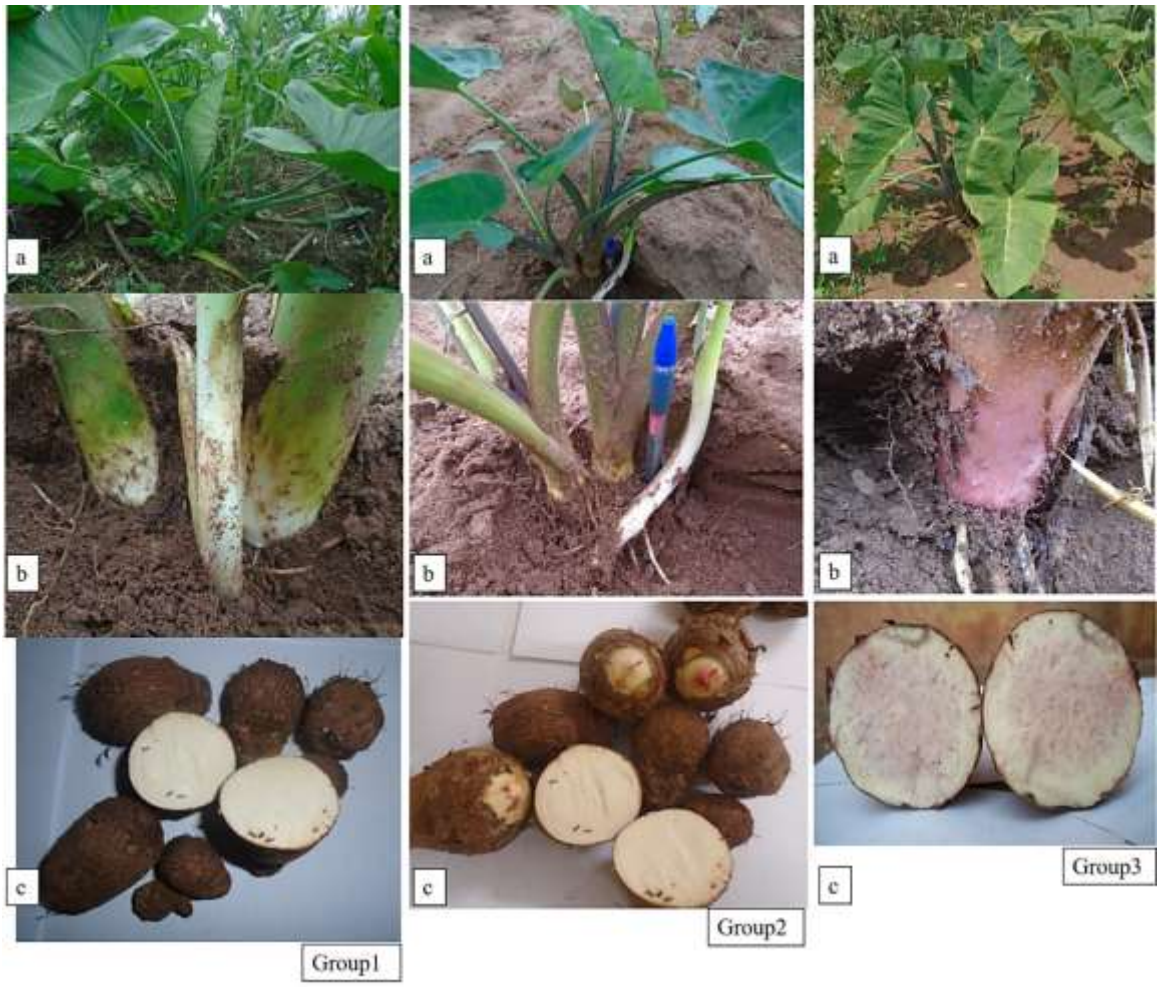

Figure 6. Accession groups of *X. mafaffa*; aboveground part (a); petiole basal ring color (b) and cormel flesh color (c)

farmers or the effect of biotic and abiotic constraints such as soil poverty, rainfall irregularity, diseases and pests. The vegetative propagation which constitutes the main way of propagation of these species suggests the existence of duplicates in the collection. In addition, the observed agro morphological variability is not always synonymous to genetic diversity. A ploidy analysis will clearly identify diploid accessions and triploid accessions for improvement. A characterization by molecular markers such as SSR is required for the identification of clones and establishment of a breeding program of these species in Togo.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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Full Length Research Paper

Evaluation of some *Musa* accessions in field collection at Ebonyi State University, Abakaliki, Nigeria

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The study was conducted to characterize and evaluate the agronomic potentials of eight *Musa* accessions in Ebonyi State University *Musa* field genebank. Qualitative descriptors were used to characterize the genotypes, while eight growth and yield traits were evaluated. Results indicated that the accessions were similar in thirteen characteristics, but differed in nine traits including pseudostem/foliage pigmentation, pseudostem/foliage waxiness, pseudostem blotching, petiole margin clasping, peduncle hairiness, persistence of neutral flowers, persistence of male bract, pulp colour of unripe fruit, and pulp colour of ripe fruit. Analysis of variance results indicated significant differences among the accessions for all the agronomic traits except fruit circumference. In terms of bunch weight, SH 3436 yielded the heaviest bunch (12.45 kg), followed by FHIA 25 (10.03 kg) and FHIA 17 (8.43 kg), respectively. These three genotypes were all banana hybrid varieties and may have adapted well to the climatic conditions of Abakaliki in southeast agro-ecological zone.

Key words: Germplasm, hybridization, *Musa* species, qualitative descriptors.

INTRODUCTION

Bananas and plantains (*Musa* species) are important staple foods in the humid tropics of the world and are sources of revenue for smallholder farmers (Vuylsteke et al., 1993a). Bananas and plantains are cultivated in compound or backyard gardens that are rich in organic matter and nutrients from household refuse. These gardens are continuously cultivated with plants growing vigorously, giving an annual yield of about 30 to 50 tonnes per hectare (Nweke et al., 1988). The fruits are high in dry-matter content, with long shelf life and good cooking qualities that make them attractive to consumers. The fruits are highly nutritious, containing large amounts of carbohydrates and minerals such as phosphorus, calcium, and potassium as well as vitamins A and C (Sharrock and Frison, 1998). Fruit production occurs throughout the year in consecutive cycles, which ensures year round food security and income for farmers (Njuguna et al., 2008).

Thus, it is important to conserve and maintain the genetic diversity of *Musa* spp., notably for use in breeding

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new lines, generating planting materials for farmers, sustaining future and extended agricultural production and ensuring food security. The *Musa* field genebank in Ebonyi State University (EBSU) was established for this purpose.

There is wide morphological variation among banana (AAA genomes) and plantain (AAB genomes) cultivars for bunch type, plant size, fruit orientation, fruit shape, size of the pseudostem and fruit colour (Simmonds and Shepherd, 1955; Tezenas du Montcel et al., 1983; Swennen, 1990). Four types of plantains have been distinguished based on inflorescence morphology, namely, French plantain, French Horn plantain, Horn and False Horn plantain (De Langhe, 1964; Tezenas du Montcel and Devos, 1978). De Langhe (1964) was the first to classify the plantain cultivars according to the size of the pseudostem into giant, medium and small types. Plant size reflects the number of leaves produced prior to flowering, potentially indicating differences in photosynthetic capacity of plants (Stover and Simmonds, 1987). To better understand the uniqueness of the accessions and varieties in EBSU Field germplasm, they needed to be characterized and evaluated.

Germplasm characterization is an important operation for a gene bank. The value of the germplasm collection depends on the availability of information relative to the accessions. Morphological and agronomic traits as well as reaction to biotic and abiotic stresses that are known to be in the individual accessions determine their relative value characterization and evaluation; they also assist in maintaining the genetic integrity of plant materials after an extended period of continuous propagation, and help germplasm users to recognize clones with desirable traits for later use in crop improvement programs.

The objectives of the study were to (a) characterize accessions in the *Musa* genebank of Ebonyi State University and (b) to evaluate these accessions for growth and yield characteristics.

MATERIALS AND METHODS

The study was conducted at the *Musa* field genebank, Department of Crop Production and Landscape Management, Ebonyi State University (EBSU), Abakaliki. Eight *Musa* accessions made up of four plantain and four banana accessions were used for the study. The plantain accessions included PITA 14, PITA 17, PITA 25 (developed by International Institute for Tropical Agriculture (IITA), Ibadan) (Vuylsteke et al., 1993b) and a local landrace called 'Agbagba'. The banana accessions included FHIA 25, FHIA 17 and SH 3436 (developed by Fundación Hondureña de Investigaçion Agricóla (FHIA) in Honduras) and a landrace denoted as 'Lagos banana'. Except 'Lagos banana' that was collected from a compound at Ikoyi, Lagos State, Nigeria, the other materials were sourced from the High Rainfall Station of IITA at Onne, Rivers State.

The field was established with minimum disturbance to the soil by adopting the zero-tillage land preparation method (Pars et al., 1990). Planting was done in 2006 following an unbalanced randomized complete block design whereby the collected accessions were assigned into non-replicated 2 row plots, each with 5 plant stands. Planting holes were prepared at a minimum size of about 30 × 30 × 30 cm^3. Suckers of acquired accessions of similar sizes were prepared for planting following procedures outlined by Swennen (1990). Prepared suckers were placed in the hole and their corm covered first with topsoil and subsequently with sub-soil. They were planted using a spacing of 3 × 2 m^2 to give a population density of 1,667 plants per hectare.

The field was maintained across years and evaluated in 2008. Mulching was done using grasses and dead leaves as well as fresh leaves and pseudostems of harvested genotypes. Weeds were controlled chemically at intervals using glyphosate and sometimes by manual weeding especially at the base of the mat. N: P: K 12:12:17 +2% MgO fertilizer was applied to each stand at the rate of 230 kg/ha. Pruning was done to eliminate young suckers except the tallest one to take over as the next ratoon after the harvest of the mother plant and to maintain plant density. Deleafing was also done regularly to ensure a neat plantation as well as good quality fruits.

Characterization of *Musa* germplasm

The *Musa* genotypes studied were characterized using qualitative descriptors as shown in Table 1.

Agronomic evaluation of field established genotypes

Data were collected for growth and yield attributes of the *Musa* genotypes as follows:

(1) Days to fruit filling (DFF), that is, the number of days elapsed from the emergence of the inflorescence to time of harvest of the bunch when at least a finger from the first two proximal hands had shown sign of ripening;
(2) Plant height at flowering (PHT, cm) measured from soil level to the point where the two highest petioles meet each other;
(3) Height of the tallest sucker at harvest (HTS, cm) measured as in PHT;
(4) Bunch weight (BWT, kg), that is, weight of a mature inflorescence of the plant carrying the fingers, grouped in hands. This was determined by weighing the bunch at harvest using a weighing balance;
(5) Total number of fruits per bunch;
(6) Number of hands per bunch;
(7) Number of fruits per hand;
(8) Fruit length (FTL) and fruit circumference (FRC): Fruit characteristics were determined from the middle fruit of the second hand and were expressed in cm.

Data analysis

Statistical analysis of data collected for agronomic parameters was done using the general linear model (GLM) procedure in Statistical Analysis System (SAS), SAS Institute (2000), Version 9; using the linear additive model for analysis of variance in RCBD experiment, thus:

$$Xij = \mu + \tau i + \beta j + Eij$$

where Xij = individual observation of i^{th} treatment in the j^{th} block; μ = overall mean of the population; τi = the effect of the i^{th} treatment; Bj = Block effect; and Eij = experimental Error (residual) per block. Significant parameters were subjected to mean separation test, using the Least Significant Difference (LSD) procedure at $P < 0.05$,

Table 1. Qualitative descriptors used in characterising accessions in Ebonyi State University *Musa* field germplasm.

Trait/State	Descriptors
Vegetative	
Leaf orientation	0-Erect, 1-drooping
Pseudostem/Foliage pigment	0-None, 3-slight, 5-moderate, 7-extensive
Pseudostem/Foliage waxy	0-None, 3-slight, 5-moderate, 7-extensive
Pseudostem colour	1-Green, 4-other
Pseudostem blotching	0-None, 3-slight, 5 moderate, 7-extensive
Petiole canal	1-Spreeding, 2-erect, 3-enrolled
Petiole margin clasping	1-Present, 0-absent
Plant juice colour	1-Watery or white, 2-pink
Sucker orientation	3-Open (stems erect), 5- intermediate, 7-dense (stems divergent)
Inflorescence	
Peduncle hairiness	0-Glabrous, 3- finely hairy, 7- coarsely hairy
Bunch compactness	1-Lax [hand internode 10cm and above], 3-dense [hand internode less than 10cm]
Persistence neutral flowers	0-Deciduous, 1-persistent
Male axis	0-Absent, 1-present
External colour of male bract	0-Male buds absent, 1-green to yellow, 2-red to purple, 3 –brown-bronze, 4-other
Texture of male bracts	1-Dull or dull-corrugated, 2-smooth and shiny
Persistence of male bracts	0-Decidous (not persistent), 1-persistent (drying off on the Male axis)
Fruit	
Arrangement in 2 rows	0-Absent, 1-present
Shape	1-Curved, 3-erect to straight
Unripe peel colour	2-Green, 4-other
Pulp colour of unripe fruit	1-White, 4-yellow orange, 5- other
Pulp colour of ripe fruit	1-Cream, 2-yellow, 3-orange yellow, 4-other
Ripe peel colour	2-Green, 3-yellow, 4-other

Source: Simmonds (1966).

while simple linear correlation was conducted based on mean values of the accessions to draw inferences on trait associations.

RESULTS

Characterization of *Musa* accessions

Results obtained using the qualitative descriptors indicated that the accessions were similar in thirteen characteristics, but different in nine traits classified under vegetative, inflorescence and fruit traits.

Vegetative traits

There were variations among the accessions for pseudostem/foliage pigmentation (Table 2). ‘Agbagba’ showed an extensive pigmentation. PITA 17, FHIA 25, FHIA 17, and SH 3436 were moderately pigmented, while PITA 14 and PITA 25 were slightly pigmented. There was no pseudostem/foliage pigmentation on ‘Lagos banana’. The accessions also varied in terms of pseudostem/foliage waxiness. ‘Lagos banana’, FHIA 17, and SH 3436 were observed to be extensively waxy. PITA 17, Agbagba, and FHIA 25 were moderately waxy, while PITA 14 and PITA 25 were slightly waxy. Similarly, the accessions differed in the extent of pseudostem blotching observed. ‘Lagos banana’, FHIA 25, and SH 3436 were extensively blotched, while the rest (PITA 14, PITA 17, PITA 25, ‘Agbagba’ and FHIA 17) possessed moderate pseudostem blotching. Petiole margin clasping was observed in PITA 14, PITA 17, and ‘Agbagba’, while it was absent in PITA 25, ‘Lagos banana’, FHIA 25, PHIA 17, and SH 3436.

Inflorescence traits

Several inflorescence traits were scored for each of the accessions studied (Table 3). Results indicated that the inflorescence peduncle of the accessions varied in degree of hairiness. ‘Lagos banana’ and FHIA 17 were coarsely hairy, while PITA 14, PITA 17, PITA 25, ‘Agbagba’, FHIA 25, and SH 3436 were finely hairy. Neutral flowers persisted in PITA 25, ‘Agbagba’, ‘Lagos banana’, and FHIA 25, while they were deciduous in

Table 2. Characterization of eight *Musa* accessions based on vegetative traits.

Genotype	Leaf orientation	Pseudostem/Foliage pigment	Pseudostem/Foliage waxiness	Pseudostem colour	Pseudostem blotching	Petiole canal	Petiole margin clasping	Plant juice colour	Sucker orientation
PITA 14	1	3	3	1	5	3	1	1	3
PITA 17	1	5	5	1	5	3	1	1	3
PITA 25	1	3	3	1	5	3	0	1	3
'Agbagba'	1	7	5	1	5	3	1	1	3
'Lagos banana'	1	0	7	1	7	3	0	1	3
FHIA 25	1	5	5	1	7	3	0	1	3
FHIA 17	1	5	7	1	5	3	0	1	3
SH 3436	1	5	7	1	7	3	0	1	3

Table 3. Characterization of eight *Musa* accessions based on inflorescence traits

Genotype	Peduncle hairiness	Bunch compactness	Persistence of neutral flowers	Male axis	External colour of male bract	Texture of male bracts	Persistence o f male bract
PITA 14	3	3	0	1	2	1	0
PITA 17	3	3	0	1	2	1	0
PITA 25	3	3	1	1	2	1	0
'Agbagba'	3	3	1	1	2	1	0
'Lagos banana'	7	3	1	1	2	1	1
FHIA 25	3	3	1	1	2	1	0
FHIA 17	7	3	0	1	2	1	0
SH 3436	3	3	0	1	2	1	0

PITA 14, PITA 17, FHIA 17, and SH 3436. Only 'Lagos banana' had persistent male bracts (that is, the male bracts dried-off on the male axis), while others had deciduous male bracts.

Fruit traits

Results indicated variations in pulp colour of unripe and ripe fruits only (Table 4). The pulp of unripe fruits of PITA 14, PITA 17, PITA 25, and 'Agbagba' were yellow-orange in colour, whereas that of 'Lagos banana', FHIA 25, FHIA 17, and SH 3436 were white. When ripe, PITA 14, PITA 17, PITA 25 and 'Agbagba' had yellow-coloured pulps, whereas 'Lagos banana', FHIA 25, FHIA 17, and SH 3436 had cream-coloured pulps.

Agronomic evaluation of *Musa* accessions

Results of analysis of variance (Tables 5 and 6) indicated very highly significant differences ($P < 0.001$) among the *Musa* accessions for days to fruit filling, plant height at flowering, number of hands per bunch and total number of fruits per bunch. It also showed highly significant difference ($P < 0.01$) among the accessions for bunch weight and average fruit length. The accessions were significantly different ($P < 0.05$) for height of tallest sucker at harvest and average number of fruits per hand. Conversely, there was no significant difference among the accessions for fruit

Table 4. Characterization of eight *Musa* accessions based on fruit traits.

Genotype	Arrangement in 2 rows	Shape	Unripe peel colour	Pulp colour of unripe fruit	Pulp colour of ripe fruit	Ripe peel colour
PITA 14	1	1	2	4	2	3
PITA 17	1	1	2	4	2	3
PITA 25	1	1	2	4	2	3
AGB	1	1	2	4	2	3
LBN	1	1	2	1	1	3
FHIA 25	1	1	2	1	1	3
FHIA 17	1	1	2	1	1	3
SH 3436	1	1	2	1	1	3

Table 5. Result of analysis of variance (mean square values) on the performance of eight *Musa* accessions grown at Ebonyi State University for some phonological traits.

Sources	DF	Days to fruit filling	Plant height at flowering	Height of tallest at harvest	Index of non-spotted leaves
Replication	1	219.76*	29076.58***	4390.42*	$1147.40^{n.s}$
Genotype	7	213.02***	8876.90***	3627.42*	16820.14**
Error	31	39.25	32480.34	1289.33	4663.32

*, **, and ***Significant at 0.05, 0.01, and 0.001 probability levels, respectively. ns: Non-significant; DF: degrees of freedom.

Table 6. Result of analysis of variance on the performance of eight *Musa* accessions grown at Ebonyi State University for some yield components

Sources	DF	Bunch Weight	Number of hands per bunch	Average number of fruits per hand	Average fruit length	Number of fruits per bunch	Fruit circumference
Replication	1	70.43*	11.95*	19.39*	33.93*	3454.47*	4.20^{ns}
Genotype	7	10.71***	9.82*	9.82*	19.96**	2571.62***	2.41^{ns}
Error	31	1.91	3.34	3.34	5.99	495.49	1.75

*, **, and ***Significant at 0.05, 0.01, and 0.001 probability levels, respectively. ns: Non-significant; DF: degrees of freedom.

circumference.

Mean performance of eight *Musa* accessions grown at Ebonyi State University for some phenological traits

The results showed that PITA 25 had the highest number of days to fruit filling (111.83 days), which differed significantly from all the other accessions studied except 'Agbagba' the plantain landrace (104 days). All the banana accessions ('Lagos banana', FHIA 25, FHIA 17, and SH 3436) had lower number of days to fruit filling compared to the plantains, and values obtained were not significantly different from each other (Table 7). The lowest number of days to fruit filling was recorded for 'Lagos banana' (approximately 92 days).

In the field, the tallest plants at flowering were FHIA 17 (256.75 cm) that significantly differed from values obtained for PITA 14, PITA 17, 'Agbagba', 'Lagos banana' and FHIA 25, but not with SH 3436 and PITA 25 (240 and 236.33 cm, respectively). The shortest plants were the 'Lagos bananas' (102.8 cm). Result also indicated that the tallest suckers were produced by PITA 25 (157 cm), closely followed by FHIA 17 (150 cm). These did not differ significantly from PITA 17 (135.7 cm), SH 3436 (129.8 cm) and 'Agbagba' (121.2 cm) suckers. The shortest suckers were produced by 'Lagos banana' (82.3 cm).

Yield components of *Musa* accessions

SH 3436 produced the biggest bunches (12.45 kg) which differed significantly from bunch weight for PITA 14, PITA 17, PITA 25, Agbagba, and 'Lagos banana'. This was followed by FHIA 25 (10.03 kg), which significantly differed from PITA 17, 'Agbagba' and 'Lagos banana',

Table 7. Mean performance and LSD values of eight *Musa* genotypes grown at Ebonyi State University for some yield components.

Genotype	Bunch weight (kg)	Number of hands per bunch	Average number of fruits per hand	Average fruit length (cm)	Total number of fruits per bunch	Fruit circumference (cm)
PITA 14	6.32	4.80	9.40	18.64	42.20	11.78
PITA 17	5.22	4.17	11.33	17.02	43.17	12.08
PITA 25	7.62	5.33	11.50	21.20	58.50	12.25
'Agbagba'	5.02	5.00	10.60	18.34	49.40	11.20
'Lagos banana'	3.80	4.75	9.00	14.60	42.75	11.95
FHIA 25	10.03	8.25	13.00	17.80	99.75	12.13
FHIA 17	8.43	7.25	12.5	17.40	87.25	11.80
SH 3436	12.45	7.00	12.17	19.98	81.00	13.42
LSD (0.05)	4.64	1.81	2.39	3.21	29.16	1.73

LSD (0.05) = Least Significant Difference at 5% probability level.

Table 8. Linear correlation coefficients among traits in eight *Musa* genotypes evaluated.

Traits	DTF	PHT	HTS	BWT	NHB	ANFH	AFL	NFB	FRC
DTF									
PHT	0.35*								
HTS	0.45**	0.71***							
BWT	0.02^{ns}	0.63***	0.39*						
NHB	-0.10^{ns}	0.46**	0.26^{ns}	0.84***					
ANFH	0.24^{ns}	0.65***	0.43**	0.70***	0.69***				
AFL	0.31*	0.57***	0.42**	0.63***	0.43**	0.28*			
NFB	-0.02^{ns}	0.56**	0.33*	0.87***	0.96***	0.83***	0.41**		
FRC	-0.03^{ns}	0.44**	0.36*	0.64***	0.47**	0.23^{ns}	0.59***	0.46**	

*, **, and ***Significant at 0.05, 0.01, and 0.001 probability levels, respectively; ns: Non-significant. DTF: Days to fruit filling; PHT: plant height at flowering; HTS: height of tallest at harvest; BWT: bunch weight; NHB: number of hands per bunch; ANFH: average number of fruits per hand; AFL: average fruit length; NFTS: total number of fruits per bunch; FCR: fruit circumference.

only. The bunch weights of the rest of the accessions were statistically the same. Results also indicated that FHIA 25 and FHIA 17 produced the highest number of hands in a bunch, having mean number of hands approximating 8 and 7, respectively. They differed significantly from PITA 14, PITA 17, PITA 25, Agbagba, and 'Lagos banana' on this trait. PITA 17 produced the least number of hands per bunch (approximately 4 hands) that was statistically the same with the number of hands recorded for PITA 14, PITA 25, 'Agbagba' and 'Lagos banana'.

In terms of average number of fruits per hand, FHIA 25 had the highest number of fruits (13.0), followed by FHIA 17 and SH 3436 (approximately 12.5 and 12, respectively). This significantly differed from number of fruits per hand for PITA 14, 'Agbagba' and 'Lagos banana'. 'Lagos banana' produced the least number of fruits per hand (9.0) that was statistically the same with PITA 14, PITA 17 and 'Agbagba'. Among the accessions, PITA 25 produced the longest fruits (21.2 cm) that differed significantly from the fruits of FHIA 17, FHIA 25, PITA 17, and 'Lagos banana'. This was followed closely by SH 3436 (19.98 cm). 'Lagos banana' produced the shortest fruits (14.6 cm) that was statistically the same with fruit length for PITA 17, FHIA 17 and FHIA 25, but differed from fruits of SH 3436, PITA 14, PITA 25 and 'Agbagba'. Conversely, FHIA 25 produced the highest number of fruits per bunch (approximately 100). This differed significantly from the number of fruits produced by PITA 14, PITA 17, PITA 25, 'Agbagba' and 'Lagos banana', but not from number of fruits produced by FHIA 17 and SH 3436 (approximately 87 and 81, respectively). PITA 14 produced the least number of fruits per bunch (approximately 42) in this experiment.

Phenotypic correlation among traits

Results indicated significant positive correlation ($P < 0.05$) between days to fruit filling, plant height at flowering, height of tallest sucker at harvest and length of fruits (Table 8). A significant and positive correlation ($P < 0.001$) was observed between plant height at flowering and height of tallest sucker at harvest, bunch weight, average

number of fruits per hand, average fruit length, and total number of fruits per bunch. Significant positive correlation ($P < 0.01$) existed between plant height at flowering, number of hands per bunch and fruit circumference. Again, strong positive correlation existed between bunch weight and its components, including number of hands per bunch, average number of fruits per hand, average fruit length, total number of fruits per bunch and fruit circumference.

DISCUSSION

To be of value, genotypes in a gene bank must be characterized. Characterization descriptors must exhibit polymorphism, either between or within taxa (Ortiz, 1997). Also, they should be highly heritable, easy to visually score and consistently expressed in all environments. The genotypes studied in this experiment exhibited differences in some vegetative traits, including level of pseudostem/foliage pigmentation, pseudostem/foliage waxiness, pseudostem blotching, and petiole margin clasping. The high level of red pigmentation observed in Agbagba in this study was as a result of the presence of anthocyanin (Ortiz, 1997). On the other hand, the absence of anthocyanin in 'Lagos banana' may have resulted in the absence of pigmentation in this accession.

Anthocyanin presence was scored during the rainy season as dry weather tends to reduce pigmentation. In this experiment, some of the accessions possessed extensive pseudostem blotching, some possessed moderate blotching, some exhibited extensive pseudostem/foliage waxiness, while others were slightly waxy. Ortiz (1997) earlier reported that tetraploid bananas had drooping leaves and extensive blotching and waxiness of the pseudostem, corroborating our observations on two banana accessions (SH 3436 and 'Lagos banana') in Ebonyi State University *Musa* field genebank.

All the genotypes were the same in leaf orientation, pseudostem colour, plant juice colour, sucker orientation and petiole canal. Leaves were drooping, pseudostems were green in colour, the plants contained white sap, petiole canal were enrolled and suckers emerged from the soil in an erect position parallel to the mother stem. For inflorescence traits, only two banana accessions ('Lagos banana' and FHIA 17) had coarsely hairy peduncles. Similar result was reported by Ortiz (1997) on Highland bananas. Accessions of PITA 14, PITA 17, PITA 25, 'Agbagba', FHIA 25, and SH 3436 possessed finely hairy peduncle and were similar to those of ABB and AAA triploids as reported by Simmonds (1966). Neutral flowers abscised from the inflorescence stalk of PITA 14, PITA 17, FHIA 17, and SH 3436, whereas those of PITA 25, 'Agbagba' and 'Lagos banana' retained neutral flowers. Only 'Lagos banana' clones retained dried male bracts on the male axis, while others had deciduous male bracts. The genotypes did not differ in bunch compactness, presence or absence of male axis, external colour of male bract, and texture of male bract as shown.

As stated by Medlicott et al. (1992), the fruit peel colour is often the major post-harvest criterion used by researchers, growers and consumers to determine whether the fruit is ripe or unripe. In some countries (e.g. Ghana, Nigeria, Honduras, etc.), consumers have developed distinct associations between colour and the overall quality of specific products. Cooking banana and plantain should be green or yellow and anything that falls short (e.g. red plantain) would be difficult to sell. Hence, colour is critical as the first visual assessment of the quality of cooking banana or plantain. In some West African countries, if the pulp colour of plantain or cooking banana is white, consumers feel that the fruit is immature and if the pulp colour is orange/yellow, it indicates that the fruit is mature. The disappearance or loss of peel green colour and the corresponding increase in yellowing of the peel during ripening are the obvious manifestations in banana, cooking banana and plantain. The loss of green colour is due to degradation of the chlorophyll structure. External changes in peel colour during ripening often reflect changes in pulp colour also (Wainwright and Hughes, 1989, 1990)

As observed in this study, peel colours of all the clones of the accessions were green when unripe and yellow when ripe. The pulp colours of plantain clones were orange/yellow when unripe, while those of banana clones were white. When ripe, the pulp of plantain clones turned yellow, while those of banana clones were cream-coloured. These observations are similar to the afore-mentioned peel and pulp colour characteristics for *Musa* species and as such, the market values of the fruits were not reduced by peel and pulp colour.

Plant height at flowering and height of tallest sucker at harvest were significantly different among the accessions studied. FHIA 17 was the tallest at flowering, while PITA 25 produced the tallest suckers at harvest. Héber and Ricardo (2001) reported similar results and indicated differences in these traits among two *Musa* cultivars (Common dwarf and Huamoa) studied in Puerto Rico. They also observed significant differences in bunch weight, number of fruits per bunch, and number of days to fruit filling among genotypes studied. Similar results were obtained in this study where, bunch weight, days to fruit filling, number of hands per bunch, number of fruits per hand and average fruit length were significantly different among the accessions indicating variation for the traits. Generally, the banana accessions required shorter number of days to fruit filling and their fruits attained the mature green stage in significantly shorter periods, compared to the plantain accessions.

The matrix of correlations between inflorescence and vegetative traits of the *Musa* accessions studied indicated

that bunch weight was significantly associated with the number of hands and fruits per bunch. Consequently, the higher the number of hands and fruits per hand, the heavier the bunch becomes (Swennen et al., 1995). Bunch weight was also significantly associated with other traits such as average number of fruits per hand, total number of fruits per bunch, average fruit length, fruit circumference, plant height and height of the tallest sucker at harvest.

A positive significant correlation between days to fruit filling and plant height at flowering indicated that taller plants required more days for their fruits to be completely filled than shorter ones. An increase in plant height at flowering resulted in an increase in the number of days to fruit filling in the eight *Musa* genotypes evaluated in this study. In the same vein, a positive significant correlation was observed between number of hands per bunch and average number of fruits per hand, total number of fruits per bunch, average fruit length and fruit circumference signified that an increase in the number of hands per bunch resulted in a corresponding increase in average number of fruits per hands, total number of fruits per bunch, average fruit length, and fruit circumference.

Conclusion

This study established that the eight *Musa* accessions in Ebonyi State University field genebank were similar in some qualitative traits and different in others. Agronomic evaluation indicated accessions with high yield potentials, including, which may be utilized as parents in crosses where feasible. The high yield of some of the accessions SH 3436 and FHIA 25, may also indicate their adaptability within the agro ecological zone and may be recommended for cultivation as an increase in the farmer's income is assured.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Evaluation of cassava hybrids performance obtained by controlled pollination of elite accessions from Niari landscape in the Republic of Congo

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Cassava is the main crop in the Congo but its low yield doesn't meet the needs of Congolese populations. The low yield is due to the use of less effective sensitive varieties to diseases, non-mastering of techniques and biotic constraint of which the African cassava mosaic. This study aims at selecting resistant genotypes to the African cassava mosaic and assessing their agronomic and production performances. Six elite accessions selected based on a villager participative approach have been crossed by controlled pollination with three clones (192/0401, 192/0325 and 197/0162) distributed by the International Institute for Tropical Agriculture (IITA). Growth, agronomic and production parameters of genotypes from the controlled pollination were evaluated at the station. Of the ten tested genotypes, the one resulting from the crossing (Mahabama x I92/0401) did not show any symptom of the cassava mosaic disease 12 months after planting. Apart from the root length, foliar surface and the height of the plant, this genotype differed from the others only by the biomass, the diameter of the stem, the harvest index, the rate of starch, the rate of dry matter and marketable or non-marketable tuberous roots. The genotype (Mahabama x I92/0401) will be included in the cassava improvement section plan in the Republic of Congo.

Key words: Cassava, Congo, African.

INTRODUCTION

Manihot esculenta is grown in the tropical and subtropical regions for its roots and leaves. These plants are a major part of the daily diet of many African populations. Cassava is the main crop in the Congo but its low yield doesn't meet the needs of Congolese populations. The cassava roots, consumed either directly in the form of "green cassava" or in the flour form, are rich in starch. They are thus a least expensive source of calories for human nutrition and animal food (Cock, 1985; FAO, 2013a; Tonukari, 2004).

Indeed, the fresh cassava roots contain between 25 to 45% of dry matter component containing 85% of starch. Cassava leaves are used as vegetables. They provide protein, vitamins and minerals to populations in East and Central Africa (Lutaladio and Ezumah, 1981; IITA, 1990; IITA, 1992; Jalloh and Dahniga, 1994). Thus, for producing countries, cassava is considered as a traditional crop for food security with its capacity to be kept in the soil, to be harvested according to the needs (DeVries and Toenniessen, 2001). For those countries, consumption needs have increasingly gone up causing an increase in prices for this commodity.

However, in Africa, the increase in cassava production is mainly related to the rise in cultivated areas (Hillocks and Thresh, 2000; Chikoti, 2011). This reflects the low yield per hectare of cassava varieties used. This poor performance cassava is also due to use of inappropriate technical by producers, the use of less efficient varieties and the fungal impact, cassava bacterial blight and viral diseases including the cassava mosaic disease (Daniel et al., 1978; Mabanza, 1980a, b; Makambila and Bakaka-Koumouno, 1982; Daniel and Boher,1985; Daniel et al., 1985; Guthrie, 1987; Fargette et al., 1985; Makambila, 1994; Gibson et al., 1996; CIAT, 1996; Thresh et al.,1997; Fokunang et al., 2000; Ntawurunga et al., 2002; Hillocks and Wydra, 2002; Neuenschwander et al., 2002).

Cassava is grown in most parts of the Republic of Congo, where 95.700 ha are under cultivation with a total production of 861.500 t (Ntawuruhunga et al., 2007). This crop mobilizes more than 70% of the rural population, mostly women, and informal activities around cassava are an important source of income for many households (MFA, 2014, FAO, 2003).

In the Congo, cassava mosaic disease is the major issue for cassava cultivation. The cassava mosaic disease is the major issue for cassava cultivation causing losses of up to 95% (Guthrie, 1987; Legg et al., 2006; Legg et al., 2005; Geddes, 1990; Mabanza et al., 1993; Thresh et al., 1994a, b; Thresh et al., 1997; Ntawuruhunga et al., 2007; Agnassim et al., 2007; Ntawuruhunga et al., 2002; Owor et al., 2004; Zinga et al., 2008; Szyniszewka et al., 2017).

An increase of the incidence of this disease causes chronic shortages of this food crop considered as a staple food for more than 90% of Congolese, in terms of crop valuation, consumption level and value chain (MAE, 2014). To overcome this cassava mosaic disease, surveillance and uprooting of infested plants was recommended as well as control of the whitefly *Bemisia tabaci* (Quiot et al., 1982; Fargette, 1987; Guthrie, 1987; Mabanza 1992). These measures have not been able to stem the disease.

In addition, the introduction of varieties selected for their resistance to the disease has been considered (Hahn et al., 1980) but the difficulty of satisfying local preferences with regard to taste, texture and agronomic traits of resistant varieties as well as their poor distribution to small farmers did not slow down their spread on local accessions (Guthrie, 1987).

Furthermore, it noted the differences between the proposed technologies and the producer's expectations. To date, integrated pest management has become a priority, including cassava breeding and the improvement of local germplasm by vitro culture to control cassava mosaic disease (Mabanza, 2006). Varietal improvement includes the development of a range of elite accessions resistant to cassava mosaic disease and cassava bacterial disease combined with high yields, stable with other agronomic qualities and traits acceptable to consumers.

F1 hybrid progeny derived from this controlled pollination were evaluated at station for their impact on cassava mosaic disease resistance as well as their growth, agronomic and yield components. The purpose of the studies was selecting resistant genotypes to the African cassava mosaic and assessing their agronomic and production performances.

MATERIAL AND METHODS

Plant material

Plant material consisted of F1 progeny obtained by controlled pollination between six elite accessions (local ecotypes) and three clones (192/0401, 192/0325 and 197/0162) distributed by International Institute for Tropical Agriculture (IIAT). These clones are cassava mosaic disease resistant, highly adaptable and highly productive (high yield). Ten crossings were made: Mauritanian x 192/0401, Mauritanian x 192/0325, Mauritanian x 197/0162, Mahabama x 192/0401, 192/0401 x Kinkeni, Manaboulenga x 192/0401, 192/0401 x Dimbouana, 192/0401 x Soleil, 192/0401 x Mauritanian and Manabulenga x 192/0325.

The IITA parental clones, native to Nigeria, were selected for their high yield potential and cassava mosaic disease resistance. Elite accessions were identified by peasant participation approach and identified according to characteristics distinguishing in positive and negative traits mentioned in Table 1. Out of 470 accessions collected in 56 surveyed localities in Bouenza, Niari and Lékoumou departments forming the Niari landscape, a hierarchy has been established according to solicitation. The accessions of Mauritanian, Mahabama, Kinkéni, Manaboulenga, Dimbouana and Soleil have had a high frequency of use, and have been described as "elite". Prior to pollination, these parental elite accessions were

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Table 1. Best accessions retained as parents of the genotypes assessed at station.

Parents	Positive trait	Negative trait to improve
I 92/ 0401*	High yield, numerous tuber, friable and sweet, CMD resistant	Small tuber size
Mauritanien	High yield, big tuber	Bitter, CMD sensitive
I 92/0325*	High yield, friable and sweet	post-maturity longevity weak CMD tolerance
Soleil	High yield, elasticity, heavy and good conservation paste	CMD sensitive
197/0162	CMD resistant	post-maturity longevity weak
Kinkéni	High yield, numerous and big tuber, friable, no fibre, good foliage quality, rot resistant, good cassava stick	Moist cassava flour, CMD sensitive
Manaboulenga	Precocity, sweet and friable, high yield, multi-users	CMD sensitive
Dimbouane	Precocity, post-maturity longevity, high yield, no fibre, white pulp, big tuber, resist an insect attack	CMD and rot sensitive
Mahabama	Big tuber, harvest distributed, high yield	CMD sensitive

*****Clone IITA CMD: Cassava mosaic disease.

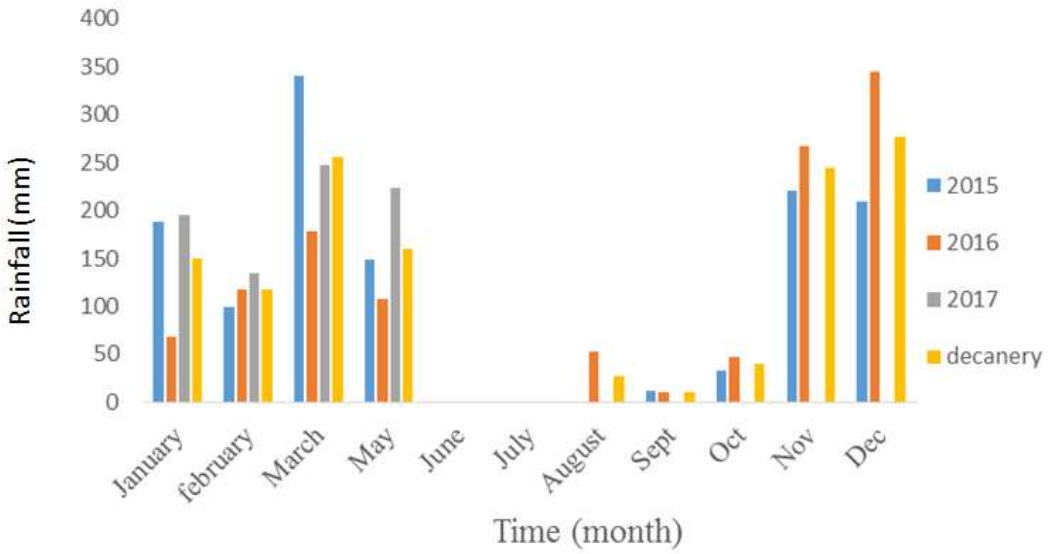

Figure 1. Distribution of the rainfall at Loudima in 2015-2016-2017.

cultivated at the Loudima Agronomy Research Station.

Description of study area

The trial was conducted in experimental plot at Loudima Research Station of the National Institute for Agricultural Research (IRA). Loudima station (13°04'21.3" and 4° 09'6.35") is located about 30 km north-east of the Nkayi town, in department of Bouenza. During 2 years of experimentation, an average monthly temperature (27.9°C) and relative humidity (90.9%) were recorded. Rainfall data were collected in experimental plot referred to as a seed nursery. Rainfall variations were recorded during 2 years of experimentation (Figure 1). Weekly total rainfall was used and expressed as sum of monthly precipitation.

Experimental layout, data collection and data analysis

The Cassava F1 progeny obtained by controlled pollination between elite accessions and IITA clones were evaluated. Seeds resulting from this pollination were germinated in screen houses. Vigorous cassava seedlings at a 4-leaf stage were transferred to seed nursery where they were planted by blocks representing a cross.

In cross block, the seedlings were transplanted in line at a space of 1 m between the lines, and in line 50 cm between the plants. After transplanting, insecticide application was carried out in

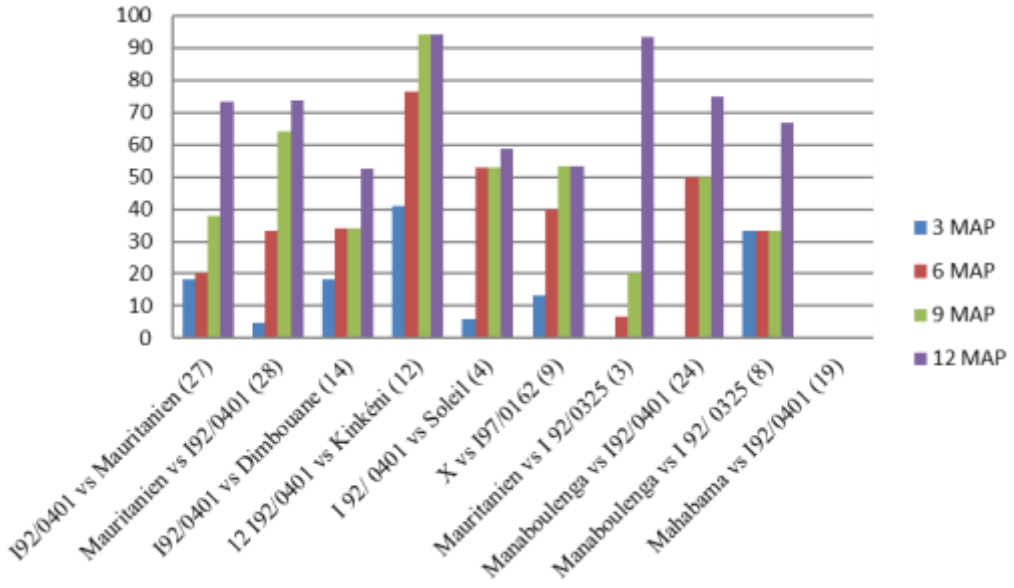

Figure 2. Evolution of cassava mosaic disease genotype at 3, 6, 9 and 12 months after planting of seedlings.

anticipation of cricket attacks. The insecticide (decis) slurry was applied at a rate of 25ml/15 L (in water). This application was repeated every fifteen day during two and half months making a total of five treatments in total. The seed nursery was maintained by weeding on demand until the end of the cycle.

In cross blocks, individuals ranged from 1 to 88 depending on seedlings number that reached 12 months after planting and were free of cassava mosaic. F1 progeny was eliminated when cassava mosaic disease symptoms appeared. The incidence of cassava mosaic was determined by counting the individuals having cassava mosaic disease symptoms out of the total of F1 progeny observed. From 12 months after planting, weekly observations were made individually for a given cross. Variables value of a given cross corresponds to the average of the individuals composing the cross. Every individual in the cross has been constituted as a repetition. These observations focused on the agronomic variables, yield components and biochemical components of cassava roots. For agronomic variables, measurements were made on leaf surface, biomass area and total biomass. To determinate the leaf surface (SF) according to Connor and Cock (1981): SF (cm^2) = 0.0067 $L^{2.042}$, with L (mm) representing the length of the central lobe of the leaf, the length of the central lobe of the fourth bloomed leaf of individual was measured using a graduated ruler. Aerial biomass was obtained by weighing stems and leaves using a scale type hanging scale. Three yield components have been estimated to evaluate the productive potential of a given genotype from different crosses. These were: harvest index, underground biomass, weight of tubers, root mass and number of tubers. The number of tubers per hybrid was counted and their weight obtained by weighing the tuber using the Hanging scale.

In addition, the roots have been calibrated. Gauging consisted of classifying the cassava roots into fleshy or not according to the volume or diameter. The fleshiest roots were said to be "marketable" and the less fleshy were called "residual roots" and therefore no marketable tubers. After harvest, the starch and dry matter content of the tubers was determined by genotype. Thus, 200 grams of tubers were taken per plant, minced and then ground using a Victoria type mill. The ground material obtained was dilacerated in 1.5 liters of water. The resulting mixture was filtered using a sieve with 500 µm mesh. The filtrate was distributed and decanted in 1.6 liter pots. After 10 hours of decantation, the supernatant was removed and the pellet constitutes the starch (starch). On a cemented drying platform, the pellet was dried in pots and the chip on plastic lids.

XLSTAT software version 7.5.3 and SPSS 10.0 were used for all statistical analyzes. For all variables measured, variance analyzes (ANOVA) included leaf area, aerial biomass, total biomass, harvest index, uunderground biomass, tuberous root weight (PRT), number of tuberous roots (NRT), root mass (MRT) and number of tuber roots. The normality of the residuals and the homogeneity of the variances have been verified. To normalize the distribution and equalize the variances, the starch and dry matter variables underwent an arcsine transformation. The comparisons between the means were made according to the Student Newman test and Keuls at the 5% threshold.

RESULTS

Cassava mosaic disease prevalence of genotypes obtained from controlled pollination

Cassava mosaic disease (CMD) incidence on station-assessed genotypes was illustrated in Figure 2. The results revealed that no cassava mosaic disease symptoms were observed in crossing (Mauritanian x I92/0325) and (Manaboulenga x I92/0401) 3 months after planting (MAP). At 3 months after planting, for CMD genotype, the least incidence was recorded in crossing (Mauritanian x I92/0401) and (I92/0401 x Soleil). At 6

Table 2. Average growth characteristics for genotypes from controlled crossing 12 months after seedlings planting in station.

Family	Crossing	Stem height (m)	Stem diameter (cm)	Branching type	Number of branching	Branching level (cm)	Gourmands
F28	Mauritanien xI92/0401	2.37^{a}	2.17^{a}	2.27^{bc}	1.64^{a}	0.43^{a}	1.00^{b}
F3	Mauritanien x I92/0325	2.50^{ab}	3.20^{a}	3.00^{c}	2.00^{a}	0.41^{a}	0.00^{a}
F19	Mahabama x I92/0401	2.54^{ab}	3.90^{a}	3.00^{c}	2.00^{a}	0.63^{a}	1.00^{b}
F12	I92/0401 x Kinkéni	2.78^{ab}	3.60^{a}	3.00^{c}	3.00^{a}	0.39^{a}	1.00^{b}
F24	Manaboulenga x I92/0401	2.91^{ab}	2.40^{a}	0.00^{a}	0.00^{a}	0.00^{a}	1.00^{b}
F14	I92/0401 x Dimbouana	3.14^{ab}	3.68^{a}	2.56^{c}	2.44^{a}	0.75^{a}	0.94^{b}
F9	Mauritanien x I97/0162	3.20^{ab}	3.49^{a}	1.57^{ab}	1.43^{a}	0.47^{a}	1.00^{b}
F4	I92/0401 x Soleil	3.24^{ab}	3.43^{a}	2.86^{c}	2.43^{a}	0.63^{a}	0.86^{b}
F27	I92/0401 x Mauritanien	3.32^{b}	3.50^{a}	2.47^{c}	2.41^{a}	0.81^{a}	0.78^{b}
F8	Manaboulenga x I92/0325	3.39^{b}	6.10^{a}	2.00^{abc}	2.00^{a}	1.13^{a}	1.00^{b}

Significat with a confidence level of 95% for the Newman-Keuls test. Values with the same index do not show a significant difference at 5% threshold. Stem heights are expressed in meters (m) and stem diameters in centimeters (cm). Branching level is the stem height where there was the first branching expressed in centimeter (cm) of which 0 no branching. Goumands is a notation whose score 0 absent and 1 presence of greedy. Branching type is a notation of which 0 absence of branching and for the presence (there are branches 1 or 2 or 3 or 4).

MAP, the CMD symptoms were observed on genotypes from 9 crossing tested. The lowest incidence (5%) was recorded in genotypes from the crossing (Mauritanian x I92/0325) while the highest incidence (58%) of CMD was observed in crossing (I92/0401 x Kinkéni) for the same period. The highest incidence (95%) was obtained at 9 and 12 MAP for genotypes from crossing (I92/0401 x Kinkeni). This same rate was found in crossing (Mauritanian x I92/0325) at 12 MAP. In addition, no cassava mosaic disease symptoms were observed from crossing (Mahabama x I92/0401). On the other hand, high cassava mosaic disease incidence was noted in crossing (I92/0401x Kinkéni) (Figure 2).

Vegetative growth components of genotypes obtained from controlled pollination at 12 months after planting

Growth components of the genotypes resulting from controlled pollination were measured at station. The results reveal that stem diameter, branching type and number of branching did not discriminate the cassava genotypes tested. No significant effect on mean stem diameter, number of branching and branching level of the genotypes was observed (Table 2).

For plant height, the genotypes from crossing (I92/0401 x Mauritanian and Manaboulenga x I92/0325) showed higher shoot height. Average plant height were 3.32 m (I92/0401 x Mauritanian) and 3.39 m (Manaboulenga x I92/0325) respectively. Mean plant height of 2.37 m recorded in genotypes from crossing (Manaboulenga x I92/0325) was lower than that from other crossing tested (Table 2). For crossing tested, the variability of branching type was observed at station. Branching type notes ranged from 0 in crossing (Manaboulenga x I92/0401) to 3 in crossing (Mauritanian x I92/0325), (I92/0401 x Soleil), (I92/0401 x Kinkeni), (I92/0401 x Dimbouane), (Mahabama x I92/0401), (I92/0401 x Mauritanian).

Genotypes from crossing (Manaboulenga x I92/0401) a branch grade score of zero (0) had an erect habit. Genotypes in crossing (Mauritanian x I92/0325), (I92/0401 x Soleil), (I92/0401 x Kinkeni), (I92/0401 x Dimbouane), (Mahabama x I92/0401) and (I92/0401 x Mauritanian) having the note 3, have a trichotomous branch. Dychotomic branches were observed on genotypes in crossing (I92/0401 x Soleil), (Manaboulenga x I92/0325), (Mauritanian x I97/0162), (I92/0401 x Mauritanian) and (Mauritanian x I92/0401) (Table 2).

For plant height and branching type, the variance analyses reveal a significant "crossing" effect at 5% threshold according to the Student Newman and Keuls test, and showed the existence of 3 homogeneous groups crossing (a, ab and b) and 5 crossing groups (a, ab, abc, bc and c) respectively. For the plant height, most pronounced effect was obtained with genotypes from crossing (I92/0401 x Mauritanian and Manaboulenga x I92/0325) (group b). For the presence of gourmands, except the genotypes from crossing (Mauritanian x I92/0325), all individuals of the tested crossing had gourmands. Statistical analyzes for the presence of gourmands reveal a significant difference at 5% threshold between the crossing tested (Table 2).

Agronomic components of genotypes obtained from controlled pollination 12 months after planting

A 12 MAP, leaf surface, harvest index and total biomass of the genotypes from different crossing were evaluated

Table 3. Average agronomic characteristics of genotypes from controlled crossing 12 months after seedlings planting in station.

Family	Crossing	SF (cm^2)	Aerial biomass (kg)	Underground biomass (kg)	Total biomass (kg)	Harvest index
F28	Mauritanien x I92/0401	102.77[a]	2.07[a]	1.48[a]	3.51[a]	0.41[a]
F3	Mauritanien x I92/0325	102.79[ab]	3.40[a]	3.70[a]	7.10[a]	0.52[a]
F19	Mahabama x I92/0401	102.91[ab]	5.90[a]	3.60[a]	9.50[a]	0.38[a]
F12	I92/0401 x Kinkéni	103.16[ab]	3.80[a]	1.90[a]	5.70[a]	0.33[a]
F24	Manaboulenga x I92/0401	102.47[a]	8.40[a]	5.60[a]	14.00[a]	0.40[a]
F14	I92/0401 x Dimbouana	102.84[ab]	6.64[a]	3.24[a]	9.88[a]	0.34[a]
F9	Mauritanien x I97/0162	103.03[ab]	4.19[a]	3.86[a]	8.04[a]	0.48[a]
F4	I92/0401x Soleil	103.32[b]	7.97[a]	4.39[a]	12.36[a]	0.38[a]
F27	I92/0401 x Mauritanien	102.79[ab]	5.32[a]	2.78[a]	8.11[a]	0.34[a]
F8	Manaboulenga x I92/0325	102.85[ab]	14.00[a]	8.10[a]	22.10[a]	0.37[a]

Significat with a confidence level of 95% for the Newman-Keuls test (SNK). Values with the same index do not show a significant difference at 5% threshold. Harvest index is the ratio of tuber roots to total biomass.

Table 4. Average tuberous roots characteristics of genotypes from controlled crossing 12 months after seedlings planting in station.

Family	Crossing	RTCom	RTRes	Root length (cm)	Starch (%)	Dry matter (%)
F28	Mauritanien x I92/0401	3.18[a]	3.64[a]	24.54[a]	17.77[a]	34.18[a]
F3	Mauritanien x I92/0325	5.00[a]	2.00[a]	46.40[b]	23.50[a]	40.50[a]
F19	Mahabama x I92/0401	3.00[a]	5.00[a]	47.00[b]	19.50[a]	32.00[a]
F12	I92/0401 x Kinkéni	3.00[a]	6.00[a]	36.10[b]	20.00[a]	43.50[a]
F24	Manaboulenga x I92/0401	5.00[a]	1.00[a]	40.20[b]	24.00[a]	42.50[a]
F14	I92/0401 x Dimbouana	3.17[a]	6.17[a]	93.34[b]	18.42[a]	36.17[a]
F9	Mauritanien x I97/0162	4.29[a]	7.43[a]	42.31[b]	20.86[a]	33.71[a]
F4	I92/0401x Soleil	5.71[a]	11.00[a]	40.59[b]	17.14[a]	40.14[a]
F27	I92/0401 x Mauritanien	3.30[a]	5.32[a]	35.02[b]	20.82[a]	38.26[a]
F8	Manaboulenga x I92/0325	7.00[a]	5.00[a]	67.00[b]	27.00[a]	42.00[a]

Significative with a confidence level of 95% for the Newman-Keuls test (SNK). Values with the same index do not show a significant difference at 5% threshold. RTCom: Marketable Tuberous Roots, RTRes : Residual Tuberous Roots ; Dry matter : content of tuber on fibres.

at station. Results show that, the leaf surface varied from 102.47 cm^2 (Manaboulenga x I92/0401) to 103.32 cm^2 (I92/0401 x Soleil) respectively (Table 3). In crossing (I92/0401 x Soleil), the leaf surface (103.32 cm^2) was larger. Statistical analyzes results of leaf area vary significantly depending on crossing made. They highlight the existence of 3 homogeneous groups of crossing made (a, ab and b). The most marked leaf area was obtained with genotypes from crossing (I92/0401 x Soleil) (group b). Analysis of all crossing did not statistically reveal any significant difference (at the 5% threshold) in aerial biomass, underground biomass (mass of all the storage roots per plant), total biomass and harvest index (Table 3). The results reveal that, these variables did not make it possible to discriminate all crossing tested at station.

Tuberous roots yield produced by 10 genotypes obtained from controlled pollination 12 months after planting

Marketable tubers, not marketable tubers, tuber length, tuber diameter, percentage of starch and percentage of dry matter of 10 genotypes tested crossing were evaluated at 12 MAP. Analysis of crossing did not statistically reveal any significant differences (at the 5% threshold) in marketable tubers, not marketable tubers, tuber diameter, starch content and root dry matter content (Table 4). The results reveal that these variables did not help discriminating between tested cassava genotypes (Table 4).The results show that tuber length varied from 24.54 cm (Mauritanian x I92/0401) to 93.34 cm (I92/0401 x Dimbouane) (Table 4). Results of

statistical analyzes of tuber length varied significantly according to cassava genotype tested, revealing the existence of 2 homogeneous groups of tested genotype (a and b) most marked was obtained with 9 genotypes evaluated (group b).

DISCUSSION

This study revealed the existence of a high cassava mosaic disease tolerance or resistance in cross (Mahabama x 192/0401) compared to other controlled crossing. For this crossing, no symptoms of cassava mosaic disease were observed until 12 MAP. The results are similar to those obtained by Hahn et al. (1980), Jennings and Hershey (1985), Kemdingao (2003), Ambang et al. (2007), Monde et al. (2013) and Bisimwa et al. (2015).

Four cassava varieties selected and popularized in Republic of Congo for their resistance to bacteriosis showed a sensibility to cassava mosaic disease (Mabanza et al., 1993). This study is the first one to set up a crossing showing an acceptable resistance to this viral disease. For a long period, it has been recognized that some varieties have acceptable resistance to mosaic when they suffer little or no damage even if they are affected (Hillocks and Thresh, 2000). Such individuals in crossing (Mahabama x I92/0401) will be used as a mean of controlling the disease.

In addition to crossing (Mahabama x I92/0401), F1 progeny from crossing (Mauritanian x I92/0401 and I92/0401 x Soleil) expressed the cassava mosaic disease incidence of 51% at 12 MAP. However, the cassava mosaic disease incidence of 95% was recorded in crossing (I92/0401 x Kinkeni and Mauritanian x I97/0162) at 12 MAP. Thus, the study results showed the existence of very clear differences in the degree of attack of the different crossing evaluated.

Difference in attack levels of cultivars or clones or varieties or genotypes with respect to cassava mosaic disease was recorded by Mabanza et al. (1993), Ambang et al. (2007), Ntawuruhunga et al. (2007), Zinga et al. (2008), Chikoti (2011), Monde et al. (2013) and Bisimwa et al. (2015). The study results showed that the cassava mosaic disease was established from 6th MAP in crossing (Mauritanian x I92/0325 and Manaboulenga x I92/0401). For these crossing, the lowest incidence of cassava mosaic disease (5% and 50%) increased to 91% and 75% at 12^{th} week after planting. This evolution of cassava mosaic disease incidence during the cultivation period was recorded for all crossing tested. Similar results were obtained by Ambang et al. (2007) and Bisimwa et al. (2015).

The study results reveal that the critical threshold for the emergence of cassava mosaic disease would be 6 MAP for the crossing tested. These results are contrary to those obtained by Mabanza et al. (1993). These authors noted that starting from the 4th month, the impact of cassava mosaic disease begins to diminish by the phenomenon of healing with four varieties selected by national program of research on cassava. To date, the use of genotypes from crossing (Mahabama x I92/0401 is a mean to manage cassava mosaic disease, given that it meets the requirements of growth, agronomy and production. Thus, in crossing (Mahabama x I92/0401) with trichotomous branching was not different from 9 other crossing tested by stem diameter, branching type, number of branch, aerial biomass, underground biomass (mass of all the storage roots per plant), total biomass and harvest index. For hybrids from crossing (Mahabama x I92/0401), the stem diameter of 3.90 cm obtained is comparable to or better than the average stem diameter of cultivars recorded by Ambang et al. (2007) and Monde et al. (2013). Those results reveal an intermediate classification of plant height, stem diameter and leaf surface of the individual of the said crossing. In hybrids from crossing (Mahabama x I92/0401), a plant height of 2.94 cm was measured, leaf surface was 102.91 cm^2 and harvest index was 0.38. These acceptable measures were similar to those of Bakayoko et al. (2007), Ambang et al. (2007), Chikoti (2011), Moundzeo et al. (2012) and Monde et al. (2013).

Similarly, it appears that crossing (Mahabama x I92/0401) is indistinguishable from other crossing for the number of marketable tubers, not marketable tubers, tuber diameter and root dry matter content. The tuber fiber content of 32% recorded in crossing (Mahabama x I92/0401) was similar to or better than that obtained by Nwangalalo et al. (1987) and Bakayoko et al. (2007). On the other hand, this content was lower than F1 hybrids of 20 families tested by Chikoti (2011).

The F1 progeny in crossing (Mahabama x I92/0401) showed tuber length of 47 cm with 8 mean number tubers per plant. These production variables in cross (Mahabama x I92/0401) were similar to those presented by cassava varieties tested (Bisimwa et al., 2015; Ambang et al., 2007, Moundzeo et al., 2012, Monde et al., 2013). Thus, F1 hybrids in Mahabama x I92/0401 which have a high tolerance to cassava mosaic disease, are interesting because of their growth, agronomic and yield components.

Conclusion

F1 progenies from crossing (Mahabama x I92/0401) showing high tolerance to cassava mosaic disease are included in the cassava selection scheme in Congo. In addition to the absence of any visible symptoms of cassava mosaic disease, these hybrids in crossing

(Mahabama x I92/ 0401) showed vegetative growth, agronomic traits, and acceptable yield components comparable to the other 9 crossing tested. This crossing is recommended in the main producing areas of the Republic of Congo, which is heavily infested with cassava mosaic disease. Before it is released, assessments in farmer's area will be carried out in order to confirm its potential to control cassava mosaic disease observed at station.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Productivity of radish fertilized with different doses of bovine manure

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The application of organic matter to the soil has considerable benefits for agricultural land, including an improvement in the physical structure and fertility of the soil, which can often be extended from one crop to another. Animal manure is one of the most widely-used types of organic fertilizer, due in part to its availability. The present study investigated the productivity of radish exposed to different doses of bovine manure. The research was conducted at the experimental area of the Nova Xavantina campus of Mato Grosso State University, in central Brazil, using the Apolo radish cultivar. The experimental design was based on the random distribution of plots, with five repetitions. Five treatments were applied, representing different doses of bovine manure: T1 = 0 t ha^{-1}, T2 = 30 t ha^{-1}, T3 = 50 t ha^{-1}, T4 = 70 t ha^{-1}, and T5 = 90 t ha^{-1}. The 50 t ha^{-1} dosage performed best in terms of the productivity and quality of the Apolo radish cultivar under the conditions of the present experiment.

Key words: *Raphanus sativus* L., organic fertilizer, plant nutrition.

INTRODUCTION

The consumption of fresh vegetables has increased worldwide, not only through population growth, but also due to the greater awareness of the importance of a healthy diet. Consumers are also becoming increasingly demanding, in terms of the quality of the produce, and its year-round availability (Bonela et al., 2017).

The Brazilian Center for Advanced Studies in Applied Economics (Cepea, 2017) reports that the total output of fresh vegetables in Brazil is 63 million tons, produced by a total area of 837,000 ha of farmland. An enormous variety of crops are cultivated, and São Paulo is the state that produces most vegetables.

The radish (*Raphanus sativus* L.) is an edible plant of the family Brassicaceae, with a globular root that has a

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bright pink external layer and a white pulp. The root is the part consumed, that is, it is the commercial product. One of the unique features of this plant is its short cycle, of approximately 30 days, which permits rapid gains of working capital (Rodrigues et al., 2013; Matos et al., 2015).

The relative advantages and disadvantages of the application of mineral and organic fertilizers for the cultivation of different crops have been amply discussed. On the one hand, mineral fertilizers make nutrients available to the plant rapidly, especially where the soil has a strict C/N relationship, although they have little effect on the physical structure of the soil. On the other hand, while organic fertilizers may not have sufficient concentrations of nutrients to guarantee the requirements of the crop, they do impact the physical, chemical, and biological properties of the soil (Olivera et al., 2015).

The rapid mineralization of organic matter under conditions of high temperature and ample sunlight is one of the principal limitations for the production of vegetables, given the reduced availability of nutrients, in particular nitrogen, in the production system (Silva et al., 2017). These authors report that one of the options available to overcome this nutrition deficiency in the plants is the application of organic fertilizers, including bovine manure, which is the most widely-used, given its availability, and potential for the full or partial fulfilment of the nutritional requirements of some crops.

Matos et al. (2015) concluded that one of the principal advantages of the productive systems based on organic fertilization, is the capacity of this process to increase the stocks of C and N in the soil, which is important for its conservation and fertility. In addition to providing nutrients such as N, P, K, S, and micronutrients, the incorporation of organic matter into the soil reduces its apparent density (Costa et al., 2006), and forms aggregates, improving aeration and the water storage capacity. Organic fertilizers also complex and solubilize some heavy metals, buffering the soil and maintaining the pH during abrupt changes in the environment. Other benefits include a reduction of the toxic effects of aluminum and an increase in microbial activity, which results in more favourable conditions for the establishment of the root system (Silva et al., 2006).

The benefits of applying organic matter to plantations have been widely reported (Silva Junior et al., 2016), and plants fertilized with organic compounds develop better and have more balanced nutrition that those fertilized using only mineral compounds. The present study investigated the productivity of radish fertilized experimentally with different doses of bovine manure in Central Brazil.

MATERIALS AND METHODS

The experiment was set up in the experimental area of the Nova Xavantina campus of Mato Grosso State University, in Central Brazil. This area is located within the Mário Viana Park, a reserve known as Bacaba Park (15°42'55" S, 52°14'54" W) at an altitude of 301 m above sea level. The region's climate is of the Aw type in the Köppen classification system, with mean annual precipitation of 1600 mm (Marimon et al., 2010), and two, well-defined seasons, a dry season from May to September, and a rainy season, from October to April.

The soil of the experimental area is a dystrophic red latosol with a sandy texture and 0 to 15% clay (Embrapa, 2013). The soil was sampled at 10 points, in the 0 to 20 cm layer (Table 1).

The experimental design was based on random blocks, with five repetitions. The treatments (T1 to 5) were based on the following doses of bovine manure: 0 t ha^{-1} (T1), 30 t ha^{-1} (T2), 50 t ha^{-1} (T3), 70 t ha^{-1} (T4), and 90 t ha^{-1} (T5), each with five repetitions for a total of 25 plots.

The plots (experimentall units) measured 1.0 m × 1.0 m, with five row of plants in each plot, at intervals of 0.30 m. The central 1 $m^{2\ of}$ each plot was sampled, with the outer portion not being included, to avoid potential edge effects.

The soil was prepared manually using a hoe to turn over the hardest, uppermost layers of the soil, and then to prepare the planting rows, raised to a height of approximately 30 cm. The analysis of the soil (Table 1) indicated that no lime was necessary. The manure was incorporated into the soil three days before sowing.

The Apolo cultivar was selected for this experiment, due to its good quality roots, robust plants, and vigorous and uniform foliage. The seeds were sown directly into the rows, with three seeds per 2 cm hole. At 7 Days After Emergence (DAE) of the seedlings, the plants were thinned, leaving a distance of 0.10 m between seedlings in the same row. Weeds were removed manually whenever necessary. Nitrogen was applied as cover in the form of ureia (100 kg ha^{-1}), in all treatments, with 50% being applied at 10 DAE, and 50% at 20 DAE. The plots were irrigated daily by sprinkling, to a depth of approximately 8 mm, to guarantee the development of the crop.

The plants were harvested 35 days after sowing, and the following parameters were determined for each treatment:

1. Total production (t ha^{-1}): Based on the weight of 27 plants collected from the sampling area, obtained using a digital balance;
2. Commercial productivity (t ha^{-1}): A total of 27 plants were collected from the sampling area of each experimental unit, and the split roots were discarded. The remaining roots were weighed immediately after harvesting to determine the commercial productivity. Roots were considered to be commercially valid when they had a diameter of at least 3 cm, and had no splits;
3. Diameter of commercial roots (cm): The diameter of the roots of 27 plants from each sample area (not including split roots) was measured at the middle of the root with a calliper (in cm);
4. Percentage of split roots (%): The percentage of split roots was determined by subtracting the commercial productivity from the total production of radish roots.

The data were analyzed and the pattern of the effect of different doses on the production parameters was evaluated using a regression, run in the Assistat 7.7 program (Silva and Azevedo, 2016).

RESULTS AND DISCUSSION

The maximum total productivity (7253.4 kg ha^{-1}) was obtained by applying 70 t ha^{-1} of manure (Figure 1). The control plots (T1: 0 t ha^{-1}) returned a productivity of 2927.2 kg ha^{-1}, 59.64% less than the maximum recorded.

Table 1. Chemical analysis of the soil (dystrophic red latosol: RL) from the area experimental in Nova Xavantina, Mato Grosso, Brazil.

	pH	Ca^{2+}	Mg^{2+}	Al	H+Al	CEC	P	K^+	Zn	Cu	Mn	B	S	BS	OM
	$CaCl_2$	$cmol_c\ dm^{-3}$							$mg\ dm^{-3}$					%	$g\ dm^{-3}$
[1]LV	5.7	1.9	0.7	0.0	1.2	4.0	8.3	39	6.6	0.5	9.1	0.25	9.5	67	17.1

[1]Method of soil analysis: EMBRAPA (2013). pH in $CaCl_2$; OM: Organic matter, determined by the Walkley-Black method; Al^{3+}: extracted with 1 mol L^{-1} KCl; BS%: Base saturation [BS% = (SB/T) × 100], SB: Sum of bases (SB = Ca^{2+} + Mg^{2+} + K^+ + Na^+); and CEC: Cation exchangeable capacity [CEC = SB + (H+Al)].

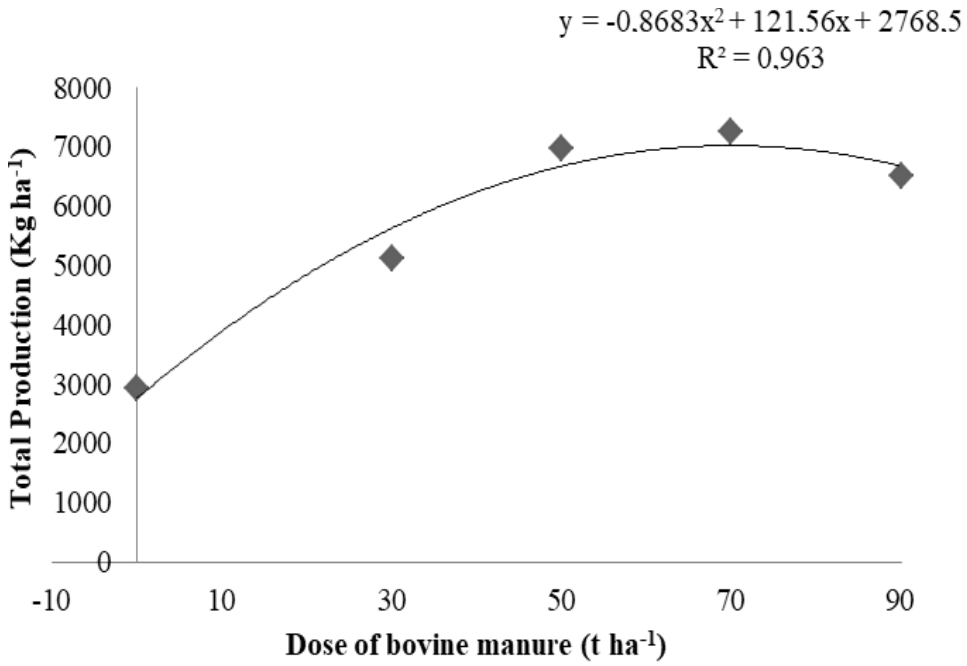

Figure 1. Total productivity of radish crops fertilized with different doses of bovine manure (0, 30 50, 70 and 90 t ha^{-1}).

Cortez (2009) obtained higher productivity (9950 kg ha^{-1}) using 75 t ha^{-1} of manure and 180 kg ha^{-1} of N. In this study, increasing doses of manure and N contributed to an increase in the height of the plant, the fresh weight of the root, and the commercial productivity of the radish. The concentration of organic matter in the soil (12.3 g dm^{-3}) was relatively low in this study, however, in comparison with the present study (Table 1). This may have made nitrogen more available to the radish plants (Vitti et al., 2007), which may account for the higher productivity recorded.

In contrast with the results of the present study, Cardoso et al. (2001) recorded relatively low levels of productivity (3.60, 4.71 and 5.05 t ha^{-1}) at doses 100, 200, and 300 kg ha^{-1} of N, respectively. In the present study, treatment (30 t ha^{-1} of manure with 100 kg ha^{-1} N) resulted in a total production similar to the maximum value recorded in this previous study.

Raij et al. (1997) concluded that doses of N of above 200 kg ha^{-1} may lead to superfluous consumption, with the plant continuing to absorb nitrogen, even after reaching maximum growth and productivity, resulting only in an increase in nitrogen concentrations in the foliage, without affecting the other parts of the plant. Taiz and Zeiger (2012) confirm this conclusion, showing that the concentration of nitrogen increases in the plant tissue, without contributing to any increase in growth or productivity, given that the plant has reached its prime.

Commercial productivity refers to the portion of the radish crop with no split roots. The maximum commercial productivity recorded in the present study (5962.0 kg ha^{-1}) was obtained at a dosage of 70 t ha^{-1} of bovine manure (Figure 2), which represents an increase of 66.97% in comparison with the minimum commercial productivity recorded here (1969.2 kg ha^{-1}), for treatment 1 (0 t of manure ha^{-1}).

A number of studies of the use of organic fertilizer have confirmed productivity equal to or higher than that

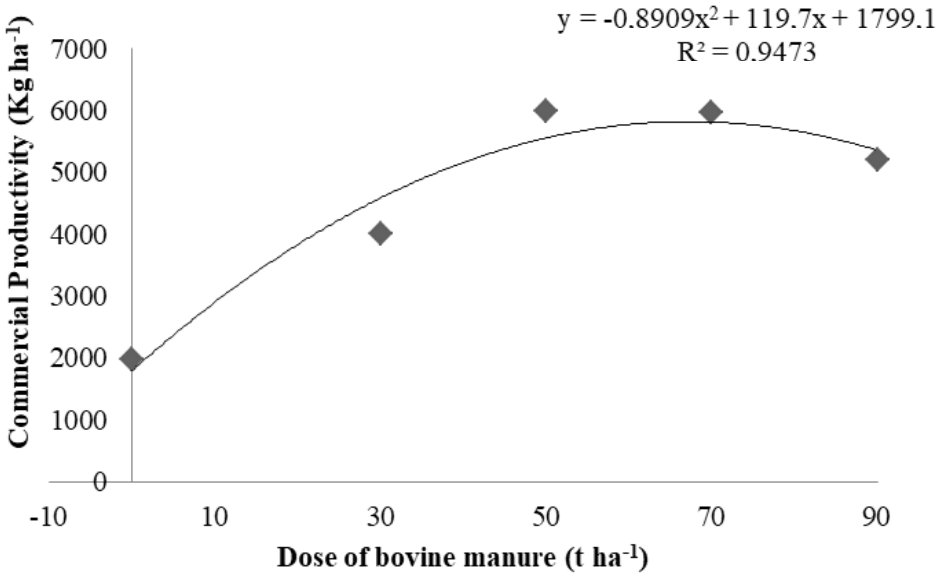

Figure 2. Commercial productivity of radish crops fertilized with different doses of bovine manure (0, 30, 50, 70 and 90 t ha^{-1}).

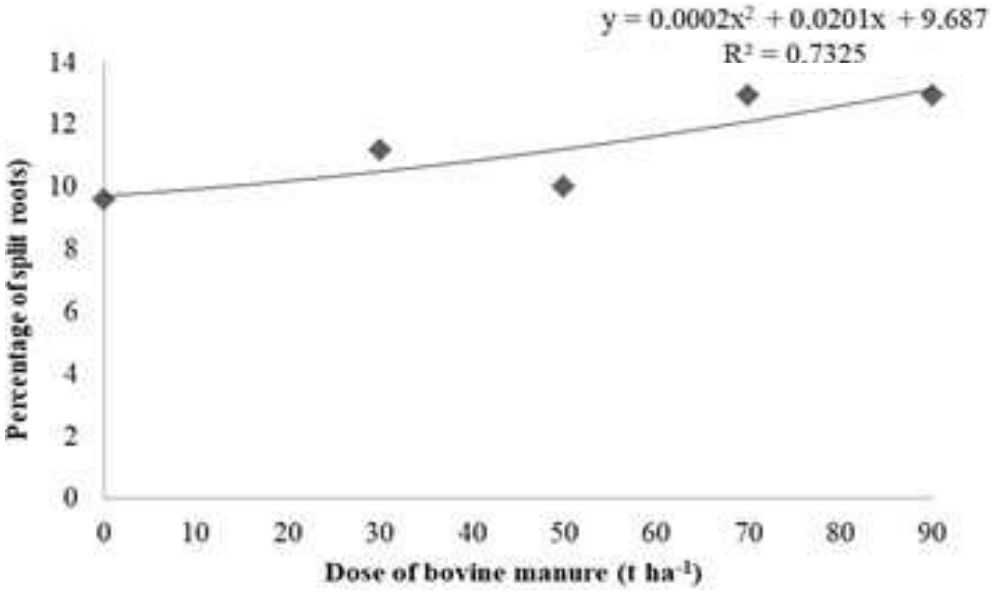

Figure 3. Percentage of split roots in the radish plants cultivated in plots fertilized with different doses of bovine manure (0, 30 50, 70 and 90 t ha^{-1}).

obtained using industrial nitrogenated fertilizers (Viana et al., 2004), confirming the results of the present experiment. Bonela et al. (2017) evaluated the productivity and quality of radish roots following the planting of lettuce with organic fertilization. In this case, the dose of 60 t of bovine manure produced the best results in terms of the quality of the roots.

In the present study, treatment 4 (70 t ha^{-1}) resulted in the highest percentage of split roots (13.73%), and the smallest value (9.72%), recorded for treatment 3, that is, 50 t ha^{-1} (Figure 3). The application of organic fertilizer may have had some effect on the appearance of splits in the radish roots. Oliveira et al. (2001) found evidence that the use of organic fertilizers resulted in deformations of the roots of carrot, as also observed by Costa et al. (2006) in radish. These authors observed a high frequency of splits in the roots of radishes cultivated using earthworm humus and bovine manure.

Kaseker et al. (2014) also concluded that the application of organic fertilizers (bovine manure) may

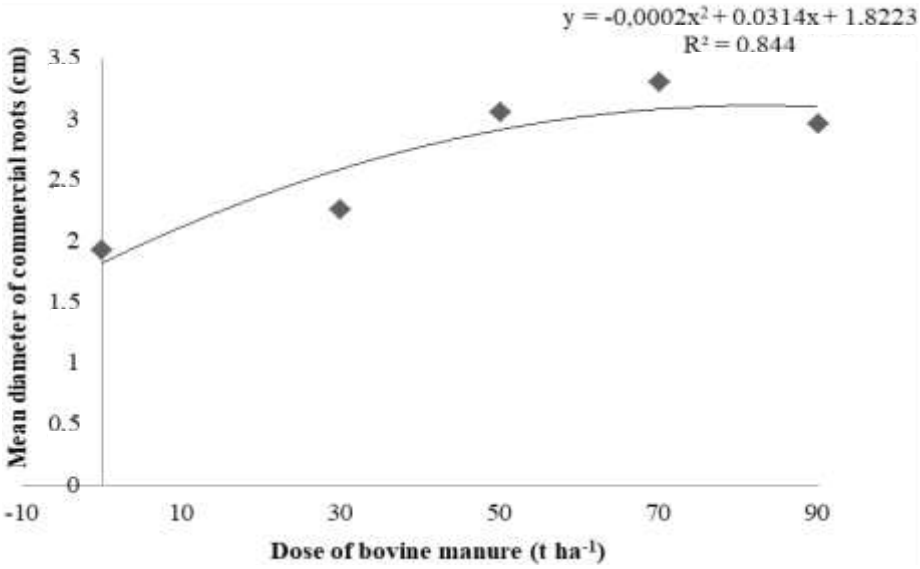

Figure 4. Mean diameter of the commercial roots of radishes cultivated in plots fertilised with different doses of bovine manure (0, 30 50, 70 and 90 t ha^{-1}).

contribute to an increase in the malformation of carrot roots. Bregonci et al. (2008) found that the oscillations in the water content and temperature of the soil, in particular its surface layer, resulting from high temperatures and the lack of mulch, which favors rapid evapotranspiration, contribute directly to the splitting of tuberous roots. Marques et al. (2005) confirmed that irregular oscillations in the irrigation regime contributed to splits in radish roots.

Raij et al. (1997) found that excessive fertilization with nitrogen may also contribute to root splitting in the radish. Cardoso et al. (2001) obtained similar results, showing that while an increase in the dosage of nitrogen resulted in an increase in productivity, it also provoked an increase in the proportion of split roots, probably due to their increased size.

Zambon et al. (2001) studied 16 radish cultivars on the high plains of the Brazilian state of Paraná, and recorded a positive correlation between the production of foliage and the concentrations of boron. Cecílio Filho (2017) not only confirmed that radish is sensitive to boron levels, but also that the scarcity of this nutrient may lead to the necrosis of the root tuber. Boron has a number of functions in the plant, but it was present at extremely low concentrations (0.25 $cmol_c dm^{-3}$) in the soil at the present study site, which may have contributed to the splits observed in the radish roots. Given these considerations, it would be important to investigate specifically the influence of this nutrient on the cultivation of radish.

Treatment 3 (50 t bovine manure ha^{-1}) returned the largest mean diameter of commercial roots (3.06 cm), while the smallest diameter was recorded in treatment 1, that is, in the absence of organic fertilizer (Figure 4). These results are consistent with the findings of Grangeiro et al. (2008), who showed that consumers preferred radishes with a root diameter of greater than 3 cm, and no splits.

The diameter and weight of the tubercles, in addition to the production of split roots are the most important criteria for the evaluation of the optimum dosage of manure to be applied as fertilizer, given that these attributes are linked directly to the quality of the product, and its commercial value. Evaluating the productivity of radish in relation to the nitrogen dosage, Silva (2015) found that the root increased significantly in size with increasing doses of N in the experimental treatments.

Conclusion

The application of 50 t ha^{-1} of bovine manure was shown to be the optimal dosage to guarantee the quality and performance of the cultivation of radish of the Apolo cultivar under the experimental conditions applied in the present study.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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