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Evolution of the Physicochemical Characteristics of Cassava Roots of the Yacé Variety According to the Stage of Harvest

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Abstract

Cassava is an important food product, due to the volume of its production and consumption. It is, in fact, an important staple food in the world, particularly in Africa. It is cultivated throughout the Ivorian territory with a predominance in the south. Its strong demand has led some producers to harvest early, regardless of the impact of the harvest stage on the physicochemical parameters of cassava roots. The objective of this work was to determine the stage of harvest (maturity) of cassava roots which allows cassava roots to be obtained with good nutritional qualities. Thus, the physicochemical characteristics were evaluated at different stages of harvest (11^{th}, 12^{th}, 13^{th} and 14^{th} month after planting the cuttings) of the cassava roots of the Yacé variety. The highest energy values (389.21 Kcal/100 g of DM) were obtained in the twelfth month of harvest. At this same stage, the carbohydrate and starch contents increased respectively by 94.65 g/100 g of DM and of 83.54 g/100 g of DM. Also, these cassava roots had a substantial share of minerals and polyphenols with very low levels of hydrocyanic acid and fiber compared to those of the other harvested stages. Thus, cassava harvested in the twelfth month of cultivation provides the best physicochemical characteristics.

Keywords: Cassava roots; harvest stage; physicochemical characteristics.

1. Introduction

Cassava (Manihotesculenta CRANTZ) is a perennial dicotyledonous plant, belonging to the Euphorbiaceae family and cultivated worldwide [1]. This starchy root crop is native to South America [2]. It was only recorded in West Africa towards the end of the 17^{th} century [3]. However, it was introduced to Ivory Coast in the 19^{th} century by Akan immigrants (Abouré and Alladjan) from southern Ghana [4]. It lends itself to polyculture, supports drought and infertile soils [5]. It is cultivated throughout the Ivorian territory with a predominance in the South [6]. It is mainly cultivated for its roots and leaves and contributes to food security [7].

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Cassava is according to [8] and [9], the 4th largest vegetable crop in the world after maize (1504.7 million tonnes), wheat (770.4 million tonnes) and rice (518.2 million tonnes). The first producing country is Thailand (18 million tonnes). World cassava production was estimated at 250 million tonnes in 2021 (792.7 kg/sec), including 117.5 million tonnes from Africa (47 % of this production) and 5 million tonnes (2 % of world production) from Côte d'Ivoire [9].

Cassava production therefore fell from 2018 to 2021. In fact, it fell from 277.07 million tonnes to 250 million tonnes globally. As for African production, it went from 160.73 million tonnes to 117.5 million tonnes. Thus, the global and African decreases are respectively 9.77 % and 26.89 % [8] and [9]. In Côte d'Ivoire, there are two types of cassava used mainly for food and livestock [10]. Sweet varieties, used artisanally for human consumption, while bitter varieties are only used after industrial processing [11]. Among the cassava varieties, the Yacé or IAC (Improved African Cassava) variety, a bitter variety introduced in Côte d'Ivoire in the 1970 and 1980, is the most cultivated in large production basins [12]. Dry or in starch justifies its choice [13]. These cassava roots are processed into several products including attiéké [14], placali [15], attoukpou [16], starch [17] and gari [18] etc. Cassava cultivation is of significant socio-economic importance for producing countries [19]. Indeed, in 2016 study by the Center for International Cooperation in Agronomic Research for Development, estimated the consumption of cassava roots by Ivorian at around one hundred kilograms per year (100 kg/year). Also, the functional analysis of the cassava sector revealed that the growing demand for some of its by-products (attiéké and placali), for urban centers and export sectors is now creating interesting income opportunities, in particular for women who are at the center of production, processing and marketing operations [12]. This significant demand for these products derived from cassava roots, pushes some producers to opt for an early harvest. However, [20], placed the harvesting stage of cassava roots of the Yacé variety between the twelfth and the twentieth month after the cuttings were planted. This too long time interval does not guarantee the stability and quality of cassava roots in the ground. Indeed, studies carried out by [21] and [22], report the obvious influence of the harvest stage on the physicochemical composition of cassava roots. However, these studies apart from those of [22], who fixed the harvest at the thirteenth month to obtain good root characteristics, could not establish or define the specific characteristics of the roots at each stage of harvest recommended which guarantee the good nutritional quality of cassava roots. Thus, given the importance of cassava in the economy and food of developing countries, it would be interesting if the ambiguities around the stages of its harvest were clarified in order to provide users with good quality raw material. To do this, the cassava root crops were harvested block by block from the eleventh to the fourteenth month of maturity. That is, one month before the interval indicated by [20] and one month after the harvest stage indicated by [22]. The general objective of this study is to contribute to the valuation of the cassava roots of the Yacé variety by determining the harvest stage (maturity), which makes it possible to obtain cassava roots with good nutritional qualities. Specifically, it will be a question of determining the harvest stage which guarantees good physicochemical characteristics of the cassava roots.

2. Plant material

The plant material used for this study consisted of the fresh roots of the Yacé variety of cassava (Manihot esculenta Crantz).

3. Methods

3.1. Experimental apparatus

The experimental plot with coordinates 5.463611 latitude, -4.1155969 longitude and 99.00 altitude was used for this 15-month study from April 2016 to June 2017. It was located at Akoupézeudji, a commune of Abidjan (Côte d'Ivoire) and was randomized four times. Its low slope allowed its good drainage in a tropical climate. Its soil was of the ferralitic type with sandy clay texture. During this experiment the average precipitation was 1744 mm with an average temperature of 25.8 °C. The 20 cm cuttings with 5 to 7 nodes, from 12 month old stems were planted for cultivation with a spacing of 0.8 m between the plants in length and width, i.e. a density of 15.625 plants/hectare. The experimental plot was delimited by a 3 m firewall and divided into 4 blocks (A, B, C and D) of 125 m^2 each and 3 m apart. Each block consisted of ten (10) logs of ten (10) plants. The lines were 0.8 m apart inside the blocks, giving a total area of 1.870 m^2. Fifteen (15) days after the cuttings were planted, the missing stems were replaced. The experimental plot was maintained weekly.

3.2. Harvest and sampling

The harvests were carried out respectively in March (block A), April (block B), May (block C) and June (block D), of the year 2017 between 7 a.m. and 10 a.m. This corresponds to the eleventh, twelfth, thirteenth and fourteenth month of harvest after planting the cuttings. Thirty (30) cassava plants were randomly selected from one of 4 blocks at the rate of 3 plants per row of ten plants. The stems were cut 30 cm from the ground with a machete and the roots pulled up, being careful not to nick them. After the harvest, a batch of 10 kg of cassava roots randomly chosen to undergo physicochemical analyzes, was transported to the biocatalysis and bioprocesses laboratory of the training and research unit of food sciences and technology, located within Nangui Abrogoua University of Abidjan, Côte d'Ivoire.

3.3. Moisture content

The moisture content was determined according to the method described by [23]. Five (5) grams of sample was placed in porcelain capsule. The sample capsule was placed in an oven at 105 ± 2 °C for 24 hours until constant weight. The capsule was removed from the oven after 24 hours and cooled in desiccator. After cooling the whole (sample + capsule) was weighed. The moisture content was therefore determined using the following mathematical relationship:

$$\text{Moisture (\% of FM)} = \frac{(m_1 - m_2)}{m_s} \times 100 \qquad (1)$$

m_s: mass (g) of the sample after baking

m_1: mass (g) of the whole (capsule + sample) before baking

m_2: mass (g) of the whole (capsule + sample) after baking

3.4. Titratable acidity

The method described by [23], was used to determine the titratable acidity. Ten (10) g of sample crushed and diluted in 100 ml of distilled water was filtered through filter paper (Whatman n°4) and the filtrate was collected in an Erlenmeyer flask. 10 ml of the filtrate were titrated with a solution of NaOH (0.1 N) in the presence of phenolphthalein until the turn pink. Then, the value of titratable acidity was determined using the following mathematical relationship:

$$\text{Titratable acidity (meqg / 100 g of FM)} = \frac{N \times V_{eq} \times 10^4}{m_s \times V_0} \quad (2)$$

V_0: volume (ml) of the test sample

V_{eq}: volume (ml) of NaOH (0.1 N) poured in equivalence

m_s: mass (g) of the sample N: normality of the soda solution

3.5. Total and reducing sugars content

The sugars were extracted according to the technique described by [24]. One (1) g of sample was weighed in a centrifuge tube. Ten (10) ml of ethanol (80 %, v/v) was added. The mixture was homogenized and centrifuged at 6000 rpm for 10 minutes. The supernatant was collected in a 50 ml Erlenmeyer flask. The pellet was taken up in 10 ml of ethanol (80 %, v/v). The mixture was homogenized and centrifuged under the same conditions as before. The supernatant was evaporated in a sand bath for 10 min. The total supernatant collected was used for the determinations of the ethanosoluble sugars.

Total sugars were determined according to the technique described by [25], using phenol and concentrated sulfuric acid. The ethanosoluble extract (150 µL) was taken and placed in a test tube. To this volume were added 1 ml of phenol (5 % w/v) and 1 ml of concentrated sulfuric acid (97 %). The reaction medium was homogenized and left to cool for 5 min. The optical density was read at 490 nm on a spectrophotometer against control containing all products except the ethanosoluble extract. The optical density was converted to the amount of total sugars using a standard line obtained from solution of glucose (1 mg/ml).

The reducing sugars were determined according to the technique described by [26], using 3.5-dinitrosalicylic acid (DNS), as the phenolic derivative. Pentoses and hexoses, under the effect of heat, transform into furfural which, in the presence of phenolic derivatives, produces a specific coloration with reducing sugars. Two hundred (200) µl of ethanol-soluble extract was added to test tube containing 200 µl of DNS. The reaction medium was heated in a boiling water bath for 5 min, then left to stand on the bench for 5 min. Two (2) ml of distilled water was added to this reaction medium. The intensity of the coloration was measured with a spectrophotometer (Shimadzu Spectrophotometer UV-120-02), at 540 nm against a control containing no ethanoic extract. Optical densities were converted into amounts of reducing sugars using calibration line obtained from a glucose solution (1 mg/ml).

3.6. Protein content

The crude protein content was determined according to the Kjeldhal method [23]. A one (1) gram sample was heated at 400 °C for 120 min in the presence of a pinch of the catalyst mixture (Selenium + potassium sulfate (K_2SO_4) and 20 ml of sulfuric acid (H_2SO_4) 95- 97 % in a digester (BUCHI, France). The mineralized product obtained was made up to 60 ml with distilled water. To this volume, 50 ml of sodium hydroxide (40 %, w/v) were added, before be brought to the boil in a LEGALLAIS type still. The ammonia which was released was trapped in a measuring vessel containing 10 ml of the acid-base mixture (4 %, w/v) mixed indicator (methyl red + bromocresolgreen) at pH 4.4-5.8. The assay was carried out with a decimolar solution of sulfuric acid until turning orange. A blank was carried out under the same conditions as the test. The protein was determined according to the following mathematical formula:

$$\text{Protein (\% of DM)} = \frac{(V_1 - V_0) \times 14 \times 6.25 \times N}{m_s} \quad (3)$$

V_0: volume (ml) of sulfuric acid solution poured for the blank test

V_1: volume (ml) of sulfuric acid solution poured for the test (sample)

N: normality of the sulfuric acid solution (0.01 N)

m_s: mass (g) of the sample

14: atomic mass of nitrogen 6.25: Conversion coefficient of nitrogen to protein

3.7. Crude fiber content

The fiber content was determined according to the method described by [23]. Two (2) grams of the dried and ground sample was homogenized in 50 ml of 0.25 N sulfuric acid. The mixture was boiled for 30 min under reflux condenser. Then, 50 ml of 0.31 N sodium hydroxide was added to the contents of the flask and again

brought to the boil for 30 min under reflux condenser. The extract obtained after boiling was filtered through Whatman No. 4 filter paper and the residue was washed several times with hot water until the alkali was completely removed. The residue was dried in an oven at 105 °C for 8 h and cooled in a desiccator and then weighed. The residue obtained was incinerated in an oven at 550 °C for 3 h, cooled in a desiccator, then the ash was weighed. The fiber content was determined using the following mathematical relationship:

$$\text{Fiber(\% DM)} = \frac{(m_1 - m_2)}{m_s} \times 100 \qquad (4)$$

m_1: mass (g) of the dried residue

m_s: mass (g) of the sample

m_2: mass (g) of ashes obtained

3.8. Lipid content

The total lipids were extracted with hexane (organic solvent) from the ground sample dried according to method [23] using SOXHLET. Ten (10) grams of dried and ground sample was placed in a pre-tared WHATMAN cartridge. A volume of 300 ml of hexane was placed in a previously weighed vacuum extraction flask. The flask, containing hexane (m_0), was placed on the heating cap (110 °C) for 7 hours for the extraction of lipids by rejection. After this extraction stage, the flask was removed from the SOXHLET apparatus and placed in an oven at 100 °C for 20 min for the total evaporation of the solvent using a rotary evaporator (HEILDOLPH Laborata 4003 Control, Schwabach, Germany). When evaporation was complete, the flask was reweighed (m_1). The lipid content was determined from the following equation:

$$\text{lipid (\% DM)} = \frac{(m_1 - m_0)}{m_s} \times 100 \qquad (5)$$

m_0: mass (g) of the empty balloon

m_s: mass (g) of the sample

m_1: mass (g) of the whole (balloon + lipids) after incineration

3.9. Carbohydrate content

The assimilable carbohydrate content was determined according to the difference method described by [27]. The carbohydrate content is obtained by the following mathematical formula:

$$\text{Total carbohydrates} = 100\ \% - [\%\ \text{proteins} + \%\ \text{lipids} + \%\ \text{fibers} + \%\ \text{ashes}] \quad (6)$$

The percentages of protein, lipids, fibers and ashes were determined according to the previous indications.

3.10. Starch content

The starch content was determined according to the difference method described by [28]. This content is obtained by the following mathematical formula:

$$\text{Starch}\ (\%) = 0{,}9 \times (\%\ \text{total carbohydrates} - \%\ \text{total sugars}) \quad (7)$$

The percentages of total carbohydrates and sugars were determined according to the previous indications.

3.11. Energetic value

The energy value was determined by calculation, according to the mathematical formula described by [29].

$$\text{EV (Kcal/100g DM)} = [4 \times (\%)\ \text{proteins}] + [9 \times (\%)\ \text{lipids}] + [4 \times (\%)\ \text{carbohydrates}] \quad (8)$$

The percentages of proteins, lipids, and carbohydrates were determined according to the previous indications.

3.12. Hydrocyanic acid content

This assay was carried out according to the method of [30]. Twenty (20) grams of sample was macerated in 200 ml of distilled water for 3-4 h, followed by distillation to collect the distillate on 20 ml of soda solution containing 0.5 g of soda. Then 100 ml of the distillate are taken and 8 ml of 5 % potassium iodide (KI) are added to it and the assay was carried out with a solution of silver nitrate (0.02 N $AgNO_3$), until obtaining the opalescent coloring. Let A be the quantity of $AgNO_3$ in ml obtained at the end of the assay, the quantity of hydrocyanic acid (HCN) in mg of sample is obtained by the following mathematical formula:

$$\text{HCN (mg / 100 g of FM)} = A \times 1.08 \quad (9)$$

3.13. Total polyphenol content

The samples were ground using Moulinex brand mixer to obtain a paste. The extraction of total polyphenols was carried out according to the protocol proposed by [31]. One (1) gram of sample was dissolved in 25 ml of an 80 % methanol mixture (methanol-distilled water 80:20; v/v), acidified with 0.1 % HCl (2 N). The mixture was left for 2 hours at room temperature, then it was centrifuged at 1800 rpm/15 min. The residue was re-extracted with 25 ml of 80 % methanol and centrifuged. At the end, the supernatants were combined and the dry extract was collected after evaporation to dryness. The determination of the total polyphenols consisted in adding to 100 µl

of polyphenolic extracts obtained by dissolving 0.02 g of dry extract in 1 ml of methanol, 250 µL of Folin reagent diluted with distilled water (50 % v/v). After 5 min of incubation at 25 °C in an oven, 250 µL of sodium carbonate ($Na_2 CO_3$) at 20 % (w/v), were added to the tubes and the whole was brought to 2000 µL with distilled water. The absorbance was read with a spectrophotometer (Shimadzu Spectrophotometer UV-120-02), at 760 nm after 60 min. The blank was prepared for each sample, replacing the polyphenolic extracts with 80 % methanol. The concentration of total polyphenols was calculated from the regression equation of the calibration curve established with gallic acid (0.03-0.50 mg/ml), based on previous tests and was expressed in mg gallic acid equivalent per gram of extract (mgEAG/g of extract), according to the mathematical formula described by [32]:

$$T = \frac{(m_1 - m_2)}{m_s} \quad (10)$$

T: total content of polyphenols (mg gallic acid equivalent/g of sample extract

C: gallic acid equivalent concentration (mg/ml)

V: volume of the extract (ml)

m_s: mass of the sample extract

3.14. Ash content

The ash content of the samples was determined according to the method described by [23]. Five (5) grams of ground sample weighed in a porcelain crucible of known mass (m_0), were placed in a muffle furnace (CERADEL, Industries) at 550 °C for 12 h. The thus incinerated sample was placed in a desiccator for cooling. The crucible containing the calcined sample was weighed (m_1). The ash content was given by the following mathematical formula:

$$\text{Ash (g / 100g of DM)} = \frac{(m_1 - m_0)}{m_s} \times 100 \quad (11)$$

m_0: mass (g) of the empty crucible

m_s: mass (g) of the sample

m_1: mass (g) of the whole (crucible + ash) after incineration

3.15. Mineral content

The mineralization process which was used is that described by [23]. A mass of 0.4 g of sample was placed in porcelain crucible and placed in a muffle furnace. The oven temperature was gradually raised in steps of 50 °C every 30 min to 550 °C and left at this temperature for 24 hours. The white ash obtained after mineralization is dissolved in 6 ml of 65 % nitric acid. The mineralized product was then taken up in a volumetric flask and its volume was made up to 50 ml. Calibration solutions of minerals (potassium, magnesium, sodium, lead, cadmium, calcium, zinc and iron) were prepared. Dilutions from 0.1, 0.25, 0.5, 1, 1.5 and 2 ml of standard solutions of each mineral (100 mg/l) were produced by supplementing the various initial volumes to 50 ml with demineralized water so as to obtain respective concentrations of 0.2, 0.5, 1, 2, 3 and 4 mg/l. These calibration solutions were then used for the calibration of the flame atomic absorption spectrophotometer. 2 ml of 3 % lanthanum solution were added to solution of 5 ml of mineralize obtained above in a 50 ml volumetric flask and made up with nitric acid up to the mark. A standard range for each mineral was established from the standard 100 mg/ml solution. With regard to phosphorus, the mineralized product obtained was treated with the vanado-molybdic reagent [33]. The phosphorus (P) content was determined by comparison with standard solution of 0.136 g of potassium dihydrogen phosphate dissolved in dilute solution containing 0.1 ml of nitric acid and 50 ml of distilled water. The determination of the various minerals was carried out using a GBC 904 AA atomic absorption spectrophotometer, Germany (limit of detection, 1.1 ppm) at wavelengths 769.9 nm, 285.2 nm, 589 nm, 830 nm, 283 nm, 229 nm, 422.67 nm, 213.8 nm and 248.3 nm respectively for potassium, magnesium, sodium, phosphorus, lead, cadmium, calcium, zinc and iron. The mineral concentration of the solution to be analyzed was given directly by the device.

3.16. Statistical analyzes

The results obtained underwent two types of statistical analyzes, one with Statistica 7.1 software and the other with R 4.0.2 software. Statistical analysis using Statistica 7.1 software, made it possible to assess the impact of the harvest stage on each of the parameters studied using one-way analysis of variance (ANOVA). The data obtained were expressed by the arithmetic mean assigned the corresponding statistical standard deviation. The one-way analysis of variance was performed on all the results obtained for each parameter, in order to determine the existence or not of significant differences between the values of the calculated means. Duncan's test was used to highlight significant differences at the 95 % confidence level. However, principal component analysis (PCA) was used to verify the existence of differences between all characteristics of cassava roots, studied according to the stage of harvest. To determine the variables underlying the differences in cassava roots, studied according to the stage of harvest, an ascending hierarchical classification of the heat map type (frequency map) was carried out. This classification made it possible to group the cassava roots, on the one hand, studied according to the stage of harvesting into main classes. In fact, the heat map matches the intensity of each variable quantity to a color chart on a two-dimensional matrix. R 4.0.2 software was used for multivariate

analyzes, including principal component analysis (PCA) and heat map, which allowed cassava roots to be classified or grouped according to the different stages of maturity tested. They also made it possible to identify the right harvest stage for obtaining good nutritional qualities.

4. Results

4.1. One-way analysis of variance of the physicochemical characteristics of cassava roots

4.1.1. Moisture content

The moisture contents of cassava roots obtained in the first three months are significantly different ($P < 0.05$) from that of cassava roots harvested in the fourteenth month (Table I). However, statistical analysis does not reveal any significant difference ($P > 0.05$) between the moisture content of cassava roots harvested in the first three months of harvest. Moisture content was higher in the eleventh month of harvest (59.96 ± 0.29 g/100 g FM) and lower in the fourteenth month of harvest (55.57 ± 1.09 g/100 g of FM).

4.1.2. Titratable acidity

The titratable acidity values of cassava roots are significantly different ($P < 0.05$), at the different harvest stages chosen (Table I). The titratable acidity value of cassava roots was higher in the fourteenth month of harvest (3.13 ± 0.01 meqg/100 g of FM) and lower in the eleventh month of harvest (1.98 ± 0.01 meqg/100 g of FM).

4.1.3. Carbohydrate content

Table I shows that by the twelfth month of harvest the carbohydrate content of cassava roots was higher (94.65 ± 0.02 g/100 g DM), compared to that of roots harvested at other stages of maturity. The lowest carbohydrate content was obtained in the fourteenth month of harvest (93.22 ± 1.05 g/100 g DM). Statistical analysis does not reveal any significant difference ($P > 0.05$) between the carbohydrate content of cassava roots harvested at the eleventh and thirteenth months. However, it reveals a significant difference ($P < 0.05$), between the carbohydrate contents of these two months and those of the other stages of harvest.

4.1.4. Total sugar content

Statistical analysis does not reveal any significant difference ($P > 0.05$) between the total sugar content of cassava roots harvested at the thirteenth and fourteenth months. However, it reveals a significant difference ($P < 0.05$), between the total sugar contents of these last two months and those of the first two months of harvest (Table I). With a value of 1.83 ± 0.02 g/100 g of DM, the roots harvested in the twelfth month contain the highest contents of total sugars. Those of the thirteenth and fourteenth months contain less with respective contents of 1.56 0.03 g/100 g of DM and 1.48 ± 0.02 g/100 g of DM.

4.1.5. Reducing sugars content

Like total sugars, the content of reducing sugars is also highest in 12 month old cassava roots (0.56 ± 0.02 g/100

g DM). Cassava roots from later harvest stages, particularly the fourteenth month, are the least endowed (0.37 ± 0.01 g/100 g DM). Statistical analysis does not reveal any significant difference ($P > 0.05$) between the reducing sugar content of cassava roots harvested at the thirteenth and fourteenth months. On the other hand, it reveals a significant difference ($P < 0.05$), between the contents of reducing sugars of these last two months and those of the other stages of harvest (Table I).

4.1.6. Protein content

Statistical analysis revealed a significant difference ($P < 0.05$) between all the protein contents of cassava roots obtained from the eleventh to the fourteenth month of harvest (Table I). Cassava roots harvested in the fourteenth month showed the highest protein value (1.71 ± 0.01 g/100 g DM), while the lowest value was obtained with roots from the eleventh month of harvest. (1.25 ± 0.01 g/100 g of DM).

4.1.7. Crude fiber content

Like the protein content, the fiber content of cassava roots reached its highest value (1.98 ± 0.02 g/100 g DM) and lowest (1.42 ± 0.08 g/100 g DM), respectively in the fourteenth and eleventh month of harvest (Table I). Statistical analysis reveals a significant difference ($P < 0.05$), between all the fiber contents of cassava roots obtained from the eleventh to the fourteenth month of harvest.

4.1.8. Lipid content

Statistical analysis revealed a significant difference ($P < 0.05$) between all the lipid contents of cassava roots obtained from the eleventh to the fourteenth month of harvest (Table I). In the eleventh month of harvest, the lipid content of cassava roots was lower (0.41 ± 0.03 g/100 g DM), compared to that of roots from the fourteenth month of harvest when it was higher (0.79 ± 0.02 g/100 g DM).

4.1.9. Starch content

The value of 83.54 ± 0.65 g/100 g of DM which was obtained in the twelfth month of harvest is the highest of the starch values of cassava roots (Table I). Statistical analysis does not reveal any significant difference ($P > 0.05$) between the starch contents of cassava roots harvested at the eleventh and fourteenth months. However, it reveals a significant difference ($P < 0.05$), between the starch contents of these two months and those of the other stages of harvest. Cassava roots from the fourteenth month of harvest showed the lowest value (82.57 ± 0.23 g/100 g DM).

4.1.10. Energetic value

The energy value of cassava roots was lowest in the fourteenth month of harvest with a value of 386.85 ± 2.06 Kcal/100 g DM. The highest value was obtained in the twelfth month of harvest (389.21 ± 0.94 Kcal/100 g of DM). Statistical analysis does not reveal any significant difference ($P > 0.05$), between the energy values of cassava roots harvested in the eleventh and twelfth months. But, it reveals a significant difference ($P < 0.05$),

between the energy values of the cassava roots of these two months and those of the other harvest months (Table I).

4.1.11. Hydrocyanic acid content

Statistical analysis reveals a significant difference ($P < 0.05$), between all the hydrocyanic acid contents of cassava roots obtained from the eleventh to the fourteenth month of harvest. The lowest (8.59 ± 0.01 mg/100 g of FM) and higher (10.58 ± 0.19 mg/100 g of FM) contents were obtained respectively with cassava roots harvested in the eleventh and in the fourteenth month (Table I).

4.1.12. Total polyphenol content

In the twelfth month of harvest, the total polyphenol contents of cassava roots were higher (135.06 ± 1.02 g/100 g DM), while in the fourteenth month they were lower (72.68 ± 0, 02 g/100 g of DM). Statistical analysis revealed a significant difference ($P < 0.05$) between all the total polyphenol contents of cassava roots obtained from the eleventh to the fourteenth month of harvest (Table I).

4.1.13. Ash content

Statistical analysis reveals a significant difference ($P < 0.05$), between all the ash contents of cassava roots obtained from the eleventh to the fourteenth month of harvest (Table I). These ash contents were 2.77 ± 0.02 g/100 g DM and 2.29 ± 0.02 g/100 g DM respectively for cassava roots from the eleventh and the fourteenth harvest month. The lowest value was obtained with cassava roots 12 months old (1.88 ± 0.02 g/100 g DM).

4.1.14. Mineral Content

Cassava roots harvested from the eleventh to the fourteenth month show no trace of lead and cadmium. On the other hand, macroelements (phosphorus, calcium, potassium and magnesium) and microelements (sodium, zinc and iron) have levels that vary from one stage to another in cassava roots. Indeed, the phosphorus content, high in the eleventh month (151.24 ± 0.26 mg/100 g of DM), reached its lowest value (135.13 ± 0.12 mg/100 g of DM), in cassava roots in the fourteenth month. Statistical analysis does not reveal any significant difference ($P > 0.05$), between the phosphorus contents of cassava roots harvested in the twelfth and thirteenth month. On the other hand, it reveals a significant difference ($P < 0.05$), between the phosphorus contents of these two months and those of the other stages of harvest (Table I). According to statistical analysis, there is no significant difference ($P > 0.05$) between the potassium contents of cassava roots harvested in the eleventh and twelfth months. However, it indicates the existence of a significant difference ($P < 0.05$), between the potassium contents of these two months and those of the thirteenth and fourteenth harvest months (Table I). In the eleventh month of harvest they were 202.40 ± 0.45 mg/100 g DM in cassava roots, before reaching the highest value of 210.29 ± 0.04 mg/100 g DM in cassava roots from the fourteenth harvest month (Table I). The contents of 52.26 ± 0.17 mg/100 g of DM, of 201.15 ± 0.14 mg/100 g of DM and of 10.11 ± 0.18 mg/100 g of DM respectively for magnesium, calcium and zinc in cassava roots were highest and reached in the eleventh month of harvest. However, these levels reached 48.25 ± 0.13 mg/100 g of DM, 197.30 ± 0.13 mg/100 g of DM and 7.80 ± 0.16

mg/100 g of DM which were their lowest values with the roots of the fourteenth month of harvest respectively for magnesium, calcium and zinc. Statistical analysis does not reveal any significant difference ($P > 0.05$) between the magnesium contents on the one hand and between those of calcium and zinc in the cassava roots harvested in the thirteenth and fourteenth months on the other. However, it reveals a significant difference ($P < 0.05$), between the magnesium contents on the one hand and on the other hand between those of calcium and zinc of the cassava roots of these last two months and those of the other stages harvest (Table I). Regarding the sodium and iron contents, their respective initial values of 15.42 ± 0.16 mg/100 g of DM and 9.58 ± 0.22 mg/100 g of DM obtained in the eleventh month of harvest were the most weak. These values then reached their maximum of 18.86 ± 0.08 mg/100 g DM and 11.94 ± 0.06 mg/100 g DM respectively in the fourteenth month of harvest. Statistical analysis revealed a significant difference ($P < 0.05$), between all the sodium contents, first and then iron, in cassava roots obtained from the eleventh to the fourteenth month of harvest (Table I). According to the statistical analysis there is no significant difference ($P > 0.05$) between the Ca/P ratios of the cassava roots harvested on the one hand in the eleventh and twelfth months of harvest and on the other hand between those cassava roots harvested in the thirteenth and fourteenth months (Table I). On the other hand, it reveals a significant difference ($P < 0.05$), between the Ca/P ratios of cassava roots harvested in the first two months and those of the last two months. These Ca/P ratios were lower (1.33 ± 0.001) and higher (1.46 ± 0.002), respectively in cassava roots from the eleventh and fourteenth harvest months.

Table I: Parameters of cassava roots of the Yacé variety harvested at different stages of maturity

Cassava roots parameters obtained during the different harvest months	**11th harvest month**	**12th harvestmonth**	**13th harvestmonth**	**14th harvestmonth**
Moisture (% of FM)	59,96 ± 0,29 b	59,46 ± 0,01 b	58,96 ± 0,01 b	55,57 ± 1,09 a
Titratableacidity (meqg/100 g of FM)	1,98 ± 0,01 a	2,46 ± 0,01 b	2,78 ± 0,02 c	3,13 ± 0,01 d
Total carbohydrates (% DM)	94,15 ± 0,31 b	94,65 ± 0,02 c	93,92 ± 0,03 b	93,22 ± 1,05 a
Total sugars (% DM)	1,76 ± 0,02 b	1,83 ± 0,02 c	1,56 ± 0,03 a	1,48 ± 0,02 a
Reducingsugars (% DM)	0,38 ± 0,01 b	0,56 ± 0,02 c	0,43 ± 0,02 a	0,37 ± 0,01 a
Protein (% of DM)	1,25 ± 0,01 a	1,39 ± 0,02 b	1,53 ± 0,03 c	1,71 ± 0,01 d
Fiber (% DM)	1,42 ± 0,08 a	1,61 ± 0,01 b	1,76 ± 0,03 c	1,98 ± 0,02 d
lipid (% DM)	0,41 ± 0,03 a	0,56 ± 0,03 b	0,69 ± 0,02 c	0,79 ± 0,02 d
Starch (%)	83,15 ± 1,03 a	83,54 ± 0,65 c	83,13 ± 1,00 b	82,57 ± 0,23 a
Energy value Kcal/100g of DM	385,27 ± 0,08 c	389,21 ± 0,94 c	388,03 ± 1,01 b	386,85 ± 2,06 a
Hydrocyanicacid (mg/100 g of FM)	8,59 ± 0,01 a	8,94 ± 0,03 b	9,84 ± 0,01 c	10,58 ± 0,19 d
Polyphenols (mg/100 g of DM)	135,06 ± 1,02 d	115,71 ± 1,71 c	93,21 ± 3,77 b	72,68 ± 0,02 a
Ash (g/100g of DM)	2,77 ± 0,02 d	1,88 ± 0,02 a	2,09 ± 0,06 b	2,29 ± 0,02 c
Phosphorus (mg/100 g of DM)	151,24 ± 0,26 c	146,66 ± 0,19 b	137,87 ± 0,21 b	135,13 ± 0,12 a
Potassium (mg/100 g of DM)	202,40 ± 0,45 a	200,34 ± 0,61 a	207,50 ± 0,20 b	210,29 ± 0,04 c
Magnesium (mg/100 g of DM)	52,26 ± 0,17 c	41,50 ± 0,15 a	46,39 ± 0,18 b	48,25 ± 0,13 b
Sodium (mg/100 g of DM)	15,42 ± 0,16 b	14,17 ± 0,12 a	17,66 ± 0,14 c	18,86 ± 0,08 d
Calcium (mg/100 g of DM)	201,15 ± 0,14 c	187,73 ± 0,11 a	194,40 ± 0,11 b	197,30 ± 0,13 b
Iron (mg/100 g of DM)	9,58 ± 0,22 b	8,88 ± 0,27 a	10,78 ± 0,19 c	11,94 ± 0,06 d
zinc (mg/100 g DM)	10,11 ± 0,18 c	6,42 ± 0,22 a	7,62 ± 0,12 b	7,80 ± 0,16 b
Lead (mg/100 g DM)	-	-	-	-
Cadmium (mg/100 g of DM)	-	-	-	-
Ca/P	1,33 ± 0,001 b	1,28 ± 0,001 a	1,41 ± 0,001 c	1,46 ± 0,002 c

On a line the means ± standard deviationfollowed by the sameletter are not statisticallydifferentat the 5% levelaccording to Duncan's test.

4.2. Multiple factor analysis of physicochemical characteristics of cassava roots

This analysis was carried out to define the values specific to each stage of harvest. Thus, principal component analysis, or PCA, was done to verify the existence of differences between the characteristics of cassava roots studied depending on the stage of harvest. According to this analysis the four months of harvest give cassava roots which have different characteristics (Figure 1). To determine the variables underlying the differences in harvested cassava roots, an ascending hierarchical heat map type classification, with a five-point scale (-2= very low, -1= low, 0= acceptable, 1= high, 2= very high), was performed (Figure 2). This classification made it possible to group cassava roots from different harvest stages into two main classes (I and II). The differences observed between the roots of class I are more important than those observed between the roots of class II. Class I consists of cassava roots harvested in the eleventh and twelfth months after planting the cuttings. However, the roots of the twelfth month of harvest are richer in sugars, starch, and polyphenols with a higher energy value compared to the roots of cassava from the eleventh month of harvest and those of class II. Class II, for its part, consists of cassava roots harvested in the thirteenth and fourteenth months after the cuttings were planted. Class II cassava roots are rich in hydrocyanic acid, fiber and fat with low energy and starch values compared to class I roots.

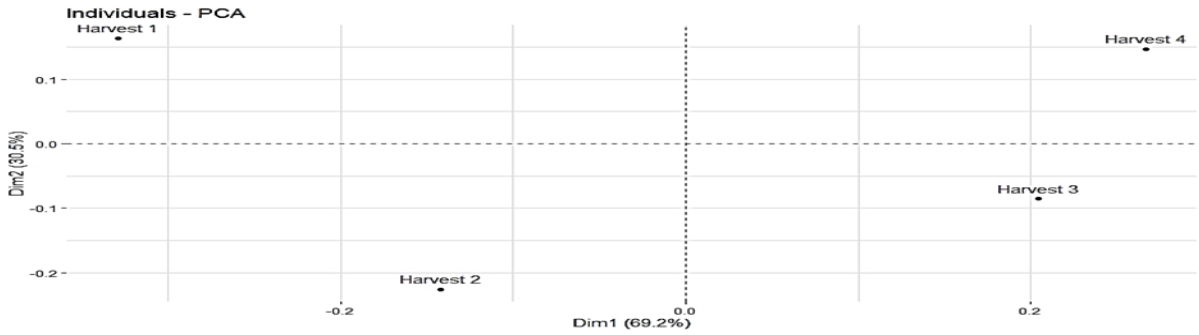

Figure 1: Analysis of the main components of cassava roots of the Yacé variety harvested at different stages of maturity.

Harvest 1: eleventh month of harvest; Harvest 2: twelfth month of harvest; Harvest 3: thirteenth month of harvest; Harvest 4: fourteenth month of harvest

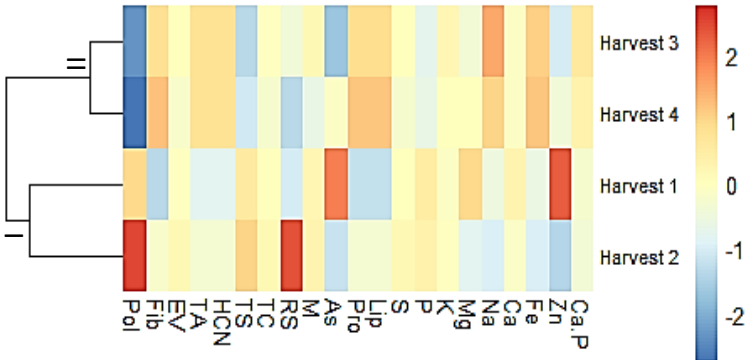

Figure 2: Ascending hierarchical heat map type classification of the components of cassava roots of the Yacé

variety harvested at different stages of maturity.

Harvest 1: eleventh month of harvest; Harvest 2: twelfth month of harvest; Harvest 3: thirteenth month of harvest; Harvest 4: fourteenth month of harvest; Pol: polyphenols; Fib: fibers; EV: energy value; TA: titratable acidity; HCN: hydrocyanic acid; TS: total sugars; TC: total carbohydrates; RS: reducing sugars; M: moisture; As: ash; Pro: protein; Lip: lipids; S: starch; P: phosphorus; K: potassium; Mg: magnesium; Na: sodium; Ca: calcium; Fe: iron; Zn: zinc; Ca.P: calcium/phosphorus ratio

5. Discussion

The decrease in moisture content in cassava roots after the twelfth month of harvest could be explained by the fact that they have reached maturity. In fact, this drop in humidity begins after the roots have fully matured [34].

The increase in the titratable acidity of fresh cassava roots is thought to be due to the degradation of sugars after the optimum maturity stage into ethanol, volatile organic compounds and CO_2 [35]. The results (1.98 to 3.12), approach in the same direction as those obtained by [36], which showed that the cassava roots were acidic (1.5), with other varieties of cassava such as Bonoua, Ouanga and Akaman.

The decrease in the levels of carbohydrates, starch, total sugars and reducing agents in cassava roots is thought to be due to the fact that after twelve months of vegetative life, the plant would have exceeded its period of physiological maturity [37]. She would therefore draw on her carbohydrate reserves for her development. This would explain this decrease in its components with the advance of the harvest stage. In addition, these components in addition to contributing to the energy value, would be involved in the expression of the sweet taste of the roots [38].

The protein content of fresh cassava root increases with the advancement of the harvest stage. This increase occurs during the ripening of cassava roots [39]. In addition, the work carried out by [40], showed that the crude proteins at the beginning of flowering increase with maturation. The relatively low protein values remain in the same range of values (1 to 4 % DM), as those reported in the literature [41]. This protein deficit could be compensated by the consumption of cassava leaves very rich in protein between 14 and 50 % DM [3].

The fiber contents of cassava roots increase with the advanced stage of harvesting because they become lignified as harvesting is delayed [42]. The fiber values in cassava roots are higher than those obtained by some authors (1.10 % [43] and 1.4 % [44], but low than those obtained by [45], during his work. (3.09 %).

The increase in lipid content in fresh cassava roots is believed to be due to the decrease in glucose content following its metabolism via cytosolic glycolysis and the resulting pyruvate is transported to the mitochondria for the synthesis and export of citrate in the cytosol. Citrate is subsequently converted by ATP citrate lyase to acetyl-CoA and then to lipids [46]. Thus, the degradation of glucose would lead to an increase in the accumulation of lipids in the cassava roots. The lipid values obtained during this study on cassava roots are higher than those obtained by [47]. Indeed, these authors obtained values between 0.2 and 0.4 % with the cassava varieties Bonoua, Akaman and Ouanga.

The decrease in the energy value of cassava roots that occurs after the twelfth month of harvest is believed to be due to the decrease in carbohydrates and specifically starch [48]. The high levels of carbohydrates and specifically of starch in cassava would induce the high energy values of fresh cassava root according to [48]. This author specifies that in most roots and tubers, carbohydrates are the main source of energy. The high energy values of the fresh cassava root, would confirm the property of energy food conferred on the cassava roots [49]. They approach in the same direction as those obtained by [50], which vary from 385.30 to 387.93 kcal/100 g of DM in cassava roots.

The increase in hydrocyanic acid content of cassava roots could be explained by the accumulation of cyanogenic glycosides in the cell tissues of cassava roots during their maturity [51] and the lack of culinary treatments [52].

The studies carried out by [53], showed that the variation of the polyphenol contents of the fresh cassava root, could be attributed to the stress undergone by the cassava plant, to the agronomic practices, to the climatic conditions and to the stages of harvest.

The decrease in ash content could be explained by the drop in the eleventh to fourteenth month harvest of minerals in cassava roots such as phosphorus, calcium, magnesium and zinc. In fact, minerals are the main components of ashes. They are used in photosynthesis, carbohydrate and nucleic acid metabolism [54]. Also, these minerals enter into the constitution of chlorophyll which contributes to the maturity of the roots [55].

The mineral contents of cassava roots are rising for some and falling for others. This decrease in minerals such as phosphorus, calcium, magnesium and zinc could be explained by their use in photosynthesis [55], carbohydrate and nucleic acid metabolism [54]. As for iron, potassium and sodium, their increase in fresh cassava root could be explained by the level of absorption of minerals from the soil [56]. Also, this increase in these minerals could be justified by the metallic fertility of the plants [57] and the salinity of the soil [58]. Cassava roots have iron contents, higher than the standard proposed by [59], in human food which is 1.37 to 2.94 mg/day. Thus, they can help reduce the anemia that affects several million people around the world [60]. The increase in potassium levels is very important. This is because potassium is an important component of cell and body fluids that helps regulate heart rate and blood pressure [61]. The Ca/P ratio of fresh cassava root is greater than 1 regardless of the month of harvest. Which is in accordance with the results of [62]. As a result, phosphorus and calcium could be assimilated in the digestive system.

6. Conclusion

This study consisted in determining the physicochemical characteristics of cassava roots harvested at different stages of maturity. Class II cassava roots are rich in hydrocyanic acid, fiber and fat with low energy values, carbohydrates, polyphenols and starch. However, those of class I, particularly those harvested in the twelfth month, were rich in carbohydrates, starch and total sugars, which will facilitate their fermentation. Also, they were richer in polyphenols, with a higher energy value and an interesting mineral and protein content, which are very important in the diet. In addition, they are less fibrous and less toxic because their levels of hydrocyanic acid are low. It would therefore be important from nutritional point of view that the harvest of cassava roots

takes place at this stage of maturity, which overall has good physicochemical characteristics. Cassava roots being rich in hydrocyanic acid, it would be interesting to process them before consumption to avoid food poisoning. Thus, these roots can be transformed into attiéké and placali to assess the impact of the type of transformation on their nutrient compounds.

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