Food and Nutrition Sciences, 2020, 11, 741-756
https://www.scirp.org/journal/fns
ISSN Online: 2157-9458
ISSN Print: 2157-944X

Physicochemical Characterization of Nine Cassava (*Manihot esculenta* Crantz) Cultivars from Chad

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How to cite this paper: Nadjiam, D., Ayessou, N.C. and Guissé, A. (2020) Physicochemical Characterization of Nine Cassava (*Manihot esculenta* Crantz) Cultivars from Chad. *Food and Nutrition Sciences*, **11**, 741-756.
https://doi.org/10.4236/fns.2020.117053

Received: June 15, 2020
Accepted: July 26, 2020
Published: July 29, 2020

Abstract

In Chad, despite the multiple culinary uses of cassava leaves and tubers, their nutritional values are untapped. In this study, the physicochemical compositions and structure of nine cultivars were assessed. The proteins were obtained by Kjeldahl's method. Total sugars were determined according to the Luff-Schoorl method. For starch content, the polarimetric method of Earle and Milner was used. Mineral elements were carried out using an atomic absorption spectrophotometry. The cyanide was evaluated by the method of Williams and Edwards. Significant variability has been demonstrated in the leaves and dry tubers except for water content and dry matter. Analysis of the variances of the components of the tubers reveals that the water contents of the cultivars vary from 5.01% to 5.86%. The ash contents vary from 4.23% (cultivar DVA2) to 8.32% (cultivar DVL2). For total sugars, the values are between 53.63% (cultivar DVL2) and 57.99% (cultivars DVL12 and KA0303). The fiber contents are lower and vary from 1.74% (cultivar DVL12) to 1.92% (cultivars SB1366, DVA2, TL0101 and PG1314). The starch content varies from 28.93% (cultivar DVL12) to 31.05% (cultivar SB1366). The variations in mineral constituents of the tubers in mg/100g are Ca (145.21 - 250.08), Mg (83.89 - 165.22), P (147.34 - 360.78), K (1534.50 - 3064.09), Zn (0.75 - 0.82) and Mn (0.78 - 0.89). Iron concentrations are from 7.72 mg/100g (cultivar BA0909) to 60.62 mg/100g (cultivar DVA2). Analysis of the variances of the leaf constituents reveals high contents of Calcium for SB1366 (2108.41 mg/100g), of iron (Fe 54.26 mg/100g) and potassium (K 1866.86 mg/100g) for DVL12, of phosphorus for TL0101 (471.87 mg/100g), of phosphorus (470.36 mg/100g) and protein (30.74%) for PG1314, for magnesium for DVA2 (383.41 mg/100g) and Copper for KA0303 (0.0147 mg/100g). The concentrations of hydrocyanic acids are high in both leaves than fresh tubers (85 - 150 ppm). Lowest values are observed in tubers (10 - 15 ppm) for cultivar DVA2. Principal component analysis of the physicochemical characteristics of the leaves revealed four groups: the first very rich in calcium, magnesium and average potassium contents. Groups 2 and 3 are poor in calcium and magnesium but Group 2 has the highest potassium content while Group 3 has an intermediate content. Group 4 is very rich in calcium but low in magnesium and potassium. According to tubers, three groups have been identified which are characterized by low, intermediate and high contents in phosphorus. Cultivars SB1366, DVA2, DVL2, TL0101 and PG1314 show promising nutritional values and chemical constituents even if some have high levels of hydrocyanic acids. They could be recommended for the national selection program and for various applications.

Keywords

Physicochemical Constituents, Leaves, Tubers, Cultivar, Cassava, Chad

1. Introduction

Cassava plays an essential role in the nutrition of urban and rural populations in many states. The production is mainly intended for human consumption [1] and it generates monetary income for rural populations [2]. But it is also used in animal feed and in the industrial sector [3]. In terms of nutritional value, [4] has shown that cassava tubers have very varied physicochemical compositions. In the Amazon area, cassava cultivars have a high content of free sugars [5] [6]. According to [7], these types of cultivars are suitable for fermentation, for the industrial production of ethanol and organic acids. Tubers are rich in carbohydrates and contain up to 35% starch but are very poor in protein (around 1.1%) according to [8]. New hybrid varieties with tubers up to 5% protein have been created [9]. Nevertheless, the leaves are richer in protein (more than 25%) and also contain many minerals and vitamins [10] [11] [12]. Unfortunately their level decreases after the processing or cooking processes [13] [14]. In general, the physicochemical composition of the leaves and tubers varies according to the cultivars, their age, cultural practices and climatic conditions [15]. Some dangerous substances are also found in Cassava such as cyanogenic acid which is at the basis of the differentiation of sweet and bitter cassava [16]. Studies carried out on several genotypes have shown their variations in tubers [17] [18] [19]. This variability was among cultivars and across localities [20]. It also depends on the cultural practices, plant age and environmental factors [21] [22] [23]. Cassava plant is characterized by a great diversity of culinary preparations from the leaves and tubers. Various foods produced from cassava have been reported in several countries [24] [25] [26] [27], and also in Chad [28] [29]. For the preparation of different cassava based foods, cultivars are often chosen according to their aptitudes and their physicochemical characteristics. Each cultivar is traditionally associated with a particular way of preparation [30]. In Chad, many cassava cultivars exist in rural areas [31]. Their tubers and leaves are eaten after blanching and sometimes drying in the form of vegetables but their physicochemical composition are not investigated. The present study aims to determine the physicochemical parameters and the structure of nine cassava cultivars in order to understand their technological changes capacities. Those with interesting traits will be included in the national varietal improvement program and for a better industrial uses purposes.

2. Material and Methods

2.1. Plant Material

Nine cassava cultivars from the collection of the Bebedjia Agricultural Research Station (8˚40'N; 16˚33'E; Altitude: 384 m) of the Chadian Institute of Agronomic Research for Development, located in the Sudanian zone of Chad, are used in this study. These different cultivars were a part of the prospection done in 5 major cassava growing regions (**Table 1**).

2.2. Sample Preparation

The nine cultivars have been planted at the Bebedjia agricultural station. Twelve months after planting, the young leaves and tubers were harvested. The leaves were spread and dried in the shade and in the open air. The fresh tubers were washed and then peeled manually with a stainless steel knife. They were then grated using a mechanical grater developed by International Institute of Tropical Agriculture (IITA). The chips obtained were spread and dried in the open air. After drying, the samples were packed and labeled.

Table 1. Vernacular names, origin and taste of cassava cultivars.

Code	Vernacular names	Origin(1)	Taste(4)	Geographical coordinates of the sampling area		
				Latitude (N)	Longitude (E)	Altitude (m)
SB1366	Simon (white peel)	Local	Bitter	9.257286	15.832521	392
DVA2	Tessem	IITA(2)	Sweet	8.675147	16.559991	346
BA0909	Kangaba	CAR(3)	Sweet	8.808787	18.489963	335
DVL2	Six mois binda	Local	Sweet	9.257300	15.832521	391
TL0101	Tolmade	Local	Bitter	8.742500	18.571300	378
KA0303	Karanga	Local	Sweet	8.818800	18.500500	379
DVL12	Mandrakako	CAR	Bitter	9.257308	15.832523	401
DVL22	Bindakasse	Local	Sweet	8.566600	16.085200	351
PG 1314	Pangassou	CAR	Bitter	8.06274	17.320400	397

(1)Origins determined during the collection phase by pesant; (2)IITA: International Institute of Tropical Agriculture; (3)CAR: Central African Republic; (4)Taste: Peasant classification.

2.3. Methods

2.3.1. Physicochemical Analyzsis of Leaves and Tubers

The constituents of the leaves and tubers were determined by the standards methods of chemical assays. The water content was obtained by the method of drying at 105˚C in the oven for 2 hours. It then made it possible to determine the percentage content of the dry matter. The proteins were obtained by the Kjeldahl method and according to the AFNOR NFV0 3-707 standard. For fibers, the samples after mineralization and filtration were incinerated at 400˚C in a muffle furnace. Total sugars were determined according to the Luff-Schoorl method. Starch content was determined by the polarimetric method of Earle and Milner. For the assays of the mineral elements which were carried out using an atomic absorption spectrometer, 2.5 g test portion of the sample is placed in previously weighed platinum. Combustion is continued until the combustion residue turns white in accordance with the French standard method AFNOR 03-760. The capsule is then cooled and the residue is taken up with 1 ml of hydrochloric acid and then heated until complete evaporation. The dry product is taken up with 3 ml of nitric acid and made up to 100 ml with distilled water. This solution is filtered and used for the analysis of mineral elements at the atomic absorption spectrometer. Sodium and potassium are determined by the reference NF EN 15505 while the others refer to the standard NF EN 14084. Potassium was evaluated by the method referenced NF EN 15505 while the reference NF EN 14084 was used for the analysis of other minerals (Ca, Fe, Mg, P, Zn, Mn, Cu).

2.3.2. Qualitative Assessment of Cyanogenic Substances in Fresh Leaves and Tubers

The cyanide presence in the cultivars was evaluated by the method developed by Williams and Edwards [32]. This method allows cyanides to be estimated by sodium picrate in the presence of toluene. The evaluation was made on the first full and fresh apical leaves and on fresh tubers.

2.3.3. Statistical Analyses

Analyzes were carried out using software XLSTAT-Pro version 2013.5.01. Data collected were analyzed using descriptive statistics and then subjected to analysis of variances. Duncan's tests at the 5% level have been performed. Principal Component Analysis (PCA) and Ascending Hierarchical Clustering (AHC) were used to identify the different group of cultivars formed.

3. Results

3.1. Descriptive Analysis of Biochemical Constituents of Dry Tubers

Results coming from nine samples analyzed in duplicate reveal small differences between the minimum and maximum values of the moisture, dry matter, ash, total sugar, fiber, starch, zinc and manganese contents. In opposite, these differences are significant for calcium, magnesium, iron, potassium and phosphorus.

The highest are those between 77.15 ppm and 606.37 ppm for iron, and 1533.39 mg/100g to 3065.35 mg/100g for potassium (Table 2).

3.2. Descriptive Analysis of Physicochemical Constituents of Dried Cassava Leaves

Significant variations in the content of mineral constituents have been highlighted in the leaves of the cultivars studied (Table 3). The differences observed between the minimum and maximum values are very high for calcium, potassium and copper which are respectively 1360.60 mg/100g, 1350.56 mg/100g and 0.072 mg/kg. The coefficient of variation ranged from 15.77% to 54.18%. High variability was found in the physicochemical constituents of leaves.

Table 2. Descriptive analysis of chemical constituents of the dry tubers.

Variable	Minimum	Maximum	Average	SD	CV
Moisture (%)	4.73	6.44	5.41	0.44	8
Dry Matter (%)	93.56	95.27	94.59	0.44	0.46
Ash (g/100g)	4.22	8.44	5.85	1.18	19.77
Total sugar (g/100g)	53.20	58.48	55.64	1.43	2.51
Fiber (g/100g)	1.70	1.96	1.84	0.07	3.52
Starch (g/100g)	28.90	31.10	29.96	0.55	1.8
Ca (mg/100g)	143.1	342	238.6	54.46	22.4
Fe (ppm)	77.15	606.37	205.26	157.66	75.38
Mg (mg/100g)	83.85	165.22	122.39	30.58	24.52
P (mg/100g)	146.92	361.25	238.89	73.33	30.12
K (mg/100g)	1533.39	3065.35	2088.29	485.59	22.82
Zn (mg/100g)	0.73	0.84	0.77	0.03	3.47
Mn (mg/100g)	0.78	0.9	0.83	0.04	4.38

SD: Standard Deviation; CV: Coefficient of Variation (%).

Table 3. Descriptive analysis of chemical constituents of dried cassava leaves.

Variable	Minimum	Maximum	Average	SD	CV
Protein (%)	17.56	31.15	25.41	4.14	15.99
Fe (ppm)	279.14	542.71	364.48	75.05	20.20
Mg (mg/100g)	287.78	488.78	346.49	55.69	15.77
Ca (mg/100g)	870.40	2110	1360.60	431.27	31.10
P (mg/100g)	300.64	473.23	405.66	60.25	14.57
K (mg/100g)	763.92	1870.2	1350.56	372.73	27.08
Cu (mg/kg)	0.0015	0.1475	0.072	0.04	54.18

SD: Standard Deviation; CV: Coefficient of Variation (%).

3.3. Analysis of Variances of Physicochemical Characteristics of Cassava's Dry Tubers

Highly significant differences were observed for four (4) of the parameters analyzed (Table 4). These characteristics enable to distinguish at least three (3) groups of cultivars. The water content and dry matter are not significant according to the Duncan test at 5%. The DVA2 cultivar has the lowest ash rate (4.23 g/100g) of all the cultivars studied. On the other hand, DVL2 has the highest ash content (8.32 g/100g) but the lowest in carbohydrates (53.63 g/100g). Cultivars PG1314 and BA0909 do not differ significantly from their carbohydrate contents. This is also the case for DVL12 and KA0303. The lowest levels of fiber (1.74 g/100g) and starch (28.93 g/100g) were observed in the cultivar DVL12. On the other hand, SB1366 has the highest starch content of the cultivars studied (31.05 g/100g).

Likewise, highly significant differences were observed for all the mineral elements (Table 5). The zinc content enabled to identify only two groups of cultivars, unlike the other constituents where there are at least six groups. The cultivars SB1366 and DVL12 statistically have the same calcium contents. High levels of calcium (340.95 mg/100g), magnesium (165.22 mg/100g), potassium (3064.09 mg/100g) and manganese (0.87 mg/100g) are observed in DVL2. For DVA2, the magnesium (83.89 mg/100g), potassium (1534.50 mg/100g) and zinc (0.76 mg/100g) contents are the lowest. Similarly, DVL12 has low levels of phosphorus (147.34 mg/100g) and zinc (0.77 mg/100g). There is no significant difference for zinc and manganese contents between the cultivars DVL22 and PG1314.

3.4. Analysis of Variances of the Chemical Constituents of Dried Cultivar Leaves

Highly significant differences were observed for all components (Table 6). Low levels of protein, phosphorus, potassium and copper have been observed in DVA2. The cultivars SB1366 and TL0101 have statistically the same protein contents. DVL22 has the highest phosphorus contents. DVL2, TL0101 and DVL12 have similar magnesium contents. The most discriminating contents are iron, calcium, potassium and copper. The calcium varies from 870.58 mg/100g for DVL12 to 2108.41 mg/100g for SB1366.

3.5. Variation in the Content of Hydrocyanic Acids in Fresh Leaves and Tubers

These contents are variable according to the cultivars (Table 7). They range from 10 to over 150 ppm in tubers. Cultivars SB1366, TL0101, DVL12 and PG1314 have the highest concentrations. While BA0909, DVL2, KA0303 and DVL22, have the average concentrations between 25 and 40 ppm. DVA2 is the least toxic cultivar. At the leaf level, the minimum concentrations are between 40 and 60 ppm for an average between 85 and 115 ppm. With the exception of cultivar BA0909, the concentrations of hydrocyanic acids in the leaves are high and vary from 85 to more than 150 ppm.

3.6. Structuring of Variability from the Physicochemical Constituents of the Leaves

Seven physicochemical characteristics were used to perform the principal component analysis (PCA) of the cultivars. The first three axes explain 83.09% of the overall variability. Six of the characteristics contribute for more than 18% to a given axe. The phosphorus and potassium contents are strongly represented on the first factorial axis. Calcium contributes to both axes 1 and 2. The protein and magnesium contents contribute to the second axe. Iron is strongly represented on the third factorial axe (Table 8).

Table 4. Analysis of variances of the biochemical components of dry tubers.

Cultivar	Moisture (%)	[1]DM (%)	Ash (g/100g)	[2]Carb (g/100g)	Fiber (g/100g)	Starch (g/100g)
SB1366	5.32	94.68	6.32 e	54.55 b	1.89 c	31.05 f
DVA2	5.01	94.99	4.23 a	57.88 d	1.91 c	29.83 c
BA0909	5.86	94.14	5.62 d	55.21 bcd	1.83 b	30.13 d
DVL2	5.46	94.54	8.32 f	53.63 a	1.82 b	30.20 de
TL0101	5.03	94.97	6.50 e	55.45 cd	1.90 c	29.89 c
KA0303	5.13	94.87	5.25 c	57.89 e	1.81 b	29.71 b
DVL12	5.50	94.50	4.54 b	57.99 e	1.74 a	28.93 a
DVL22	5.86	94.14	6.38 e	55.05 bc	1.79 b	29.65 b
PG1314	5.50	94.5	5.46 d	55.16 bcd	1.92 c	30.27 e
p-value	**0.095**	**0.095**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**

[1]DM: Dry Matter; [2]Carb: Carbohydrate. Values with same letters and in the same column are not significantly different according to the Duncan test at 0.05.

Table 5. Analysis of variances of the mineral constituents of dry tubers.

Cultivar	Iron (ppm)	Ca (mg/100g)	Mg (mg/100g)	P (mg/100g)	K (mg/100g)	Zn (mg/100g)	Mn (mg/100g)
SB1366	88.70 b	273.08 g	142.45 f	253.27 f	2514.46 h	0.80 b	0.78 a
DVA2	606.28 h	207.38 c	83.89 a	182.05 c	1534.50 a	0.76 a	0.84 c
BA0909	77.23 a	250.08 f	110.44 e	260.18 g	1888.48 e	0.75 a	0.85 c
DVL2	174.98 f	340.95 h	165.22 i	346.27 h	3064.09 i	0.77 a	0.87 d
TL0101	132.61 c	233.75 d	144.66 g	244.71 e	2279.17 f	0.77 a	0.80 b
KA0303	160.73 e	145.21 a	88.04 b	192.29 d	1542.05 b	0.82 b	0.89 e
DVL12	161.80 e	273.35 g	95.84 c	147.34 a	1866.81 d	0.77 a	0.81 b
DVL22	138.96 d	184.24 b	107.96 d	360.78 i	2349.69 g	0.75 a	0.80 b
PG 1314	306.09 g	239.36 e	163.02 h	163.18 b	1755.36 c	0.75 a	0.81 b
p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**

Values with same letters and in the same column are not significantly different according to the Duncan test at 0.05.

Table 6. Chemical composition of the dried leaves of 9 cassava cultivars.

Cultivar	Protein (%)	Iron (ppm)	Mg (mg/100g)	Ca (mg/100g)	P (mg/100g)	K (mg/100g)	Cu (mg/kg)
SB1366	28.73 f	364.48 f	478.64 g	2108.41 i	414.29 d	1369.16 e	0.0465 b
DVA2	17.66 a	279.67 a	383.41 f	2065.44 h	302.92 a	764.21 a	0.0015 a
BA0909	19.98 b	352.42 e	344.49 d	1254.43 f	334.59 b	1059.12 c	0.0600 e
DVL2	27.19 e	345.48 d	309.50 b	1019.23 b	431.84 e	1019.48 b	0.0501 c
TL0101	28.64 f	409.17 h	310.52 b	1169.96 d	471.87 g	1378.18 f	0.0583 d
KA0303	24.65 d	330.77 c	363.42 e	1514.19 g	343.80 c	1155.58 d	0.1472 i
DVL12	27.19 e	542.61 i	309.58 b	870.58 a	429.78 e	1866.86 i	0.0945 g
DVL22	23.97 c	369.88 g	330.81 c	1038.55 c	451.52 f	1826.05 h	0.0931 f
PG1314	30.74 g	285.85 b	288.07 a	1204.65 e	470.36 g	1716.41 g	0.0998 h
p-value	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**

Values with same letters and in the same column are not significantly different according to the Duncan test at 0.05.

Table 7. Hydrocyanic acid content of fresh leaves and tubers.

Cultivar	Fresh tubers	Fresh leaves
	*HCN (ppm)	HCN (ppm)
SB1366	115 - 150	115 - 150
DVA2	10 - 15	115 - 150
BA0909	25 - 40	40 - 60
DVL2	25 - 40	>150
TL0101	85 - 115	85 - 115
KA0303	25 - 40	85 - 115
DVL12	>150	115 - 150
DVL22	25 - 40	>150
PG 1314	85 - 115	85 - 115

*HCN: Hydrocyanic Acid.

Table 8. Proper values and contributions of the leaf constituents to the factorial axes.

Factorial Axes	F1	F2	F3
Proper values	3.765	1.206	0.845
% Variability	53.791	17.222	12.072
% Cumulative	53.791	71.013	83.085
Protein	14.024	**25.460**	8.936
Ca	**18.246**	**21.888**	0.114
Iron	9.155	0.045	**72.693**
Mg	11.070	**37.186**	8.162
P	**18.923**	9.576	5.790
K	**19.282**	5.096	2.924
Cu	9.300	0.749	1.380

In bold: Significant contributions values of the variables to the factorial axes.

Ascending hierarchical classification analysis of six relevant physicochemical parameters, identify four groups of cultivars (**Table 9**). The first group consists of SB1366 rich in calcium (2108.41 ± 192.27 mg/100g), magnesium (478.64 ± 24.59 mg/100g) and moderately in potassium (1369.16 ± 133.76 mg/100g). The cultivar DVA2 is in the fourth group. It is also rich in calcium (2065.44 ± 192.27 mg/100g) but poor in magnesium (383.41 ± 24.60 mg/100g) and potassium (764.21 ± 133.76 mg/100g). The cultivars DVL12, PG1314 and DVL22 of the second group have high potassium contents (1803.10 ± 77.23 mg/100g) but very little calcium (1037.93 ± 111.01 mg/100g) and magnesium (309.48 ± 14.20 mg/100g). Cultivars KA0303, TL0101, BA0909 and DVL2 of the third group, contain moderately potassium (1153.09 ± 66.88 mg/100g), very little calcium (1239.45 ± 96.13 mg/100g) and magnesium (331.98 ± 12.30 mg/100g).

3.7. Variability of Cultivars Based on Chemical Characteristics of Tubers

The principal component analysis of the dried tubers of the cultivars was carried out using 11 mineral elements. Significant contributions were observed on the three factorial axes for all the contents studied except calcium. The biplot (**Figure 1**) highlighted the relationships between the cultivars and the mineral constituents. PG1314 is very associated with fibers. The starch content is strongly associated with SB1366 like iron with DVA2 and manganese with KA0303. In contrary DLV12 is relatively linked to manganese. The cultivar DVL22 is very linked to phosphorus. This bond is less between BA0909 and phosphorus. DVL2 is strongly associated with potassium, with ash contents but moderately with phosphorus. As for TL0101, it is only relatively associated with magnesium.

In **Table 10**, the ascending hierarchical classification analysis of cultivars based on seven physicochemical constituents of tubers, allowed them to be divided into three groups. Except for the phosphorus content, significant differences were not observed between the different groups of cultivars. Group 1, composed of SB1366, KA0303, DVA2, TL0101, BA0909 and DVL2 are characterized by intermediate contents (246.46 ± 21.99 mg/100g). The cultivars DVL12 and PG1314 belong to group 2 whose phosphorus concentrations are the lowest (155.26 ± 38.09 mg/100g). On the contrary, the cultivar DVL22 belongs to group 3 and whose phosphorus contents are the highest (360.78 ± 53.87 mg/100g) of all the cultivars studied.

4. Discussion

The importance of the variability of the physicochemical constituents highlighted in this study, testifies to the richness in nutritive elements of the cultivars. In similar studies, many authors have also shown the existence of such a variation in the nutritional quality of cassava tubers [4]. The descriptive analysis showed either small or high differences in the contents of the constituents. The coefficients of variation are between 1.8% and 75.38% for tubers and from 14.57% to 54.18% at the level of the leaf constituents.

Table 9. Characteristics of leaves of cassava cultivars groups from ascending hierarchical clustering.

*G	Protein (%)	Ca (mg/100g)	Fer (ppm)	Mg (mg/100g)	P (mg/100g)	K (mg/100g)
1	28.73 ± 3.64	2108.41 ± 192.27 b	364.48 ± 86.96	478.64 ± 24.59 b	414.29 ± 53.59	1369.16 ± 133.76 b
2	27.30 ± 2.10	1037.93 ± 111.01 a	399.44 ± 50.21	309.48 ± 14.20 a	450.55 ± 30.94	1803.10 ± 77.23 c
3	25.11 ± 1.82	1239.45 ± 96.13 a	359.46 ± 43.48	331.98 ± 12.30 a	395.52 ± 26.80	1153.09 ± 66.88 b
4	17.66 ± 3.64	2065.44 ± 192.27 b	279.67 ± 86.96	383.41 ± 24.60 a	302.92 ± 53.59	764.21 ± 133.76 a

*G: Group. Values with same letters and in the same column are not significantly different (Duncan test at 0.05).

Table 10. Characteristics of tubers of cassava cultivars groups from ascending hierarchical clustering.

*G	Cendres	Mg	P	K	Zn	Carb	Fiber
G1	6.04 ± 0.53	122.45 ± 14.71	246.46 ± 21.99 ab	2137.12 ± 224.05	0.78 ± 0.01	55.43 ± 0.63	1.86 ± 0.03
G2	5.00 ± 0.91	129.43 ± 25.49	155.26 ± 38.09 a	1811.08 ± 388.07	0.76 ± 0.02	56.57 ± 1.09	1.83 ± 0.05
G3	6.38 ± 1.29	107.96 ± 36.04	360.78 ± 53.87 b	2349.69 ± 548.81	0.75 ± 0.03	55.05 ± 1.55	1.79 ± 0.07

*G: Group. Values with same letters and in the same column are not significantly different (Duncan test at 0.05).

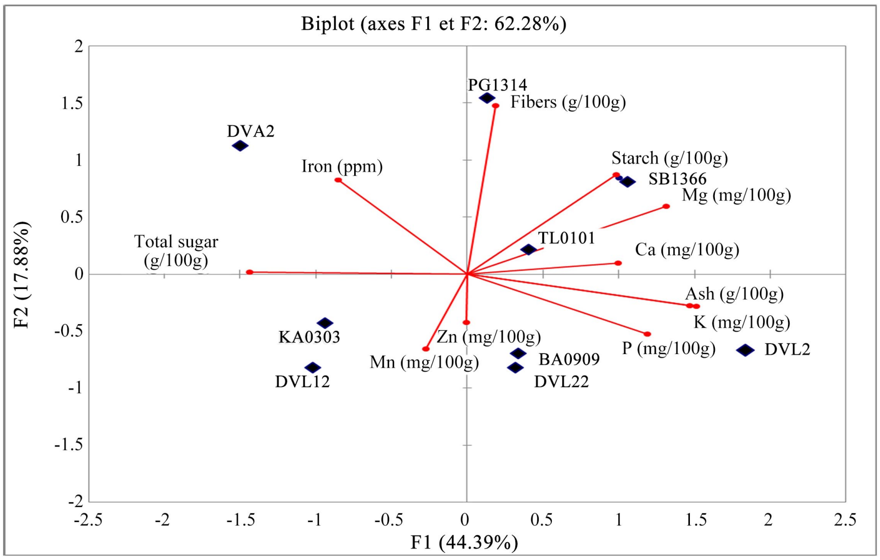

Figure 1. Biplot of relationships between cultivars and physicochemical constituents of tubers. Ca: Calcium; P: Phosphorus; K: Potassium; Zn: Zinc; Mn: Manganese; Mg: Magnesium.

Analysis of the variances of the physicochemical constituents of the tubers of the nine cultivars reveals that the water contents are very low (5.01% to 5.86%) and similar to the water contents of the flours of certain cassava cultivars (4.21% to 5.85%) of Côte d'Ivoire [33]. And they are significantly lower than 13%, the standards recommended by the codex [34]. The starch contents vary from 28.93 g/100g to 31.05 g/100g (on average 29.96 g/100g). These values seem close to the results of Afoakwa *et al.*, (2011) [7] and those obtained on Zambia varieties Shadrack *et al.*, (2019) [35]. But much lower than the contents between 75.36 and 77.70 g/100g reported in a study done in Côte d'Ivoire [36]. These results agree with those of [37] who reported that there are significant genetic variations in the physicochemical properties of starch in both exotic and traditional cassava genotypes.

Ash contents of the cultivars analyzed are between 4.23 to 8.32 g/100g and are higher than those of [36] which vary between 2.29 and 2.67 g/100g. Likewise, total sugar concentrations are higher than those reported by many authors [7] [36] [38]. However, their fiber contents are very low compared to the work of Gil and Buitrago [39]. Average potassium values are significantly higher than those reported by Richardson [40]. Compared to the results of Chávez *et al.*, (2005) [4], the contents of calcium, phosphorus, magnesium and potassium are lower. In contrast, the average zinc concentrations of certain tubers are similar to those studied by Burns *et al.*, (2012) [20].

In general, at the level of the tubers, the analysis of the results shows that three cultivars have at least two constituents with high concentrations. SB1366 is rich in potassium and zinc. High levels of zinc and manganese are observed in cultivar KA0303. The DVL2 cultivar contains the greatest number of constituents, calcium, magnesium, phosphorus and potassium with high concentrations. Similar work done on tubers of *Dioscorea alata* showed that the ash and total carbohydrate contents on the basis of dry weights [41] are low compared to the cassava tubers evaluated in this study. However, the starch and fiber are higher. Phosphorus, calcium, magnesium, potassium and manganese are also so while the zinc content is low.

From the analysis of the variances of the physicochemical constituents of the leaves, it appears that the calcium and copper contents are low while the phosphorus and potassium are high compared to the results of Cereda [42]. About 55.56% of the cultivars have high protein contents which are similar to those obtained by [43]. However, these are lower than the minimum of 32% reported by Nassar and Ortiz (2010) [9]. The cultivars DVA2 and BA0909 have lower contents (17.66% and 19.98% respectively) below the values between 23.90% and 34.70% obtained by Nhu Phuc *et al.*, (2000) [44] on fresh leaves.

Compared to the cyanide concentrations of fresh leaves and tubers, the study revealed that they are above 10 ppm, a value recommended by the FAO and WHO [45]. These contents vary according to the cultivars. The differentiation of sweet and bitter cassava depends on the cyanogenic glucoside content of their tubers [16] [46]. Analysis of these contents in tubers has shown that cultivars SB1366, TL0101, DVL12 and DVL3 have high concentrations of cyanide. The concentrations of cultivars DVA2, BA0909, DVL2, KA0303 and DVL22 which are classified as sweet by farmers, except DVA2, are varying between 25 and 40 ppm in tubers. In addition, they exceed the standards of the Codex Alimentarius. Indeed, for reasons of health security, the United Nations systems through FAO and WHO have set up standards for cassava flour intended for human consumption [34] [45]. Consequently, the consumption of these cultivars in fresh form or not presents risks of toxicity. The peasant practices of classification of cassava into sweet or bitter type is close to that suggested by two authors [16]

[47]. According to these authors, the cultivars having less than 100 ppm of hydrocyanic acid are considered to be sweet and bitter for the concentration higher than 100 ppm. In other way, similarly studies done by [48] shows also that sweet and bitter manioc landraces are differentiated in South America but not in Africa. In fact, the same also found that some clones of cassava are classified by some farmers as sweet and by others as bitter.

As Mehouenou *et al.*, (2016) [49] showed, cyanide content does not affect much the choice of cultivars but it help pesant to select the appropriate method to eliminate it. Finally, the results showed high toxicity (>100 ppm HCN) in some fresh tubers and leaves of Chadian cassava varieties was also found in Senegalese cassava varieties [50].

Analysis of the variability structure of cultivars from the physicochemical characteristics of the leaves revealed significant contributions (>18%) of six variables to the factor axes. Four groups of cultivars have been identified with widely varying concentrations of chemical constituents. The promoter traits highlighted in each cultivar can be used in a variety selection program. As for the analysis of the variability of the cultivars from the characteristics of the tubers, this revealed that there are no significant differences between the cultivars except phosphorus. In the three groups identified, the phosphorus contents are very high in the third group and even higher than those reported by Chávez *et al.*, (2005) [4]. On the other hand, the magnesium contents of all the groups are similar to the values obtained by the same author [4].

5. Conclusion

The study reveals a significant variability in the physicochemical constituents. Four groups of cultivars were identified on the basis of the physicochemical characteristics of the leaves. Cultivars are rich in calcium and magnesium, cultivars poor in calcium and magnesium; cultivars are rich in potassium and those characterized by high contents of calcium but low concentrations of magnesium and potassium. Compared to tubers, phosphorus has made it possible to classify cultivars in three groups among which the cultivar DVL22 is rich in phosphorus. High levels of hydrocyanic acid have been observed both in the leaves and in the fresh tubers. Only the cultivar DVA2 is less toxic. Likewise, cultivars rich in starch, total sugars and ashes have been identified. Even if all the cultivars in the collection have physicochemical constituents which are interesting for varietal creation work, SB1366, DVA2, DVL2, TL0101 and PG1314 have promising nutritional values.

Acknowledgements

We are grateful to the staff of PRASAC, ITRAD and to Mrs. Monembaye Tolmbaye Odette. This work was supported through a scholarship by the Chadian Institute for Agronomic Research for Development (ITRAD), PRASAC and European Union.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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