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Physicochemical, organoleptic and nutritional characteristics of four sweet cassava (*Manihot opi*) varieties

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There exist a wide variety of tropical tubercles in Martinique French West Indies (F.W.I.). This study was carried out in order to investigate the development of local varieties of sweet cassava (*Manihot opi*). The purpose of this research was to enhance knowledge of the nutritional and agricultural characteristics of these tubers. The first step in the research project was to carry out a survey and screening of selected varieties, which was undertaken by the local department of agriculture throughout the region of Martinique. Phenotypic characterization and identification were then established. The four varieties were distinguished from each other by phenotypic, organoleptic, physicochemical and nutritional characteristics. Sweet cassavas in Martinique are richer in nutritional compounds and vitamin C than ordinary potatoes. Their sensory specificity, high nutritional value and suitability for industrial processing have also been highlighted. Variety KM07 seemed to offer the best compromise between size, nutritional profile and sensory characteristics and would therefore be recommended for production.

Key words: Martinique, *Manihot opi*, physicochemical characteristics, nutritional characteristics, sensory profile, sweet cassava, gallic acid equivalent (GAE).

INTRODUCTION

Cassava belongs to the Euphorbiaceae family and can be divided into two categories: Arboreae and Fructicoseae. Originally from South America, cassava was introduced into Martinique by the Caribbean Indians (Jackson et al., 1991; Silvestre and Arraudeau, 1983). There are two varieties of cassava. *Manihot opi* is the sweet cassava, the roots and leaves of which are consumed fresh. *Manihot esculenta* Crantz (*Manihot utilissima*) is the bitter cassava and the most cultivated because its production yield is higher, despite being inedible without pre-treatment. It contains toxic cyanide glycosides, which, under the effect of an enzyme, are transformed into hydrogen cyanide (Nartey, 1968; Conn, 1969; McMahon et al., 1995). Hydrogen cyanide (HCN) is a strong inhibitor of many metallo-enzymes, especially cytochrome oxidase, a key enzyme in cellular respiration. Cyanogenic glycosides

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are synthesized by cassava from germination (Dunstan et al., 1996). There are high concentrations in parts of the plant that carry out photosynthetic activity and during the period when the plant grows the fastest (Louembe et al., 1997). Not all varieties of cassava contain the same amount of HCN, and predictions of cyanide contents exists (Sanchez et al., 2014). Sweet varieties contain 30 to 130 ppm of HCN when raw, bitter varieties 80 to 400 ppm, and very bitter varieties 275 to 500 ppm of HCN (Nassar and Ortiz, 2006). The global detoxification procedures for cassava have been reviewed by Coursey (1973), Lancaster et al. (1982) and Padmaja (1995). The effects of traditional as well as modified processing techniques in reducing the cyanogen levels have been studied by several scientists (Cooke, 1982; Fukuba et al., 1984; Nambisan and Sundaresan, 1985; Mahungu et al, 1987; O'Brien et al., 1992; Padmaja et al., 1994). The poisonous substance, present in larger quantities in the peel is removed by peeling, washing or cooking, sun drying or fermentation. Mild method for removal of cyanogens from cassava leaves with retention of vitamins and protein has been developed (Bradbury and Denton, 2014). The dried roots are processed into tapioca, cassava or flour. Tapioca is a fecula of cassava that is used to thicken soups, puddings, creams or custards. There are many cultivars of bitter varieties, for example, 'Chaspagna', 'Green cassava', 'Pilotin', 'Saint Vincent', etc. (Germosén-Robineau, 1999).

Cassava is now widely grown in tropical countries. It grows best in wetland and sunny areas but accepts any type of soil (Jennings, 1995). It multiplies through cutting stems or tubers. Planting usually takes place during the rainy season. The harvest occurs 8 to 36 months later. Cassava is a shrub growing between 1 and 3 m high with tuberous roots and white flesh rich in starch. The skin of the bitter cassava tuber is thin and adherent, whereas in the sweet variety it is thick and easily removed. Its underground part comprises feeder roots which penetrate deep into the ground (up to 1 m) and tuberous roots located just below the soil's surface. These roots form a bundle of 5 to 10 plants and can reach a length of 30 to 120 cm, with a diameter of 4 to 15 cm and a weight of 1 to 8 kg [it is these roots that are consumed (Cock, 1985)].

Nineteen million hectares of cassava are grown worldwide, including 12 million hectares in Africa, 2 million hectares in South America and 4 million hectares in Asia. World production reached 233 million tons in 2009 (FAOSTAT, 2009). Nigeria is the largest producer with 36 million tons, followed by Thailand (30 million tons) and Indonesia (22 million tons). In 2009, Martinique produced 194 tons of cassava, covering 76 ha. Cassava in Martinique is used mainly in the form of flour. The roots of sweet varieties are eaten boiled. In addition to the use of tubers and leaves for food, cassava is selected for starch production. The bitter cassava starch has a variety of uses and its properties are similar to those of potato starch (Delpeuch et al., 1978). In some countries, such as Brazil, a large-scale cassava industry has developed. The starch is used as a food thickener or as glue in stationery production. The majority of cassava imported to Europe is used for animal feed. Indeed, it constitutes a very good source of energy and the presence of fibres makes it very digestible. Asian countries such as Thailand and Cambodia specialize in its export.

In order to expand opportunities for consumption of cassava in the French West Indies (F.W.I.) the Trade Council of Guadeloupe initiated a study in 1997 in order to analyse the causes of the decline in production and consumption of cassava. This program also defined how to boost production. With the development of new eating habits, new ways to consume cassava have been identified, including in the form of bread (many traditional African methods lead to making cassava starch bread) and cassava couscous (also based on a method of making African "attiéké") (Regez and Mulumba, 1987). Other by-products were also valued, including glue made from starch and animal feed made from cassava leaves following detoxification. Investigation of ethanol productivity of cassava crop as a source of biofuel in tropical countries has been studied (Adelekan, 2013).

In order to promote the production and consumption of cassava and integrate it into the daily diet, we decided to study the physicochemical and nutritional properties of four local varieties of cassava grown in Martinique. We wanted to compare the different qualities of these selected cultivars. This study is therefore an evaluation of cassava characteristics focussing on: (i) a sensorial analysis of four cassava cultivars and (ii) the physicochemical and nutritional characteristics of these four tubers.

MATERIALS AND METHODS

Plant material

Varieties were provided by the local department of agriculture and local producers. A minimum of 30 tubers were collected from each variety of cassava in order to have representative samples for each variety. A set of physical parameters was measured on each tuber (size and weight). They were then cleaned, peeled, sliced and steamed. Physicochemical analyses were carried out on cooked slices (texture and colour) or on crushed cooked pulp (energy, fibres, starch, polyphenols, sugars, minerals and vitamin C content).

Morphology and composition of sweet cassava

Morphological and physical characterization

The proximate analyses of cultivar size were carried out using a calliper for fruit length and width and a precision balance for cassava weight (Shimadzu UW4200HV). Texture parameters were measured with a LLOYD Instruments TA plus texture analyser, using a piston 4 mm in diameter and 30 mm / min speed. The tuber colours were determined with a Minolta CR-200 Chroma meter using the three parameters (L^*, a^* and b^*) established by the International Commission on Illumination: L^* for lightness to

distinguish light colours from dark colours, *a** used to classify red to green colours, and *b** used to classify yellow to blue colours.

Physicochemical characterization of the tuber

For each analysis and sample, three replicates were performed.

Dry matter content (DM): Flesh samples (2 g of crushed, homogenized flesh) were collected from each cassava for DM determination in triplicate, using a ventilated oven at 70°C for 5 h at reduced pressure (- 1 bar).

Ash content: Cassava ash content was calculated from a crushed sample (1 g) following heating to 525°C for 5 h as per the AOAC official method 923.03 (1996).

Protein content: The protein content was determined through the quantification of total nitrogen using Kjeldahll's method. Following mineralization of the sample (2 g) in 25 ml of 95% H_2SO_4 using a catalyst and a Turbotherm mineralizator (Gerhardt Laboratory Systems, Königswinter, Germany), the mineralizate was distilled using soda in a Vapodest distiller (Gerhardt Laboratory Systems, Königswinter, Germany). The distillate was collected in 40 ml of boric acid 40 $g.l^{-1}$ with the use of some drops of Tashiro's indicator. The distillate was titrated by hydrochloric acid HCl (0.1 N).

Lipid content: Lipids were extracted from the sample (2 g) after acid hydrolysis with 50 ml of 8 N HCl, at 80°C. The mixture was filtered and rinsed with boiling water until a neutral pH was obtained, after which the filters were dried. The residues were placed in glass cartridges with 140 ml of 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.

Carbohydrate content: This was obtained by finding the difference [(dry extract – (ash + lipids + proteins)]. Carbohydrates represent the total fibre, starch and sugar content.

Energy value: Energy value was determined by adding lipid, carbohydrate and protein contents.

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

Fibre content: Fibre content was determined with the AOAC 985.29 method.

Polyphenol content: Total polyphenols were determined using Folin and Ciocalteu's method described in Georgé et al. (2005). Only raw extracts were analysed.

Ca, K, P, Zn and Mg: Ca, K, P, Zn and Mg contents were determined with the Cofrac program 60. Ca, K, P, Zn and Mg rates were determined by atomic absorption spectrometry, respectively at 422.7, 766.5, 430, 213.8 and 285.2 nm.

pH: About 25 g of flesh (cooked or raw) was blended with ~ 250 ml deionised water (10% w/w) for 30 min using a magnetic stirrer. The pH of the blended solution was determined at ambient temperature with a Sentix 81 (WTW) probe.

Enzymology: Measures were carried out on raw and cooked cassava. 2 g of samples were dissolved in 0.5 mM ascorbic acid, 1 M NaCl. Peroxidases reacted with gaiacol 55 mM and its enzymatic activity was measured by absorption spectrometry at 470 nm every second for 20 s using a spectrophotometer (JENWAY 7305). 2 g of sample 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 s using a spectrophotometer (JENWAY 7305). Lipoxigenase activity was determined using a spectrophotometer (JENWAY 7305).

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

Vitamin B3: Vitamin B3 was determined with the EN 15562 2009 method.

Cyanhydric acid: Cyanhydric acid determinations were undertaken using the HS-GC-NPD method.

Sensorial analyses

Sweet cassava samples were cleaned, peeled, bleached, placed in plastic bags, frozen and warmed just before sensorial analyses. Twelve individuals were selected as panel members, all of them inexperienced in sensory analysis. Five 2-h training sessions were carried out until they were able to recognize and rate the characteristics of different cassava varieties according to the AFNOR 8586-1 and 8586-2 standards. Fifteen (15) attributes represented the sensory profile according to the AFNOR 13299 standard. Significant differences ($p<0.05$) were found for the 15 sensory attributes. Homogeneity in the group was also tested by two-way analysis of variance (ANOVA) for each attribute and the training was considered complete when no panellists × samples interaction was found. ANOVA were carried out with FIZZ®, UNIWIN Plus v6.1 and StatGraphics CENTURION® XV 2005 software with a confidence interval of 5%.

Data statistical analysis

The physical and chemical mean values of triplicate measurements or analysis were statistically analysed. ANOVA, based on student tests, principal component analysis (PCA) and Duncan's multiple range test (DMRT) were performed using the software StatGraphics CENTURION® XV 2005 and Uniwin PLUS® v6.1.

RESULTS

Agronomic data

The first step was a survey and screening of varieties by the local department of agriculture throughout the region of Martinique. Phenotypic characterization and identification were then established. Sweet cassavas were grown on contiguous plots and in the same agro-climatic conditions for a minimum of nine months. Cropping system data was collected using a delivery sheet, provided by the department of agriculture, and is summarized in Table 1. Cultivars '*KM06'*, '*KM07'* and '*KM08'* exhibited phenotypic differences such as colour of the petiole. '*KM06'* and '*KM08'* had the same flesh colour.

'*KM08'* is distinguished by a pink-coloured cortex. '*KMRA'*

Table 1. Cropping system data of the four sweet cassava varieties studied.

Variety	*KM06*	*KM07*	*KM08*	*KMRA*
Average rainfall (mm)	1900 to 2000 mm			
Irrigation	in extra	in extra	in extra	no use of water
Soil type	Ferralitic			Sandy and pumice soil
Previous crop	Fallow			
Treatments	No fungicide, insecticide and nematicide Chemical weed control (glyphosate) around Weeding at will Satisfactory level of fertility Phosphorus and potassium deficiency rectified through fertilizer contribution Search chlordecone negative			Manual weeding No fungicide, insecticide and nematicide
Observations	Dense vegetation Plant height: 2.5 m Flesh colour: white Petiole colour: green Parchment/cortex colour: white	Moderately dense vegetation Plant height: 2 m Flesh colour: yellow Petiole colour: green Parchment/cortex colour: White	Very dense vegetation Plant height: 2.5 m Flesh colour: white Petiole colour: red Parchment/cortex colour: pink	Flesh colour: white Petiole colour: purple Parchment/cortex colour: white

Table 2. Average scores out of 7 for sensorial analysis descriptors of the four sweet cassava varieties.

Sensory attribute	*KM06*	*KM07*	*KM08*	*KMRA*
Colour***	$3.08 \pm 1.71_{b}$	$5.54 \pm 1.33_{a}$	$3.00 \pm 1.47_{b}$	$3.46 \pm 1.56_{b}$
Colour homogeneity	5.62 ± 1.33	5.62 ± 0.87	5.38 ± 1.04	5.15 ± 0.99
Odour	4.31 ± 1.11	4.62 ± 1.12	4.77 ± 1.30	4.77 ± 1.01
Taste	4.46 ± 1.33	4.38 ± 1.45	4.38 ± 1.66	4.85 ± 1.21
Earthy taste	2.85 ± 1.57	3.00 ± 1.78	3.15 ± 1.68	3.08 ± 1.75
Saltiness	3.15 ± 1.21	2.92 ± 1.12	3.08 ± 0.86	3.15 ± 1.34
Bitterness***	$2.69 \pm 1.55_{bc}$	$2.08 \pm 1.50_{c}$	$4.15 \pm 1.41_{a}$	$3.00 \pm 1.68_{b}$
Astringency	2.85 ± 1.77	2.85 ± 1.46	3.23 ± 1.42	3.00 ± 1.68
Firm texture**	$4.62 \pm 1.19_{ab}$	$5.15 \pm 1.21_{a}$	$3.62 \pm 1.39_{c}$	$3.85 \pm 1.14_{bc}$
Mealy texture	5.00 ± 1.19	4.46 ± 1.51	4.46 ± 1.05	5.38 ± 1.26
Fibrous texture	3.08 ± 1.66	3.46 ± 1.85	3.62 ± 1.39	3.08 ± 1.71
Sticky texture	4.62 ± 1.04	3.62 ± 1.50	4.08 ± 1.38	4.23 ± 1.01
Melting texture**	$3.77 \pm 1.36_{ab}$	$2.92 \pm 1.32_{b}$	$4.62 \pm 1.56_{a}$	$3.69 \pm 1.25_{ab}$

*Significant descriptors at 5%; **Significant descriptors at 1%; ***Significant descriptors at 0.1%; NS, No significant. Different letters (a-c) within the same line indicate significant differences at ($p<0.05$), using Duncan's multiple-range test.

tubers had a phenotypic appearance similar to '*KM06*'.

Sensorial analysis

A sensorial analysis was carried out on the four cassavas. Thirteen (13) descriptors were selected. Table 2 shows the results with the average scores out of seven for these descriptors. An analysis of variance was performed to evaluate the organoleptic characteristics and differences between the samples of cassavas presented to specialized juries, and for each descriptor. The interpretation of results can highlight significant descriptors, descriptors which reveal a statistically reliable difference between the samples. In contrast, no difference between the samples can be established for insignificant descriptors. The statistical analysis of this data reveals that 4 of the 13 descriptors evaluated varied significantly: colour, bitterness, firm texture and melting texture (Table 2). For the other criteria evaluated, no significant differences were found in the four varieties of cassavas. Their specific taste and smell, astringency and mealy and sticky mouth texture were comparable. They

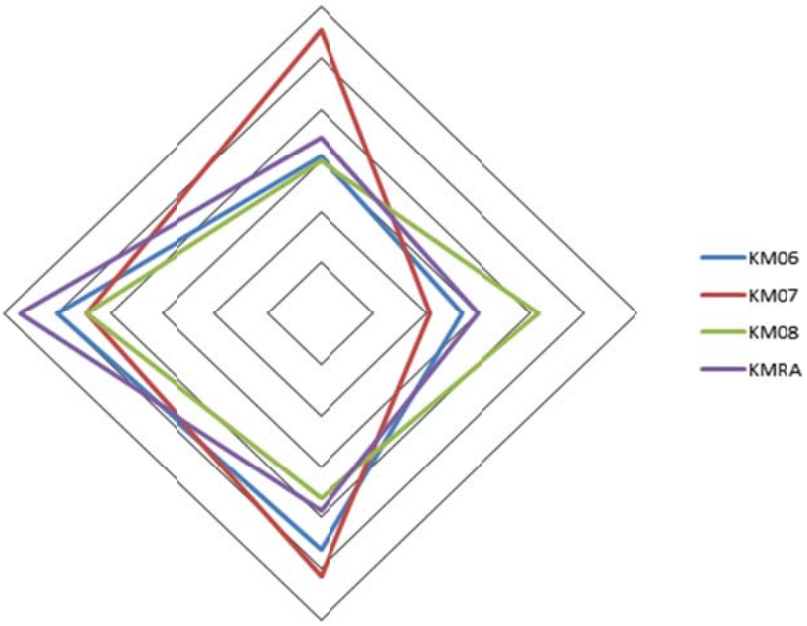

Figure 1. Plot of scoring averages for sensory analyses (out of 7) for the four sweet cassava varieties. *Significant at 5%, **significant at 1%, ***significant at 0.1%, NS: no significant.

had the following general characteristics: a consistent colour, a moderate overall intense odour, overall a slightly earthy, bitter, salty, astringent taste, a firm mealy, slightly sticky, fibrous and melting texture. A profile was established for each cultivar and presented in Figure 1. We noted, however, that the intense mealy mouth texture tended to be different (5.86%) between samples. Cassava '*KM07*' differed significantly from the other four cultivars by its more intense colour, slightly bitter taste and firm and slightly sticky mouth texture. Conversely, the '*KM08*' cultivar was distinguished by a more intense bitterness, slightly firm and very smooth mouth feel. Cassava '*KM06*' was statistically comparable to '*KMRA*'. Both cultivars were placed in the middle position for these four criteria. With regard to mealy mouth textures, '*KM06*' and '*KMRA*' cultivars tended to have the highest intensity.

Technological characteristics

All samples were weighed and measured to determine their calibre. The results are shown in Table 3. ANOVA was performed on the data obtained (diameter, length and weight) to highlight the features and significant differences observed for each class of samples. Analysis of the results revealed that, in terms of size, varieties differed statistically by 5% for their diameter ($p = 0.0034$). Multiple range tests (method of Fischer minimum significant differences (LSD), 95% confidence level) highlights three groups. '*KM08*' had the smallest diameter and '*KMRA*' the largest. '*KM06*' and '*KM07*' were in an intermediate position. We noted, however, in terms of weight, that the cultivar '*KM08*' tended ($p = 0.07$) to be lighter than the cultivar '*KM06*'. Other cassavas belonged to the same statistical group and were placed in an intermediate position. Figure 2 shows average trans-formation yields of the four samples of cassava. The four cultivars of cassava had close average cooking yields (~ 91 ± 1%). The four cultivars differed in their peel yield; '*KM06*' and '*KM07*' samples were close, with lower peel yields. Conversely, '*KM08*' had the highest peel yield (86%). Finally, the overall flesh yield had the same profile as the peel yield. This yield was average for '*KM06*' and '*KM07*' cultivars, with 58%. It was highest for '*KM08*'.

Texture analyses were performed on the four cooked slices of cassava samples. The results of the five texture parameters studied are shown in Table 3. ANOVA was performed to highlight the characteristics and significant texture differences observed for each sample. This analysis of the different varieties revealed that four texture parameters of the five evaluated differed significantly between cultivars. '*KM08*' cultivar was characterized by lower hardness and cohesion and higher tensile strength than other cultivars. Cassava '*KMRA*' demonstrated higher chewiness values than other cultivars. '*KM07*' was significantly harder. Finally, '*KM06*' was in an intermediate position for all parameters evaluated. Texture results corroborate the data obtained by sensory analysis, including hardness values. Indeed, we observed the same profile for '*KM07*' and '*KM08*', that is, firmer and less firm, respectively.

The colour of a product according to the parameters

Table 3. Physical parameters of the four sweet cassava varieties.

Cultivar	Length (cm)	Diameter (cm)	Weight (g)	Hardness (kgf)	Cohesion	Elasticity (mm)	Chewiness (kgf.mm)	Tensile strength (kgf)	L	a	b
KM06	29.60 ± 10.58	5.26 ± 1.19	531.67 ± 304.61	5.91 ± 1.39	0.06 ± 0.02	11.48 ± 2.25	5.79 ± 2.23	0.03 ± 0.02	81.96 ± 0.17	- 0.16 ± 0.02	23.41 ± 0.20
KM07	27.95 ± 11.76	4.57 ± 0.66	376.77 ± 200.29	6.31 ± 1.55	0.07 ± 0.03	12.69 ± 0.55	5.56 ± 1.47	0.03 ± 0.01	78.61 ± 0.05	- 1.34 ± 0.02	46.75 ± 0.03
KM08	26.8 ± 5.56	4.41 ± 0.59	274.95 ± 135.23	2.59 ± 1.00	0.15 ± 1.00	13.05 ± 0.04	4.60 ± 1.26	0.05 ± 0.01	82.1 ± 0.23	- 0.21 ± 0.01	22.35 ± 0.09
KMRA	26.65 ± 4.81	5.77 ± 0.61	467.2 ± 130.44	4.79 ± 1.03	4.79 ± 1.03	13.46 ± 4.18	11.07 ± 6.19	0.02 ± 0.01	108.04 ± 10.23	3.88 ± 1.02	32.89 ± 5.16

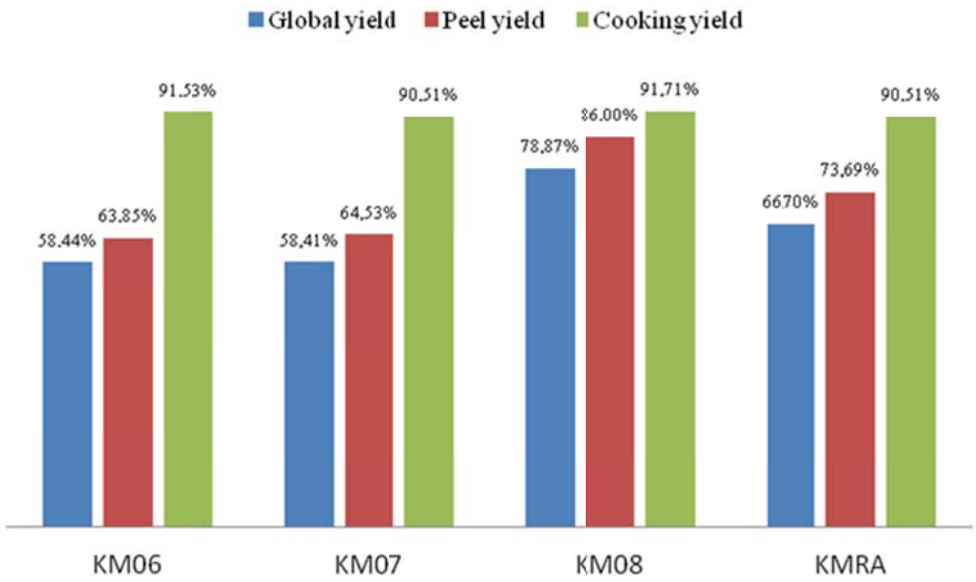

Figure 2. Average transformation yields of the four cassava varieties.

*L**, *a** and *b** results in its positioning in three-dimensional space. Values were measured on cooked slices of the four cassava cultivars (Table 3). ANOVA was performed to bring out the characteristics and statistical colour differences observed for each variety. This analysis revealed that the three colour parameters varied by 5%. The parameter *L** defines the brightness of product: 0 black, 100 white. There was a statistically

Table 4. Nutritional composition of the four sweet cassava varieties (Abbreviation used: GAE: Gallic Acid Equivalent).

Parameter	KM06	KM07	KM08	KMRA
Moisture (%)	55.28	54.72	65.97	59.5
Dry matter (%)	44.73	45.28	34.03	40.5
Ash (%)	1	0.93	1.04	1.2
Carbohydrates (g/100 g)	42.45	42.82	31.27	38.64
Starch (g/100 g)	8.64	18.78	7.44	20.15
Proteins (g/100 g)	1	1.34	1.57	0.56
Lipids (g/100 g)	0.29	0.2	0.16	0.13
VE (Kcal/100 g)	176.35	178.45	132.75	157.9
Total polyphenols (mg of GAE/100 g	34.8	49.95	41.8	36.75
Fibres (g/100g)	2.5	2.4	2.9	3.6
Vitamin C (mg/100 g)	17.4	29.8	14.3	18.35
Vitamin B3 (mg/100 g)	0.898	0.937	0.837	0.734
P (mg/100 g)	1.62	2.65	2.7	2.94
Ca (mg/100 g)	32.15	25.17	17.97	18.4
K (mg/100 g)	285.95	260.1	225.54	327.91
Zn (mg/100 g)	0.16	0.38	0.25	0.21
Mg (mg/100 g)	1.12	0.65	0.45	0.55
HCN (mg/kg)	< 0.5	< 0.5	< 0.5	< 0.5
PPO (AU/s/100 g)	0	0	0	0
Peroxidase (Au/s/100 g)	0	0	0	0
Lipoxigenase (Au/s/100 g)	0	0	0	0
pH	5.94	6.25	6.06	5.94

significant 5% difference in average brightness amongst the cultivars. Multiple range tests (low significant differences using Fischer method (LSD), 95% confidence level) highlighted two groups. The cultivar '*KMRA'* showed the highest brightness values. '*KM06*', '*KM07'* and '*KM08'* showed no difference between them. They had lower brightness than '*KMRA'*. The parameter "a" represents the axis from green (-60) to red (60). The parameter "b" represents the axis from blue (-60) to yellow (60). There was a statistically significant difference of 5% between average *a** and *b** in different cultivars. Multiple range tests (low significant differences using Fischer method (LSD), 95% confidence level) highlighted 2 groups for parameter *a**. '*KMRA'* is characterized by the highest value for *a**. There was no significant difference between the three other cultivars. Multiple range tests (low significant differences using Fischer method (LSD), 95% confidence level) highlighted 3 groups for parameter *b**. '*KM08'* and '*KM06'* had the lowest value for *b**. Conversely, '*KM07'* had the highest value for *b**. '*KMRA'* was in an intermediate position. These results fit in with the sensory results because the '*KM07'* cultivar can be distinguished by its intense colour.

Physicochemical analyses

Nutritional analyses were performed on cooked products. Table 4 summarizes the results of measured nutritional parameters. The hydrocyanic acid content of all cultivars studied is less than 0.5 mg/kg. According to Codex Alimentarius (CX / CF 03/09/11 December 2008), varieties can be defined as sweet cassava if their cyanide hydrogen content is less than 50 mg/kg. '*KM06'* and '*KM07*' cultivars have similar energy values, carbohydrates and dry matter and show the highest values. '*KM08'* had the lowest levels for these three parameters. '*KMRA'* offered the highest levels of total ash (1.2%) and starch (20.15 g/100 g). '*KM07'* also presented high starch content compared to '*KMRA'* but the lowest level of total ash.

Overall, all four cassava cultivars had low levels of vitamin B3. '*KM07'* had the highest level of vitamin C (29.8 mg/100 g) and total polyphenols (value 49.95 mg of GAE[1] /100 g), and the lowest fibre content. Levels of vitamin C for '*KM06'* and '*KMRA'* were similar (statistically significant). '*KM08'* was also a source of vitamin C (14.3 mg/100 g). The highest fibre content was found in the '*KMRA'* cultivar, which is classed as rich in fibre (> 3 g/100 g). Finally, all cultivars' total polyphenols content were higher than 34 mg of GAE/100 g. '*KM06*' had the lowest content of total polyphenols (34.8 mg of GAE/100 g). Mineral content was highly variable depending on cultivar; values were generally low. '*KMRA'* was the only source of potassium with 327.91-mg/100 g. '*KM06'* had the highest manganese and calcium contents, with 1.12 and 32.15 mg/100 g respectively. Its zinc and phosphorus concentrations were the lowest of the four cultivars. '*KM07'* had the highest zinc content (0.38 mg/100 g). '*KM08'* was in an intermediate position

Table 5. Comparison between the average nutritional composition of the four cultivars of sweet cassava studied and an average sweet cassava studied globally.

Nutritional composition	Average nutritional composition of the four sweet cassavas studied	Average data for sweet cassavas - international nutritional composition tables	Average data for potatoes - international nutritional composition tables
Moisture (%)	58.87 ± 3.87	60.07 ± 2.23	78.9 ± 3.36
Ash (g/100 g)	1.04 ± 0.08	0.92 ± 0.32	0.70 ± 0.28
Energy value (kcal)	161.36 ± 16.04	150.43 ± 11.62	81.60 ± 9.05
Proteins (g/100 g)	1.12 ± 0.34	1.12 ± 0.19	2.20 ± 0.43
Lipids (g/100 g)	0.20 ± 0.05	0.27 ± 0.11	0.26 ± 0.06
Carbohydrates (g/100 g)	38.80 ± 3.84	36.15 ± 2.34	17.80 ± 1.80
Fibres (g/100 g)	2.85 ± 0.40	1.91 ± 0.55	2.05 ± 0.62
Starch (g/100 g)	13.75 ± 5.71	-	15.8 ± 1.45
Minerals			
K (mg/100 g)	274.88 ± 32.06	297.60 ± 32.84	395.33 ± 108.21
Vitamins			
Vitamin C (mg/100 g)	19.96 ± 4.92	28.47 ± 5.22	18.52 ± 9.51
Niacin (B3) (mg/100 g)	0.85 ± 0.07	0.67 ± 0.16	1.74 ± 0.15

for its contents of phosphorus and zinc. It had the lowest calcium, potassium and manganese contents. '*KMRA'* had the highest content of potassium and phosphorus of the four cultivars, with 327.91 and 2.94 mg/100 g respectively. The enzymatic activity of four cultivars was null for the three enzymes studied, polyphenoloxidase, peroxidase and lipoxigenase. The average pH of the four varieties is about 6.4 ± 0.12.

DISCUSSION

All sweet cassavas studied in Martinique were rich in minerals, vitamin C and polyphenols. Vitamin C is known for its antioxidant properties (Padayatty et al., 2003). Vitamin B3 values were also high. Vitamin B3, also called niacin, is most frequently found in meat. It plays an important role in the release of energy from food, the functioning of the nervous system and also reduces cholesterol (Sauve, 2008). Total polyphenols are the most abundant antioxidants in our diet and foods rich in polyphenols are thought to play a role in the prevention of certain diseases (Scalbert et al., 2005). Therefore, based on these results and the vitamin and mineral contents observed, it can be argued that Martiniquan sweet cassavas have numerous health benefits (Sarkiyari and Agar, 2010).

The total polyphenol content and polyphenol oxidase activity lead to enzymatic browning. The higher the content or activity, the greater the sensitivity to enzymatic browning. Polyphenol oxidase is an enzyme with an essential role in the oxidation of phenolic compounds. In the presence of oxygen, it is responsible for the trans-formation of polyphenol into coloured compounds. Polyphenol oxidase is therefore a good indicator of enzymatic browning. It can be inhibited by exposure to high temperatures for short durations (bleaching). Visually, browning of the flesh was not observed during cassava processing (during peeling, cooking and whilst awaiting treatment). It remained the same throughout processing. This correlates with the enzymatic activities of three enzymes, which are null. Brightness has been identified as a factor influencing results. Indeed, it relates to the lighter or darker appearance of a product. The higher the value, the lighter the product and *vice versa*. Factors *a** and *b** express the colour itself and therefore were not of interest here in translating enzymatic browning. Results were therefore obtained only from the factor *L**. We did not observe any change in the value of *L** over time. This also correlates with the absence of enzyme activity and no visual observation of browning of cassava flesh during treatment.

Table 5 compares the average nutritional composition of the four varieties studied to the nutritional composition of sweet cassava averages based on international tables of compositions (USA, France, Germany, South Africa, Denmark, Finland, Australia, Pacific and Brazil). The four varieties grown in Martinique were advantageously positioned in relation to the globally identified data for their energy values, proteins, lipids, carbohydrates, fibre, vitamin C and niacin (vitamin B3) content. Conversely, their potassium content is lower than the average sweet cassava worldwide. Compared to potatoes, sweet cassavas in Martinique have greater nutritional potential. Their energy value was almost twice as much as for normal potatoes. Sweet cassavas also contained more

vitamin C and fewer lipids than potatoes.

In comparison with other vegetables for the rate of total polyphenols (Brat et al., 2006), sweet cassava would be in twelfth position, with about 40.82 mg of GAE/100 g on average, before potatoes and peas (respectively, 23.1 and 36.1 mg of GAE/100 g). We attempted to demonstrate different ways of using sweet cassavas (fresh and processed). We selected specific criteria to conduct this analysis (size / shape, sensory profile, nutritional value, average yield of transformation). Sweet cassavas with small size and regular shape are best for selling directly to consumers (purchase volume, ease of cutting and peeling). Cultivars with uniform colour, firm and / or melting textures and high nutritional potential also have greater commercial potential in relation to consumers. Conversely, sweet cassavas with large, irregular shapes, fibrous appearance, granular or powdery texture and / or low nutritional properties are more suitable for industrial uses (flour, mashed, flakes). Finally, when cultivars are characterized by intermediate criteria, they can be used both as a fresh product or processed. Thus, '*KM06'* is most suitable for processed products because of its large size, very firm, mealy and sticky texture (very unpopular with consumers) and nutritional characteristics - mineral levels (high K and Ca contents), carbohydrates and dry matter content. '*KM07'* displays criteria that make it suitable for fresh consumption or processing: its small size, regular shape, colour and nutritional properties (high vitamin C, carbohydrates and dry matter content) make it suitable for fresh consumption, whilst high dry matter content and texture make it suitable for processing into flour or frozen products.

Variety 'KM07' therefore seemed to offer the best compromise between size and nutritional and sensory characteristics and it would thus be recommended for production. In contrast, '*KM08'* would be better for processed products because of its slightly firm and melting texture and low nutritional potential, including vitamin and mineral levels. Its small size and high concentration of polyphenols are the only criteria in its favour in terms of fresh consumption. The regular form of '*KMRA'*, together with its starch and high mineral content, give it greater value. However, it is very fibrous and lacks texture, which may be considered a disadvantage. Conducting consumer tests on these cultivars will determine their acceptability criteria with relation to consumers in Martinique.

Conclusions

This study is the first in investigating varietal characterization of four sweet cassavas in Martinique. It is also one of the first study of the cassava variety *M. opi* and the variety *M. esculenta* Crantz is one of its primary areas of focus. The four cultivars were distinguished by their phenotypic, sensory, physicochemical and nutritional characteristics. '*KMRA'* cultivar was distinguished by its cultivation techniques but had the same phenotypic characteristics as '*KM06'*. There was no significant difference between the lengths of cassavas, but varieties differed significantly with respect to their colour. '*KMRA'* was the brightest and '*KM07'* had a rather yellow tint. '*KM08'* was significantly narrower, had the best average yield of transformation and the lowest carbohydrate content. '*KM08'* was also less firm but had a cohesion and tensile strength significantly higher than other cultivars. '*KM07'* cultivar was the hardest and had the highest total polyphenol content. '*KMRA'* rated highest for chewiness. '*KM06'* had the lowest total polyphenol content. Martinique sweet cassavas are richer in nutriational compounds and vitamin C than potatoes. Sweet cassavas also have a lower glycaemic index, which means they could be of interest for individuals affected by obesity and diabetes. Fact sheets were developed for each studied cultivar combining all the data obtained, as well as recommendations in terms of value and usefulness of each cultivar. Their sensory specificity, high nutritional value and suitability for industrial processing have also been highlighted. In view of their potential in terms of consumption and processing, further investigations into the qualities of these tubercles are needed. Further studies could aid in highlighting their positive characteristics and thus encourage further development within professional agriculture and agribusinesses. A cassava research-for-development program was carried out in the Democratic Republic of Congo and highlighted impact at the farm level (Rusike et al., 2014). This work is thus especially helpful for optimal management of crop harvesting in a region of agriculture and climatic contrasts.

Conflict of Interests

The author(s) have not declared any conflict of interest.

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