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Characterization of the proximate composition, the amino acid, mineral and hydrogen cyanide contents of 16 cassava (*Manihot esculenta* Crantz) germplasms

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Abstract

Cassava (*Manihot esculenta* Crantz) is one of the most important food crops grown in the tropical regions of the world. Even though cassava is also cultivated and consumed in southern China, there is little knowledge of the composition of the cassava grown here. Therefore, 16 cassava germplasms collected from Hainan Province in China were used in the present work to determine the proximate composition, amino acid, mineral, and hydrogen cyanide contents of their roots. The results showed significant differences among the cassava germplasms. The cassava germplasms contained 85.56 - 90.50 g/100 g carbohydrate, 0.03 - 1.28 g/100 g crude lipid, 1.41 - 4.74 g/100 g crude protein, 2.90 - 8.60 g/100 g moisture, and 2.89 - 4.38 g/100 g ash. The mineral contents were 62.89 - 467.36, 425.01 - 1474.71, and 070 - 7.95 mg/kg for Ca, Mg, and Pb, respectively; and 1523.08 - 4749.46, 75.57 - 766.33, 9.57 - 282.83, 4.48 - 26.69, 0.75 - 373.60, and 10.43 - 29.04 mg/kg for K, Na, Zn, Mn, Cu, and Fe, respectively. The HCN content ranged from 0.32 - 1.53 mg/g. Among the 16 cassava germplasms, ZMH1071, ZMJ615, and SC12 yielded higher carbohydrate content and lower HCN content, making them suitable for direct consumption or processing; and germplasm M484 yielded high cyanide and carbohydrate content, making it more suitable for starch processing.

Introduction

Manihot esculenta Crantz is a perennial erect shrub of the genus *Manihot* of the Euphorbiaceae family (Leite *et al.,* 2017). It is also listed as one of the world's three major root crops along with sweet potatoes and potatoes. It is also known as "underground food", and the sixth largest crop in the world, after sugar cane, corn, rice, wheat, and potatoes. It is native to Brazil, and among the major tropical crops. It is now widely cultivated in many parts of Asia, Africa, and South America; and the world's most abundant grain product (FAO, 2017).

The cassava roots are basically for starch storage; therefore, high starch content is the main source of energy and makes it as a good starch crop (Jackson and Chiwona-Karltun, 2018); 64 - 72% of the cassava root is made up of starch, approximately 83% is in the form of amylopectin, and 17% is amylose. Moreover, it has been reported that cassava can produce 250 × 103 cal/ha/day as compared to 200 × 103 cal/ha/day for maize, 110 × 103 cal/ha/day for wheat, 176 × 103 cal/ha/day for rice, and 114 × 103 cal/ha/day for sorghum (Okigbo, 1980). Therefore, it is generally considered to be the third largest source of carbohydrates, and consumed as a staple food in many parts of the developing world (Díaz *et al.,* 2018). Cassava is often considered a source of carbohydrates, riboflavin, thiamine, and niacin but not a source of protein, fat, or some minerals or vitamins (Zhu, 2015). Cassava roots contain small quantities of sucrose, glucose, fructose, and maltose (Ngolong Ngea *et al.,* 2016). These sugars are only present in minute quantities that range between 1.57 and 2.89% on a dry weight basis (Aryee *et al.,* 2006). However, it has been reported that in some germplasms, the sucrose content can reach as high as 17% (Drewnowski and Popkin, 1997). In terms of vitamins, only vitamin C is present in relatively high amounts, ranging from 15 - 45 mg/100 g (Anyanwu *et al.,* 2015). Concerning minerals, there have been reports of calcium levels of 1.6 - 3.5 mg/kg, with zinc ranging from 3 - 140 ppm and iron levels from 8 - 24

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mg/kg (Okigbo, 1980; Charles *et al.,* 2005). Although it is a poor source of protein (1 - 2%) (Charles *et al.,* 2005), its amino acid profile is remarkable as compared to other root tubers in terms of some essential amino acids, particularly lysine and threonine (Charles *et al.,* 2005; Morgan and Choct, 2016).

Hydrogen cyanide (HCN) is a compound that has a great influence on the nutritional value of cassava. Cassava is classified into sweet cassava and bitter cassava based on the content of cyanide (calcium hydrocyanate). Generally, a variety with hydrocyanic acid content less than 20 mg/kg is called sweet cassava, and a variety with more than 20 mg/kg is called bitter cassava (FAO, 2017). The National Food Safety Standards of China stipulates that the allowable amount of cyanide (in terms of HCN) in the original grain is ≤ 5 mg/kg, which was used as a benchmark in the present work. Reports have shown that age, variety, and environmental conditions influence the occurrence and concentration of HCN in various parts of the cassava plant at different stages of development (Charles *et al.,* 2005).

Cassava compares in most respects to corn, rice, and wheat starch currently in use (Tonukari, 2004). It is mainly used for food (48%), feed (34%), and raw materials (18%), as well as biofuels and biochemistry (FAO, 2017). Due to the increasing starch utilisation industry in developing countries, cassava production was the largest for roots and stems in 2018, reaching 263 million tons, with the highest production in Brazil, where production is expected to reach approximately 1.88 million tons by 2020 (FAO, 2017). Hence, studying the diversity in nutrient composition among the different germplasms of cassava is the first step to understanding its contribution to the human diet, its potential for further value added, and its timely and potential commercial use. The present work thus presents the variation in proximate composition, hydrogen cyanogen, amino acid, and element contents of the mature tubers among 16 cassava germplasms experimentally grown under similar conditions on Hainan Island in China.

Materials and methods

Plant materials

Sixteen cassava germplasms were collected from local plantations in Hainan, China (Table 1). The roots were cleaned and oven-dried at 60°C (YiHeng Scientific Instrument Co. Ltd., Shanghai, China) for 2 d. The dried cassava roots were ground using a grinder and then sieved over 40 meshes. The powder was kept at 4°C. The chemicals used were of general and analytical grades.

Proximate analysis

All nutritional quality parameters were determined based on the national standards of the People's Republic of China (PRC), and the results were expressed in dry weight. The moisture content was determined by oven-drying the cassava roots bat 105°C overnight until a consistent weight (GB 5009.3-2010). The ash content was determined by incineration at 550°C for 4 h (GB/T 5009.4-2010). The crude protein content was determined in a Kjeltec digestion apparatus (1007 Digestion Unit, Tecator, Sweden) using the micro-Kjeldahl method (GB/T 5009.5-2010). The crude lipid content was determined

Table 1. Descriptions of the 16 cassava germplasms assessed in the present work.

Accession no.	Origin	Breeding method	Planting site	Physiological maturing time (day)	Collection year	Yield (t/ha)
50	China	Artificial hybridisation	Danzhou, Hainan	> 8 months	2018	2.56
SC9	China	Breeding of local varieties through multiple generations of clones	Danzhou, Hainan	> 8 months	2018	1.85
SC12	China	Artificial hybridisation	Danzhou, Hainan	> 8 months	2018	2.67
196	China	Artificial hybridisation	Danzhou, Hainan	> 9 months	2018	1.95
571	China	Artificial hybridisation	Danzhou, Hainan	> 8 months	2018	2.32
417	China	Artificial hybridisation	Danzhou, Hainan	> 8 months	2018	1.98
ZM8229	China	Artificial hybridisation	Danzhou, Hainan	> 9 months	2018	1.65
ZMJ615	China	Artificial hybridisation	Danzhou, Hainan	> 8 months	2018	1.89
521	China	Artificial hybridisation	Danzhou, Hainan	> 8 months	2018	2.52
SC8013	China	Natural hybrid	Danzhou, Hainan	> 8 months	2018	1.48
274	China	Artificial hybridisation	Danzhou, Hainan	> 10 months	2018	1.96
428	China	Artificial hybridisation	Danzhou, Hainan	> 8 months	2018	2.22
6068	China	Natural hybrid	Danzhou, Hainan	> 8 months	2018	2.32
MB	China	Artificial hybridisation	Danzhou, Hainan	> 8 months	2018	1.65
NM	China	Artificial hybridisation	Danzhou, Hainan	> 8 months	2018	1.77
ZMJ696	China	Artificial hybridisation	Danzhou, Hainan	> 8 months	2018	1.88

using a Soxhlet apparatus with petroleum ether as the solvent (GB/T 5009.6-2003). The carbohydrate content was determined by subtraction: carbohydrate content (g/100 g DW) = 100 – (moisture + protein + ash + crude fat).

Hydrogen cyanide

The hydrogen cyanide content was determined follwoing the method described by Zou *et al.* (2014) with modification. A sample of a certain mass was placed in a 50 mL test tube, and 10 mL of pre-heated 80% methanol was added to the sample. The sample test tube was boiled in a water bath for 1 h and centrifuged at high speed (4,000 rpm for 5 min) to collect 10 mL of the supernatant. One millilitre of the extract was vacuum-dried and added to 1 mL of ultrapure water, which was accurately measured to 0.5000 mL in a test tube. Then, 2 mL of acetonitrile:water (1:1, v/v) mixed solvent was added, and a 0.45 μm organic filter was used prior to high-performance liquid chromatography analysis. The high-performance liquid chromatography parameter settings on Atlantis C_{18} column were as follows: mobile phase of acetonitrile-water (85:15, v/v); flow rate of 1 mL/min; column temperature of 30°C; and injection volume of 5 μL. The evaporative photodetector parameter setting was as follows: gas flow rate of 2 L/min; drift tube temperature of 85°C; and gain value of 2.

The accurately weighed standard sample of linolenic acid and the prepared respective standard solutions were dissolved in 50% acetonitrile - 50% water at a concentration of 1 mg/μL. The linear regression was performed on the integral area of leptin at the injection volumes of 1, 3, 5, 7, and 9 μL, respectively, and the linear regression equations and correlation coefficients of the three standards were obtained.

Free amino acids

The free amino acid content was determined following the method described by Kim *et al.* (2013) with some modification. A L-8800 automatic amino acid analyser (Hitachi High-Technologies Corporation, Tokyo, Japan) equipped with a 4.6 mm (ID) × 6 mm ion-exchange column (Hitachi High-Technologies Corporation, Tokyo, Japan) was used. The measurement conditions were as follows: a buffer flow rate of 0.4 mL/min; reagent flow rate of 0.35 mL/min; reactor heater temperature of 135°C; column temperature of 75°C; autosampler temperature of 5 - 8°C; sample injection volume of 20 μL; and detection wavelength of 570 nm (for proline) or 440 nm (for all other amino acids). The purity standard of free amino acid was > 98% (Wako Pure Chemical Industries, Osaka, Japan). An external standard was used to calculate the concentration of each amino acid.

Minerals

The mineral concentrations were determined following the method described by Tabarsa *et al.* (2012) with a flame atomic absorption spectrophotometer (Philips, PU 9400, USA) equipped with single hollow-cathode lamps for each element and an air-acetylene burner. The mineral concentrations were quantified using calibration curves from various standards. To determine the biomolecules, the samples (500 mg) were dissolved in 1 M hydrochloric acid and filtered, and the resulting volume was then increased to 100 mL with distilled water. The solution was stored and used for analysis. For trace element measurements, a dried sample (1 g) was dissolved in mixtures consisting of 10 mL of 63% HNO_3 (nitric acid) and 5 mL of 37% HCl (hydrochloric acid), and the sample volumes were increased to 100 mL with distilled water for the analysis.

Statistical analysis

All experiments were performed in triplicate (n = 3), and the results were expressed as the means ± standard deviation (SD). Duncan's test and one-way analysis of variance (ANOVA) were used for multiple comparisons with the SPSS 13.0 software package. Differences were considered to be statistically significant if $p < 0.05$. Principal components analysis (PCA) was performed in Unscrambler and Origin 2017 software. Heatmaps based on the composition of the variables and samples were plotted using Origin 2017 software.

Results and discussion

Moisture

Moisture values were significantly different among 16 cassava germplasms assessed, and varied between 2.90 and 8.60 g/100 g. Germplasm 418 had the highest moisture content, followed by SC9 (7.42 g/100 g) and 6068 (6.57 g/100 g), whereas ZMJ615 had the lowest (Figure 1a). The difference in moisture content may be related to cassava germplasms and the proximate composition (Chukwu and Abdullahi, 2015).

Crude protein

The values of crude protein content were found to be significantly different among all cassava germplasms, and ranged from 1.41 - 4.74 g/100 g, with germplasm 274 exhibiting the highest crude protein content, followed by SC8013 (4.50 g/100 g), 428 (3.63 g/100 g) and 196 (3.62 g/100 g), while ZM8229 had the lowest (0.48%) (Figure 1b). The coefficient of variation of the sixteen cassava germplasms was

34.53%. Some researchers have reported that the total protein content of cassava range from 1.4 - 2.8% and 2.47 - 3.14%, which are in good agreement with the results obtained in the present work (Ceballos *et al.,* 2006; Chauynaron *et al.,* 2015). The variations in protein content of different cassava accessions might be due to several factors, such as water supply, handling, application of fertiliser (soil nitrogen availability), environmental stresses (such as alkalinity and salinity, temperature, and disease), location of the growing areas, growing conditions, time, genes, and heredity (Ceballos *et al.,* 2006).

Carbohydrate

The contents of carbohydrate in different cassava germplasms are shown in Figure 1c, which were between 85.56 and 91.65 g/100 g, with ZMJ696 having the highest starch content, and germplasm 417 had the lowest (Figure 1c). The coefficient of variation for the carbohydrate content of the 16 cassava germplasms was 1.57%, and the differences in cassava carbohydrate content among the different germplasms was not significant. All cassava germplasms exhibited a fairly high amount of carbohydrate.

Cassava consists almost exclusively of carbohydrates and approximately 1 - 3% of crude protein (Morgan and Choct, 2016). The findings obtained in the present work agree with Saree *et al.* (2017) who reported that the carbohydrate content ranged from 80 - 90%, in dry matter. Studies have shown that approximately 80 - 90% of the carbohydrates are produced as starch (Tappiban *et al.,* 2019); and the carbohydrate of cassava comprises small quantities of glucose, maltose, fructose, and sucrose (Tewe and Lutaladio, 2004). With starch being the principal energy source in cassava, such germplasms could contribute to high energy requirement diets such as baby-food.

Crude fat

Figure 1d shows the crude fat content of the 16 cassava germplasms, which ranged from 0.03 g/100 g (ZMJ615) to 1.28 g/100 g (M484) (Figure 1d). The variation coefficient of the cassava crude fat in the 16 germplasms was 75.67%, and the crude fat content of each germplasm was quite different. The results agree well with a previous study by Rojas *et al.* (2007) who found that the lipid values varied between 0.6 and 1.4%. Compared to yam, the 16 cassava germplasms also exhibited lower fat content, which makes them healthy food sources (Olatoye and Arueya, 2019).

Ash

Germplasm M484 had the highest amount of ash (4.38 g/100 g), followed by 571 (4.37 g/100 g) and 50 (4.31 g/100 g), while SC9 had the lowest (2.89 g/100 g) (Figure 1e). The variation coefficient of ash in the 16 cassava germplasms was 13.8%.

Ash content plays an important role, as it reflects the mineral elements of a food sample (Mbatchou and Dawda, 2013) and provides an estimate to determine the levels of essential minerals present in a food (Edeogu *et al.,* 2007). The values obtained in the present work are similar to those of peeled bitter cassava (2.41% on a dry weight basis) and sweet cassava (4.44% on a dry weight basis) (Okigbo, 1980), but higher than that of the root tubers (0.84%) reported by Kortei *et al.* (2014). The different results could be due to different growing regions and seasons (Charles *et al.,* 2004).

Hydrogen cyanide

The cyanide content of all the tested cassava germplasms ranged from 0.32 - 1.53 mg/g, with germplasm 6068 had the highest cyanide content, and SC9 the lowest (Figure 1f). The difference between the cyanide contents was statistically significant.

Consumption of residual cyanogens (e.g. linamarin and lotaustralin) in incompletely processed cassava roots can cause various health disorders that render a person unsteady and uncoordinated, such as acute cyanide intoxication, konzo, spastic paraparesis (Kashala-Abotnes *et al.,* 2019), tropical neuropathy, and goitre and cretinism (Vetter, 2000). The cyanogen content was significantly higher than that reported by Oluwole *et al.* (2007) (22 - 244 mg/kg), and Franck *et al*. (2011) (79.1 - 189 mg/kg), but lower than Mlingi and Bainbridge (1994) (1090 and 1550 mg/kg). This variability might be due to differences in germplasm, soil composition, geographical location, environmental conditions, age, and the part of the plant tested. China set a safe limit of 5 ppm total cyanide for cassava flour. In the studied germplasms, cyanide contents were above the recommendations. However, most of the cyanide (HCN) could be removed by the traditional processing methods of grating, fermenting, boiling, and/or drying (Ceballos *et al.,* 2006).

Amino acids

To assess the nutritional quality of proteins in cassava germplasms, we compared the amino acid composition of each protein (Table 2). The nutritional quality of a protein is basically determined by the content, proportion, and availability of essential amino acids. Table 2 shows the results for the amino acids (expressed as g of amino acid per 100 g of crude protein in DW) in all the cassava germplasms analysed. Significant differences were found in the mean concentrations of all amino acids of the studied germplasms.

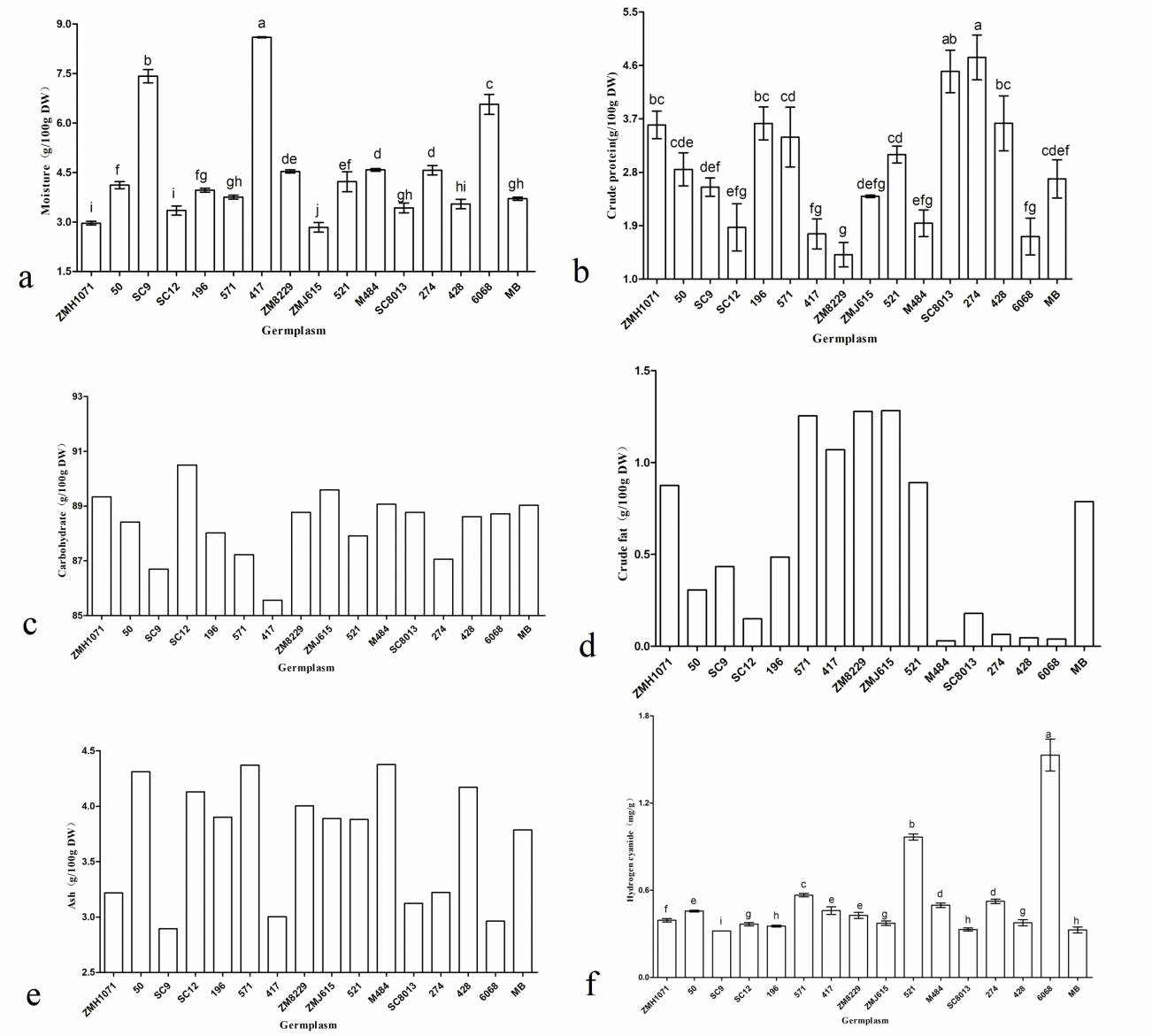

Figure 1. Proximate composition and hydrogen cyanide content of the 16 cassava germplasms assessed in the present work. a) moisture, b) crude protein, c) carbohydrate, d) crude fat, e) ash, and f) hydrogen cyanide content. DW = dry weight. Different lowercase letters denote statistically significant differences ($p < 0.05$) by ANOVA and Duncan's test.

Glutamic acid was the most abundant amino acid in all the cassava germplasms, followed by arginine, while proline was the lowest. The results are consistent with the findings of Onwueme (1978). The valine content of germplasm ZMH1071 was significantly lower than the other germplasms, and was the first limiting amino acid of ZMH1071. The main limiting amino acids of the remaining germplasms were lysine and leucine, which are consistent with the results of Diasolua Ngudi *et al.* (2003). The highest content of lysine and leucine was found in germplasm 571, and the lowest was found in germplasm ZMJ696; but all the germplasms had excess threonine.

Cassava tubers have low protein content (0.7 - 1.3% in fresh weight) (Ngiki *et al.,* 2014). Compared to other tubers, cassava has a very low essential amino acid content (Olugbemi *et al.,* 2010). Approximately 50% of the crude protein is composed of whole protein, while the rest consists of free amino acids, mainly glutamic acid, and aspartic acid (Saree *et al.,* 2017). According to Gomes and Nassar (2013), proteins in cassava have higher arginine content but lower methionine, threonine, cysteine, phenylalanine, isoleucine, and proline contents (Onwueme, 1978). These results are the same as those obtained in the present work. However, it is worth noting that some studies have reported that cassava roots are low in protein and lack of several essential amino acids (Gomes and Nassar, 2013). Therefore, a cassava-based diet must include a source of protein that provides a sufficient supply of methionine and lysine, which may not be easily attained. To resolve this problem, the addition of the

Table 2. Non-essential, essential, and semi-essential total amino acid contents of 16 cassava germplasms (g/100 g DW) assessed in the present work.

Accession no.	Essential and semi-essential total amino acids (ESAA) (g/100 g DW) ± SD									
	Thr	**Tyr**	**Cys**	**Val**	**Met**	**Trp**	**Phe**	**Ile**	**Leu**	**Lys**
ZMH1071	1.30 ± 0.08^{cdefg}	0.94 ± 0.02^{abcd}	1.34 ± 0.12^{a}	0.2 ± 0.00^{i}	0.38 ± 0.01^{bcde}	0.32 ± 0.03^{ef}	1.31 ± 0.17^{a}	1.17 ± 0.15^{abc}	2.05 ± 0.08^{ab}	1.15 ± 0.13^{de}
50	1.49 ± 0.62^{bcdef}	0.91 ± 0.02^{abcd}	1.20 ± 0.08^{abc}	1.42 ± 0.01^{cd}	0.42 ± 0.01^{bcd}	0.66 ± 0.04^{bc}	1.00 ± 0.01^{bcde}	0.97 ± 0.02^{cde}	1.52 ± 0.01^{cd}	1.13 ± 0.04^{de}
SC9	0.85 ± 0.05^{fg}	0.89 ± 0.03^{bcd}	1.05 ± 0.10^{abcd}	1.11 ± 0.01^{efg}	0.41 ± 0.01^{bcd}	0.66 ± 0.12^{bc}	0.87 ± 0.01^{def}	0.84 ± 0.01^{efgh}	1.29 ± 0.04^{cdefg}	0.83 ± 0.02^{fg}
SC12	1.29 ± 0.76^{cdefg}	0.72 ± 0.14^{de}	0.74 ± 0.28^{e}	1.12 ± 0.08^{efg}	0.37 ± 0.04^{de}	0.90 ± 0.19^{a}	0.83 ± 0.11^{ef}	0.78 ± 0.06^{efgh}	1.23 ± 0.11^{defg}	0.77 ± 0.08^{g}
196	2.10 ± 0.16^{abc}	0.89 ± 0.14^{abcd}	1.11 ± 0.23^{abcd}	1.47 ± 0.14^{bc}	0.44 ± 0.04^{b}	0.72 ± 0.03^{ab}	1.04 ± 0.10^{bcd}	1.06 ± 0.10^{bcd}	1.60 ± 0.18^{cd}	1.20 ± 0.14^{de}
571	2.27 ± 0.06^{ab}	1.13 ± 0.03^{a}	1.29 ± 0.15^{ab}	1.81 ± 0.01^{a}	0.53 ± 0.03^{a}	0.73 ± 0.06^{ab}	1.33 ± 0.03^{a}	1.34 ± 0.04^{a}	2.11 ± 0.03^{a}	1.68 ± 0.00^{a}
417	1.82 ± 0.24^{abcd}	0.98 ± 0.09^{abc}	0.98 ± 0.11^{cde}	1.15 ± 0.09^{ef}	0.42 ± 0.04^{bcd}	0.56 ± 0.04^{bcd}	0.98 ± 0.07^{bcde}	0.82 ± 0.06^{efgh}	1.30 ± 0.18^{cdefg}	1.13 ± 0.15^{de}
ZM8229	1.93 ± 0.07^{abcd}	0.86 ± 0.03^{bcd}	1.07 ± 0.03^{abcd}	1.17 ± 0.03^{e}	0.38 ± 0.01^{cde}	0.46 ± 0.19^{de}	1.08 ± 0.09^{bc}	0.92 ± 0.08^{def}	1.37 ± 0.07^{cde}	0.85 ± 0.03^{fg}
ZMJ615	1.71 ± 0.22^{abcde}	0.70 ± 0.02^{de}	0.93 ± 0.09^{cde}	0.97 ± 0.07^{fgh}	0.27 ± 0.00^{fg}	0.64 ± 0.02^{bcd}	0.76 ± 0.11^{f}	0.70 ± 0.05^{ghi}	1.17 ± 0.05^{defgh}	0.77 ± 0.08^{g}
521	0.89 ± 0.01^{fg}	1.07 ± 0.05^{ab}	1.04 ± 0.06^{bcd}	1.66 ± 0.08^{ab}	0.41 ± 0.03^{bcd}	0.69 ± 0.02^{b}	1.15 ± 0.07^{ab}	1.21 ± 0.08^{ab}	1.47 ± 0.44^{cd}	1.42 ± 0.05^{bc}
M484	2.01 ± 0.00^{abc}	0.90 ± 0.10^{abcd}	0.97 ± 0.13^{cde}	1.26 ± 0.07^{de}	0.33 ± 0.03^{ef}	0.19 ± 0.01^{f}	0.96 ± 0.03^{cde}	0.76 ± 0.03^{fgh}	1.34 ± 0.11^{cdef}	1.00 ± 0.09^{ef}
SC8013	0.93 ± 0.21^{effg}	0.99 ± 0.16^{abc}	0.97 ± 0.06^{cde}	0.91 ± 0.16^{h}	0.38 ± 0.05^{bcde}	0.70 ± 0.06^{b}	0.84 ± 0.07^{ef}	0.51 ± 0.01^{i}	0.74 ± 0.10^{h}	1.23 ± 0.12^{cd}
274	2.48 ± 0.08^{a}	1.13 ± 0.02^{a}	0.99 ± 0.00^{cde}	1.55 ± 0.02^{bc}	0.43 ± 0.01^{bc}	0.57 ± 0.06^{bcd}	1.27 ± 0.04^{a}	1.17 ± 0.06^{abc}	1.68 ± 0.21^{bc}	1.50 ± 0.05^{ab}
428	0.79 ± 0.00^{fg}	0.80 ± 0.23^{cde}	0.83 ± 0.09^{de}	0.80 ± 0.03^{h}	0.33 ± 0.01^{ef}	0.49 ± 0.03^{cde}	0.96 ± 0.05^{cde}	0.91 ± 0.03^{defg}	0.86 ± 0.14^{gh}	1.41 ± 0.14^{bc}
6068	0.56 ± 0.03^{g}	0.60 ± 0.06^{e}	0.82 ± 0.05^{de}	0.81 ± 0.14^{h}	0.26 ± 0.00^{g}	0.45 ± 0.03^{de}	0.72 ± 0.03^{f}	0.64 ± 0.23^{hi}	0.90 ± 0.30^{fgh}	0.71 ± 0.03^{g}
MB	1.15 ± 0.82^{defg}	0.88 ± 0.10^{bcd}	0.97 ± 0.06^{cde}	0.93 ± 0.13^{gh}	0.29 ± 0.03^{fg}	0.47 ± 0.05^{cde}	0.71 ± 0.06^{f}	0.72 ± 0.08^{fgh}	0.95 ± 0.31^{efgh}	0.77 ± 0.10^{g}

Accession no.	Non-essential total amino acids (NEAA) (g/100 g DW) ± SD							
	Arg	**Ala**	**Asp**	**Glu**	**Ser**	**His**	**Gly**	**Pro**
ZMH1071	9.55 ± 0.04^{b}	2.21 ± 0.03^{ab}	2.03 ± 0.03^{d}	9.20 ± 0.92^{bc}	1.1 ± 0.02^{bc}	1.01 ± 0.07^{ab}	1.16 ± 0.03^{bc}	0.64 ± 0.01^{bcd}
50	4.27 ± 0.31^{g}	2.17 ± 0.04^{ab}	1.36 ± 0.01^{f}	5.31 ± 0.09^{gh}	0.81 ± 0.03^{def}	0.41 ± 0.32^{cd}	1.00 ± 0.01^{cd}	0.53 ± 0.07^{bcde}
SC9	4.64 ± 0.06^{fg}	1.52 ± 0.01^{de}	1.65 ± 0.04^{ef}	6.51 ± 0.09^{efg}	0.66 ± 0.02^{efg}	0.66 ± 0.10^{bc}	0.77 ± 0.01^{e}	0.54 ± 0.12^{bcde}
SC12	1.99 ± 0.32^{ij}	1.42 ± 0.21^{def}	1.55 ± 0.19^{ef}	6.10 ± 0.76^{fgh}	0.57 ± 0.06^{fg}	0.40 ± 0.14^{cd}	0.77 ± 0.10^{e}	0.40 ± 0.03^{e}
196	6.17 ± 0.53^{cde}	2.01 ± 0.18^{b}	2.51 ± 0.06^{bc}	6.75 ± 0.82^{efg}	1.02 ± 0.23^{bcd}	0.64 ± 0.06^{bc}	1.05 ± 0.11^{bc}	0.54 ± 0.06^{bcde}
571	9.17 ± 0.09^{b}	2.41 ± 0.04^{a}	2.12 ± 0.03^{d}	7.84 ± 0.18^{cde}	1.12 ± 0.03^{b}	0.79 ± 0.37^{bc}	1.35 ± 0.02^{a}	0.70 ± 0.03^{abc}
417	6.24 ± 0.71^{cde}	1.72 ± 0.15^{cd}	1.35 ± 0.16^{f}	6.97 ± 0.98^{def}	0.85 ± 0.03^{cde}	0.67 ± 0.04^{bc}	0.84 ± 0.10^{de}	0.67 ± 0.09^{bcd}
ZM8229	2.90 ± 0.13^{hi}	1.56 ± 0.02^{de}	1.86 ± 0.08^{de}	7.13 ± 0.06^{def}	0.95 ± 0.07^{bcd}	0.62 ± 0.03^{bc}	0.77 ± 0.01^{e}	0.64 ± 0.21^{bcd}
ZMJ615	6.43 ± 0.62^{cd}	1.66 ± 0.13^{cde}	2.06 ± 0.21^{d}	6.68 ± 0.80^{efg}	0.64 ± 0.17^{efg}	0.67 ± 0.09^{bc}	0.68 ± 0.07^{ef}	0.40 ± 0.06^{e}
521	5.25 ± 0.00^{efg}	2.32 ± 0.10^{a}	2.50 ± 0.30^{bc}	7.82 ± 0.28^{cde}	1.06 ± 0.02^{bcd}	1.02 ± 0.02^{ab}	1.22 ± 0.04^{ab}	0.62 ± 0.01^{bcd}
M484	5.56 ± 0.44^{cdef}	1.92 ± 0.02^{bc}	2.79 ± 0.02^{ab}	8.47 ± 0.54^{bcd}	0.96 ± 0.09^{bcd}	0.69 ± 0.27^{bc}	0.83 ± 0.06^{de}	0.48 ± 0.00^{de}
SC8013	6.71 ± 1.01^{c}	1.39 ± 0.11^{ef}	2.68 ± 0.18^{ab}	12.04 ± 1.15^{a}	0.59 ± 0.07^{efg}	0.76 ± 0.32^{bc}	0.57 ± 0.06^{fg}	0.89 ± 0.14^{a}
274	10.6 ± 0.63^{a}	2.41 ± 0.07^{a}	3.04 ± 0.02^{a}	9.70 ± 0.57^{b}	1.64 ± 0.14^{a}	1.32 ± 0.00^{a}	1.06 ± 0.07^{bc}	0.74 ± 0.12^{ab}
428	5.46 ± 0.11^{def}	1.44 ± 0.02^{def}	2.16 ± 0.04^{cd}	7.77 ± 0.53^{cde}	0.60 ± 0.03^{efg}	1.04 ± 0.09^{ab}	0.67 ± 0.05^{ef}	0.59 ± 0.05^{bcde}
6068	1.64 ± 0.06^{j}	0.87 ± 0.03^{g}	2.56 ± 0.43^{b}	4.92 ± 0.20^{h}	0.41 ± 0.03^{g}	0.21 ± 0.06^{d}	0.49 ± 0.03^{g}	0.49 ± 0.01^{cde}
MB	3.18 ± 0.95^{h}	1.15 ± 0.35^{f}	1.46 ± 0.15^{f}	7.59 ± 0.80^{def}	0.66 ± 0.25^{efg}	0.71 ± 0.12^{bc}	0.56 ± 0.21^{fg}	0.50 ± 0.10^{cde}

Means within the same column with the same lowercase superscript were not significantly different ($p > 0.05$) based on ANOVA and Duncan's test. Asp = Aspartic acid, Ala = Alanine, Arg = Arginine, Gln = Glutamine, Gly = Glycine, His = Histidine, Cit = Citrulline, Ile = Isoleucine, Leu = Leucine, Lys = Lysine, Met = Methionine, Phe = Phenylalanine, Pro = Proline, Ser = Serine, Thr = Threonine, Glu = glutamic acid, Tyr = Tyrosine, and Val = Valin.

protein-rich cassava leaves and seeds to the diet (Ngiki *et al.,* 2014), or the inclusion of supplemental synthetic amino acids, may be considered.

Minerals

Minerals are well-known essential nutrients and provide a vital role in the effective functioning of bodily activities (Wang *et al.,* 2011). The 16 cassava germplasms are rich in minerals and as showed in Table 3, 21 elements were measured. The data indicate that macro-elements (K, Na, Mg, and Ca) were the major constituents in the 16 cassava germplasms tested. K content was the highest (1523.08 - 4749.46 mg/kg), followed by Mg (425.01 - 1474.71 mg/kg), Na (75.57 - 743.2 mg/kg), and Ca (62.89 - 467.36 mg/kg). Ca is an important structural component of bone, meanwhile Mg helps to maintain normal muscle and nerve functions and keeps the heart rhythm steady. In addition, K, Ca, and Mg are all needed for repairing worn-out body cells and the generation of red blood cells. It is worth noting that high Ca and K contents in these cassavas makes them an incredible natural source for pregnant and lactating women, as well as for children and elderly people. The amounts of Ca and K reported in the present work are lower than those reported by Charles *et al.* (2005) and Rojas *et al.* (2007).

Zn and Cu in germplasm SC12 were significantly higher than in the other 15 cassava germplasms; at 282.83 and 373.60 mg/kg, respectively. The other 15 cassava germplasms had Zn contents between 9.57 and 38.93 mg/kg, and Cu contents between 0.75 and 2.5 mg/kg. The microelements contents were 0.63 - 1.49, 4.48 - 26.69, 10.43 - 29.04, and 7.47 - 16.25 mg/kg for Se, Mn, Fe, and Ni, respectively. Microelements such as Fe and Zn are essential for enzyme metabolism. The Fe content is lower than the values reported on a fresh weight basis (0.7 mg/g) (Okigbo, 1980), and 1.7 mg/g from Julián and Buitrago (1990). The Cu content is significantly lower than that (0.2 mg/g) reported by Okigbo (1980). The Zn content is similar to that reported by Charles *et al.* (2005), but significantly lower than that reported by Julián and Buitrago (1990) in cassava roots (1.4 mg/g based on fresh weight). The Mn content is similar to that reported by Rojas *et al.* (2007), but significantly lower than that reported by Julián and Buitrago (1990).

The 16 cassava germplasms contained potentially toxic substances, but at low doses, and they may have essential functions in the human body. This includes Al (6.64 - 16.29 mg/kg), Pb (0.2 - 7.95 mg/kg), As (0.09 - 0.24/kg), Hg (0.01 - 0.23 mg/kg), and Cd (0.03 - 0.21 mg/kg). The germplasm SC12 had significantly higher Pb (7.95 mg/kg) than the other germplasms. The Hg content was high in the 16 germplasms, with the highest found in the germplasm ZMH1071 (0.23 mg/kg). However, under normal intake conditions, these elements will not harm the human body if they are consumed within the allowable levels as proposed by FAO/WHO. The remaining elements such as Li, Be, Rb, Sr, Ba, and La were found in lower amounts.

Principal component analysis (PCA)

PCA was conducted using the data set related to the proximate composition, amino acid, minerals for all the cassava germplasms. In a typical PCA, the desired percentage in the total variation is between 70 and 90%, and the selected PCs make a higher contribution (Jolliffe, 2002). Two principal components explained 96.0% of the data variation and differentiated the cassava samples as determined by the factor loading analysis (Figure 2).

For amino acid principal component analysis, the variables with the highest positive factor loadings in PC1 that accounted for approximately 88.0% of variance were valine, tryptophan, and methionine. Germplasms 571, ZM8299, and 196 were grouped based on their influences in these variables. In PC2, tyrosine, serine, cysteine, and glycine had the highest factor loading values and explained 8.0% of the total variance. Regarding the mineral PCA, the variables with the highest positive factor loadings in PC1,

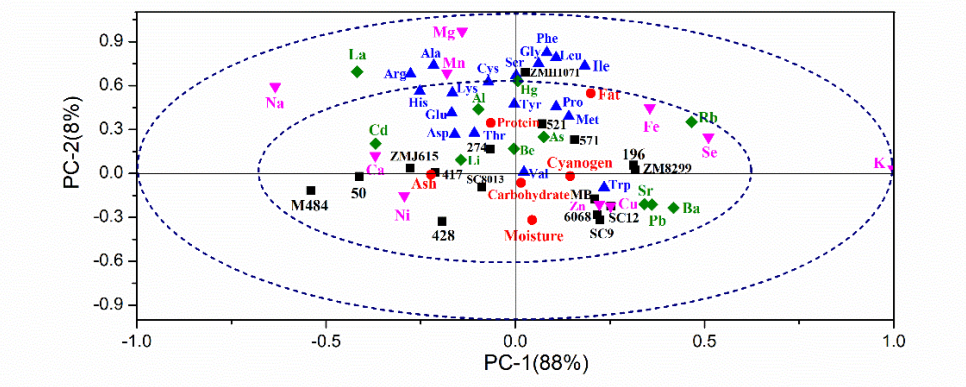

Figure 2. Correlation loading map of the principal component analysis (PCA).

Table 3. The elements in 16 cassava germplasms (mg/kg DW) assessed in the present work.

Accession no.	Macro- and microelement (mg/kg DW) ± SD									
	K	Na	Mg	Ca	Mn	Ni	Fe	Zn	Cu	Se
ZMH1071	3752.38 ± 178.27^{d}	743.2 ± 38.01^{a}	1474.71 ± 71.26^{i}	138.54 ± 6.92^{f}	26.69 ± 0.7^{a}	12.83 ± 0.49^{b}	17.66 ± 0.71^{k}	13.17 ± 0.48^{defg}	1.76 ± 0.06^{b}	1.29 ± 0.08^{abc}
50	1967.87 ± 18.82^{h}	535.27 ± 6.88^{b}	830.37 ± 7.93^{h}	212.09 ± 0.65^{d}	11.27 ± 0.04^{ef}	13.36 ± 0.23^{b}	11.53 ± 0.41^{jk}	24.44 ± 0.21^{c}	1.29 ± 0.02^{b}	1.03 ± 0^{abcd}
SC9	4244.34 ± 27.15^{bc}	88.78 ± 0.74^{ij}	425.01 ± 7.39^{gh}	62.89 ± 1.63^{j}	9.79 ± 0.17^{gh}	12.36 ± 0.11^{b}	13.65 ± 0.21^{jk}	12.66 ± 0.64^{efg}	1.14 ± 0^{b}	0.97 ± 0.09^{abcd}
SC12	4345.72 ± 27.22^{abc}	118.62 ± 0.91^{h}	557.17 ± 1.94^{gh}	86.04 ± 0.83^{hi}	7.24 ± 0.01^{k}	13.9 ± 0.06^{b}	13.21 ± 0.23^{ij}	282.83 ± 12.63^{a}	373.6 ± 19.47^{a}	0.9 ± 0.18^{abcd}
196	4573.07 ± 5.03^{ab}	127.38 ± 0.06^{h}	817.57 ± 4.44^{g}	107.7 ± 0.39^{g}	9.13 ± 0.13^{ij}	7.47 ± 8.67^{b}	25.19 ± 0.28^{hi}	20.05 ± 0.19^{cde}	1.64 ± 0.08^{b}	0.63 ± 0.35^{cd}
571	4057.6 ± 13.8^{cd}	410.84 ± 2.02^{d}	955.31 ± 2.69^{f}	179.37 ± 3.24^{e}	17.63 ± 0.04^{b}	14.13 ± 0.15^{b}	14.54 ± 0.06^{gh}	17.87 ± 0.15^{cdef}	1.09 ± 0.01^{b}	1.49 ± 0.35^{a}
417	2674.19 ± 4.18^{fg}	436.47 ± 2.71^{cd}	821.73 ± 5.72^{e}	114.85 ± 1.63^{g}	16.71 ± 0.01^{c}	13.65 ± 0.06^{b}	10.96 ± 0.02^{fg}	20.1 ± 0.54^{cde}	1.92 ± 0.01^{b}	0.56 ± 0.08^{d}
ZM8229	4583.37 ± 12.33^{ab}	115.86 ± 0.28^{hi}	787.79 ± 2.62^{e}	92.72 ± 0.71^{h}	9.59 ± 0.09^{ghi}	14.01 ± 0.29^{b}	11.14 ± 0.05^{f}	24.67 ± 0.23^{c}	1.73 ± 0.02^{b}	0.9 ± 0.36^{abcd}
ZMJ615	2530.64 ± 158.45^{g}	234.35 ± 14.84^{f}	1027.02 ± 57.57^{e}	385.39 ± 16.96^{b}	10.07 ± 0.7^{g}	14.71 ± 0.62^{b}	15.3 ± 0.69^{e}	38.93 ± 1.79^{b}	2.5 ± 0.06^{b}	0.82 ± 0.27^{bcd}
521	3760.29 ± 45.97^{d}	363.53 ± 1.83^{e}	1143.73 ± 15.34^{e}	82.63 ± 1.15^{hi}	10.76 ± 0.07^{f}	15.11 ± 0.3^{b}	29.04 ± 0.85^{e}	12.88 ± 0.22^{efg}	1.57 ± 0.06^{b}	1.33 ± 0.11^{ab}
M484	1523.08 ± 37.55^{i}	766.33 ± 29.22^{a}	671.32 ± 23.54^{e}	83.08 ± 2.91^{hi}	8.58 ± 0.21^{j}	15.24 ± 0.8^{b}	10.43 ± 0.24^{e}	16.85 ± 0.71^{defg}	0.75 ± 0.04^{b}	0.9 ± 0.36^{abcd}
SC8013	3081.67 ± 32.87^{ef}	145.19 ± 0.07^{h}	778.2 ± 3.81^{d}	467.36 ± 3.45^{a}	9.33 ± 0.18^{hi}	15.33 ± 0.38^{b}	15.16 ± 0.06^{d}	11.56 ± 0.04^{fg}	2.14 ± 0.04^{b}	1.05 ± 0.37^{abcd}
274	3247.67 ± 21.33^{e}	459.15 ± 1.15^{c}	943.57 ± 2.37^{d}	233.13 ± 4.71^{c}	11.69 ± 0.04^{e}	15.51 ± 0.06^{b}	19.72 ± 0.29^{d}	20.61 ± 0.27^{cd}	1.36 ± 0.06^{b}	0.83 ± 0.45^{abcd}
428	2693.88 ± 9.51^{fg}	193.86 ± 1.25^{g}	529.09 ± 0.08^{e}	113.13 ± 2.36^{g}	15.98 ± 0.04^{d}	14.95 ± 0.04^{b}	12.06 ± 0.07^{c}	12.61 ± 0.16^{efg}	1.75 ± 0.01^{b}	0.83 ± 0.27^{abcd}
6068	4166.59 ± 47.67^{bcd}	75.57 ± 0.69^{j}	483.57 ± 14.24^{b}	67.18 ± 1.11^{j}	4.48 ± 0.01^{m}	16.25 ± 0.69^{a}	17.9 ± 0.44^{b}	12.61 ± 0.09^{efg}	1.15 ± 0.02^{b}	1.16 ± 0.18^{abcd}
MB	4749.46 ± 776.64^{a}	221.19 ± 7.21^{f}	515.89 ± 20.97^{a}	78 ± 0.4^{i}	4.55 ± 0.28^{l}	16.24 ± 0.48^{b}	12.74 ± 0.42^{a}	9.57 ± 0.57^{g}	1.15 ± 0.07^{b}	0.95 ± 0.27^{abcd}
Name of accession	**Potentially toxic elements and other elements (mg/kg DW) ± SD**									
	Pb	**Cd**	**Hg**	**As**	**Al**	**Li**	**Be**	**Rb**	**Sr**	**Ba**	**La**
ZMH1071	0.2 ± 0^{m}	0.12 ± 0.02^{e}	0.23 ± 0.01^{a}	0.23 ± 0.03^{a}	13.11 ± 1.73^{i}	0.58 ± 0^{ab}	0 ± 0^{d}	58.76 ± 1.69^{a}	4.61 ± 0.08^{d}	10.17 ± 0.23^{c}	3.9 ± 0.09^{a}
50	0.6 ± 0.02^{k}	0.06 ± 0.02^{de}	0.12 ± 0.01^{b}	0.14 ± 0.04^{bc}	8.97 ± 0.06^{hi}	0.46 ± 0.22^{b}	0.26 ± 0.12^{b}	31.76 ± 0.41^{h}	3.63 ± 0.06^{g}	1.89 ± 0.12^{l}	1.7 ± 0.02^{e}
SC9	1.01 ± 0.01^{g}	0.06 ± 0.01^{de}	0.07 ± 0.01^{c}	0.09 ± 0.01^{c}	6.64 ± 0.16^{ghi}	0 ± 0^{c}	0 ± 0^{d}	56.97 ± 0.1^{b}	6.22 ± 0.09^{a}	20.38 ± 0.19^{a}	0.35 ± 0.01^{j}
SC12	7.95 ± 0.04^{a}	0.05 ± 0.01^{de}	0.06 ± 0.01^{cd}	0.13 ± 0.07^{bc}	6.73 ± 0^{fghi}	0.6 ± 0.42^{ab}	0.17 ± 0^{c}	25.42 ± 0.42^{j}	5.35 ± 0.28^{b}	8.86 ± 0.04^{d}	0.09 ± 0.01^{k}
196	2 ± 0.05^{b}	0.03 ± 0^{cde}	0.05 ± 0^{d}	0.15 ± 0.02^{bc}	15.59 ± 0.37^{efghi}	0.29 ± 0^{bc}	0.33 ± 0^{a}	48.05 ± 0.11^{c}	3.03 ± 0.04^{h}	2.52 ± 0.03^{k}	1.22 ± 0.01^{g}
571	1.34 ± 0.01^{d}	0.04 ± 0.01^{cde}	0.07 ± 0.01^{cd}	0.2 ± 0.06^{ab}	8.91 ± 0.71^{efgh}	0.29 ± 0^{bc}	0 ± 0^{d}	42.18 ± 0.54^{d}	3.23 ± 0.07^{h}	3.91 ± 0.02^{h}	3.04 ± 0.06^{c}
417	1.24 ± 0^{e}	0.03 ± 0.01^{cde}	0.03 ± 0^{e}	0.16 ± 0.01^{abc}	7.4 ± 2.33^{efgh}	0.29 ± 0^{bc}	0.16 ± 0^{c}	30.33 ± 0.15^{hi}	3.16 ± 0.11^{h}	2.86 ± 0.01^{jk}	1.25 ± 0.01^{g}
ZM8229	1.07 ± 0^{f}	0.04 ± 0.01^{cde}	0.03 ± 0.01^{ef}	0.13 ± 0.03^{bc}	7.95 ± 0.16^{defg}	0.9 ± 0^{a}	0 ± 0^{d}	25.61 ± 0.09^{j}	4.93 ± 0.02^{e}	7.46 ± 0.23^{e}	0.07 ± 0.01^{k}
ZMJ615	0.55 ± 0.01^{l}	0.21 ± 0.03^{cde}	0.03 ± 0.01^{ef}	0.18 ± 0.01^{ab}	12.72 ± 1.45^{def}	0.89 ± 0^{a}	0.16 ± 0^{c}	31.95 ± 1.9^{h}	5.19 ± 0.14^{b}	2.49 ± 0.25^{k}	3.5 ± 0.06^{b}
521	1.67 ± 0.03^{c}	0.05 ± 0.01^{cd}	0.02 ± 0^{ef}	0.19 ± 0.01^{ab}	11.21 ± 0.71^{cde}	0 ± 0^{c}	0.17 ± 0^{c}	34.05 ± 0.23^{g}	2.53 ± 0.14^{i}	3.26 ± 0.18^{i}	1 ± 0.02^{h}
M484	0.25 ± 0.01^{m}	0.06 ± 0.01^{cd}	0.02 ± 0.01^{ef}	0.14 ± 0.06^{bc}	8.53 ± 0.09^{bcd}	0.3 ± 0^{bc}	0 ± 0^{d}	19.38 ± 0.4^{k}	2.09 ± 0.1^{j}	4.86 ± 0.16^{f}	1.62 ± 0.01^{e}
SC8013	0.73 ± 0^{i}	0.03 ± 0.01^{cd}	0.02 ± 0^{ef}	0.18 ± 0.01^{ab}	12.28 ± 0.5^{bc}	0.31 ± 0^{bc}	0 ± 0^{d}	30.71 ± 0.35^{hi}	4.33 ± 0.04^{e}	1.54 ± 0.04^{l}	1.38 ± 0.01^{f}
274	0.91 ± 0.04^{h}	0.03 ± 0.01^{cd}	0.02 ± 0.01^{ef}	0.16 ± 0.01^{abc}	16.29 ± 0.46^{b}	0.45 ± 0.21^{b}	0.17 ± 0^{c}	35.47 ± 1.15^{g}	4.07 ± 0.14^{f}	3.33 ± 0.12^{i}	2.02 ± 0.04^{d}
428	1.23 ± 0.02^{e}	0.05 ± 0^{c}	0.02 ± 0.01^{ef}	0.24 ± 0.01^{a}	9.92 ± 0.6^{b}	0.45 ± 0.21^{b}	0 ± 0^{d}	29.81 ± 0.46^{i}	3.77 ± 0.08^{g}	4.43 ± 0.31^{g}	1.06 ± 0.02^{h}
6068	0.67 ± 0.02^{j}	0.04 ± 0.01^{b}	0.01 ± 0^{f}	0.17 ± 0.04^{abc}	10.54 ± 1.21^{a}	0 ± 0^{c}	0 ± 0^{d}	37.35 ± 0.51^{f}	4.88 ± 0^{e}	11.68 ± 0.27^{b}	0.3 ± 0.01^{j}
MB	0.53 ± 0^{l}	0.02 ± 0.01^{a}	0.01 ± 0^{f}	0.17 ± 0.04^{abc}	9.14 ± 0.64^{a}	0.3 ± 0^{bc}	0 ± 0^{d}	39.22 ± 0.04^{e}	2.51 ± 0.03^{i}	3.12 ± 0.03^{ij}	0.45 ± 0.01^{i}

Means within the same column with the same lowercase superscript were not significantly different ($p > 0.05$) based on ANOVA and Duncan's test.

accounting for approximately 88.0% of the variation, were K, Se, Cu, Zn, and Fe. Germplasms 196, ZM8299, MB, and SC12 were grouped based on the influences of these variables. In PC2, Mg, Mn, Na, and Fe had the highest factor loading values and explained 8.0% of the total variance. Germplasms ZMH1027, 274, 521, and 571 were differentiated based on the value of these variables.

Conclusion

Due to the demand for cassava, it has been in increased production worldwide; therefore, understanding the diversity of cassava nutrients is becoming increasingly important to increase the potential of cassava and promote its potential commercial use. In the present work, we found that there were significant differences in the proximate composition, hydrogen cyanide, amino acid, and elements of the 16 cassava germplasms. Cassava contains a large number of carbohydrates. Although it has a low protein content, it includes rich amino acids and minerals. It is a good source of carbohydrate and minerals. In addition, cassava-containing diets must be carefully formulated, especially in terms of the limiting amino acids (lysine and leucine) and mineral balance. Much attention must be paid in supplementing foods that are relatively rich in lysine and leucine to prevent potentially toxic mineral poisoning. Among the 16 cassava germplasms, ZMH1071, ZMJ615, and SC12 yielded the highest carbohydrate and lowest cyanide content, rendering them suitable for direct and simple processing; and the germplasm M484 yielded high cyanide and carbohydrate content, making it more suitable for processing than for eating. The present work only analysed the proximate composition, hydrogen cyanide, and amino acid distribution of 16 cassava germplasms. However, cassava starch is an important part of the cassava root, and the quality of the cassava starch from each germplasm remains to be studied.

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