

Investigating Eggplant Fruit (*Solanum* spp.) Cultivated in Côte d'Ivoire for Their Physicochemical and Antioxidant Characteristics

Agnan Marie-Michel Combo^{1*} Patrick Aubin Dakia² Obouo Hugues Jonathan Gildas Kobi¹
Djédoux Maxime Angaman¹

1. Department of Biochemistry-Microbiology, Laboratory of Agrovalorization, Jean Lorougnon Guédé University, BP 150 Daloa, Côte d'Ivoire

2. Department of Food Science and Technology, Nangui Abrogoua University, 02 BP 801 Abidjan 02, Côte d'Ivoire

Abstract

Eggplant is one of the most commonly consumed vegetables in Côte d'Ivoire. For this purpose, the nutrient constituents of eggplant varieties (Niguema, N'drowa, Aliona, Bello, Kotobi, Italy, Tiger, Kalenda and Gnanngnan) were evaluated by standard procedures. The proximate composition in dry weight basis was significantly ($P < 0.05$) varied and ranged: dry matter 86.72-93.29%, crude protein 9.94-22.11%, crude fat 5.07-20.43%, crude fiber 23.15-50.53%, crude ash 5.14-10.09%, carbohydrate 12.41-39.22%, and energy value 211.53-320.94 kcal/100g. Gnanngnan had the highest content in fat. Kalenda had the highest protein content, N'drowa had the highest fiber content, Bello had the highest content in carbohydrate, while Tiger presented the highest content in both ash and energy values. The phenolic content ranges from 618.28 to 977.35 mg/100g while the vitamin C ranges from 92.88 to 150.59 mg/100g in dry weight basis. Italy had the highest content in phenolic while Kalenda had the highest content in vitamin C. Interrelationships between the parameters analysed and the different eggplant varieties were investigated by principal component analysis (PCA). PCA revealed differences between the eggplant varieties and classified them into three clusters on the basis of the measured parameters: Cluster 1 (Gnanngnan), Cluster 2 (Niguema, N'drowa, Italy and Aliona) and Cluster 3 (Bello, Kalenda, Kotobi and Tiger) This study is a contribution to the knowledge of the nutritional composition of eggplant cultivated in Côte d'Ivoire. In view of these results, eggplant can help to reduce the nutrition-related disorders in Africa.

Keywords: Eggplant, Varieties, Proximate composition, Antioxidant

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1. Introduction

Fruits and vegetables, being rich sources of nutrients, have been of interest due to their potential health benefits in preventing several chronic diseases (Slavin & Lloyd 2012). Vegetables are considered essential for the diet of human in many parts of the world and play a significant role in human nutrition. They supply vitamins, minerals, dietary fiber and phytochemicals (João 2012).

Eggplant known as aubergine is a plant belonging to the Solanaceae family and to the genus *Solanum* (Chérifa 2014). The family Solanaceae is prevalent in tropical and subtropical regions of south America. Eggplant cultivation is possible in varied climates (temperate, tropical dry or humid). It contains different species and varieties which are distinguished in particular by the color, size and shape of the fruits (Furini & Wunder 2004). It is of great economic importance because several species are cultivated and consumed in the world (Sultana *et al.* 2018). The most cultivated species are *Solanum macrocarpon*, *Solanum melongena* and *Solanum aethiopicum* (Wei *et al.* 2019). Unlike *Solanum melongena*, which is native to Asia (Meyer *et al.* 2012), *S. macrocarpon* and *S. aethiopicum* are native to Africa (Daunay *et al.* 2001).

Eggplants are nutritious and good source of vitamins and minerals (Mandal 2010). It is ranked among the top ten vegetables in terms of antioxidant capacity due to the phenolic constituents such as caffeic acid and chlorogenic acid (5-O-caffeoyl quinic acid) (Cao *et al.* 1996). They are used in traditional medicine and used to treat many diseases. Some authors reported that eggplant improves digestion, fights constipation, curing cancer, high blood pressure and hepatitis. It is also used to reduce cholesterol (Sangaré *et al.*, 2009, Lekadou *et al.* 2019).

In sub-Saharan Africa, *S. macrocarpon* and *S. aethiopicum* are important because they are mostly used for their fruits and leaves (Schippers 2000). Eggplants are an essential component that enters in the diet. They are indispensable ingredients of soups or sauces that accompany carbohydrate staples (Chweya & Eyzaguirre 1999).

In Côte d'Ivoire, since the 2000s, eggplant yields have increased significantly (Sangaré *et al.* 2009). Thus in 2017, the national production was estimated at 99000 tons with an average yield of 5.22 tons/ha (Lekadou *et al.* 2019). Different varieties of eggplant are cultivated and sold in Côte d'Ivoire for their economic and food potential and yet their nutritional contribution is unknown to consumers. Hence, an attempt was made in the present study to evaluate the nutritional and antioxidant characteristics of the different eggplant varieties consumed in Côte

d'Ivoire in order to contribute to the knowledge on nutritional composition of these vegetables.

2. Materials and Methods

The biological material used in this study comes from the Laboratory of crop improvement, agroforestry Unit, Jean Lorougnon Guédé University (Daloa, Côte d'Ivoire). It consists of nine varieties of eggplant, including five varieties (Niguema, N'drowa, Kotobi, Aliona and Bello) of the specie *S. aethiopicum*, three varieties (Italy, Tiger and Kalenda) of the specie *S. melongena* and one variety (Gnangnan) of the specie *S. anguivi* (Figure 1). The three names (Niguema, N'drowa and Gnangnan) are from the Akan ethnic group in Côte d'Ivoire. The eggplant fruits were at physiological maturation and fresh. All reagents used in this study were of analytical grade.

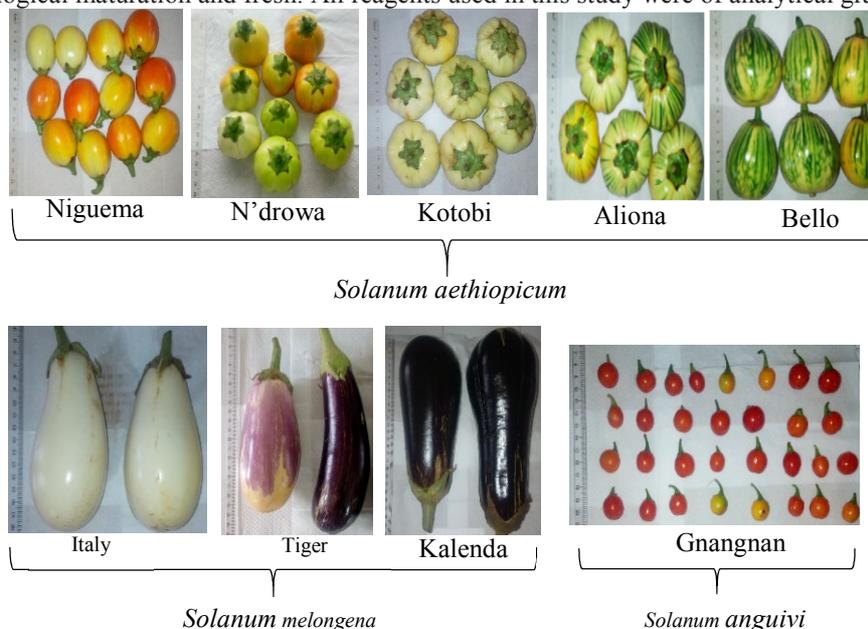


Figure 1. Varieties of Eggplant Studied

2.1 Preparation of Samples

The eggplant fruits were transported to the laboratory. These fruits were washed with tap water and then with distilled water. The consumable parts were finely cut using a stainless steel knife into rings, oven-dried at 62°C for 24 hours, and grounded into fine powder and stored in an airtight container for experimental use. Determinations of physicochemical parameters and antioxidant content were carried out by triplicate. The results were expressed as gram per one hundred gram of dry matter (g/100 g DM).

2.2 Determination of Physicochemical Parameters of Eggplant Species

The samples were evaluated by the following analyses: pH, dry matter, ash, crude protein, crude fat, crude fiber, total carbohydrate and gross energy. The methods of the Association of Official Analytical Chemists (AOAC 1995) were used for pH and dry matter determination. One hundred mL of distilled water was homogenized with 10 g of sample, and the pH was measured with a combined glass electrode pH-meter (Hanna Instruments, Romania). Dry matter was determined by hot oven (Memmert, Schwabach, Germany) drying at 105°C for 24 hours to constant weight.

The ash content was determined by incinerating 5 g of oven-dried eggplant samples in a muffle furnace at 550°C during 12 h (AOAC 1990).

Crude protein was determined by using Kjeldahl method for the dosage of the total nitrogen (BIPEA 1976). About 1 g of eggplant was mineralized and heated with 25 mL of concentrated H₂SO₄ at 400°C for 2 hours, in the presence of potassium sulfate (K₂SO₄) catalyst. The mineralisate sample was transferred into a 100 mL flask and adjusted with distilled water. Ten mL of the mineralized sample solution was taken and then 10 mL of 40% NaOH was added and distilled for 10 min. The distillate was trapped in a flask containing 20 mL of 2% boric acid and a mixed indicator (methylen bromocresol reagent). The content of the flask was titrated against 0.1 N HCl until the solution became colorless. Crude protein was deduced by multiplying the percent total organic nitrogen (N) by a conversion factor of 6.25.

Crude fat was carried out by Soxhlet extraction with hexane as solvent (Razon *et al.* 2013). Ten grams of powdered eggplant were weighed into a cellulose cartridge. 300 mL of hexane was poured into previously dried and weighed round bottom flask. The sample was then placed into the soxhlet extractor and connected to a

condenser. The crude fat was extracted for 4 hours at 68°C.

Crude fiber was determined by digestion method (Wolf 1968). Two grams of sample was accurately weighed and transferred into beaker containing 50 mL of H₂SO₄ (0.25 N). After boiling for 30 minutes under reflux refrigerant, 50 mL of NaOH (0.31 N) was added and boiled. After 30 minutes, the solution was filtered. Residues were washed with hot water and transferred to crucible. Crucible containing residue was dried at 105°C for 8 hours to a constant weight. The crucible was then cooled in a desiccator and weighed. The residues were placed in muffle furnace at 550°C for 3 hours and then the sample was cooled in a desiccator and weighed. Crude fiber content was taken as difference between residues before and after incineration.

Total carbohydrate content was calculated adding the total values of crude protein, crude fat, crude fiber and total ash contents of the sample and subtracting it from 100% according to Boakye *et al.* (2018).

The gross energy was calculated from the total carbohydrate content, crude protein and crude fat using the conversion factors for energy Atwater fruits namely 4 Kcal per 1 g of carbohydrate, 9 kcal per 1 g lipid and 4 kcal per 1 g of protein (FAO 2003).

2.3 Determination of Antioxidant Content

The total phenolic content in the eggplant was determined using the Folin-Ciocalteu reagent, gallic acid was used as standard (Singleton *et al.* 1999). Methanolic extracts of eggplant (1 mL) were transferred into different test tubes, and then mixed with 1 mL of Folin–Ciocalteu reagent. After 3 min for allowing the reaction to take place, 1 mL of 20% sodium carbonate (Na₂CO₃) was added. The test tubes were placed in the dark for 30 min at ambient temperature, and the absorption was measured at 725 nm using spectrophotometer (DR 3900) against a blank, which contained methanol in place of sample. Gallic acid was used as calibration standard, and the total phenolic content was expressed as gallic acid equivalent in mg/100g dry weight (mg GAE/100g DW).

The ascorbic acid (vitamin C) content was determined according to the 2,6-dichlorophenol – indophenols dye method (Ponczak *et al.* 1971). Five grams of each sample was mixed with 40 mL of 2% metaphosphoric acid at room temperature. The mixture obtained was centrifuged at 3000 rpm for 20 min. The supernatant was introduced into a 50 mL flask and adjusted with distilled water. Test sample of the diluted sample was titrated with 2,6-dichloroindophenol (2,6-DCPIP, 0.5 g/L) until it turns pale pink.

2.4 Statistical Analysis

The statistical processing of the data consisted of an analysis of variance (ANOVA) with a classification criterion using the Statistica software (Statistica 7.1). Means were compared by the Duncan test at the 5% significance level. A principal component analysis (PCA) was also carried out using R software (version 3.5.0) in order to structure the variability between eggplant and nutritive content.

3. Results and Discussion

3.1 Proximate Composition of Eggplant Varieties

The proximate composition of eggplant varieties of the species *S. aethiopicum*, *S. melongena* and *S. anguivi* is shown in Table 1. There were significant differences ($P < 0.05$) between eggplant varieties for the measured parameters (dry matter, pH, ash, crude fat, crude protein, crude fiber, total carbohydrate and gross energy). The pH of the eggplant varieties ranged from 4.36 to 5.02. Gnanngan variety had the highest pH (5.02) while Italy variety had the lowest pH (4.36).

Regarding the dry matter, the values obtained from the nine eggplant varieties are between 86.72 and 93.29%. Gnanngan variety recorded the highest content (93.29%) while Tiger variety obtained the lowest content (86.72%). These values obtained falls in line with the report of other previous researchers (Ossamulu *et al.* 2014). Indeed, these low water contents reflect the high solids content of the eggplant fruits. This facilitates their preservation.

The ash contents in the studied eggplant varieties varied from 5.14 to 10.09% on dry weight basis. The variety Tiger obtained the highest ash content (10.09%) while the variety Gnanngan recorded the lowest ash content (5.14%). Values obtained in this study were higher than those in the work of Agoreyo *et al.* (2012) which was within the range of 1.96-3.15%.

The crude fiber contents of the eggplant varieties ranged from 23.15 to 50.53% on dry weight basis. The N'drowa variety with 50.53% was the most important source of fiber. The variety Tiger (23.15%) recorded the lowest grade. These results are similar to those of Nwana *et al.* (2019) which obtained high fiber value. The high value of fiber reported for eggplant fruit can improve its digestibility and absorption processes in large intestine, helping to stimulate peristalsis, thereby preventing constipation (Alaofe *et al.* 2008). This result established that the studied eggplant varieties can be ranked as fiber rich vegetable. The estimated value for crude fiber in Italy (37.27%) and Kalenda (33.94%) can be compared well with 39.19% reported for *S. melongena* (Scorsatto *et al.* 2017).

With regard to fat, the results show that eggplant varieties contained a high fat content. These contents calculated on the dry weight basis varied between 5.07 and 20.43%. Gnanngan variety had the highest fat content

(20.43%) while Aliona variety had the lowest content (5.07%). The values of crude fat (5.07-20.43%) in this study were lower than 37.66% DW for *S. aethiopicum* (Eze & Kanu 2014). The fat contents obtained for *S. aethiopicum* and *S. anguivi* species were respectively lower the 13.60% reported for *S. aethiopicum* and higher than the 15.20% reported for *S. anguivi* (Oyeyemi *et al.* 2015). The fat content in these eggplant varieties is low. They are therefore ideal fruits for people with increased serum lipid levels, as solanum species have been reported to reduce low density lipoprotein (LDL)/high density lipoprotein (HDL) ratio and increase HDL/LDL ratio in hypercholesterolemic rabbits (Eletta *et al.* 2017).

Table 1. Proximate Composition of Eggplant Varieties (on Dry Matter Basis)

Samples	pH	DM	Ash	C. fiber	C. fat	C. prot.	T. carb.	GE
Niguema	4.78 ^d ± 0.02	91.25 ^d ± 0.27	6.14 ^b ± 0.02	39.02 ^d ± 2.30	6.49 ^{ab} ± 0.17	20.07 ^c ± 0.04	28.29 ^b ± 2.50	251.85 ^b ± 8.26
N'drowa	4.83 ^e ± 0.01	89.10 ^b ± 0.30	7.75 ^{cd} ± 0.26	50.53 ^e ± 0.94	8.39 ^{bc} ± 0.09	21.60 ^g ± 0.09	12.41 ^a ± 0.44	211.53 ^a ± 0.62
Aliona	4.67 ^c ± 0.00	90.02 ^{bcd} ± 1.27	7.62 ^c ± 0.12	36.05 ^{cd} ± 7.34	5.07 ^a ± 0.52	9.94 ^a ± 0.45	31.56 ^{bcd} ± 6.30	211.57 ^a ± 28.04
Bello	4.80 ^{de} ± 0.01	89.63 ^{bc} ± 0.18	7.65 ^{cd} ± 0.18	28.10 ^{ab} ± 1.12	5.55 ^{ab} ± 0.10	19.48 ^d ± 0.09	39.22 ^c ± 1.30	284.77 ^{cd} ± 5.73
Kotobi	4.63 ^b ± 0.01	87.63 ^a ± 0.16	7.94 ^{cd} ± 0.06	29.38 ^{abc} ± 2.77	5.10 ^a ± 0.57	20.97 ^f ± 0.00	36.62 ^{cde} ± 2.14	276.22 ^{bcd} ± 13.70
Italy	4.36 ^a ± 0.01	90.44 ^{cd} ± 0.06	8.00 ^d ± 0.01	37.27 ^d ± 1.87	7.11 ^{ab} ± 1.39	11.50 ^b ± 0.01	36.13 ^{cde} ± 0.50	254.47 ^{bc} ± 14.34
Tiger	4.63 ^b ± 0.01	86.72 ^a ± 0.72	10.09 ^f ± 0.23	23.15 ^a ± 1.56	10.78 ^c ± 2.17	18.80 ^c ± 0.08	37.20 ^{de} ± 0.50	320.94 ^e ± 18.01
Kalenda	4.78 ^d ± 0.02	87.66 ^a ± 0.28	8.42 ^e ± 0.18	33.94 ^{bcd} ± 1.32	5.72 ^{ab} ± 1.37	22.11 ^h ± 0.28	29.83 ^{bc} ± 2.79	259.20 ^{bc} ± 2.28
Gnangnan	5.02 ^f ± 0.01	93.29 ^e ± 0.09	5.14 ^a ± 0.02	46.02 ^e ± 1.68	20.43 ^d ± 1.78	10.11 ^a ± 0.12	18.32 ^a ± 3.36	297.55 ^{de} ± 2.12

Values are averages ± standard deviation of replicate determinations (n = 3). Means not followed by the same superscript letters in the same column are significantly different (P < 0.05). C. fiber= Crude fiber, C. fat = Crude fat, C. prot = Crude protein, T. carb.= Total carbohydrate, GE= Gross Energy.

The crude protein contents on the dry weight basis ranged from 9.94 in Aliona variety to 22.11% in Kalenda variety. The results in this study was higher than that reported by Uthumporn *et al.* (2016) in dried eggplant, which were in the range of 12-15%. The protein content of Italy variety (11.50%) is close to that of the variety *Solanum melongena* (13.34% DW) mentioned by Scorsatto *et al.* (2017). Kalenda (22.10%) and Tiger (18.80%) have higher levels than this variety. The eggplant varieties may therefore be an ideal vegetable for protein supplementation. Indeed, Proteins play a very important role in the body. They are involved in the growth, development and maintenance of the body (Kouassi *et al.* 2013).

In terms of total carbohydrates, the contents obtained varied from 12.41% to 39.22% in N'drowa variety and Bello variety respectively. The studied eggplant varieties can be considered as sources of carbohydrates although they contain less than cereals. Italy (36.13%) and Tiger (37.18%) obtained similar levels but lower than those (57 - 65% DW) of Rodriguez-Jimenez *et al.* (2018) on the variety *Solanum melongena*. The low carbohydrate observed in this study makes them good for diabetic patients and those watching their weight (Odetola *et al.* 2004).

The gross energy (GE) was calculated by multiplying the mean values of crude fat, crude protein and total carbohydrate by Atwater factors of 9, 4 and 4 respectively. The average gross energy values range from 211.53 Kcal/100 g to 320.94 Kcal/100 g. Tiger variety had higher energy value (320.94 Kcal/100 g) whereas N'drowa variety had the lowest content (211.53 Kcal/100 g) but this did not differ significantly from Aliona variety (211.57 Kcal/100 g). These GE are much higher than those of the four eggplant varieties (22.90 - 34.02 kcal/100 g DW) analyzed by Ossamulu *et al.* (2014). This very strong VE observed indicates that the eggplant fruits of the present study can be a good source of energy for the body.

3.2 Antioxidant Contents of Eggplant Varieties

Total phenolic and ascorbic acid contents in the nine studied eggplant varieties are presented in table 2.

Table 2. Antioxidant Contents of Eggplant Varieties

Eggplant Varieties	Total phenolic (mg GAE/100g DM)	Vitamin C (mg/100g DM)
Niguema	807.24 ^{bcd} ±30.66	105.21 ^b ±0.31
N'drowa	628.06 ^{ab} ±49.38	111.13 ^{bc} ±5.14
Aliona	618.28 ^a ±2.53	123.29 ^{de} ±2.96
Bello	831.90 ^{cd} ±58.80	117.16 ^{cd} ±4.96
Kotobi	834.79 ^{cd} ±186.58	124.96 ^e ±2.65
Italy	977.35 ^d ±19.47	92.88 ^a ±0.07
Tiger	775.35 ^{abc} ±70.34	117.63 ^{cde} ±0.97
Kalenda	967.58 ^d ±28.87	150.59 ^f ±0.48
Gnangnan	658.83 ^{abc} ±50.98	118.98 ^{de} ±4.43

Values are averages ± standard deviation of replicate determinations (n = 3). Means not followed by the same superscript letters in the same column are significantly different (P < 0.05). GAE: Gallic acid equivalent, DM: Dry Matter.

Total phenolic and ascorbic acid contents in the nine studied eggplant varieties are presented in table 2. Analysis of the antioxidant nutrients revealed differences between the eggplant varieties studied. In all cases, total phenolic was the major group of compounds. It varied between 618.28 mg GAE/100g (Aliona variety) and 977.35 mg GAE/100g DW (Italy variety). The high values observed confirm that common eggplant is one of the vegetables with higher antioxidant capacity (Cao et al., 1996). However, the phenolic contents were lower than those reported (1540 mg/100 g DM) by Scorsatto *et al.* (2017) on the variety *Solanum melongena*. This difference in phenolic content could be due either to the variety of eggplant or to the stage of maturity of the eggplants. Thus, total phenolic content of eggplant is particularly important since works has shown a strong impact of phenolic compounds on reducing the risk of cancer and chronic diseases (Obrenovick *et al.* 2010).

Among the antioxidant nutrients, ascorbic acid or vitamin C, a water soluble antioxidant play a vital role in protecting the body from infection and diseases. It is not synthesised by the human body and therefore must be acquired from fruits and vegetables. The vitamin C content ranged from 98.88 (Italy variety) to 150.59 mg/100 g DW (Kalenda variety) which were lower than those obtained (406 mg/100g DW and 197.77 mg/100g DW) respectively by Eze & Kanu (2014) and Arkoub-Djermoune *et al.* (2016). The reduction of the vitamin C content is mostly the result of thermal destruction and oxidation (Chuah et al., 2008).

3.3 Differentiation Between the Eggplant Varieties Studied

Principal component analysis (PCA) was used for revealing the relationships that might exist between different eggplant varieties by considering all parameters simultaneously. Thus, parameters such as dry matter, protein, fat, fiber, ash, carbohydrate, vitamin C and total phenolic were used as classification criteria. PCA has been done while considering the first two factors (F1 and F2) that explained 64.77% of the total information. The projection of the parameters studied is presented on the fig. 2.

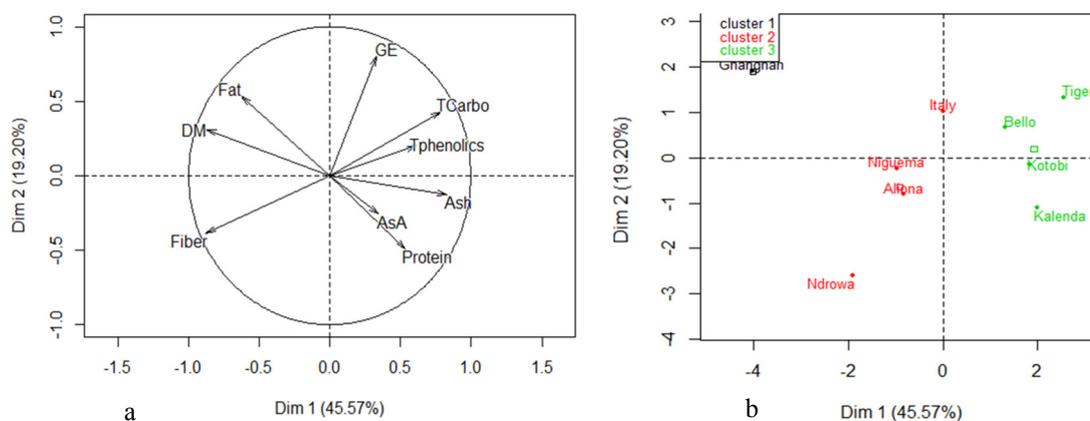


Figure 2. Principal Component Analysis: a) Correlation Circle (TCarbo = Total carbohydrate, AsA = Ascorbic acid, GE = Gross energy); b) Clustering of Eggplant Varieties on the Factorial Plane.

Observation of the correlation circle (Fig 2a) showed that the parameters studied are well represented, apart from ascorbic acid parameter. On the other land, most of the eggplant varieties were clustered around the center of the quadrant (Fig 2b). The point cloud of the eggplant varieties from the PCA revealed the presence of three

groups according to their similarity criteria (Fig 2b). The first group includes the Gnanngnan variety, characterized by its high fat content and low ash content. The second group includes the Niguema, N'drowa, Aliona and Italy varieties which mostly seem to have a high fiber content in common. The third group includes varieties sharing the parameters like protein, ash and carbohydrate. They are Tiger, Kalenda, Bello and Kotobi.

The result of the hierarchical cluster analysis (HCA) is shown as a dendrogram (Fig. 3) in which three well defined groups were visible. Group 1 contained Gnanngnan alone, Group 2 was composed of Niguema, N'drowa, Aliona and Italy and group 3 comprised Tiger, Kotobi, Kalenda and Bello. Classification results of eggplant varieties are consistent between PCA and HCA. On one side, compared to PCA, HCA provides more detailed information regarding recognitions of subgroups. These groups are because of their differences good criteria for a better choice for the consumer.

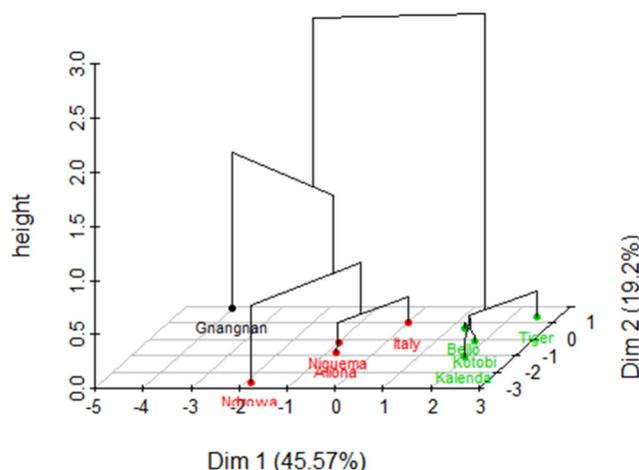


Figure 3. Dendrogram of Hierarchical Clusters of Eggplant Varieties.

4. Conclusions

The present work allows to know the nutritional composition of eggplant fruits cultivated in Côte d'Ivoire. The findings obtained shown that eggplants are good sources of essential nutrients, considering protein, fiber, ash. Therefore, promoting the consumption of such interesting vegetables will be beneficial to human health by providing the necessary macro-elements and energy to the body. The results obtained showed also that eggplants constitutes an important source of antioxidants that make them therapeutically beneficial.

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