Physicochemical, nutritional and sensorial qualities of Boutou yam (Dioscorea alata) varieties

Emy Njoh Ellong, C. Billard, Dalila Pétro, S. Adenet, K. Rochefort

Journal of Experimental Biology and Agricultural Sciences

http://www.jebas.org

ISSN No. 2320 – 8694

PHYSICOCHEMICAL, NUTRITIONAL AND SENSORIAL QUALITIES OF *Boutou* YAM (*Dioscorea alata*) VARIETIES

Njoh Ellong E[1], Billard C[1], Pétro D[2], Adenet S[1,*] and Rochefort K[1]

[1]Pôle Agroalimentaire Régional de Martinique (P. A. R. M.), Habitation Petit Morne 97232 Le Lamentin, Martinique, France

[2]INRA, Unité de Recherche 1321 ASTRO Agrosystèmes tropicaux. Centre de recherche Antilles-Guyane, Petit-Bourg, Guadeloupe, France

Received – January 08, 2015; Revision – January 18, 2015; Accepted – February 09, 2015
Available Online – April 25, 2015

DOI: http://dx.doi.org/10.18006/2015.3(2).138.150

KEYWORDS

Yam

Dioscorea alata

Anthracnose

Physicochemical characteristics

Nutritional characteristics

Sensory profile

ABSTRACT

Yam crop is highly susceptible to Anthracnose; various research projects have been carried out into the development of anthracnose-resistant varieties. Boutou yam is one example of a disease-resistant variety; it gives high yields and thus is of high economic interest. The present study aims to optimize growing conditions and the harvesting stage of production in Martinique (F.W.I). Furthermore, the physicochemical, nutritional and sensory qualities of the harvested product are analysed. Results of the study indicate that the optimum harvesting time for Boutou is the ninth month after sowing. Harvesting at this stage gave the highest values for energy, carbohydrates and dry matter. The influence of fertilization on the physicochemical, nutritional and organoleptic qualities of Boutou was also analysed. In addition, new cultivars (of Boutou yam) were compared with the five already established cultivars – this comparison led to the conclusion that cultivars AL56 and Boutou are the best cultivars for yam production. These varieties met the expectations and preferences of the local market and had recoverable nutritional characteristics.

* Corresponding author

E-mail: adenet@parm.asso.fr (Adenet S)

Peer review under responsibility of Journal of Experimental Biology and Agricultural Sciences.

Production and Hosting by Horizon Publisher (www.my-vision.webs.com/horizon.html).

1 Introduction

Yam (*Dioscorea alata*) belongs to the family *Dioscoreacees* and the genus *Dioscorea*. It is a tropical climbing plant that produces edible tubers with varied shape. Yams constitute an economically important staple food for millions of people in tropical and subtropical regions (FAO, 2002). The most important cultivated species in the West Indies were introduced during the slave trade by Portuguese and Spanish navigators (Agricultural council of Guadeloupe and Martinique, 2003). In the French West Indies (F.W.I.) yam was primarily a food crop, but the tuber is now used as the raw material in a food production chain to the benefit of both producers and consumers.

Among various cultivated species, three major species of yam, viz *Dioscorea alata*, *Dioscorea cayenensis* and *Dioscorea rotundata,* are the most cultivated species in the Martinique region. *Dioscorea alata* originates from the Far East and is considered the most representative species because of its greater availability and economic value. This species is characterized by a square stem with tubers varying in shape, and white, creamy yellow or purple flesh. The weight of these tubers is generally more than 500g. The other two species, *Dioscorea cayenensis* and *Dioscorea rotundata,* are from Africa and have distinguishable agronomic characteristics, including the tuber flesh *D. cayenens* is produces yellow-fleshed tubers, while the flesh of *D. rotundata* is white. Another species, *Dioscorea trifida,* is also available in the study area and was introduced from the Amazonia region - this species has a non-thorny stem. Tubers of this species are usually small (less than 500 g), more or less pear-shaped, with white or purple flesh (International Institute of Tropical Agriculture- IITA, 2010).

Of these species, *D. alata* is probably the most widely grown through out the world. It is mainly disseminated via vegetative propagation, a commonly used technique in the tropics where mechanization is simplistic. It is harvested only once in a year and can be grown in flat beds without support and stored for 5 months after harvesting (Ano et al., 2005; Pavis, 2006). In comparison to *D. rotundata*, it has superior characteristics for sustainable production, including high yield potential, ease of propagation, early vigor for weed suppression and storability of tubers.

The life cycle of the yam plant varies from 5 to 12 months depending on species and variety. The life cycle can be divided into several stages, from germination of the tubers to the seed set. The germination of the first bud inhibits the growth of other buds. Germination is followed by the growth stage and it is characterized by the development of roots and shoots. The next stage is the filling phase of the tubers, which evolve with the aerial growth of the plant to leaf senescence, starting from two and half months after planting. Next is the maturation stage and in yams there are two types of maturation commonly reported. Biological maturity is characterized by the end of translocation of photosynthetic products between leaves and tubers. At this stage there is an aging of the leaves and a decrease in the dry matter of the tubers. Commercial maturity corresponds to the time of harvest, which depends on the variety and environmental conditions and often precedes biological maturity. Dormancy is a resting period occurring after the biological maturation, during which the tubers cannot germinate (IITA, 2010).

Fertilization is an important aspect of yam cultivation. Doses and types of fertilizer used for yam production vary according to the farming conditions, soil types and organic matter input (Agricultural council of Guadeloupe and Martinique, 2003). Susceptibility of yam cultivars to anthracnose disease is a major limitation in the field and can have a devastating impact on productivity. Anthracnose, caused by the fungus *Colletotrichum gloesosporioides,* has a negative impact on *D. alata*yam cultivation in the F.W.I. This disease causes leaf necrosis and dieback of yam vines, leading to a reduction in the effective photosynthetic surface area of the crop, with a concomitant reduction in the ability of the yam tuber to store food reserves. Disease resistant varieties from other growing areas like Haiti were introduced in the 1980s. Meanwhile, studies have been carried out to identify effective fungicides to be used against the fungus. However in 1989, the fungus developed resistance to available fungicides and started infecting all newly introduced varieties (Bayart & Pallas, 1994). To overcome this problem an extensive research program was implemented at the Institute National de la Recherche Agronomique (INRA) in order to develop anthracnose-resistant varieties in the F.W.I. More than 2,000 hybrid seedlings were field tested between 1996 and 2001 and evaluated for their resistance to anthracnose and the quality of their tubers under natural conditions (Ano et al., 2005; Petro, 2009). Among the tested verities, Boutou and *Inra15* hybrids were reported to be more productive (potentially up100 t/ha) and helpful in reducing the use of pesticide treatments against anthracnose (INRA 2014; Guyader et al., 2012). To deal with the high level of genetic diversity of *C. gloeosporioides* in yams (Abang et al., 2003), the use of sustainable resistant yam varieties is the most reliable approach for disease management. The availability of molecular markers linked to the QTLs of anthracnose resistance will facilitate marker assisted selection in breeding programs (Petro et al., 2011).

These projects to develop new anthracnose resistant varieties selected with strong development potential. The *Boutou* variety was selected in this study because it has a high resistance to anthracnose. Diffusion tests are also in progress from producers in Martinique, whilst the physicochemical, nutritional and sensory specifications have not yet been established. The study of these new varieties will help to optimize growing conditions. Optimum harvesting stage was identified on the basis of organoleptic and physicochemical properties, caliber and yield. Furthermore, the influence of manure on *Boutou* cultivation was also analysed in the present study.

Table 1 Experimental plot characteristics.

Species	*Dioscorea alata*
Variety	Boutou
Location ofthe parcel	Chopotte, François, Martinique (F.W.I.)
Soil type	Ferralitic soil
Irrigation	Supplemental irrigation
Previous crop	Yam cycle following a long grazing period (10 years)
Soil analysis	Satisfactory level of fertility - Mean deficiency in phospohorus - High potassium deficiency
Observations	Plot driving in conventional technical route: mineral fertilizer, no insecticide or fungicide Weed control by herbicides and manual weeding - Negative regulatory search of chlordecone

The comparative study between *Boutou* and other anthracnose resistant varieties according to their physicochemical, nutritional and sensory properties will allow an assessment of their potential compared to *Boutou*. This study is therefore an evaluation of the characteristics of new varieties according to different factors, focusing on: (*i*) the impact of the harvest stage on the morphological, physical and analytical characteristics of *Boutou*, (*ii*) *Boutou* variety's physicochemical characteristics following use of two different manures, and (iii) the comparison of *Boutou* with five other resistant yam varieties grown in Martinique.

2 Materials and Methods

2.1 Plant material

Six diploid *D. alata* hybrids (*Boutou*, *Inra15*, *AL56*, *AL54*, *AL18* and *A17*) were collected from the INRA breeding programme and used to carry out the present study. Female and male parents were cross-pollinated in the field. In testing, the hybrids selected have consistently shown field resistance to anthracnose across all location.

Tubers were collected between 8 and 11 months after planting from the same experimental plot. Approximately 30 tubers were collected from each variety. A set of physical parameters was measured for each tuber (width, length and weight). They were then cleaned, peeled, and cooked. Physicochemical analyses were carried out on a slice cooked by steaming (texture, colour, energy, fibres, starch, polyphenols, sugars, minerals and vitamin C content).

2.2 Impact of manures on the quality of *Boutou*

Two different types of manure were used for this study. The manure 1 (M1) was tested at 1000 kg/ha and composed of 15:12-24: NPK, while manure 2 (M2) was applied at the rate of 700 kg/ha and composed of 15:12:36 NPK. M1 is considered the bench mark manure in the cultivation of yams. The study was carried out in the experimental plot of the Agricultural Council of Martinique. The characteristics of this experimental plot are presented in Table 1.

2.3 Morphology and composition of yams

2.3.1 Morphological and physical characterization

The proximate analyses of tuber size were carried out using a caliper for length and width and a precision balance for yam weight (Shimadzu UW4200HV). Texture parameters were measured with a LLOYD Instruments TA plus texture analyser by using a piston of 4 mm diameter at 30 mm / min speed. Furthermore, the colour of the tubers was determined with the aid of a Minolta CR-200 chromameter using the three established parameters (L*, a*, b) of the International Commission on Illumination -"L" for lightness, to distinguish light colours from dark colours, "a" to classify red to green colours and "b" used to classify yellow to blue colours.

2.3.2 Physicochemical and nutritional characterization of the tubers

2.3.2.1 pH and Soluble dry extract (SDE)

About 25 g of fresh and cooked flesh was blended with about 250 ml deionised water (10% w/w) for 30 mins using a magnetic stirrer. The pH of the blended solution was determined at ambient temperature with a Sentix 81 (WTW) probe. The SDE was measured in the filtered solution, in Brix degrees, and expressed as SDE per 100 g of fresh matter, using a refractometer (Bellingham, Stanley Ltd RFM 340™) at 20°C (Huber™ thermostat).

2.3.2.2 Dry Mattercontent (DM)

2 g of crushed, homogenized flesh samples were collected in triplicate from each yam for determination of DM using a ventilated oven at 70°C for 5 hours at reduced pressure (- 1 bar).

2.3.2.3 Starch Content

The starch content was measured using the K-TSTA 11/05 Megazyme enzymatic kit (Megazyme, Wicklow, Ireland). The flesh samples were crushed and cooked. The absorbance at 334 nm, proportional to the amount of glucose released by the hydrolysis of starch which was recorded using a spectrophotometer (JENWAY 7305).

2.3.2.4 Polyphenol content

Total polyphenol content was determined using Folin and Ciocalteu's method described in Georgé et al. (2005).

2.3.2.5 Amount of Vitamin C

Amount of Vitamin C was measured using the K-ASCO 11/05 Megazyme kit. This is a colorimetric method and the absorbance at 578 nm was recorded using a spectrophotometer (JENWAY 7305).

2.3.2.6 Ash Content

Yam ash content was calculated from 1g crushed sample of each yam by heating it to 525°C for 5hrs as per method 923.03 given by AOAC (2000).

2.3.2.7 Lipid Content

Lipids were extracted from the 2 g sample by acid hydrolysis with 50 ml of 8N HCl at 80°C. The mixture was filtered and rinsed with boiling water until a neutral pH was registered. The filtrates were dried and the residues were placed in glass cartridges with 140 ml petroleum benzene and some pumice stones to extract the lipids in a Soxtherm extractor (Gerhardt Laboratory Systems, Königswinter, Germany). After extraction, the cartridges were oven dried at 101°C (COFRAC n°60, 2009).

2.3.2.8 Protein Content

The protein content was determined through the quantification of total nitrogen using Kjeldahll's method (Deschreider & Meaux, 1973). Following mineralization of the 2 g flesh sample in 25 ml of 95% H_2SO_4 in the presence of a catalyst in a turbo therm mineralizator (Gerhardt Laboratory Systems, Königswinter, Germany), the mineralizate was distilled, in the presence of soda, in a Vapodest distiller (Gerhardt Laboratory Systems, Königswinter, Germany). The distillate was collected in 40 ml of boric acid 40 $g.l^{-1}$ in the presence of some drops of Tashiro's indicator. The distillate was titrated with hydrochloric acid HCl (0.1N) (COFRAC n°60, 2009).

2.3.2.9 Carbohydrate Content.

This was obtained by finding the difference between fresh and dry extract – (ash + lipids + proteins)) (COFRAC n°60, 2009). Carbohydrates represent the total fibre, starch and sugar content.

2.3.2.10 Energy value

Energy value was determined by adding lipid, carbohydrate and protein contents (COFRAC n°60, 2009).

2.3.2.11 Fibre content

Fibre content was determined using the AOAC 985.29 method.

2.3.2.12 K, Cu and Mn

Yam samples were incinerated and ashes added to chlorhydric acid solution. K, Cu and Mn rates were determined by atomic absorption spectrometry at 766.5, 324.8 and 279.5 nm respectively (JO, 1977).

2.3.2.13 Glucose, Fructose and Sucrose

Sugar content was determined using the K-SURFG 12/05 Megazyme enzymatic kit) (Megazyme, Wicklow, Ireland). Sugars were extracted from dried samples by homogenizing, and boiled in 80% ethanol. After centrifugation, the ethanol extract containing free sugars was kept at –20°C until sugar analysis was performed according to the manual (Megazyme 716 260).

2.3.2.14 Nitrite and Nitrate content

The nitrogen content was determined only in cooked yam. Nitrite rates were determined by enzymatic analysis and photometric determination at 550 nm (NF EN 120414-3 and NF EN 12014-5). While Nitrate rates were determined by reaction with sulphanilamide and photometric determination at 550 nm (NF EN 12014-3 and NF EN 12014-5)

2.3.2.15 Enzymology

Enzymatic content was measured in raw and cooked yams – a 2 g flesh sample was dissolved in 0.5mM ascorbic acid,1MNaCl. Peroxidases reacted with gaiacol 55 mM and showed enzymatic activity, which was measured by absorption spectrometry at 470 nm every second for 20 seconds using a spectrophotometer (JENWAY 7305). 2 g samples were dissolved in 0.18 mM citric acid, 16 mM Na_2HPO_4, PVPP 10%. Polyphenoloxidase reacted with catechol and its enzymatic activity was measured by absorption spectrometry at 400 nm every second for 30 seconds using a spectrophotometer (JENWAY 7305).

2.4 Sensorial analyses

Cleaned, peeled and bleached yam samples were placed in a plastic bag. These samples were stored at -18°C and warmed just before sensorial analyses. The selection of panel members started with twelve individuals, none of whom had experience in sensory analysis. Five 2-hour training sessions were carried out until they were able to recognize and rate the characteristics of different yam varieties according to the AFNOR 8586-1 (1993) and 8586-2 (2008) standards.

Table 2 Agroclimatic conditions during the study period.

Stage of harvest	7 months	8 months	9 months	11 months
Average cumulative rainfall (mm)	1259.7	1900	1407.68	1604.71
Temperature in the month of harvest (°C)	25.9	-	25.5	26.2

Table 3 Physicochemical data for *Boutou* variety at four harvest stages.

Stage of harvest	7 months	8 months	9 months	11 months
Dry matter (%)	23.75 ± 1.18	23.96 ± 0.00	24.77 ± 0.42	29.38 ± 0.20
Ashes (%)	0.70± 0.03	0.81 ± 0.01	0.85± 0.05	0.67± 0.01
Proteins (g/100g)	3.86 ± 0.09	2.21± 0.02	3.29 ± 0.24	5.61± 0.28
Lipids (%)	0.20± 0.00	0.20± 0.01	0.10± 0.00	0.30± 0.00
Carbohydrates (g/100g)	19.32± 0.97	20.94 ± 0.04	20.54± 0.13	22.80± 0.01
Starch (g/100g)	10.80 ± 0.20	10.70 ± 0.80	15.05 ± 0.05	9.30 ± 0.30
Energy value (kcal/100g)	93.05 ± 4.55	92.70 ± 0.00	96.15 ± 1.45	116.35 ± 0.75
Total polyphenols (mg/100g)	7.80± 0.20	13.15 ± 6.95	11.05 ± 0.45	40.05 ± 0.65
pH	6.05± 0.00	5.78 ± 0.00	5.95 ± 0.00	5.71± 0.00
PPO enzymatic activity (AU/s/100g)	7,56 $x10^5$± 0.00	6,95 $x10^6$± 0.25	75.6± 0.10	54.65 ± 0.65

The standard deviation is shown here with ± indicating a repeatability of 3 experiments for each value.

Five attributes represent the sensory profile according to the AFNOR 13299 standard (2010). Significant differences (p<0.05) were found for the five sensory attributes. Homogeneity in the group was also tested by two-way ANOVA for each attribute and the training was considered to be concluded when no interaction between panelists' × samples was found. *Variance analyses* (ANOVA) was carried out with FIZZ® 2005 v1.0, UNIWIN Plus® 2005 v6.1 and StatGraphics CENTURION® XV 2005 software with a confidence intervalof5%.

2.5 Data statistical analysis

The physical and chemical mean values of triplicate measurements or analyses were statistically analysed. Analysis of variance *(ANOVA)* based on Student Test, *Principal Component Analysis (PCA)* and *Duncan's multiple range test* (DMRT) were performed using the software Stat Graphics CENTURION® XV 2005 and Uniwin PLUS®2005 v6.1.

3 Results

3.1 Impact of harvesting stage on the quality of the Boutou cultivar

This study compares the quality of the *Boutou* yam variety at four stages of maturity in order to determine the optimum stage for harvesting. Cropping system data for the yam samples are presented in Tables 1 & 2. Monitoring of the nutritional composition and sensitivity to browning were also performed.

The study revealed that harvesting at seven, eight, nine or eleven months gave the best results. These stages correspond to the categories of commercial maturity. Tables 3 and 4 present all the physicochemical and nutritional characteristics of the yams.

Evolution of energy values is shown in Figure 1.The amount of energy increased with later harvesting. The energy value of *Boutou* was on average 99.58 kcal/100g. It should be noted that this result is the average energy value measured in *Boutou* at the different stages of harvesting. The energy value increased over time up to the 11th month after planting. Figure 2 shows carbohydrate content, dry matter and starch content according to the stage of harvesting. The carbohydrate content increased steadily during the growth phase in soil, with no further evolution between 8 and 9 months. It increased about 3% at each harvest stage. Like energy, carbohydrate content also increased over time until the 11th month after planting. Dry matter also increased with later harvest times, peaking 11 months after the date of planting. This result correlates with the carbohydrate content since these compounds constitute the bulk of the tuber's dry matter. The starch content is slightly higher at the 9-month stage where as after it decreases.

Monitoring of the sensitivity to browning was also performed. Total polyphenols and enzymatic activity of polyphenoloxidase (PPO) were analysed and results are presented in Figure 3 for the four stages of harvest. By the 8th month, polyphenol content is at its highest, thereafter it decreases and tends to until the 11- month stage.

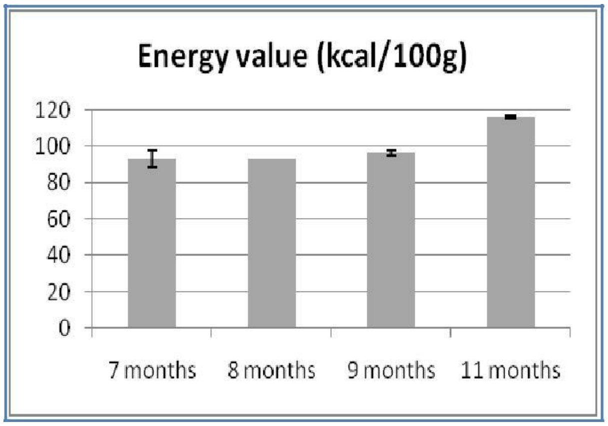

Figure 1 Energy value depending on the stage of harvest (The standard deviation is shown here with small bar indicating a repeatability of 3 experiments for each value).

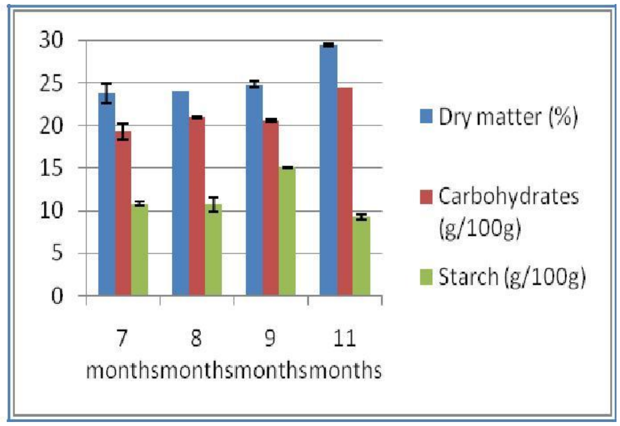

Figure 2 Carbohydrate content, dry matter and starch content depending on the stage of harvest (The standard deviation is shown here with small bar indicating a repeatability of 3 experiments for each value).

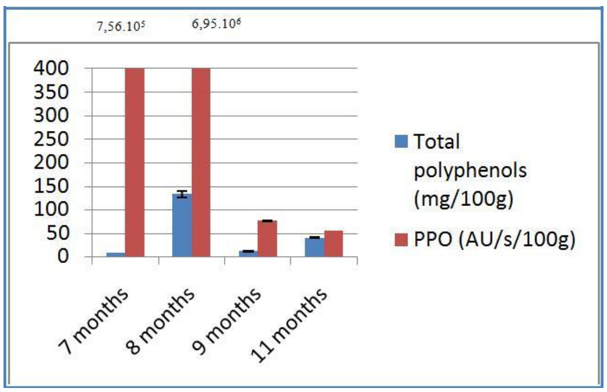

Figure 3 Total polyphenols and enzymatic activity of polyphenoloxydase for the four stages of harvesting (The standard deviation is shown here with small bar indicating a repeatability of 3 experiments for each value).

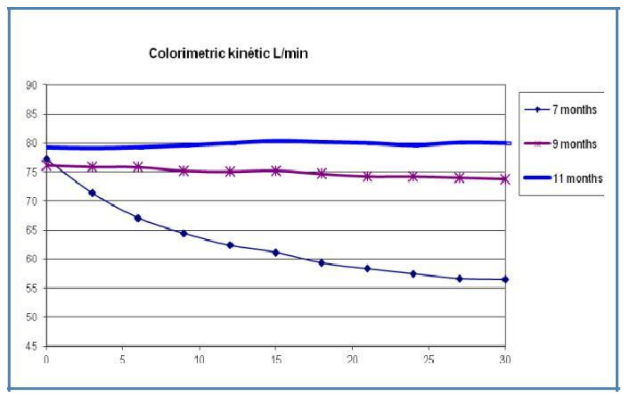

Figure 4 Colorimetric kinetic monitoring yam browning at different stages of harvest.

The 8-month stage would be of most interest in nutritional terms with regards to antioxidant content. Conversely, sensitivity to browning is also highest at this stage. The results for the 9 and 11-month stages were on a par and show similar values during processing: during trimming and grinding, these yams show less susceptibility to browning than those harvested at 8 months. At the 7 and 8-month stages, enzyme activity is very high. Yams at 7-8 months are extremely sensitive to browning and at this stage polyphenol content is at its highest. The PPO activity decreases over time while polyphenols tend to stagnate. Yams at the 9 and 11-month stages are less prone to browning. At 7-8 months, they are most sensitive to enzymatic browning.

For the colorimetric kinetic, only the 7-9 and 11-month stages were studied. Brightness was identified as a factor affecting results. This factor better reflects browning, as shown in Figure 4. Brightness at 11 months stage is constant over time, with little or no browning. At the nine-month stage the value is slightly lower. Yam slices at seven months are therefore most susceptible to browning.

3.2 Influence of manure on the quality of the *Boutou* cultivar

The aim of this study was to determine the impact of manure on physicochemical and nutritional quality of the *Boutou* cultivar. Results of the study are represented in table 4 and reveal that the highest physicochemical and nutritional qualities were reported in the tubers harvested at 9 months. Sensorial analysis was performed for the two manures viz. M1 and M2 and the results are represented in Figure 5.

Table 4 Physicochemical and nutritional data of two manure protocols.

	Characteristics	Manure 1	Manure 2
Caliber	Length (cm)	21.95 ± 7.46	24.10± 7.26
	Width (cm)	10.75 ± 3.07	10.10± 2.66
	Weight (g)	906.25± 647.85	1023.46± 621.64
	Transformation yield (%)	88.82	60.18
Texture	Hardness (kgf)	2.58 ± 0.76	2.74 ± 1.28
	Chewiness (kgf.mm)	2.25 ± 1.05	2.53 ± 1.84
	Tensile strength (kgf)	0.84 ± 1.29	1.01 ± 1.12
	Cohesion	0.12 ± 0.02	0.15 ± 0.02
	Elasticity (mm)	7.62 ± 3.10	5.33 ± 1.36
Color	L	72.53 ± 4.74	73.31± 3.02
	A	1.72 ± 1.32	1.78 ± 1.55
	B	18.57± 2.26	19.24± 1.84
Physicochemical and nutritional analyzes	Energy value (kcal/100g)	94.20 ± 0.00	98.10± 0.14
	Carbohydrates (g/100g)	21.18 ± 0.08	22.31± 0.23
	Glucose (g/100g)	0.88 ± 0.01	0.54 ± 0.01
	Fructose (g/100g)	0.63 ± 0.00	0.31 ± 0.01
	Sucrose (g/100g)	3.28 ± 0.00	1.61 ± 0.01
	Starch content (g/100g)	13.15 ± 0.07	13.10± 0.00
	Dry matter (%)	24.25 ± 0.21	25.60± 0.57
	Fibres (g/100g)	3.50 ± 0.82	3.20 ± 0.79
	Vitamin C	3.51 ± 0.00	3.15 ± 0.01
	Total polyphenols (mg/100g)	124.45 ± 30.45	204.70± 14.20
	K (mg/100g)	423.00 ± 0.00	481.50 ± 0.71
	Cu (mg/100g)	0.19 ± 0.00	0.19 ± 0.00
	PPO activity on raw yam (UA/s/100g)	179.9 ± 0.14	118.4± 0.14
	PPO activity on cooked yam (UA/s/100g)	58.2 ± 0.21	77.35± 0.07

The standard deviation is shown here with ± indicating a repeatability of 3 experiments for each value.

An analysis of variance for this data was performed for the highlighted characteristics and organoleptic differences between yam samples presented to panels of experts, and for each descriptor. Analysis of the results reveals that no descriptor was evaluated as showing significant differences between the two manures. Manure type has no impact on the assessment of organoleptic and sensory characteristics.

An analysis of variance (ANOVA) was performed to highlight the effects of all physicochemical and nutritional parameters. The analysis of variance performed on the data representing length (incm), thickness (incm) and weight (ing) revealed no significant difference in caliber (5%) between these two manures. Texture parameters viz. hardness, cohesiveness, elasticity, chewiness and tensile strength were also studied.

Results of ANOVA revealed that two texture parameters, cohesion and elasticity, were statistically significant at 5% with regards to manure effect. Samples grown in manure 2 had greater cohesiveness and elasticity than those grown in manure 1.

Table 4 shows the three factors of color (L,a, b) characterizing yams' average colorimetry for the two manures. This analysis was performed on each batch of cooked slices of yam. The ANOVA performed in order to highlight the characteristics and significant differences in color observed for each sample revealed that manure has no impact on the assessment of color characteristics.

Nutritional analyzes were performed on cooked and shredded samples. Indeed, the samples grown in manure 1 had high energy values (94.20kcal/100g) while in manure 2 the energy value was 98.10kcal/100g. Analysis of the results reveals that there are significant differences (5%) between the two manures in terms of energy values. The energy values correlate strongly with carbohydrate values important elements in this type of product. Carbohydrates are composed of sugars and starch. There are significant differences (5%) between the two manures in terms of sugars. Results of the study reveal that sucrose was dominant compared to the other two sugars. Samples grown in manure 1 had higher rates of sucrose, fructose and glucose -about twice as high as those grown in manure 2.

Table 5 Physicochemical and nutritional data of Boutou variety compared with five new *Dioscorea alata* varieties of yam.

	Characteristics	*Boutou*	*AL56*	*AL54*	*AL18*	*INRA15*	*A17*
	Transformation yield (%)	88.82	63.50	62.59	65.91	58.82	67.50
Texture	Hardness (kgf)	2.58 ± 0.76	4.10 ± 0.81	6.17 ± 1.82	3.00 ± 1.21	2.95± 1.01	2.96± 0.83
	Chewiness (kgf.mm)	2.25 ± 1.05	4.15 ± 1.42	3.66 ± 1.77	2.38 ± 2.72	3.02± 1.61	2.77± 1.73
	Tensile strength (kgf)	0.84 ± 1.29	2.27 ± 2.28	2.92 ± 3.25	0.21 ± 0.56	0.99± 1.23	0.99± 1.42
	Cohesion	0.12 ± 0.02	0.16 ± 0.04	0.12 ± 0.01	0.12 ± 0.02	0.16± 0.01	0.13± 0.02
	Elasticity	7.62 ± 3.10	6.73 ± 2.31	4.59 ± 1.19	5.22 ± 2.62	6.06± 2.04	6.73± 2.75
Color	L	72.53 ± 4.74	74.85 ± 2.24	65.12 ± 4.71	76.69± 3.22	78.54 ± 2.29	79.09± 1.35
	a	1.72 ± 1.32	4.41 ± 0.97	7.81 ± 1.77	2.05 ± 1.60	1.39 ± 0.74	0.58± 0.54
	b	18.57 ± 2.26	13.34 ± 0.63	19.52 ± 6.21	12.91± 2.22	16.26 ± 1.22	16.93± 1.66
Physicochemical and nutritional analyzes	Energy value (kcal/100g)	94.20 ± 0.00	119.30 ± 1.50	124.15 ± 0.65	125.90 ± 0.40	93.09 ± 1.11	121.04 ± 1.31
	Carbohydrates (g/100g)	21.18 ± 0.08	27.01 ± 0.61	28.28 ± 0.14	28.72± 0.48	20.83 ± 0.16	27.50 ± 0.28
	Glucose (g/100g)	0.88 ± 0.01	0.30 ± 0.00	1.10 ± 0.10	0.20 ± 0.00	0.30 ± 0.00	0.20 ± 0.00
	Fructose (g/100g)	0.63 ± 0.00	0.15 ± 0.05	1.00 ± 0.20	0.10 ± 0.00	0.40 ± 0.00	0.25 ± 0.05
	Sucrose (g/100g)	3.28 ± 0.00	4.50 ± 0.00	4.85 ± 0.25	3.90 ± 0.00	9.45 ± 0.05	5.10 ± 0.10
	Starch content (g/100g)	13.15 ± 0.07	18.20 ± 0.00	15.05 ± 0.05	19.05± 0.05	12.05 ± 0.05	18.60 ± 0.20
	Dry matter (%)	24.25 ± 0.21	30.45 ± 0.37	31.78± 0.20	32.23± 0.16	24.36 ± 0.31	31.34 ± 0.35
	Fibres (g/100g)	3.50 ± 0.82	3.10 ± 0.78	4.00 ± 0.87	3.40 ± 0.81	3.40 ± 0.81	3.20 ± 0.79
	Vitamin C (mg/100g)	3.51 ± 0.00	3.53 ± 0.00	3.88 ± 0.00	3.48 ± 0.01	3.13 ± 0.00	3.13 ± 0.02
	Total polyphenols (mg/100g)	124.45 ± 30.45	52.13 ± 8.36	140.30 ± 9.15	123.35± 24.15	64.07 ± 7.78	26.20 ± 2.93
	K (mg/100g)	422.74 ± 0.00	462.67 ± 0.00	526.31 ± 0.00	524.29 ± 0.00	498.96 ± 0.00	701.83 ± 0.00
	Cu (mg/100g)	0.19 ± 0.00	0.21 ± 0.00	0.25 ± 0.00	0.26 ± 0.00	0.17 ± 0.00	0.21 ± 0.00
	pH on raw yam	5.63 ± 0.5	5.76 ± 0.00	5.56 ± 0.00	5.9 ± 0.00	5.73 ± 0.00	5.88 ± 0.00
	pH on cooked yam	5.67 ± 0.5	5.77 ± 0.00	5.58 ± 0.00	5.78 ± 0.00	5.72 ± 0.00	5.88 ± 0.00
	PPO activity on raw yam (UA/s/100g)	179.9 ± 0.14	243.05 ± 0.05	24.80 ± 0.10	63.65± 0.15	381.95 ± 0.05	462.05 ± 0.05
	PPO activity on cooked yam (UA/s/100g)	58.2 ± 0.21	58.35 ± 0.05	21.50 ± 3.20	43.15± 0.15	164.90 ± 0.10	360.80 ± 0.20

The standard deviation is shown here with ± indicating a repeatability of 3 experiments for each value.

Starch contents were very similar for the two lots of yams studied, with an average of 13.15g/100g in manure 1 against 13.10g/100g in manure 2. There was not statistically significant effect on starch content from fertilization.

In the case of vitamin C, manure 1 shows a statistically significant difference compared to manure 2. The total polyphenol content was statistically higher for sample 2 manure with a value of 204.70g/100g against 124.45g/100g for manure 1. In terms of enzymes, there was a sharp decrease in PPO activity between raw and cooked samples. Indeed, these enzymes show heat sensitivity and were therefore altered by cooking. The PPO activity was statistically higher in the cooked samples from the manure 2 group, similar to the total polyphenol content. Peroxidases activity was null for all samples. pH was the same for all batches of yams studied and was between 5.6 and 5.7 in raw or cooked samples. As regards minerals, potassium levels were statistically higher for samples from the manure 2 group, with a value of 481.50 g/100g against 423.00 g/100 for manure 1.

3.3 Comparison of new hybrids of *Dioscorea alata* with *Boutou*

Five cultivars of the Anthracnose resistant variety viz *AL56*, *AL54*, *AL18*, *INRA15* and *A17* (*Dioscorea alata*) were compared with the widely grown yam species *Boutou*. Physicochemical, nutritional and sensorial characteristics of these selected varieties were studied and compared with *Boutou*. For this part of the study, all yams were harvested ninth months after planting. Table 5 shows the different results for the physicochemical and nutritional parameters studied.

A study of the texture of these six varieties was performed. Three of the five parameters, viz. hardness, cohesion and tensile strength, showed statistically significant differences at 5% compared with the averages for the studied varieties. It emerges that *Boutou* is the softest variety with 2.58 ± 0.76 kgf. *INRA15* and *A17* have the closest values to *Boutou* in terms of hardness. *AL54* is statistically harder than other varieties. *Boutou* has the lowest cohesion value (0.12 ± 0.02) compared to *AL54* and *AL18*. Among all the tested cultivars, *AL56* and *INRA15* are characterized by statistically higher cohesion values than other varieties. Similarly, in terms of tensile strength, *Boutou* has the lowest value, with 0.84 ± 1.29 kgf. *AL54* is characterized by the highest tensile strength, and can be distinguished from *AL18*, which gave the lowest value.

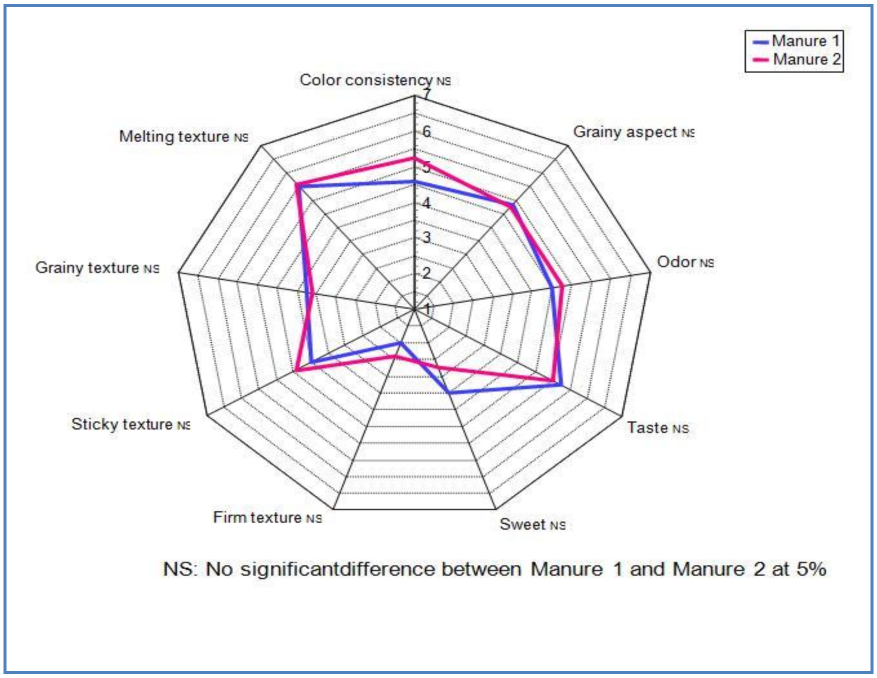

Figure 5 Sensorial profile of Boutou variety harvested in two different manures, M1 and M2

Boutou is characterized by low hardness and cohesion, with the highest elasticity and average for chewiness and tensile strength. *AL54* is characterized by high tensile strength, high hardness and low cohesion. *AL18* is characterized by low hardness, low cohesion, and low tensile strength. *INRA15* is characterized by low hardness and high cohesion. *AL56* and *A17* are in an intermediate position.

The color of the yams is variable and depends on the variety. The lightest varieties are *A17* and *INRA15*, while Boutou is the darkest variety along side AL54. The values obtained lead to conclude that yams are in color shades of gray white to light yellow.

With regard to energy, *INRA15* and *Boutou* show the lowest energy values, while the cultivar *AL54* and *AL18* show the highest energy values. Cultivar *AL56* and *A17* are positioned intermediately. The energy value is strongly correlated with the carbohydrate content, which is an important element in this type of vegetable. In parallel, *AL54* and *AL18* have the highest carbohydrate content, followed by *AL56* and *A17* and the lowest carbohydrate value was found in *INRA15* and *Boutou* cultivars. The average carbohydrate level of these samples stands at 26.5 g/100g. Among these sugars, sucrose was predominant. When comparing the verities, *INRA15* has the highest amount of sucrose, while the lowest sucrose content is for *Boutou*. The highest concentrations of glucose and fructose were reported for *AL54* and *Boutou,* but they remained relatively low. *AL18*, *A17* and *AL56* are richer in starch. *INRA15* and *Boutou* have the lowest starch content. The mean starch content recorded for these six varieties of yam is about 16g/100g. *INRA15* (24.36%) and *Boutou* (24.25%) have the lowest dry matter content. Other varieties have values higher than 30%, the highest being that of *AL18* (32.2%). The average fiber content of these five varieties is 3.4g/100g.The highest content is that of *AL54* with 4g/100g and Boutou, with 3.50 g/100g.

In terms of vitamin C levels, there is no significant difference among the cultivars and all the samples were similar with an average of 3.4mg/100g. Variety *AL54* has the highest content of vitamin C. *Boutou* has a content of 3.51 mg/100g. of the minerals detected, potassium is the most prominent. *A17* has the highest content of potassium and *Boutou* the lowest. Levels of copper were also determined. The highest copper contents were reported from the *AL18* and *AL54* varieties, while the lowest copper contents can be found in *INRA15* and *Boutou*.

Regarding the total polyphenol content, there was a high variability depending on the variety. Three groups can be distinguished i.e. *AL54* has the highest value, with 140.30 mg/100g. *Boutou* and AL18 also have high values of about 124.45 and 123.35 mg/100g respectively. *AL56* and *INRA15* are in an intermediate position. *A17* has the lowest value. There is a sharp decrease in polyphenoloxidase (PPO) activity between raw and cooked samples regardless of the variety. Indeed, this enzyme is heat sensitive and therefore altered by cooking. Before or after cooking, *INRA15* and *A17* varieties show the most important enzymatic activities, followed by *AL56* and *Boutou*. *AL18* and *AL54* have the lowest enzymatic activities. pH value was the same for all the six yam varieties studied. Average pH was reported to be 5.7 for the raw or cooked yam cultivars. A sensorial analysis was performed for the six varieties of yams (Figure 6).

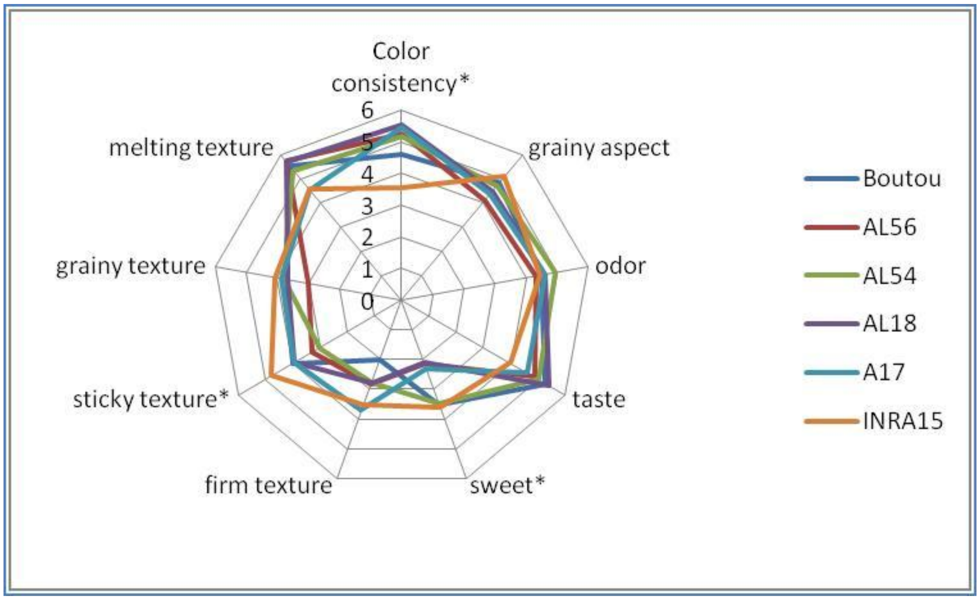

Figure 6 Sensorial profile of six varieties of yams (on a scalefrom 1 to 7).

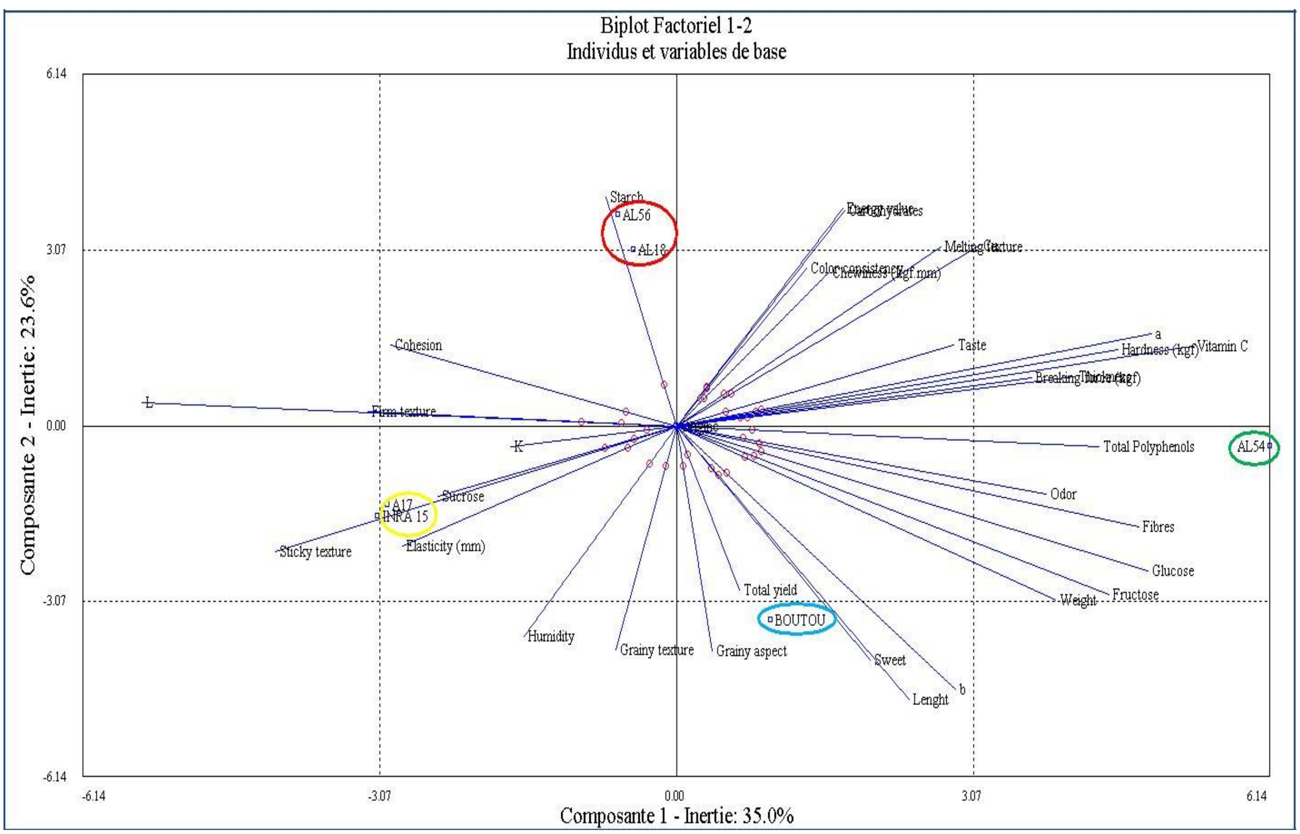

Figure 7 Principal Component Analysis comparing six varieties of *Dioscorea alata* yams.

An analysis of variance for this data was performed to highlight the characteristics and organoleptic differences between sample yams presented to panels of experts, and for each descriptor. Analysis of the results reveals that 3 out of 9 evaluated descriptors were significant for these varieties. They are color consistency, sticky texture and sweet flavour. *Boutou* has the lowest value for texture and weak color consistency. The variety *INRA15* differs significantly from other varieties with a less homogeneous color on the edges, a very sticky mouth feel and an intense sweet flavor. *AL54* is characterized by a slightly sticky mouth feel and intense sweet flavor. Variety *AL56* is comparable to *AL54* for its slightly sticky texture, but is characterized by little sweetness. Varieties *A17* and *AL18* are significantly similar and are still in an intermediate position compared to other varieties. *A17* and *AL18* are characterized by relatively sweet flavor and relatively intense sticky texture.

The data was processed in Principal Component Analysis (Figure 7). The principal component analysis distinguished four groups. *Boutou* was anti-correlated (opposite along axis 2) with *AL18* and *AL56* varieties. It is characterized by higher humidity and overall transformation yield than other varieties. It has a rather sweet flavor, grainy texture and aspect compared to other yams. *AL54* was anti-correlated (opposite along axis 1) with *A17* and *INRA15* varieties. It is characterized by higher levels of vitamin C, fiber, glucose, fructose and total polyphenols than the other varieties. Its texture was harder than the other varieties. *AL18* and *AL56* are characterized by higher starch content than other varieties. Their energy values and carbohydrate content were rather high compared to others. Finally, they tend to be less sweet and less grainy in texture than other yams. *A17* and *INRA15* were characterized by stickier texture and higher elasticity than other varieties. Conversely, their vitamin C content and hardness were lower. Moreover, *A17* was distinguished by a high content in potassium and low homogeneity compared to other varieties. *INRA15* had higher sucrose content than other yams.

Discussion

Energy values increase in yams with later harvesting. This increase can be explained by the accumulation of carbohydrates (reserves) during growth of the tubers. In fact, yam flesh is mostly made up of carbohydrates that accumulate during the growth phase. Furthermore, with higher carbohydrate presence, proteins and fats are reported in very low amounts (Agricultural council of Guadeloupe and Martinique, 2003). Dry matter increased with later harvesting. However, high dry matter content (between 20 and 25%) indicates high mealines and disintegration during cooking. Dry matter and carbohydrate values increased up to 11 months, but a reduction in starch content was observed. This reduction in starch content could be due to hydrolysis, which leads to the formation of simple carbohydrates: in tuber metabolism, simple carbohydrates are produced through the process of starch hydrolysis. The reduction in starch starts from the ninth month, which is the tuber's stage of biological maturity, at which point the level of other sugars starts to increase. Tuber maturity results in early senescence of leaves. The total polyphenol content and PPO activity mean higher levels of enzymatic browning. The higher the rate or activity, the greater the sensitivity to enzymatic browning. Polyphenoloxidase is an enzyme which plays an essential role in the oxidation of phenolic compounds. In the presence of oxygen this enzyme is responsible for the transformation of polyphenols in to colored compounds (Vámos-Vigyázó & Haard, 1981). This enzyme is therefore a good indicator of enzymatic browning. It can be inhibited bye exposure to high temperatures for short durations (bleaching)(Vámos-Vigyázó & Haard, 1981). Brightness has been identified as a factor affecting results. It reflects a lighter or darker appearance. A higher level of enzymes indicates a light product and vice versa. Factors a* and b* express the color itself and therefore were not of interes there in terms of translating enzymatic browning. Results were therefore measured solely from the factor L. In nutritional terms, the seven-month stage shows the lowest energy values, particularly in terms of starch and carbohydrates. The 9 and 11-month stages showed significant energy values. Carbohydrate and starch contents were high only at the 9 month stage. From a nutritional stand point, yams at the 7-month stage are of the least interest and not optimized in terms of maturity. The nutritional composition increased with longer growing times. Stages 7 to 11 months correspond to the tuber's maturation phase. The physicochemical analyses have shown that yams harvested at 11 months give the best results in nutritional terms. Harvesting at 7 months seems to be less suitable for commercial maturity (showing high sensitivity to enzymatic browning and poorer nutritional composition in terms of energy, carbohydrates and starch). The 8 and 9-month stages were close in nutritional terms. But at the 8-month stage, tubers were more sensitive to browning and had better polyphenol content than at the 9 month stage. At eleven months, yam maturity is too advanced (starch hydrolysis). Starch concentration was low in contrast to high sugar levels. The yam was less sensitive to enzymatic browning and polyphenol content was low. The optimum stage for harvesting therefore seems to be 9 months, since it was observed that the best compromise between nutritional composition and enzymatic browning.

Concerning the influence of manure on yam characteristics, the mode of fertilization had no direct impact on the color and size of the samples. Yams grown in manure 2 had higher cohesion and elasticity than those grown in manure 1. In nutritional terms, fertilization has no effect on starch content. Yams grown in manure 1 had higher levels of sugars and vitamin C than those grown in manure 2. In contrast, yams grown in manure 2 had higher energy values, carbohydrates, total polyphenols and potassium content than those grown in manure 1. It is very interesting to note that the levels of sugars and starch were higher in manure 1. In contrast, the level of total carbohydrates was higher in manure 2. Finally, in terms of enzymology, there is no peroxidase activity and yams grown in manure 2 showed higher PPO activity in cooked samples than those grown in manure 1. From a commercial point of view, size and color were similar for yams from both manures, and both would be viable for the local market. From a nutritional point of view, the second manure led to higher values than manure 1. For the production of yam products, yams grown with manure 1 were less susceptible to browning and seem more suitable than those grown in manure 2. Suja & Sreekumar (2014) studied manure influence on tuber quality and were in agreement with present observations.

A total of five cultivars of *Dioscorea alata* yams were compared to *Boutou* for resistance to anthracnose and evaluation of physicochemical, nutritional and sensorial characteristics. Regarding total polyphenol content, there was a high variability depending on variety. A study conducted by Brat et al. (2005) on fruits and vegetables rich in polyphenols placed artichoke in first position for vegetables, with a polyphenol content of 321.3mg/100 g. The potato comes in 19^{th} place with a content of 23.1mg/100g. Yams studied here are therefore four times richer than potatoes in total polyphenols, with an average content of 81.21 mg/100g. In addition to its visual appearance, *Boutou* variety is more satisfactory in terms of consumer tastes. Its small size and regular shape make it a suitable product to be sold fresh. Apart from its polyphenol content, this variety is of less interest from a nutritional point of view. However, due to its transformation yield, it is of interest to the food production industry. Despite its nutritional characteristics, cultivar *AL54* is not suitable for local market requirements. Its high caliber and irregular shape make it more suitable for processing, for example, into mashed yam, flakes or even flour, thanks to its fiber content. *AL56* variety is one of the favorite varieties for consumers in Martinique amongst the six varieties tested. Nutritionally and physicchemically, it is occupies an intermediate position except for its high cohesion value. Its average size and regular shape make it more suitable for consumption. The product is calibrated, which is an advantage in terms of mechanization of peeling and cutting. Its nutritional qualities are also good, leading to a processed product with high added value. Variety *A17* is comparable to the variety *AL56* in terms of its sensory characteristics. However, its high caliber and irregular shape can be a barrier to selling it as fresh produce. It is therefore of more value in processed form. Frozen would be a good alternative in order to preserve the sensory quality of this variety and overcome the difficulties associated with the fresh tuber from a consumer perspective. In contrast, *AL18* can be recommended for use as a fresh vegetable. Indeed, it is also comparable to the variety *AL56* in sensory terms and has a low gauge. Finally, the variety *INRA15* is the least appreciated by consumers. It has a sticky texture, average nutritional quality and large size. In view of these elements, it is more suited to mashing or flaking. INRA15 and A17 had the highest PPO activity, which can be correlated with high polyphenols content and enzymatic browning (the highest L color factor).

Conclusions

The characteristics of *Boutou* yams were similar between the 9 and 11-month stages of harvesting. Harvesting after 9 months is therefore recommended in order to obtain the best compromise between technological considerations, nutritional potential and growing time. In physicochemical terms, commercial maturity can be achieved after 9 months in the ground. On the whole, fertilization had little effect on the quality of *Boutou*, though yams grown in manure 2 appeared to have more advantageous nutritional and technological characteristics. In terms of sensory, physicochemical, nutritional and agronomic elements, *Boutou* varieties is best choice for the development of yam production in Martinique. With the highest energy value, higher levels of carbohydrates, fiber, vitamin C, copper, high levels of potassium and sugars and the highest total polyphenol content, *AL54* is the variety with the best nutritional qualities. This new variety will be offered to producers as an alternative or complement to the *Boutou* variety. This comprehensive study of yam characteristics will help local producers to optimize their production and offer better quality vegetables.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

We would like to thank the Regional Council of Martinique (France) and FEDER for its financial support. Producers who provided tubers are also greatly thanked. Thanks also go to the Agricultural Council of Martinique and INRA Antilles-Guyane. Ms Annie Batten who provided language help is also thanked.

References

Abang MM, Winter S, Mignouna HD, Green KR, Asiedu R (2003) Molecular taxonomic, epidemiological and population genetic approaches to understanding yam anthracnose disease. African Journal of Biotechnology 2:486-96

Association Française de la NORmalisation (AFNOR) 8586-1 (1993) Analyse sensorielle - guide général pour la sélection, l'entraînement et le contrôle des sujets – Partie 1 : sujets qualifiés.http://www.boutique.afnor.org, accessed on 27 August 2014.

Association Française de la NORmalisation (AFNOR) 8586-2 (2008) Analyse sensorielle – Lignes directrices générales pour la sélection, l'entraînement et le contrôle des sujets – Partie 2 : sujets experts sensoriels.http://www.boutique.afnor.org, accessed on 27 August 2014.

Association Française de la NOR malisation (AFNOR) NF EN ISO 13299 (2010), Analyse sensorielle - Méthodologie - Directives générales pour l'établissement d'un profil sensoriel.http://www.boutique.afnor.org, accessed on 27 August 2014.

Agricultural council of Guadeloupe and Martinique (2003) L'igname, poto mitan des cultures vivrières, Manuel du planteur. Edition Chambre d'Agriculture, Guadeloupe, Martinique.

Ano Georges, Jean Gelabale, Pierre Marival (2005) L'igname D. alata, la génétique et l'anthracnose. Phytoma La Défense des végétaux 584:36-39.

Association of Official Analytical Chemists (AOAC) (2000) Official Methods of Analysis Method 923.03 Ash of flour: direct method (17th Ed.). Arlington, VA.

Association of Official Analytical Chemists (AOAC) (2000) Official Methods of Analysis Method 985.29 Total dietary fibres in food (17th Ed.). Arlington, VA.

Bayart JD, Pallas B (1994) Tolerance of yam anthracnose to benzimidazoles: Results of the first study conducted in Guadeloupe. Phytoma 461:37-40.

Brat P, George S, Bellamy A, Du Chaffaut L, Mennen L, Scalbert A, Amiot MJ (2005) Polyphenol fruits and vegetables database: determination of the French polyphenol intake. In: Fruit, vegetable and health congress, Québec.

Commité Français d'Accréditation (COFRAC) program 60 (2009) Analyses des aliments diététiques et de régime et analyses destinées à l'étiquetage nutritionel des aliments.http://www.cofrac.fr/, accessed on 27 August 2014.

Deschreider AR, Meaux R (1973) Utilisation d'Une Electrode Ionique Spécifique pour le Dosage de l'Azote par la Méthode de Kjeldahl. Analusis 2:442-445.

International Institute of Tropical Agriculture (IITA) (2010) "Yam".

Food and Agriculture Organisation of the United Nations (FAO) (2002) FAOSTAT Agriculture data. http://apps.fao.org/collections, accessed on 27 August 2014.

Georgé S, Brat P, Alter P, Amiot MJ (2005) Rapid determination of polyphenols and vitamin C in plant-derived products. Journal of Agricultural and Food Chemistry 53:1370-3.

Guyader S, Salles M(2012) INRA Améliorer la production d'igname. http:// www.inra.fr/ Images de science/› Au coeur des labos, accessed on 15 August 2014.

INRA (2014) Améliorer la production des cultures d'igname en guadeloupe.http://www.antilles.inra.fr/.../Ameliorer_production_cultures_definitif.pdf, accessed on 15 August 2014.

Journal officiel (JO) (03 novembre 1997) Méthodes officielles d'analyse des produits diététiques et de régime.http://www.journal-officiel.gouv.fr/, accessed on 17 november 2003.

Norme Française (NF) 12014-3 (September 2005) Produits alimentaires - Détermination de la teneur en nitrates et/ou en nitrites - Partie 3 : détermination spectrométrique de la teneur en nitrates et en nitrites des produits carnés après réduction enzymatique des nitrates en nitrites, http://www.boutique.afnor.org, accessed on 15 August 2014.

Norme Française (NF) 12014-5 (Juin 1997), Produits alimentaires - Détermination de la teneur en nitrates et/ou en nitrites - Partie 5 : détermination enzymatique de la teneur en nitrates des aliments à base de légumes, http://www.boutique.afnor.org, accessed on 15 August 2014.

Pavis C (2006) Ignames:des fleurs pour de nouveaux hybrides. http://www.inra.fr/presse/ignames, accessed on 15 August 2014.

Petro D, Onyeka TJ, Etienne S, Rubens S (2011) An intraspecific genetic map of water yam (Dioscorea alata L.) based on AFLP markers and QTL analysis for anthracnose resistance. Euphytica 179:405.

Petro D(2009) Les avancées sur l'anthracnose de l'igname, INRA.http://www.antilles.inra.fr, accessed on 24 December 2014.

Suja G, Sreekumar J (2014) Implications of organic management on yield, tuber quality and soil health in yams in the humid tropics. International Journal of Plant Production 8:291-310.

Vámos-Vigyázó L, Haard NF (1981) Polyphenol oxidases and peroxidases in fruits and vegetables. Critical Reviews in Food Science & Nutrition 15:49-127.