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Heterogeneity in Nutritional and Biochemical Composition of Cassava Varieties in Uganda

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ABSTRACT

Cassava (*Manihot esculenta* Crantz) has been prioritized by the New Partnership for African Development to spur development in Africa. However, the nutritional and biochemical composition of the cassava diversity has not been adequately assessed to inform the various user needs. Comparative analysis of macro, micro nutrients and biochemical composition of sixteen varieties of cassava in Uganda was undertaken following standard analytical techniques. Results showed significant differences in macro nutrients ($p \leq 0.000$) except carbohydrate, starch and amylose contents. With the exception of Calcium and Iron, the varieties were significantly different ($p \leq 0.000$) in micronutrient composition. The Cyanide and dry matter content were also significantly different ($p \leq 0.000$) among the varieties. Overall, Mukibi, Juguja, Bao, Nigeria, ranked highest in dry matter, cyanide, macro and micronutrients content, respectively. Therefore varieties differ in nutritional and biochemical composition; information crucial in the development of new varieities and deployment of cassava diversity in various value chains.

Keywords: composition, cyanide, macronutrient, micronutrient

1. Introduction

Cassava (Manihot *esculenta* Crantz) is an important food security crop for millions of people, particularly in Sub-Saharan Africa (Luna *et al.*, 2020). It is also an income-generating crop for millions of smallholder farmers (El-Sharkawy, 2012). The crop is gaining economic importance globally for its starch utilization in food, feed and industry (Legg, 1999;Jansson *et al*., 2009; Nuwamanya *et al*., 2019). It is easy to cultivate and tolerates poor soils, low rainfall, and high temperatures (El-Sharkawy, 2003; De Tafur *et al*., 1997). Cassava provides 50,000 kcal/ha/day, in comparison to about 20,000 to 25,000 for wheat, rice and maize (FAOSTAT, 2016; USDA, 2016). It is a good source of carbohydrates, minerals and vitamins, and leaves also provide proteins (South Pacific Trade Commission, 2000). However, cassava contains high levels of cyanogenic glycosides (α-hydroxy nitrile glucosides), a chemical compound which breaks down when chewed and digested releasing toxic cyanide (HCN) (Alves, 2002).

All parts of the plant are reported to be toxic (Montagnac *et al*., 2009) and several studies have shown that age and environmental conditions may influence the concentration of these toxins in the different parts of the cassava plant (Bokanga *et al*., 1994; Mahungu, 1994; Manano *et al*., 2017). According to Riis *et al*., (2003) and Nambisan *et al*., (2011), cyanogenic glycosides levels in roots are generally lower than that in the leaves and stems. Detoxification practices, such as soaking, drying, and scraping, are to be performed before consumption to reduce the cyanogenic glycosides content. Acute cassava-associated cyanide poisonings are rarely described, but in 2017 an outbreak of suspected cyanide poisoning was reported in Uganda, where 98 cases with two deaths, occurred in western Uganda. Laboratory investigation identified consumption of a cassava flour dish made from wild cultivars of cassava with high cyanogenic content. (Alitubeera *et al.,* 2019).

Uganda is one of the major cassava producing countries in the world and it is a food crop in several parts of this country. There exists a diversity of cassava varieties with both

sweet and bitter taste. Sweet varieties can be eaten raw, boiled, or cooked without prior processing, while bitter varieties need to be processed to reduce the risk of residual cyanogen prior to consumption (Ellen and Soselisa, 2012). Several causes are threatening cassava genetic diversity in Uganda such as diseases like cassava mosaic and cassava brown streak, that have resulted into reduced productivity and loss of varieties (Kawuki *et al.*, 2016; J Legg and Fauquet, 2004). The current global focus of breeding cassava varieties for industrial purposes further threatens the cassava genetic resources as farmers prefer to grow cassava for commercial purposes (Jansson *et al.*, 2009). In many parts of Uganda, farmers are mainly growing the improved varieties from the cassava breeding program and it is becoming difficult to find landraces (Nakabonge *et al.*, 2018). Previous studies on management and differentiation of local varieties by farmers in Uganda revealed that on-farm selection and cultivation of varieties is influenced by cultural views (Kizito *et al.*, 2007). For instance, in some cultures bitter varieties are not considered as food, whereas in other cultures in mid-northern and north-western Uganda, bitter varieties are considered to be tastier after processing (Kizito *et al.*, 2007). Nakabonge *et al* .. (2018) showed that farmers' preferences, such as culinary attributes, storability in the ground, maturity time, and cooking quality, influence the decisions taken to retain or abandon cultivation of certain varieties.

Cassava is emerging as one of the market-oriented commodities that could improve the livelihoods of smallholder farmers in Uganda. Its utilization is limited to semi-processed products through the informal sector, but through the application of existing technology the crop could be used and marketed as a raw material for agro-industrial products, such as flours for baked products, animal feeds and industrial starch. Characteristics of cassava varieties play an important role in the type of product made hence in the choice made for particular products depending on end-user needs (Chiwona-Karltun *et al.*, 2015; Manano *et al.*, 2017). Commercialization of high-value cassava products is currently occurring at a small scale, as is the case of cassava flour. Between March 2011 and March

2012, a total of 805.3 tonnes of high quality flour was sold across the following sectors: biscuits (2 tonnes), paperboard (177 tonnes), rural bakeries (275.1 tonnes) and Agri foods in form of composite flours (388.9 tonnes) (Kleih *et al* 2012). Nuwamanya *et al.* (2011), recommended understanding the different marketable products that can be gotten from tuber and root crops, cassava inclusive and Kleih *et al.* (2012), recommended the production of fact sheets regarding technical properties and specifications of different cassava varieties for the stakeholders in the private sector dealing in the improvement of the cassava value chain.

Some studies have endeavoured to address those recommendations, for example Manano *et al.* (2017), investigated the chemical composition of five major cassava varieties grown in Nebbi district (Uganda), namely: Nyamatia and Nyarukeca (local varieties) as well as NASE 3, NASE 14, and NASE 19(improved varieties), to assess their potential as industrial raw materials. The physiochemical and functional characteristics of starch from Ugandan cassava varieties (five improved varieties, four landraces and their progenies) was studied by Nuwamanya et al. (2010). However, no study has been conducted to assess both the cyanogenic glycoside and nutrient content of a diversity of cassava varieties, for the enhancement of the nutrient quality and safety of the cassava products for human nutrition and animal consumption. The objective of this study was to analyse the nutrient and biochemical composition (dry matter and cyanide content) of 16 cassava varieties, both local and improved, to understand if there are differences among the varieties. The hypothesis was that there was no significant difference in nutrients, dry matter and cyanogenic glycoside content among the sixteen varieties. The experimental design involved analysing tubers of each variety picked from farmers' fields in two locations, Nakaseke and Nakasongola districts of Uganda. The farmers were purposively selected to ensure that they had the studied varieties.

Availability and access of detailed information on nutritional and biochemical properties of different varieties would enable maximization of the nutrient value in the cassava

products and reduction of the poisoning effect by the cyanogenic glycoside thereby ensuring safety of the products to the consumers. In addition, it would increase the marketability of cassava products, enhance the production and conservation of the different cassava varieties thereby enhancing the cassava value chain.

2. Materials and Methods

2.1 Description of the sites from where the samples were collected

The samples were collected from the districts of Nakaseke ($0^0$43′29″ N, 32^0 54′04″ E) and Nakasongola ($1^0$18′32″ N, 32^0 27′23″ E) located in the Central Wooded Savanna ecological zone of Uganda. Nakaseke falls within an altitudinal range of 1086–1280 masl, mean annual rainfall of 1100 mm and temperatures ranging from 16^0 C to 30^0C. Nakasongola is within an altitudinal range of 600-1160 masl with a mean annual rainfall of 1000 mm and is characterized by prolonged droughts and floods (Nimusiima *et al*., 2013) with a mean maximum temperature of 30^0C. The two districts are largely under small scale farming with Nakaseke having a broader mixed cropping system than Nakasongola which has a more pronounced crop-livestock system. The detailed description of the sites is provided in Nankya *et al*., (2021).

2.2 Sample collection

A total of 16 varieties of cassava were collected: 14 traditional (local) varieties (Kakutakamyufu, Kakobe, Nigeria, Mukiibi, Kitikimu, Nakalalo, Kateteyi, Bao, Makanika, Njule, Solidalidad, Mbwazirume, Juguja, Mbwa) and 2 modern varieties (Nase14 and NaroCas1). Tubers were collected from 48 cassava farmers and for each variety, four tubers were collected from four different farmers in each site. The villages and farmers were purposively selected to ensure that they had the studied varieties. The tubers for each variety were clearly marked by name, kept separated and brought to the Food Bioscience and Agribusiness laboratory under the National Agricultural Research Laboratories in Kawanda, when still fresh.

2.3 Preparation of samples for chemical analysis

In the Food Bioscience and Agribusiness laboratory, the tubers of the same variety from both sites were grouped together, taking care not to mix varieties. The tubers were washed, peeled and samples extracted randomly from each heap and treated as specified in the method of analysis for each biochemical element.

2.4 **Analytical Methods**

2.4.1 Proximate Composition

The moisture content of the samples was determined using the standard Air Oven Method (AOAC,1999) Method No. 925.10 by means of a hot box oven. Protein content was determined basing on the standard Kjeldahl method No.960.52 (Khoury *et al.*, 2014) using a Kjeltec machine. Crude lipid was determined using Method No. 920.39C (Khoury *et al.*, 2014) using a soxhlet machine. Ash was determined by the direct heating method in a muffle furnace at 525^0C for 24 hours as described by Association of Analytical Chemists (2005).

2.4.2. Determination of Cyanide

Two cassava tubers were randomly taken per variety, washed, peeled and diced. The diced samples of each variety were thoroughly mixed and 100 g were extracted with about 150 mL of 0.1M orthophosphoric acid and the cyanide content analysed using the method by Cooke (1978). Extracts were filtered and volumes recorded. A mixture of 0.1 mL sample extract, 0.1 mL of linimarase and 0.4 mL of pH buffer 7 were incubated in a shaking water bath at 30^oC for 15 minutes; and 0.6 mL of 0.2M NaOH was added to stop the reaction of linimarase. The colour was developed by adding 0.2 ml of chloramin T reagent followed by pyridine/pyrazolone reagent. The sample was left to stand for 90 minutes for the colour to develop. All samples were analysed in triplicates. A series of standards ranging from 0-1.65 μg of HCN were prepared and colour developed as above. The cyanide content was determined from the standard calibration curve and computed using the formula:

mg/kg cyanide = µg/mL of cyanide x final volume (mL) x 10

Sample wt

2.4.3. Determination of carbohydrates

A 200 mg of Anthrone was dissolved in 100 mL of ice cold 95% H_2SO_4. A glucose stock solution of 100 mL was prepared by dissolving 100 mg of glucose in 100mL of water. Five drops of toluene were added and the solution kept under refrigeration.

A subsample of 100 mg cassava flour was extracted for each variety and placed into a boiling tube, hydrolysed by keeping it in boiling water bath for 3 hours with 5 mL of 2.5 N-HCl and cooled to room temperature. The sample was neutralised with solid sodium carbonate until the effervescence ceased. The volume was topped up to 100 mL and centrifuged at 1000 rpm for 5 minutes. The supernatant was collected and 0.5 ml aliquot was taken for analysis. Standards were prepared by taking 0, 0.2, 0.4, 0.6, 0.8 and 1 mL of the working standard. '0' served as blank. The volume topped up to 1 mL in all the tubes including the sample tubes by adding distilled water. After adding 4 mL of Anthrone reagent, the tubes were heated for 8 minutes in a boiling water bath. The tubes were cooled rapidly and the green to dark green colour was read at 630 nm using Biomate Spectrophotomer. A standard graph was drawn by plotting concentration of the standard on the *X*-axis versus absorbance on the *Y*-axis. From the graph the amount of carbohydrate present in the sample tube was calculated as follows:

Amount of carbohydrate present in 100 mg of the sample

= (mg of glucose ÷ Volume of test sample) X 100

a. **2.4.4. Determination starch yield**

Starch was extracted by a adapting the method described by Nuwamanya, *et al*., (2019). Two tubers per variety were randomly selected, peeled and cleaned with distilled water. The cleaned tubers were blended in distilled water (500 g of tuber in 1000 ml of water) using a blender (Waring ® Commercial Blender, HBB2WTG4, USA). The pulp was stirred for 2 min and filtered using a triple cheese cloth. The filtrate was allowed to stand until

the starch sedimented, the top liquid was decanted and discarded. The starch sediment was again washed with distilled water, and the supernatant solution discarded. The starch produced was oven-dried on aluminium pans at 60 ºC until a constant dry weight was obtained and then stored in dry plastic airtight containers at room temperature.

The starch yield was calculated as follows:

Starch yield = (WDS/WFTR) x 100

Where: WDS = weight of dried starch

WFTR = weight of fresh tuberous roots

2.4.5. Determination of dry matter content

The dry matter content was determined using the method by Uarrota *et al*. (2016). Two tubers of each variety were randomly selected, cut into 2 cm slices using a stainless-steel knife, mixed thoroughly and triplicates of 100 g samples (W1) were dried at 60°C for 48 hours in an oven drier (Leader, Leader Engineering Widnes, United Kingdom). After 48 hours sample weight was recorded and then taken dried for 2 additional hours in the oven drier until a constant weight (W2) was obtained. Percent dry matter content (DM %) was calculated as follows:

Dry matter content = $100 * (W_2/W_1)$

2.4.6. Determination of amylose content in cassava starch

For each variety, 100g of starch was transferred separately into a volumetric flask, wetted with ethanol (95%, 1 ml; VWR® Chemicals, UN1170, France) and distilled water (10 ml), followed by NaOH solution (10%, 2 ml; Lobachemie® Reagents and Fine Chemicals, 0589800500, India). The contents were heated in a water bath (Grant Instruments) at 60ºC until a clear solution was formed. The flask with its contents was cooled at room temperature and diluted to the mark (100 ml) with distilled water. A portion of distilled water (5 ml) was added and acidified slightly with HCl (6M, 3 drops; Sigma-Aldrich®, UN1789, Germany). The contents were homogenized by shaking for 5 s and Iodine

solution (10%, 5 ml) was added. Absorbance of the solution was read at 640 nm and amylose content quantified spectrophotometrically.

2.4.7. Determination of digestible starch

Distilled water (0.1 ml; blank), standard corn starch (98%; 0.1 g) and 100 g of starch for each variety were separately transferred to a clean test tube and 10% sulphuric acid (5 ml; Lobachemie® Reagents and Fine Chemicals, 1830, India) added. The test tube was placed in a water bath (Grant Instruments Ltd, TXF200, England) at 80°C for 30 min. The supernatant (0.5 ml) was transferred into a clean dry test tube as well as 5 serial dilutions for the standard solution; distilled water (1 ml), and phenol (0.5 ml, 5%; VWR® Chemicals, France) were added to the contents in the test tube and vortexed (Labonet® International, 50200, United Kingdom) for 5 s. Concentrated sulphuric acid (1 ml) was added to the contents in the test tube, shaken for 5 s, allowed to cool at room temperature for 15 min and then absorbance was recorded with a spectrophotometer (WPA Biowave II+, England) at a wavelength of 490 nm. The spectrophotometer was zeroed by reading absorbance of the blank then the absorbance of the prepared sample. The standard sample and serial dilutions of known concentrations were also measured. A graph of the data obtained from the readings obtained from the standard sample was plotted with the solution concentration on the x-axis and the absorbance on the y-axis**.** The equation of the "best-fit" straight line was determined using MS Excel© 2013. This equation gave the mathematical relationship between solute concentration and absorbance. The concentration of digestible starch in the cassava starch sample was derived as follows;

$y = 0.418x - 0.43$

Where y is the absorbance, x is the concentration

2.4.8. Determination of reducing sugar content

A tuber for each variety was selected, dried separately and converted into flour of which 500 mg for each variety was mixed with ethanol (1 ml, 95%) and distilled water (2 ml) in a centrifuge tube. Hot ethanol at 60 °C (10 ml, 95%) was added to the resultant solution,

vortexed for 5 min and centrifuged (Labofuge 400R, Thermo Electron Corporation, Germany) for 10 min. The supernatant was decanted into a volumetric flask and made up to 100 ml with distilled water. 10 ml of this solution were used for quantification of reducing sugars. The supernatant, distilled water (blank) and 0.5 ml serial dilutions of 99% glucose (standard) were pipetted into separate clean dry test tubes. Distilled water (1 ml) and 5 ml phenol (5%; UNILAB®, 1159, Ajax Finechem, Australia) were added to the contents in each of the test tubes and vortexed for 3-5 s. Concentrated sulphuric acid (1 ml) was added to the contents in the test tubes, shaken for 3-5 s and allowed to cool for 15 min and then the reduce sugar content was quantified using a spectrophotometer at a wavelength of 490 nm.

2.4.9. Mineral analysis procedure

The mqH_20 obtained from a Milli-Q Plus water purification system (Millipore, Australia), was employed to prepare all standard and sample solutions. Trace Select®, for trace analysis, ≥ 69 % (T) HNO_3 (Sigma, Australia) and EMSURE ISO-H_2O_2 30 % (Perhydrol^R) for analysis (Merck, Germany) were used for sample dissolution. Mono-elemental, high-purity grade 1000 mg L^{-1} stock 2 % HNO_3 solutions were purchased from Merck (Australia) for analysis of the following elements: Calcium (Ca), Iron (Fe), Potassium (K), Manganese (Mn), Phosphorus (P), and Zinc (Zn). The purity of the (MPAES) plasma torch argon was greater than 99.99 %.

Sample digestion was performed according to Wheal *et al*. (2011). Given weights (approx. 0.3 g) of oven dried (Gallenkamp. England) cassava milled samples from each variety were weighed by the analytical balance (Mettler Toledo, Switzerland) into 50 mL polypropylene (PP) tubes with HDPE screw caps (cat # 227261, Greiner Bio-One, Germany). Maximum sample mass did not exceed 0.35 g in order to prevent gas pressure build-up during initial heating risks rupture of the PP tubes and caused samples to dry out during digestion. Method blanks (MB) with no added plant material were also treated in the same manner. Digestion was initiated by adding 2 mL HNO_3 (Sigma, Australia)

and 0.5 mL H_2O_2 (Merck, Germany using calibrated Dispensette® bottle top dispensers. The caps were hand-tightened and the tubes vortexed (Vortex 2 genie, Scientific Industries, USA) to ensure entire sample was wetted. The samples were pre-digested overnight at room temperature (20 – 22°C). The tubes were vortexed (Vortex 2 genie, Scientific Industries, USA) again before incubation in a DigiPREP digestion block system (Perkin-Elmer, Singapore) at 80°C for 30 minutes. The pressure built up during the 30 minutes incubation was released by loosening each cap sufficiently to release pressure in the tube. The tubes were immediately retightened firmly and replaced in the digestion block. The temperature of the DigiPREP digestion block system (Perkin-Elmer, Singapore) was raised to 125^{0}C and samples were incubated for 120 minutes. The digested samples were removed from digestion block and allowed to cool to room temperature. Samples were then made up to final volume in two stages to allow for cooling of diluted acid. Initially approximately 22 mL of mqH_2O from a Dispensette® bottle-top dispenser was added. Then the remaining volume of water to make the total sample volume 25 mL was added using a fine tip HDPE wash bottle. The caps were sealed and the samples agitated by an orbital mixer (Ratek instruments, Australia) at 300 rpm for 5 min. Undissolved material (silicates) were allowed to settle for at least 60 min. Settled sample extracts were decanted into 15 mL PP tubes with HDPE screw caps (# 227261, Greiner Bio-One, Germany). Settled sample extracts were filtered into clean 15 mL PP tubes using 0.45 µm Millex® HV disposable syringe filters (Millipore®, Germany) to ensure the removal of particulates. Tubes were stored at room temperature or immediately analysed by MP-AES (Agilent, Australia).

2.5 Statistical Analysis

Data for each variety was summarised using descriptive statistics with means represented with respective standard errors . All variables were tested for normality using Shapiro-Wilk test and the strongly skewed variables were transformed prior to analysis of variance to meet the assumption of normality and homogeneity of variances.

Variables expressed as percentages (%) were arcsine-square-root (+0.5) transformed, while counts of individuals were log (log(x +1)) transformed. Where transformation were not sufficient to improve data shape, an appropriate non-parametric test was applied. The differences among varieties in nutrient content were compared using analysis of variance (ANOVA), and post-hoc means separation tested using Tukey (HSD) at 5% probability level. To assess similarity among varieties, hierarchical cluster analysis using Bray-Curtis distance measure was used to depict variety composition similarity with dendrogram and the groups of varieties within similar range were obtained using the average linkage or the unweighted pair group method using an arithmetic average (UPGMA). Principal Component Analysis with Varimax rotation and appropriate normalization was used to assess associations between macro and micro nutrient composition, among varieties. All the tests were done using R (R Development Group, 2020).

3. Results

3.1 Nutrient and biochemical content of the varieties

There were significant differences ($p \leq 0.00$) in macro compounds content among the cassava varieties except for carbohydrate, starch and amylose contents (Table 1). The dry matter content, ash, protein, fat, starch yield, reducing sugar and hydrogen cyanide content were significantly different at ($p \leq 0.00$) (Table 1). The dry matter content was highest in Mukiibi (67.59%) and lowest in Solidalidad (42.84). The ash content ranged from 1.92 - 3.53% with Solidalidad having the lowest and Bao, the highest. The protein content ranged from 0.28 - 1.11 with Mbwazirume and Kakobe varieties having the lowest while Bao had the highest content. The fat content ranged from 0.22 - 0.82% with Kakutakamyufu variety having the lowest while Nakalalo had the highest content. The starch yield was highest in Nakalalo (45.65%) with Solidalidad variety having the lowest (5.65%). The reducing sugar content ranged from 8.78% in Kakutakamyufu to 16.08 in

Nase 14 varieties. The cyanide content ranged from 17.11 mg/kg CN in Mbwazirume to 179.53 mg/kg CN in Juguja variety (Table 3).

With exception of iron and potassium, all the other minerals content was significantly different at $p \leq 0.00$ (Table 2). Phosphorus was lowest in Bao variety (323.07 ppm) and highest in Mbwazirume variety (901.11 ppm). Zinc was lowest in NASE 14 variety (3.11 ppm) and highest in Kakobe variety (20.10 ppm). Mbwazirume variety had the lowest calcium content (164.99 ppm) while Nigeria variety had the highest (653.80 ppm). Nakalalo had the lowest content of manganese (169.61) and magnesium (177.40 ppm) compared Juguja variety that had the highest content of both minerals (Mg 440.18ppm; Mn 411.86 ppm) (Table 4).

When the varieties' content of macro and micro nutrients and cyanide was ranked according to the average position (table 5); the best four varieties in macro nutrients were: Bao, Nase 14, Kitikimu and Nakalalo, respectively while the least were Solidalidad, Makanika, Mbwazirume and Kakobe. The best four in micronutrients were: Nigeria, Kakobe, Mukiibi and Kateteyi respectively while the least were Nakalalo, Nase14, Narocas and Solidalidad. The varieties with the highest cyanide content were: Juguja, Kitikimu, Nigeria and Kakutakamyufu respectively while the lowest in content were Kakobe, Mukibi, Mbwazirume and Makanika.

Table 1: Proximate macro compounds content of the root tubers of different cassava varieties

Variety	Dry matter%	% Ash	Protein%	Fat%	Cyanide (Mg CN)	Starch yield %	% Carbohydrates	% Starch content	% amylose	% reducing sugar
Nigeria	61.34±7.6ab	2.43±0.04bcd	0.41±0.0ef	0.57±0.1abc	86.80±6.3bc	27.92±0.9ab	46.95±2.8a	38.32±0.7a	29.61±5.9a	8.83±0.2cd
Kitikimu	63.35±3.4ab	3.27±0.1ab	0.85±0.0b	0.72±0.0ab	102.03±4.4b	15.52±3.0bc	52.23±0.1a	43.57±1.3a	32.73±2.2a	10.16±0.7bcd
Juguja	58.89±3.0ab	2.53±0.0bcd	0.47±0.0de	0.61±0.0abc	179.53±9.09a	14.26±1.87bc	57.74±0.4a	43.89±0.6a	34.55±1.1a	14.57±0.0ab
Mukiibi	67.59±3.7a	2.75±0.3abcd	0.32±0.0ef	0.59±0.2abc	29.27±4.1ef	12.80±0.2bc	58.53±4.2a	41.42±3.6a	38.31±6.2a	12.47±3.6abcd
Kakutakamyufu	62.39±1.1ab	2.51±0.1bcd	0.39±0.0ef	0.22±0.0c	93.07±2.5bc	24.06±1.9b	49.45±1.4a	44.91±0.7a	33.51±4.0a	8.78±0.1d
Kakobe	62.38±3.5ab	2.34±0.3cd	0.28±0.0f	0.36±0.1bc	24.34±3.8f	16.21±2.6bc	54.57±3.9a	41.25±1.4a	33.51±1.9a	12.23±2.8abcd
Kateteyi	62.83±3.8ab	2.17±0.1d	0.60±0.0cd	0.34±0.1bc	48.46±4.6def	6.50±1.8c	55.36±1.5a	43.02±1.3a	36.36±3.6a	14.29±0.3abc
Bao	65.31±2.0ab	3.52±0.0a	1.11±0.0a	0.31±0.0bc	51.48±3.8def	18.98±1.2bc	57.85±1.1a	37.66±0.6a	26.75±5.5a	14.73±0.1ab
NaroCas	51.79±0.2bc	2.83±0.0abcd	0.68±0.0bc	0.35±0.0bc	65.83±0.8cd	22.10±0.9bc	46.45±3.5a	45.54±1.6a	37.66±0.4a	14.63±0.2ab
Njule	52.39±8.4bc	2.86±0.2abc	0.63±0.1cd	0.28±0.0c	39.75±5.4def	16.78±1.4bc	44.91±1.5a	43.79±4.9a	31.95±3.0a	15.61±0.3ab
Makanika	44.63±2.3c	2.36±0.5cd	0.34±0.0ef	0.44±0.1abc	30.77±4.8ef	10.45±2.0bc	51.24±2.7a	47.02±5.4a	40.52±5.0a	14.23±0.6abcd
Nase14	52.72±0.4bc	2.60±0.0abcd	0.34±0.0ef	0.70±0.1ab	53.35±3.6de	17.10±5.6bc	54.55±0.2a	44.36±0.5a	47.53±9.9a	16.08±0.1a
Mbwazirume	43.98±2.2c	2.11±0.2d	0.28±0.0f	0.51±0.1abc	29.84±2.84ef	6.16±1.13c	54.95±9.2a	43.87±0.7a	36.49±5.1a	15.81±0.2a
Nakalalo	56.54±0.6abc	2.73±0.02abcd	0.48±0.0cde	0.82±0.0a	56.29±5.8de	45.29±0.2a	49.85±2.0a	48.24±1.1a	32.21±2.2a	14.60±0.3ab
Solidalidad	42.84±1.0c	1.92±0.1d	0.33±0.0ef	0.41±0.1abc	36.95±3.5ef	5.65±1.1c	44.29±1.43a	42.44±0.7a	34.29±0.7a	15.56±0.0ab
Pr > F(Model)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.048	0.208	0.449	<0.0001
Significant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes

Values followed by the same letters are not significantly different

Table 2: Mineral content of root tubers from the different cassava varieties

Variety	P(ppm)	Zn(ppm)	Ca(ppm)	Fe(ppm)	K(ppm)	Mn(ppm)	Mg(ppm)	Na(ppm)
Nigeria	874.25±50.2ab	19.33±1.4a	653.80±35.14a	19.26±1.6a	692.12±80.2a	323.49±95.5abc	385.43±46.6ab	6.38±0.4ab
Kitikimu	588.01±221.7abc	16.18±2.9ab	286.21±22.6bcd	14.41±2.1a	532.42±30.8a	273.78±20.3abc	301.25±30.5abc	7.87±2.5ab
Juguja	687.27±78.3abc	12.22±1.40ab	185.28±13.3cd	11.41±0.3a	929.15±80.2a	411.86±36.6a	440.18±40.4a	2.60±0.1b
Mukiibi	648.02±45.1abc	15.35±2.2ab	502.33±174.5abc	13.92±5.4a	594.73±25.3a	304.01±24.3abc	322.49±45.5abc	6.24±2.2ab
Kakutakamyufu	501.10±42.4abc	15.43±1.6ab	510.10±28.9ab	14.81±5.5a	869.51±10.7a	288.17±16.3abc	282.44±8.5abc	8.19±2.3ab
Kakobe	799.11±95.6ab	20.10±1.9a	276.62±55.6bcd	13.78±2.2a	1164.02±98.6a	319.63±27.4abc	324.77±30.1abc	12.50±4.5a
Kateteyi	559.00±53.8abc	9.12±2.4ab	309.06±56.8bcd	16.99±4.6a	487.66±62.4a	378.27±10.3ab	376.07±92.8ab	6.37±2.6ab
Bao	323.07±42.7c	12.08±0.5ab	377.96±19.8abcd	12.65±3.9a	640.84±20.4a	296.34±48.8abc	313.23±32.6abc	3.09±0.1b
NaroCas	458.28±29.6bc	4.20±1.8bc	404.88±41.5abcd	11.86±0.8a	1589.73±37.2a	204.44±16.1bc	224.48±33.2bc	2.36±0.5b
Njule	810.18±171.3ab	16.62±3.0ab	223.74±45.4bcd	10.50±1.1a	947.84±56.9a	306.46±68.0abc	302.03±59.3abc	1.96±0.4b
Makanika	677.19±250.4abc	12.11±0.7ab	224.64±20.7bcd	14.55±2.6a	987.91±68.8a	239.93±25.1abc	246.23±29.2bc	4.17±1.2b
Nase14	449.76±78.1bc	3.11±0.6bc	254.64±1.74bcd	10.53±2.1a	911.61±27.1a	205.43±30.1bc	157.02±28.4c	3.00±0.0b
Mbwazirume	901.11±61.3a	19.71±4.7a	164.99±13.2d	13.518±2.7a	1136.46±30.5a	235.30±42.0abc	222.90±39.6bc	4.67±1.1b
Nakalalo	392.73±97.6bc	7.81±0.2bc	172.43±8.1d	12.48±1.8a	495.17±79.4a	169.61±8.6c	177.40±6.9c	4.84±0.6ab
Solidalidad	548.59±22.1abc	13.09±1.40ab	242.69±9.3bcd	10.84±1.7a	721.71±37.8a	229.23±34.0abc	235.81±41.0bc	7.21±0.0ab
Pr > F(Model)	<0.0001	0.000	<0.0001	0.567	0.173	0.001	0.000	0.000
Significant	Yes	Yes	Yes	No	No	Yes	Yes	Yes

Values followed by the same letters are not significantly different

Table 3. Varieties ranked from the highest to the lowest content for macro compounds which were significantly different among varieties

Variety	Dry matter%	Variety	% Ash	Variety	Protein%	Variety	Fat%	Variety	Starch yield %	Variety	% reducing sugar	Variety	Cyanide (Mg CN)
Mukiibi	**67.59±3.7a**	**Bao**	**3.52±0.0a**	**Bao**	**1.11±0.0a**	**Nakalalo**	**0.82±0.0a**	**Nakalalo**	**45.29±0.2a**	**Nase14**	**16.08±0.1a**	**Juguja**	**179.53±9.09a**
Bao	**65.31±2.0ab**	**Kitikimu**	**3.27±0.1ab**	**Kitikimu**	**0.85±0.0b**	**Kitikimu**	**0.72±0.0ab**	**Nigeria**	**27.92±0.9ab**	**Mbwazirume**	**15.81±0.2a**	**Kitikimu**	**102.03±4.4b**
Kitikimu	**63.35±3.4ab**	**Njule**	**2.86±0.2abc**	**NaroCas**	**0.68±0.0bc**	**Nase14**	**0.70±0.1ab**	**Kakutakamyufu**	**24.06±1.9b**	**Njule**	**15.61±0.3ab**	**Kakutakamyufu**	**93.07±2.5bc**
Kateteyi	**62.83±3.8ab**	**NaroCas**	**2.83±0.0abcd**	**Njule**	**0.63±0.1cd**	**Juguja**	**0.61±0.0abc**	**NaroCas**	**22.10±0.9bc**	**Solidalidad**	**15.56±0.0ab**	**Nigeria**	**86.80±6.3bc**
Kakutakamyufu	**62.39±1.1ab**	**Mukiibi**	**2.75±0.3abcd**	**Kateteyi**	**0.60±0.0cd**	**Mukiibi**	**0.59±0.2abc**	**Bao**	**18.98±1.2bc**	**Bao**	**14.73±0.1ab**	**NaroCas**	**65.83±0.8cd**
Kakobe	**62.38±3.5ab**	**Nakalalo**	**2.73±0.02abcd**	**Nakalalo**	**0.48±0.0cde**	**Nigeria**	**0.57±0.1abc**	**Nase14**	**17.10±5.6bc**	**NaroCas**	**14.63±0.2ab**	**Nakalalo**	**56.29±5.8de**
Nigeria	**61.34±7.6ab**	**Nase14**	**2.60±0.0abcd**	**Juguja**	**0.47±0.0de**	**Mbwazirume**	**0.51±0.1abc**	**Njule**	**16.78±1.4bc**	**Nakalalo**	**14.60±0.3ab**	**Nase14**	**53.35±3.6de**
Juguja	58.89±3.0ab	Juguja	2.53±0.0bcd	Nigeria	0.41±0.0ef	Makanika	0.44±0.1abc	Kakobe	16.21±2.6bc	Juguja	14.57±0.0ab	Bao	51.48±3.8def
Nakalalo	56.54±0.6abc	Kakutakamyufu	2.51±0.1bcd	Kakutakamyufu	0.39±0.0ef	Solidalidad	0.41±0.1abc	Kitikimu	15.52±3.0bc	Kateteyi	14.29±0.3abc	Kateteyi	48.46±4.6def
Nase14	52.72±0.4bc	Nigeria	2.43±0.04bcd	Makanika	0.34±0.0ef	Kakobe	0.36±0.1bc	Juguja	14.26±1.87bc	Makanika	14.23±0.6abcd	Njule	39.75±5.4def
Njule	52.39±8.4bc	Makanika	2.36±0.5cd	Nase14	0.34±0.0ef	NaroCas	0.35±0.0bc	Mukiibi	12.80±0.2bc	Mukiibi	12.47±3.6abcd	Solidalidad	36.95±3.5ef
NaroCas	51.79±0.2bc	Kakobe	2.34±0.3cd	Solidalidad	0.33±0.0ef	Kateteyi	0.34±0.1bc	Makanika	10.45±2.0bc	Kakobe	12.23±2.8abcd	Makanika	30.77±4.8ef
Makanika	44.63±2.3c	Kateteyi	2.17±0.1d	Mukiibi	0.32±0.0ef	Bao	0.31±0.0bc	Kateteyi	6.50±1.8c	Kitikimu	10.16±0.7bcd	Mbwazirume	29.84±2.84ef
Mbwazirume	43.98±2.2c	Mbwazirume	2.11±0.2d	Kakobe	0.28±0.0f	Njule	0.28±0.0c	Mbwazirume	6.16±1.13c	Nigeria	8.83±0.2cd	Mukiibi	29.27±4.1ef
Solidalidad	42.84±1.0c	Solidalidad	1.92±0.1d	Mbwazirume	0.28±0.0f	Kakutakamyufu	0.22±0.0c	Solidalidad	5.65±1.1c	Kakutakamyufu	8.78±0.1d	Kakobe	24.34±3.8f

Table 4. Varieties ranked from the highest to the lowest content of micronutrients which were significantly different among varieties

Variety	P(ppm)	variety	Zn(ppm)	Variety	Ca(ppm)	Variety	Mn(ppm)	Variety	Mg(ppm)	variety	Na(ppm)
Mbwazirume	**901.11±61.3a**	**Kakobe**	**20.10±1.9a**	**Nigeria**	**653.80±35.14a**	**Juguja**	**411.86±36.6a**	**Juguja**	**440.18±40.4a**	**Kakobe**	**12.50±4.5a**
Nigeria	**874.25±50.2ab**	**Mbwazirume**	**19.71±4.7a**	**Kakutakamyufu**	**510.10±28.9ab**	**Kateteyi**	**378.27±10.3ab**	**Nigeria**	**385.43±46.6ab**	**Kakutakamyufu**	**8.19±2.3ab**
Njule	**810.18±171.3ab**	**Nigeria**	**19.33±1.4a**	**Mukiibi**	**502.33±174.5abc**	**Nigeria**	**323.49±95.5abc**	**Kateteyi**	**376.07±92.8ab**	**Kateteyi**	**6.37±2.6ab**
Kakobe	**799.11±95.6ab**	**Njule**	**16.62±3.0ab**	**NaroCas**	**404.88±41.5abcd**	**Kakobe**	**319.63±27.4abc**	**Kakobe**	**324.77±30.1abc**	**Kitikimu**	**7.87±2.5ab**
Juguja	**687.27±78.3abc**	**Kitikimu**	**16.18±2.9ab**	**Bao**	**377.96±19.8abcd**	**Njule**	**306.46±68.0abc**	**Mukiibi**	**322.49±45.5abc**	**Solidalidad**	**7.21±0.0ab**
Makanika	**677.19±250.4abc**	**Kakutakamyufu**	**15.43±1.6ab**	**Kateteyi**	**309.06±56.8bcd**	**Mukiibi**	**304.01±24.3abc**	**Bao**	**313.23±32.6abc**	**Nigeria**	**6.38±0.4ab**
Mukiibi	**648.02±45.1abc**	**Mukiibi**	**15.35±2.2ab**	**Kitikimu**	**286.21±22.6bcd**	**Bao**	**296.34±48.8abc**	**Njule**	**302.03±59.3abc**	**Mukiibi**	**6.24±2.2ab**
Kitikimu	588.01±221.7abc	Solidalidad	13.09±1.40ab	Kakobe	276.62±55.6bcd	Kakutakamyufu	288.17±16.3abc	Kitikimu	301.25±30.5abc	Nakalalo	4.84±0.6ab
Kateteyi	559.00±53.8abc	Juguja	12.22±1.40ab	Nase14	254.64±1.74bcd	Kitikimu	273.78±20.3abc	Kakutakamyufu	282.44±8.5abc	Mbwazirume	4.67±1.1b
Solidalidad	548.59±22.1abc	Makanika	12.11±0.7ab	Solidalidad	242.69±9.3bcd	Makanika	239.93±25.1abc	Makanika	246.23±29.2bc	Makanika	4.17±1.2b
Kakutakamyufu	501.10±42.4abc	Bao	12.08±0.5ab	Makanika	224.64±20.7bcd	Mbwazirume	235.30±42.0abc	Solidalidad	235.81±41.0bc	Bao	3.09±0.1b
NaroCas	458.28±29.6bc	Kateteyi	9.12±2.4ab	Njule	223.74±45.4bcd	Solidalidad	229.23±34.0abc	NaroCas	224.48±33.2bc	Nase14	3.00±0.0b
Nase14	449.76±78.1bc	Nakalalo	7.81±0.2bc	Juguja	185.28±13.3cd	Nase14	205.43±30.1bc	Mbwazirume	222.90±39.6bc	Juguja	2.60±0.1b
Nakalalo	392.73±97.6bc	NaroCas	4.20±1.8bc	Nakalalo	172.43±8.1d	NaroCas	204.44±16.1bc	Nakalalo	177.40±6.9c	NaroCas	2.36±0.5bc
Bao	323.07±42.7c	Nase14	3.11±0.6bc	Mbwazirume	164.99±13.2d	Nakalalo	169.61±8.6c	Nase14	157.02±28.4c	Njule	1.96±0.4bc

Table 5. Average position of each variety according to its content of the macronutrients, micronutrients and cyanide

Variety	Average position of variety according to the macronutrient and dry matter content	Variety	Average position of variety according to the micronutrient content	Variety	Cyanide (Mg CN)
Bao	4.4	Nigeria	2.8	Juguja	179.53±9.09a
Nase 14	5.4	Kakobe	4	Kitikimu	102.03±4.4b
Kitikimu	5.6	Mukiibi	5.8	Kakutakamyufu	93.07±2.5bc
Nakalalo	5.6	Kateteyi	5.8	Nigeria	86.80±6.3bc
Narocas	5.7	Kakutakamyufu	6.3	NaroCas	65.83±0.8cd
Juguja	6.4	Kitikimu	6.8	Nakalalo	56.29±5.8de
Mukiibi	6.7	Juguja	7.3	Nase14	53.35±3.6de
Njule	7.9	Njule	7.7	Bao	51.48±3.8def
Kakutakamyufu	8	Makanika	7.8	Kateteyi	48.46±4.6def
Nigeria	8.4	Mbwazirume	8.8	Njule	39.75±5.4def
Kateteyi	8.6	Bao	9.2	Solidalidad	36.95±3.5ef
Kakobe	8.9	Solidalidad	9.3	Makanika	30.77±4.8ef
Makanika	10.8	Narocas	11.7	Mbwazirume	29.84±2.84ef
Mbwazirume	11	Nase14	12.8	Mukiibi	29.27±4.1ef
Solidalidad	11.7	Nakalalo	13	Kakobe	24.34±3.8f

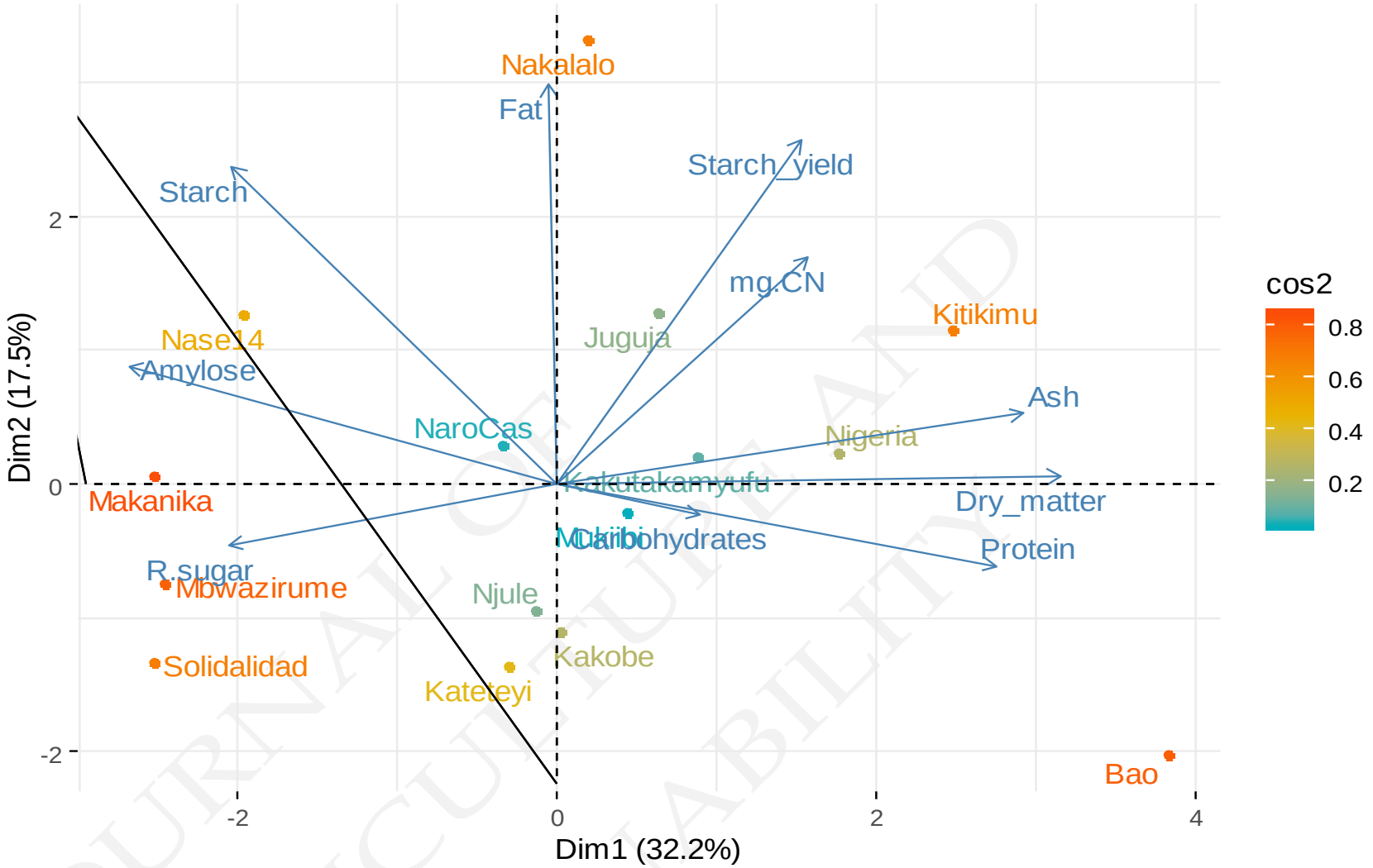

Figure 1A. 3D Biplot of the mean macro compounds content of cassava varieties derived from Principal Component Analysis

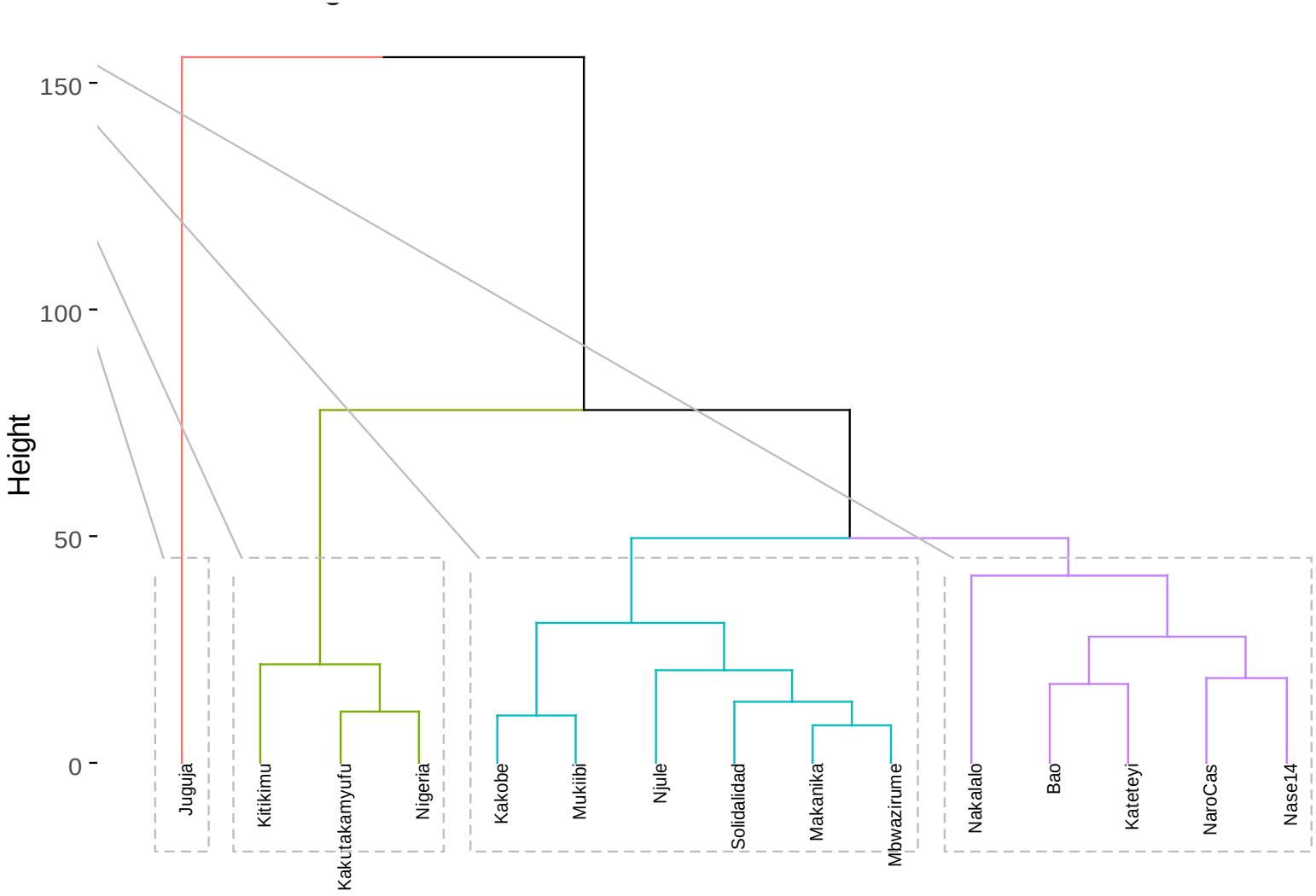

Figure 1B. Dendrogram showing the hierarchical clustering variation and the distance among clusters in multivariate data space among the cassava varieties based on the calculated Euclidean coefficients using mean macro compounds content

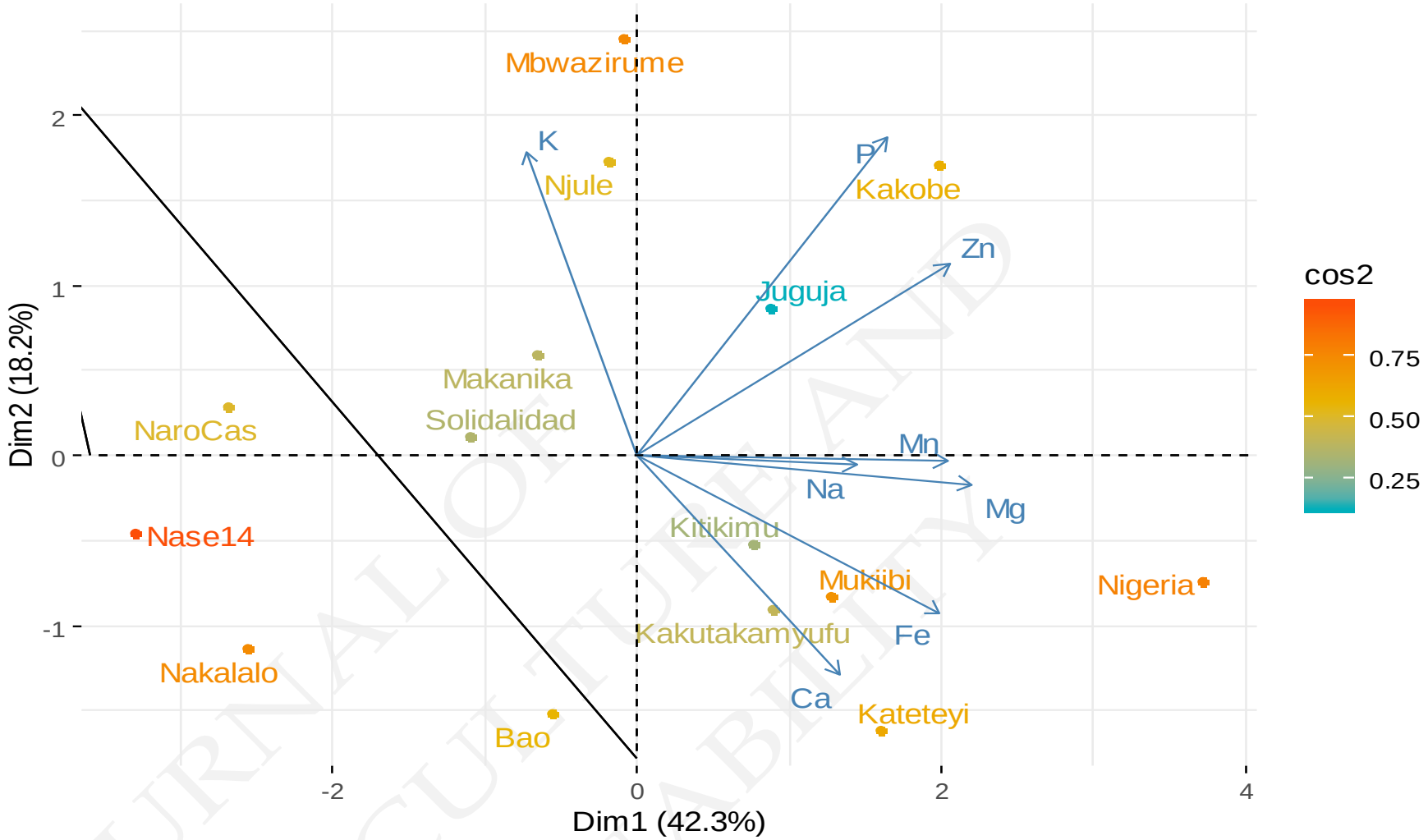

Figure 2C. 3D Biplot of the mean mineral content of the cassava varieties derived from Principal Component Analysis

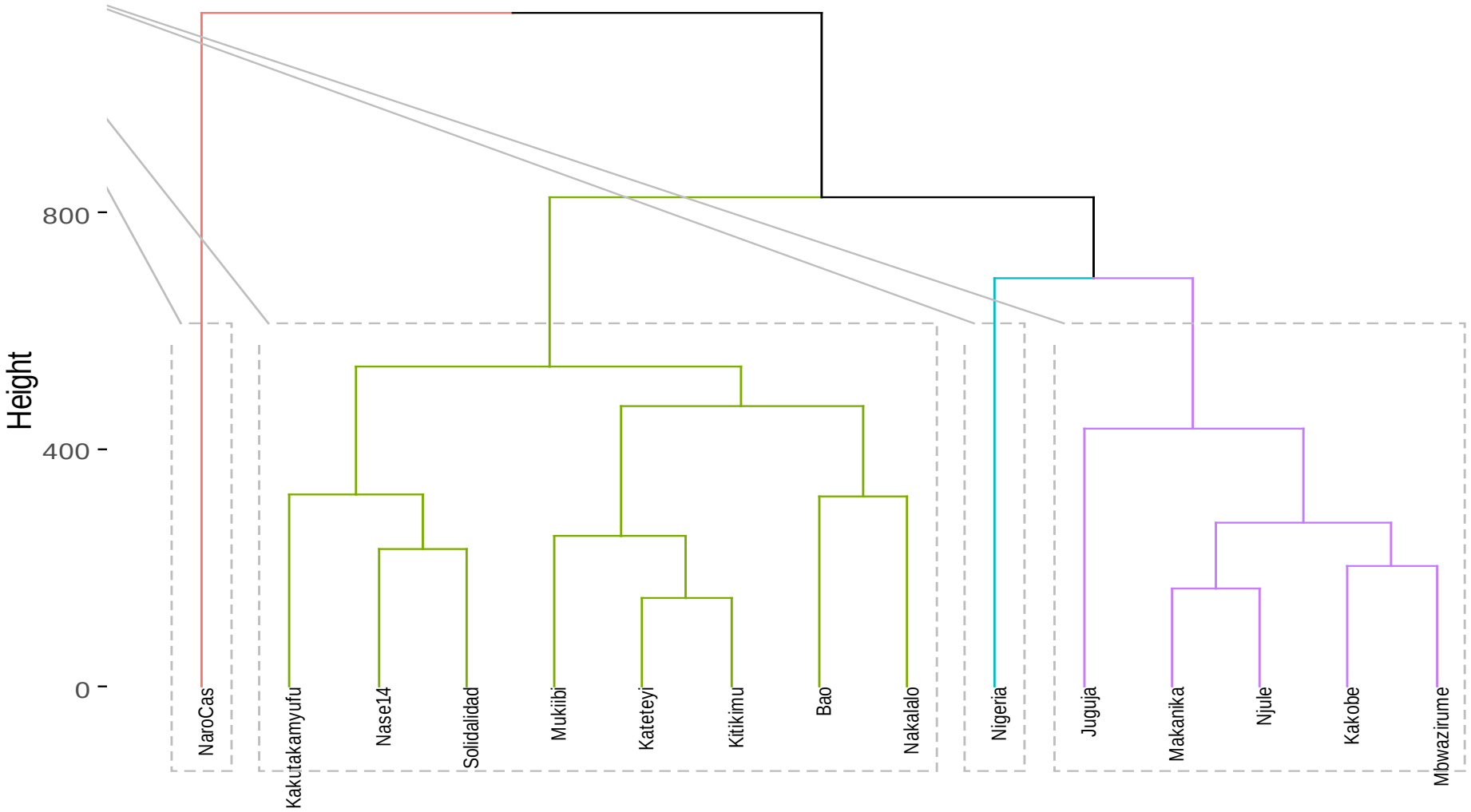

Figure 1D. Dendrogram showing the hierarchical clustering variation and the distance among clusters in multivariate data space among the cassava varieties based on the calculated Euclidean coefficients using mean minerals content

3.2 Associations between varieties and macro compounds and mineral composition

3.2.1. Correlation and clustering of varieties according to the macro compounds content (Fig.1A and Fig.1B)

The two principal components (PCs) plotted in Fig.1A accounted for 49.7% of the variability in the data with PC1 accounting for 32.2% of the variables and PC2 accounting for 17.5%. Carbohydrate, Protein, Dry matter, Ash, Cyanide and starch yield content were associated with PC1 and were positively and significantly (p=0.000) correlated with varieties: Nakalalo, Jugujja, Nigeria, Kitikimu, Kakutakamyufu, Bao, Kakobe and Mukiibi. Fat, Starch and Amylose content were associated with PC2 and positively correlated with NASE14, Narocas1 and Makanika varieties. Only reducing sugar content was associated with PC2 and negatively correlated with varieties: Njule, Solidalidad, Kateteyi and Mbwazirume.

The hierarchical clustering depicted three significantly ($p \leq 0.000$) unique clusters (Fig. 1B) with Juguja standing alone. Juguja is unique from the rest because it had the highest amount of cyanide. One cluster consisted of five varieties whereby Nase 14 was paired with Narocas; Kateteyi paired with Bao yet Nakalalo stood alone. This cluster had varieties with the highest amounts of many macro compounds; highest amount of ash, protein, second highest amount of dry matter and carbohydrates (Bao variety); highest fat, starch yield and starch content (Nakalalo variety); highest amount of amylose and reducing sugars (Nase 14 variety) and the other varieties in this cluster also had high levels of these elements yet low to medium level of cyanide. Nakalalo stood alone because it had relatively low amounts of ash, protein and dry matter compared to other members of this cluster. The other cluster was of six varieties where Mbwazirume paired with Makanika; Kakobe with Mukiibi yet Solidalidad and Njule stood alone. This cluster was characterized by the lowest content of cyanide and protein as well as medium content of dry matter, ash, starch yield and fats. Njule stood alone in this cluster because of its slightly higher content of cyanide, ash, protein, starch and fats compared to the other varieties in the group while Solidalidad stood alone because of its slightly higher starch yield, protein, ash, and dry matter

content. The third cluster was made of three varieties whereby Nigeria paired with Kakutakamyufu and Kitikimu stood alone. What makes this cluster unique is the high to medium content of dry matter, cyanide, ash, fat and starch yield but least content of protein. Kitikimu stood alone because of its medium content of protein compared to the other members of this group.

3.2.2. Correlation and clustering of varieties according to the mineral content (Fig.1C and Fig.1D)

The two principal components (PCs) plotted in Fig. 1C accounted for 60.5% of the variability in the data, PC1 accounted for 42.3% of the variables and PC2 accounted for 18.2%. phosphorus, zinc, manganese, sodium, magnesium, iron and calcium content were associated with PC1, positively and significantly ($p \leq 0.000$) correlated with varieties: Juguja, Nigeria, Kitikimu, Kakutakamyufu, Kateteyi, Kakobe and Mukiibi. Only Potassium content was associated with PC2 and positively correlated with Mbwazirume, Njule, Solidalidad, Narocas and Makanika varieties. No micronutrient content was associated with PC2 negative quadrat which had the following varieties: Nase 14, Nakalalo, and Bao.

The hierarchical clustering depicted three significantly ($p \leq 0.000$) unique clusters (Fig. 1D) and segregated Nigeria and NaroCas to stand alone. Nigeria stood alone because it is a winning variety as it was among the varieties with the highest amount of zinc, calcium; high amount of phosphorus, magnesium, sodium and high to medium content of manganese. Narocas also stood alone because it had high content of zinc, manganese, magnesium, sodium and high to medium content of calcium and phosphorus. One cluster consisted of five varieties whereby Makanika was paired with Njule because both varieties had very high to medium content of phosphorus, zinc, manganese, magnesium and high content of sodium and high to medium content of calcium. Kakobe paired with Mbwazirume because they were among those with the highest amount of zinc, phosphorus, sodium; high manganese and magnesium as well as high to medium amount of calcium. Juguja stood alone because it was among the varieties with the highest amounts of manganese and magnesium, high sodium

and zinc content as well as high to medium content of phosphorus and calcium. The other cluster was of five varieties where Nakalalo was paired with Bao; Kateteyi paired with Kitikimu and Mukiibi stood alone. This cluster was characterized by very high to medium content of phosphorus, zinc, manganese, magnesium, sodium and high to medium content of calcium. Mukiibi stood alone here because it was the only variety in this cluster that had very high to medium content of calcium. The third cluster was made of three varieties, whereby Nase14 was paired with Solidalidad while Kakutakamyufu stood alone. This group was unique because it had very high to medium content of phosphorus, zinc, manganese, magnesium, sodium and high to medium content of calcium. Kakutakamyufu stood alone here because it had very high to medium content of calcium.

4. Discussion

The following compounds were found in the root tubers of cassava varieties: dry matter, ash, protein, fat, starch yield, reducing sugar, hydrogen cyanide, amylose, starch, carbohydrates, potassium, calcium, sodium, manganese, magnesium, zinc, phosphorus and iron. This is in conformity with earlier studies that highlighted the existence of these compounds in the cassava tubers (Charles *et al.,* 2005; Sarkiyayi *et al.,* 2010; Manano *et al.,* 2017; Li *et al.,* 2017). The dry matter, ash, protein, fat, starch yield, reducing sugar and hydrogen cyanide content were significantly different among the varieties unlike the carbohydrate, starch and amylose content. With exception of iron and potassium, all the other minerals content was significantly different. The results of the current study are similar to the finding of Manano *et al.* (2017), who carried out research on 5 cassava varieties from re other parts of Uganda of which NASE14 is the only variety that was among the varieties we focused on in our study. Manano *et al.* (2017), reported a mean crude protein percentage of 1.51 for NASE 14 which is higher than 0.34 that we realized in our study and that local varieties had less protein compared to the improved varieties. In our study, crude protein content was highest in the local varieties Bao (1.11%) and Kitikimu (0.85%) and these other varieties; Njule, Nigeria, Nakalalo, Kateteyi and Kakutakamyufu had higher

protein than NASE14, the improved variety. Safo-Kantanka and Acquistucci (1995), and Baah *et al.* (2005), reported protein values of between 0.24 % and 1.0 % among cassava varieties investigated in other countries and the values we obtained in our study were within this same range although the varieties studied were also different. However, Sarkiyayi and Agar (2010), reported higher protein values (2.69 % for sweet and 3.37 % for bitter varieties) elsewhere still focusing on different varieties.

In the same way, Charles *et al*., (2005) reported higher content of carbohydrates (80.1-86.3) but lower content of ash (1.3-2.8), fat (0.1-0.8), calcium (10.9-39.9), magnesium (15.2-32.3) and phosphorus (9.3-54.1) in the varieties they studied as compared to the content of the same nutrients observed in the varieties of our study. The crude fat content obtained in this study was less in all the varieties compared with fat content (3.92% for sweet and 3.82 % for bitter cassava varieties) obtained by Sarkiyayi and Agar (2010). Safo-Kantanka and Acquistucci (1995), also reported higher lipid values of 1.5 % and 2.2 % for the cassava varieties they studied. However, the fat content range observed in our study is similar to that obtained by Manano *et al.* (2017), and Charles *et al.* (2005), in the both improved (0.35 to 0.70 %) and local (0.22 to 0.82 %) varieties (Table 1).

Starch content did not vary significantly among the varieties studied. It ranged between 37.66 - 48.24% which is lower than what has been reported by most earlier studies but higher than that reported by Nyakaisiki (2016), who reported starch content ranging from 14 to 18 %. According to Manano *et al.* (2017), the starch content varied between the improved (84.42 % for NASE 3, 75.25 % for NASE 14, and 66.72 % for NASE 19) and the local varieties (78.44 % for *Nyamatia* and 71.75 % for *Nyarukeca*) although the values were within range . Nuwamanya *et al*. (2010), also reported starch contents ranging between 70.36 and 93.85 % (dry basis) among local and improved cassava varieties grown in Uganda. Safo-Kantanka and Acquistucci (1995), reported starch contents ranging from 69 to 71 % in Ghana and Nigeria, while Baah *et al.* (2005) reported starch yields of 68.89 % and 79 % in cassava varieties in Ghana. Carbohydrate content ranges from 32% to 35% on a fresh–weight basis and 80% to 90% on a dry–

weight basis according to Charles et *al.,* 2005; Montagnac *et al.,* 2009; Sarkiyayi and Agar, 2010. Our cassava varieties recorded low carbohydrate content where the highest value was close to 60% compared to the findings of those earlier studies.

Delange *et al.* (1994), reported residual levels of cyanide in cassava after processing, and classified them according to their toxicity levels to humans as; nontoxic (less than 50 mg HCN kg^{-1} in fresh roots), moderately toxic (50-100 mg HCN kg^{-1}) and dangerously toxic (above 100 mg HCN kg^{-1} of fresh roots). The lethal dose of cyanide in humans has also been reported by Akiyama *et al.* (2006), as ranging between 50 to 300 mg kg^{-1} body weight. Most of the cassava varieties tested in our study were in the moderately toxic range with exception of Kitikimu (102.03mg/kg CN) and Juguja (179.53 mg/kg) varieties whose cyanide levels were in the dangerous range. The lowest amount was 24.34 mg/kg CN was found in Kakobe variety and non-toxic range was found also in Mukibi, Mbwazirume, Kateteyi, Njule, and Makanika local varieties was. The other varieties were in the moderately toxic to the dangerously toxic range which poses a high risk of toxicity to the consumers if care is not taken to process them in an appropriate manner to reduce the poisonous effect of the cyanide., Narocas and Nase14 the modern varieties (Tables 1, 4, 5), were in the moderately toxic range. Sarkiyayi and Agar (2010), reported much lower cyanogenic glucoside values of 4.6 mg/kg and 6.5 mg/kg for sweet and bitter cassava varieties respectively. Muyinza et al. (2016), reported cyanogenic glucoside contents ranging between 28 and 53 mg/kg and Rawel and Kroll (2003) reported a range of 6-370 mg/kg.

The most abundant mineral in all the cassava varieties studied was potassium followed by phosphorus, calcium, magnesium, manganese, zinc, iron, and sodium respectively. Potassium content ranged from 48.7mg/100g to 158.9 mg/100g. Results obtained for these varieties were generally lower than the reported 32,400−55,400 mg/100g by Charles *et al*. (2005), but higher than the values 0.25−0.36 mg/100g reported by Afoakwa *et al.* (2011). Sodium was found with values ranging from 1.25mg/ 100g ("Kakobe") to 0.19 mg/100g ("Njule"). These were, however, higher than values reported by Afoakwa *et al.* (2011) of 0.021−0.03 mg/100g and higher than the greatest

value (0.95) and within the range of means reported by the OECD from three other studies of 2009.

The dry matter content was highest in Mukiibi (67.59%) and lowest in Solidalidad (42.84%) which is higher than the range reported by Braima *et al.* (2000), of 17 -47%. According to Teye *et al*. (2011), values above 30% are considered high, this high content of dry matter in the varieties results in a high economic value not only for home consumption but also for industrial use as the amount of dry matter contained in a variety reflects the true biological yield and is directly proportional to the quantity of products that can be gotten out of it (Teye *et al*., 2011).

These differences highlighted above in the biochemical composition specifically the cyanide and dray matter content as well as the nutrient composition among the studied varieties and the differences reported by earlier studies could be attributed to the varieties studied having been different but also to the differences in geographical location and the related agro-climatic conditions as reported by Forster *et al.,* (2002); post-harvest handling (Corbishley and Miller 1984); and processing (Uchechukwu-Agua *et al.,* 2015). The chemical composition of cassava roots also differs depending on cultural practices like pruning, age and maturity of the root at harvest, storage conditions, , post-harvest practices and geographic origin (Corbishley and Miller, 1984). Several studies (FAOSTAT 2011a; Salvador *et al.* 2014) have reported that nutrition content depends on the specific part of the plant (roots or leaves), geographic location, variety, age of the plant and environment conditions.

Conclusion

The potential of cassava as a raw material for agro-industrial products has not been fully exploited and the findings from this study can form a strong basis for maximizing the use of the studied varieties for different products depending on their unique nutritional and cyanide content. Equally important is the need to do further studies in this regard to better understand the characteristics of all the cassava diversity and possibly generate a database as a reference for further development of the cassava value chain. The diversity of products that can be produced from cassava is equally remarkable, notably flours for baked products,

animal feeds and starch; fermented and unfermented products including cassava bread, fermented cassava flour, fermented starch, whereas the unfermented products include tapioca, cassava chips and pellets, unfermented cassava flour and starch (Manano *et al*., 2017). New food uses of cassava include gluten free flour or gluten-reduced products (e.g., bread, biscuits) (Falade and Akingbala 2010). The list could be endless due to the current advancement in technology. This study certainly represents another step in the right direction as better understanding of the nutritional and biochemical composition differences among varieties will improve the safety of consumers and enhance the use of cassava diversity in the food industry. The conservation of this diversity cannot be overlooked as it is key to the continued availability of diverse varieties for diverse products.

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