AIMS Agriculture and Food

AIMS Agriculture and Food, 4(4): 869–891.
DOI: 10.3934/agrfood.2019.4.869
Received: 30 July 2019
Accepted: 01 October 2019
Published: 22 October 2019

http://www.aimspress.com/journal/agriculture

Research article

Proximate composition, cyanide contents, and particle size distribution of cassava flour from cassava varieties in Zambia

Shadrack Mubanga Chisenga[1,*], Tilahun Seyoum Workneh[1], Geremew Bultosa[2] and Mark Laing[3]

[1] Department of Bioresources Engineering, University of KwaZulu-Natal, Private Bag X01 Scottsville, Pietermaritzburg, KZN, South Africa
[2] Department of Food Science and Technology, Botswana University of Agriculture and Natural Resources, Private Bag 0027, Gaborone, Botswana
[3] Africa Centre for Crop Improvement, University of KwaZulu-Natal, Private Bag X01 Scottsville, Pietermaritzburg 3209, KZN, South Africa

* **Correspondence:** Email: 216075862@stu.ukzn.ac.za; Tel: +27332606140; Fax: +27332605818.

Abstract: The utilisation of cassava in the food industry is on the rise in Africa. However, information about the quality traits of raw material derived from new cassava varieties is limited. Cassava flours processed from six cassava varieties (*Bangweulu, Katobamputa, Mweru, Kariba, Kampolombo* and *Chila*) were assessed for particle size distribution, dry matter, starch yields; proximate contents, cyanides and whiteness index. The variety effect was analysed. The moisture, protein, lipid, ash, and fibre contents were in the range 10.43–11.18, 1.21–1.87, 0.15–0.63, 1.21–1.78, and 0.03–0.60%, respectively. The average particle size distribution at D90 (250.44–334.34 μm) and D10 (35.56–48.52 μm) varied ($p < 0.05$) among varieties. The bulk and packed density ranged 0.40–0.47 and 0.62–0.67 g/cm^3, respectively. Bulk density correlated positively ($p < 0.05$) with moisture content. The cassava root dry matter contents varied in the range 40.04–47.25%, and correlated negatively with lipid ($p < 0.01$), ash content ($p < 0.05$) and positively with fibre ($p < 0.01$). Starch yield ranged between 20.76 and 28.31%. The cassava cyanide contents were in the range 23.60–238.12 and 8.62–15.48 mg HCN/kg for roots and flours, respectively. The cyanide reduction was in the range 60.76–93.86%. Degrees of lightness (L*) were in the range between 93.65 and 94.55, yellowness (b*) 6.52–8.15 with greenness in the range −0.03 to 0.44. The whiteness index of flours was in the range 89.90 to 91.46. Whiteness index negatively correlated with fibre content ($p < 0.01$). The quality traits varied among the cassava varieties, and source of variations were due to differences in flour particle size, fibre and ash contents.

Keywords: colour; cyanides; dry matter; particle size; proximate; starch yield

1. Introduction

Cassava (*Manihot esculenta* Crantz), is cultivated for edible leaves and root, and grows in tropical and subtropical regions and is known by different names in different parts of the world. It is called *yucca* or *manioc* in Spanish and Latin America, *mandioca* in Portuguese, and *tapioca* in French [1]. Cassava is one of the staple foods of many, predominantly poor, communities in Sub-Saharan Africa, Latin-America, and Asia. In Zambia, it is a prominent source of dietary calories to the 30 percent of the population ranking second after maize on the national food basket and is cultivated among the poor resource households in the rural areas mainly Luapula, Northern, part of Central and Western provinces. Commercially, cassava flour is used as inclusion ingredient in the bakery and brewing industry. Nevertheless, the application is largely dependent on the suitability of cassava varieties for processing. Proximate, dry matter, starch yield and cyanide contents are some of the primary quality indicators for the selection of raw materials in the food industry. Particle size measurement is a quality technique for characterizing the distribution of particles in flours and can be the basis for investigating the physicochemical properties of cassava derived flours and starches.

The factors affecting chemical composition include cultivar, the geographical location, maturity stage of the plant, and environmental conditions [2,3]. The dry matter, lipids, proteins, and fibre contents in cassava roots have been reported. Cassava is rich in carbohydrates and deficient in proteins and fats. On a dry matter basis, cassava root has carbohydrate content of 70–82%, which is predominantly starch containing amylopectin and amylose polymers [4,5]. The functionality of flours may vary due to chemical composition of flours. Protein and lipid may affect rate of hydration [6]. Fresh cassava root is highly perishable due to high moisture content, 33–72% moisture [3,7] and has short postharvest life of less than 72 hours. Thus, immediately after harvest, cassava is transformed into shelf-stable primary products such as flour, chips and pellets. Processing fresh cassava roots into flour reduces cyanide contents.

Cyanide glucosides content is a limiting quality trait for both human and animal consumption of cassava roots and their derived products [8]. Consumption of high dietary cyanogens causes Konzo, a permanent and clinically upper motor neurone disease. The groups at risk include children and women of child-bearing age. Furthermore, cassava dietary toxicity has been reported to cause tropical ataxic neuropathy in the elderly, a progressive myeloneuropathy that was first described in Nigeria and is characterized by a progressive onset of ataxia [9]. Primary processing techniques have been developed with a common goal of reducing cyanides to safe levels in shelf-stable products such as cassava flour, chips, and starch [10]. The high cyanide cassava roots have been reported, 1090–1550 mg HCN/kg [10,11]. Cyanide content is used as criteria for selecting cassava varieties and their flour for use in the breeding programs and food industry [12,13].

Particle characterization of powder materials is a requirement for food product development and product specification applications. The particle size distribution of flours may have a significant effect on the final product performance on content uniformity, dissolution, and stability. Foods are commonly in the form of fine particles during processing and marketing [14]. The physical properties such as bulk density, compressibility, and flowability of a food powder are highly dependent on particle size and size distribution. In product manufacturing, particle size distribution can influence processes such as mixing, granulation, drying, milling, and blending, which ultimately impact the quality of the final product [14]. For quality control and system property specifications, particle diameters of flours are described using appropriate procedures such sieving and laser diffraction [15] and are often used in the classification of flour materials to obtain cumulative particle size distribution [16]. The use of cassava flours in various food industry applications would require that particle size distribution is specified to ascertain sifting size aperture.

Variety plays a very important role in the production of diversified food products due to inherent characteristics which vary from one cassava to the other. Such characteristics include proximate composition (proteins, lipids, fibre, ash, and moisture), starch yields and dry matter contents. Physical properties such as particle size, colour, and bulk density of derived cassava flour would require specifying to enhance selection for product formulation and development. Nevertheless, there is limited information on chemical composition and particle size of cassava flours of the released (improved) cassava varieties in Zambia. In view of this, the aim of this study was to evaluate the proximate composition, cyanides and particle size distribution of six different cassava varieties, five improved varieties (*Bangweulu, Mweru, Kariba, Kampolombo* and *Chila)* and one indigenous variety (*Katobamputa*) commonly cultivated in Zambia. Table 1 shows the agronomic characteristics of cassava varieties released in Zambia.

2. Materials and methods

2.1. Source of materials

Six cassava varieties were planted at Mansa Root and Tuber Research Station, a branch of Zambian Agriculture Research Station (ZARI), Mansa District, Luapula Province, Zambia. The station is located 29 °00’E, 11 °30’E, and elevation of about 1200 m. The region receives rainfall (1000 and 1500 mm per year) and has mean annual minimum temperature 10 °C and maximum temperature 31 °C. The six cassava varieties (*Bangweulu, Katobamputa, Mweru, Kariba, Kampolombo* and *Chila)* were planted in a completely randomized block design in triplicates on a plots of 5 m × 5 m with plant spacing of 1 m × 1 m in January 2016. Root of each of five cassava plants that were randomly selected from each block were harvested after 18 months of planting (July 2017).

2.2. Native starch isolation and starch yield

The extraction of starch was conducted using the method of Numfor and Walter [17]. The cassava roots were brought to the laboratory for analysis immediately after harvest. The fresh cassava roots were washed, peeled, chopped into small pieces and then pulverising in a blender (Marlex, Ecella model, Kanchan International Limited, Daman, India). The pulp was suspended in potable water in the ration 1:10 (the volume of water 10x the volume of pulp), and the well-stirred mixture was filtered using double cheesecloth. The collected filtrate was allowed to sediment, and after decanting of the supernatant, the sediment was washed six times. The resultant starch was washed using distilled water, and after decanting, the starch was oven-dried at less than 40 °C for 12 h. Starch yield was determined based on 400 g of peeled and blended cassava.

Table 1. Selected agronomic characteristics of some cassava released varieties in Zambia.

	Variety					
Trait	*Kariba*	*Bangweulu*	*Katobamputa*	*Chila*	*Mweru*	*Kampolombo*
Tip colour	Purplish green	Purple	Light purple	Light green	Light green	Light purple
Petiole colour	Green	Purple	Red	Light green	Green purple	Light green
Old leaf colour	Green	Dark green	Green	Light green	Light green	Green
Leaf shape	Lanceolate	Spear shape	Lanceolate	Broad	Lanceolate	Lanceolate
Number of lobes per leaf		5	7	5	7	5
Stem colour	Grey	Grey	Silvery green	Light green	Grey	Reddish brown
Outer root skin colour	Light Brownn	Greyish	Cream	Cream	Brown	Brown
Inner skin colour	White	White	White	White	Cream	Pink
Flesh colour	White	White	White	White	White	White
Root shape	Cylindrical	Oblong	Conical/Cylindrical	Long	Fusiform/Long	Cynical-cylindrical
Plant architecture	Semi-branching	Semi-branching	Branching	Semi-branched	Un-branched	Highly branched
Taste	Sweet	Bitter	Flat	Bitter	Sweet	Sweet
Flowering ability	Good	Poor	flowering	Flowering	Non flowering	Flowering
Plant height at maturity	3–4 m	2–3 m	1–2 m	2–3 m	1–6 m	2–3 m
Maturity	16 months	12–16 months	16–24 months	16 months	16 months	16 months
Yield (t/ha)	34–16	31–16	29–24	35–24	41–24	38–24
Reaction to pests/diseases	Tolerant	Moderately resistant	Moderately susceptible	Moderately tolerant	Tolerant	Moderately tolerant
Root dry matter (%)	41	39	41	41	42	40
Year Released	2003	1993	Indigenous (local)	2003	2003	2003

Note: Source: Mansa Root and Tuber Research Station, Zambia Agriculture Research Institute (ZARI).

2.3. Production of cassava flour

The cassava roots were processed into flour using the method of Eriksson et al. [18]. The fresh cassava roots were peeled, washed, grated, dewatered and then sun-dried followed by oven drying at about 45 ℃ for 12 h. The dried grits were milled using a hammer mill (Brook Crompton Series 2000, England).

2.4. Dry matter content

The dry matter content was determined as described in [19]. A 200 ± 05 g fresh peeled cassava tubers from undamaged roots selected randomly from 3 plants after medial sections were chipped into strips and mixed thoroughly were dried at 65 ℃ until it attains constant weight (about for 72 h) in triplicates. The dry matter content was estimated as the difference between the mass before drying and the mass loss on drying.

2.5. Moisture content

The moisture content of the dried flour sample was determined in a triplicate according to AOAC (2012) method 925.10 by drying of about 3.0 g sample at 105 ℃ overnight.

2.6. Ash content

The flour ash content was determined according to AOAC [20] method 923.03 by taking about 3.0 g sample after carbonization and ignition at 500 ℃ for 6 h in the muffle furnace (J M Ney furnace, model 2-525).

2.7. Determination of crude protein content

The crude protein content was determined as described in Nuwamanya et al. [20] using Dumas combustion method of nitrogen content analysis (Leco Truspec Model FP-528, St Joseph Mi, USA) by taking about 0.3 g of sample and using the conversion factor % protein = % N × 6.25.

2.8. Determination of crude lipid content

The crude lipid was determined using a standard method 920.39 of AOAC [21]. About 0.5 g of the sample was extracted using petroleum ether in Soxhlet extraction unit (Soxhlet, BÜCHI 810, Switzerland).

2.9. Determination of crude fibre content

The crude fibre content was determined using the method 962.09 of AOAC [21]. About 0.5 g of was boiled in 50 mL of 0.3 M H_2SO_4 under reflux for 30 min, followed by filtering through 75 μm sieve under suction pressure. The residue was washed with distilled water to remove the acid. The residue was then boiled in 100 mL, 0.25 M of sodium hydroxide under reflux for 30 min and filtered under suction. The insoluble was washed with hot distilled water to free the alkaline. The insoluble was dried to the constant weight in the oven at 100 °C, 2 h, then cooled in the desiccator. The dried sample was ashed in a muffle furnace to subtract the mass of ash from fibre after then the % of fibre was determined.

2.10. *Determination of cyanides content*

Cyanogenic potentials of cassava root and flour samples were determined as described in Orjiekwe et al. [22]. The standard curve for cyanide assay was drawn using standard stock of potassium cyanide (0.2%). From this stock solution, varying concentrations (1 to 10 ppm) was prepared. The potassium cyanide solutions in glass bottles were subsequently acidified with 20% hydrochloric acid solution in ratio 1:1 to release the free cyanide and immediately sealed with 3 picrate impregnated filter paper strips. The resulting solution was incubated in a water bath at 95 °C for 5 min and was subsequently removed from bath and kept on the laboratory at room temperature for 24 h. The red coloured picrate paper strips from each glass bottle were removed and rinsed in 5 mL of 50% ethanol solution and kept for 30 min. The absorbance of the solution was measured using a spectrophotometer at 490 nm wavelength against a similarly prepared blank developed without potassium cyanide solution. The standard curve, $y = 0.0098x + 0.00303$ ($R^2 = 0.849$) where y = absorbance and x = concentration of sample, was subsequently used for evaluation of cyanide concentration in the test samples.

2.11. *Whiteness of flours*

The whiteness of flours was analysed using a HunterLab ColourFlex instrument (Hunter Associate Laboratories Inc, Reston, CA, USA). The colour of flours regarding L^*, a^* and b^* were measured after being standardized using Hunter Lab Colour standards and their Hunter 'L' (degree of lightness), 'a' (redness to greenness) and 'b' (yellowness to blueness). The whiteness index was calculated as described by Zhu et al. [23] using the equation:

$$\text{Whiteness index} = 100 - [(100 - L)^2 + a^2 + b^2]^{\frac{1}{2}} \tag{1}$$

2.12. *Fractionation of cassava flours based on particle size*

Flour particle size distribution test was determined as described in Sonaye and Baxi [24] by sieving 250 g of sample for 5 min using seven sieves with opening dimensions of 425, 300, 180, 150, 106, 90 and 38 µm. The sieves were serially stacked in the descending order with the receiver pan at the base. The sample was loaded on the largest sieve on top and covered. The column was placed on the vibratory mechanical shaker (DuraTap, Model DT168, Advantech Mfg. Co., New Berlin). After shaking was completed the sample on each sieve was weighted. The weight of the materials on each sieve was then divided by sample weight to obtain percentage retained on each sieve. The next step was then to find the cumulative percent of the retained in each sieve. The cumulative percent passing was calculated by subtracting the percent cumulative retained from 100%.

$$\text{Retained (\%)} = \frac{W_{\text{sieve}}}{W_{\text{sample}}} \tag{2}$$

$$\text{Cumulative (\%)} = 100 - \text{\%Cumulative Retained} \tag{3}$$

where W_{sieve} is the weight of fraction retained on the sieve, and W_{sample} is weight of sample. The percent passing (finer than size) was plotted as the function of sieve sizes. The limits of D10, D30, D60 and D10, D50 and D90 were selected as they are commonly used in classification of powder materials. These parameters refer to the percentages cumulative size distribution of passing particles finer than the particular sieve size. D10, D30, D50, D60 and D90 is defined as the size value corresponding to cumulative size distribution at 10%, 30%, 50%, 60% of 90% by weight, which represents the size of particles below which 10%, 30%, 50%, 60% of 90% of the sample lies.

2.13. Data analysis

The experiment was conducted in a completely randomized design of one factor (variety). A triplicate data were analysed using one-way ANOVA by using GenStat 18th Edition software. The mean differences were determined using Fisher's Least Significance Difference (LSD) test at the 5% significant level. Correlation coefficients were analyzed by using Pearson's correlation test.

3. Results and discussion

3.1. Particle size distribution

Table 2 shows results for percentage cumulative particle passing (finer than size). Table 3 shows results for particle size distribution at selected percentage cumulative of particles passing finer than sieve size. The percentage of flour particles passing through 38, 90, 106, 150, 180, 300, and 425 µm standard sieves were in the ranges 6.47–11.77, 17.13–49.53, 20.51–61.69, 68.21–78.96, 77.03–82.05, 88.22–93.15, and 94.64–95.85%, respectively, and significantly varied ($p < 0.05$) among varieties across all sieve sizes. This suggests that cassava flours were a mixture of various particle sizes. The flour particle size distribution between 90 and 10% cumulative of particles passing finer than sieve were estimated from the particle distribution curve (Figure 1). The average particle sizes of flours at D90, D60, D50, D30, and D10 were in the ranges 250.44–334.34, 103.76–142.42, 90.59–133.19, 63.09–114.75 and 35.56–48.52 µm, respectively, and varied ($p < 0.05$) among the varieties. *Kampolombo* had the largest particles size recorded across the distribution levels except at D10 and exhibited smaller amount of flour passing at all sieve sizes except at lowest aperture sieve (38 µm). The flour particle size can significantly affect the behaviour of starch suspension (starch in excess water) in function of heat. Ahmed et al. [25] reported that the onset gelatinisation temperatures of quinoa flours decreased from 72.9 to 60.8 °C with decrease in particle size, suggesting that the smaller flour particle exhibited lower gelatinisation temperatures. The particle size of flours affects the rate of water absorption during processing as fine particles resulted in faster absorption of water [26]. Lazaridou et al. [27] reported that coarse flour doughs exhibited increased stiffness and resistance to deformation and flow. A related study on rice reported that coarse particles had lower solubility compared with fine and medium particles, and large particle size retarded digestion [28]. The selection of sieve size would depend on the end-use of flours and nature of food system. The reduced digestibility in large particle could be suggested for application in formulation of starch resistant products. Etuk and Akpan [29], reported that extract yield increased with decrease in proportional of coarse particle and increased fineness of sorghum grit. The reduced particle size of cassava flours from 16.30 to 5.60 µm resulted in decreased peak, hot paste and final viscosities [30].

3.2. Bulk density

The bulk density ranged between 0.40 and 0.47 g/cm^3 (Table 4) and differed significantly among the varieties ($p < 0.05$). The highest bulk density was recorded in *Mweru* and lowest in *Chila*. The bulk density positively correlated with protein (r = 0.31, $p < 0.01$), and lipid (r = 0.42, $p < 0.01$) and negatively with fibre (r = −0.17, $p < 0.001$). Lower protein and lipid contents were characterized with lower bulk densities as exhibited in *Chila*. Similar was observed by Oladunmoye et al. [31], who attributed the lowest bulk density in cassava flour to lower protein and fat content of cassava flour. Eleazu et al. [32] reported bulk density of cassava flour in the range 0.59–0.68 g/cm^3 lower than 0.77 g/cm^3 in wheat flour. This is justified as wheat flour has higher protein than cassava flour. Higher bulk density had lower fibre content as exhibited in *Mweru*, which justifies the negative correlation. Reduced fibre content resulted in finer flour particle size which supports the negative correlations with particle size at all levels of cumulative particle distribution. The positive correlation with moisture content (r = 0.56, $p < 0.05$) suggests that bulk density increases with moisture content. Similar was reported in a related study on roasted Bengal gram flour, where moisture content increased with bulk density [33]. The negative correlation between bulk density and particle size (D90) (r = −0.71, $p < 0.05$) suggests that lower particle size had higher bulk density as shown in *Mweru* which recorded lowest particle size (250.43 µm) and highest bulk density. The bulk density values can find use in packaging, handling, and processing requirements. Instant products require reduced bulk densities [34].

3.3. Packed density

The packed density were in the range 0.62–0.67 g/cm^3, and varied ($p < 0.05$) among the varieties. Packed is the maximum packing density of powder (or blend of powders) achieved under the influence of well defined, externally applied forces. The packed densities were higher than bulk densities. This variation could be due to factors such as geometry, size, solid density and surface properties of the flour materials and could be improved when the particles are small, compactible, properly tapped/vibrated and with a suitable packaging material [35]. Bulk density influences flowability of flours, package design and can be used in determining the requirements of packaging material [36]. It follows that the higher the bulk density, the denser the packaging material required. *Mweru* exhibited both the highest bulk and packed densities. The increase in bulk density is desirable as it offers greater packaging advantage as a greater quantity may be packed within a constant unit volume [37].

Table 2. Percentage cumulative particle passing (finer than size) of cassava flours from six varieties grown in Zambia.

Variety	Cumulative particle passing finer than sieve size (µm)						
	38	90	106	150	180	300	425
Bangweulu	9.17(0.10)^{d}	34.76(0.06)^{n}	45.58(0.07)^{o}	67.64(0.15)^{r}	74.87(0.15)^{u}	89.19(0.24)^{E}	95.24(0.39)J
Katobamputa	11.77(0.00)^{f}	49.53(0.03)^{p}	61.69(0.01)^{q}	77.63(0.05)^{w}	81.81(0.01)^{z}	91.30(010)^{F}	95.67(0.15)^{K}
Mweru	9.51(0.01)^{e}	33.74(0.04)^{l}	49.46(0.05)^{p}	78.96(0.05)^{y}	85.53(0.02)^{B}	93.15(0.04)^{H}	96.79(0.01)^{M}
Kariba	6.47(0.01)^{a}	28.43(0.00)^{k}	34.46(0.05)^{m}	72.96(0.005)^{t}	77.03(0.01)^{v}	88.41(0.01)^{D}	94.51(0.01)^{I}
Kampolombo	8.46(0.00)^{c}	18.66(0.00)^{h}	20.51(0.00)^{i}	68.21(0.00)^{s}	74.76(0.00)^{u}	88.22(0.00)^{C}	94.64(0.03)^{I}
Chila	8.19(0.00)^{b}	17.13(0.00)^{g}	22.42(0.01)^{j}	78.46(0.04)^{x}	82.05(0.00)^{A}	91.73(0.00)^{G}	95.85(0.00)^{L}
Significance level							
Variety	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$

All values are means of three replications. Within the same column, the values with different letters are significantly different at $p < 0.05$ by LSD test.

Table 3. Particle size (µm) distribution at selected percentage cumulative of particles passing finer than sieve size.

Variety	D90	D60	D50	D30	D10
Bangweulu	312.00(0.00) ^{A}	134.80(0.01)^{o}	114.71(0.01) ^{n}	80.29(0.01)^{h}	39.78(0.01)^{c}
Katobamputa	282.53(0.03) ^{z}	103.76(0.01)^{l}	90.59(0.01) ^{j}	63.09(0.01)^{g}	35.56(0.01)^{a}
Mweru	250.43(0.03) ^{x}	121.69(0.01)^{p}	123.71(0.01)^{q}	81.92(0.02)^{i}	39.02(0.00)^{b}
Kariba	332.52(0.02) ^{B}	135.17(0.03)^{u}	123.72(0.03) ^{q}	94.12(0.01)^{k}	46.35(0.00)^{e}
Kampolombo	334.43(0.01)^{C}	142.42(0.01)^{w}	133.19(0.01) ^{s}	114.75(0.01)^{o}	45.82(0.00)^{d}
Chila	278.49(0.00) ^{y}	135.48(0.00)^{v}	127.64(0.00) ^{r}	111.94(0.03)^{m}	48.52(0.00)^{f}
Significance level					
Variety	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$

Note: All values are means of three replications. Within the same column, the values with different letters are significantly different at $p < 0.05$ by LSD test.

3.4. Root dry matter contents

The dry matter contents ranged between 40.04 and 47.25%, (Table 5) and varied ($p < 0.05$) among varieties with the highest recorded in *Bangweulu* and lowest in *Kariba*. The indigenous variety *Katobamputa* did not differ significantly ($p > 0.05$) from the improved varieties of *Mweru, Kariba,* and *Chila*. The dry matter content is a basis of accepting raw materials in the industry. Dry matter contents in cassava roots varied among the accessions and were in the average range of between 20 and 47% [38]. The dry matter contents above 30% are considered to be high. Teye et al. [38] reported the dry matter content in the range 31.45–40.74% for cassava root harvested at 13 months after planting, which are relatively lower than the values in the current study for cassava roots harvested 18 months after planting. The differences in dry matter content could be due to variations in nutrients as dry matter correlated negatively with lipid ($r = -0.39$, $p < 0.01$) and positively with fibre ($r = 0.40$, $p < 0.01$). This was shown in *Bangweulu* which exhibited highest dry matter with highest fibre content. Beyene et al. [39] reported that bio-fortification of nutrients in cassava reduced dry matter contents. The factors influencing dry matter contents include harvest age, seasons and growing locations [40].

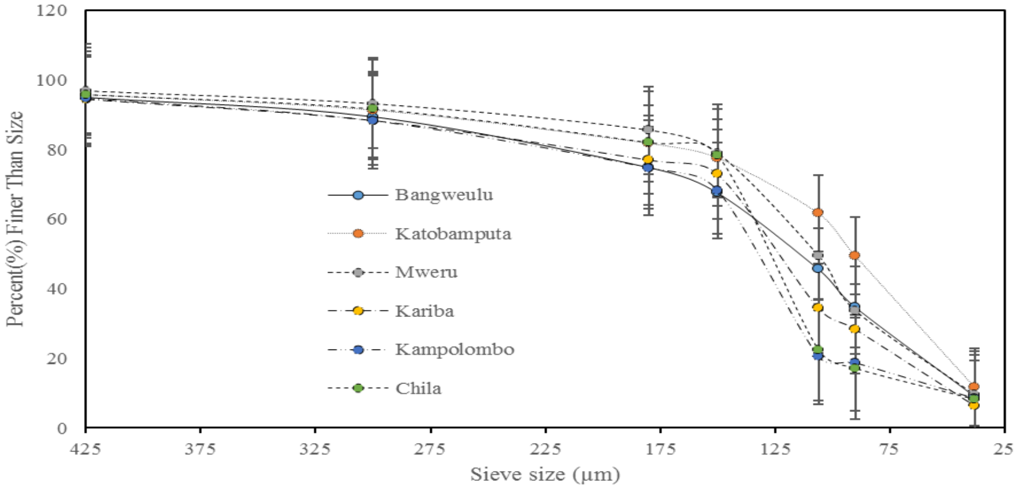

Figure 1. Particle size distribution curves for cassava flours from six different varieties at selected percentage cumulative of particles passing finer than sieve size.

Table 4. Bulk and packed density of cassava flours from six different varieties.

	Bulk Density	Packed Density
Bangweulu	0.42(0.004)^{b}	0.66(0.007)^{bc}
Katobamputa	0.47(0.003)^{d}	0.64(0.003)^{b}
Mweru	0.56(0.003)^{e}	0.67(0.009)^{d}
Kariba	0.41(0.004)^{a}	0.62(0.009)^{a}
Kampolombo	0.43(0.002)^{c}	0.67(0.009)^{d}
Chila	0.40(0.002)^{a}	0.66(0.007)^{c}
Significance level		
Variety	$p < 0.05$	$p < 0.05$

Note: All values are means of three replications. Within the same column, the values with different letters are significantly different at $p < 0.05$ by LSD test.

3.5. Starch yield expressed as fresh weight of cassava

The starch extraction yield expressed as a percentage of isolated starch to the fresh weight of peeled cassava was in the range of 20.76 to 28.31% (Table 5). *Kariba* had lowest starch yield and significantly different ($p < 0.05$) from the other five varieties, and the highest starch yield was recovered from *Chila*. Starch is the main constituent of cassava, and a similar wide range of starch yields have been reported based on wet weight, 20.7–27.8% [41]. Various factors affecting starch yield have been reported. Genotype was reported to have a huge influence on starch yield [19]. Starch yield showed a weak positive correlation with dry matter ($r = 0.07$, $p \leq 0.0001$). Lowest starch yields (20.76 ± 0.59) were recovered from *Kariba* which had lowest dry matter contents (40.04 ± 1.62). Hence supporting the conclusion of Pérez et al. [42] who reported that starch content is dry matter dependent since high dry matter in the cassava tubers is correlated with high starch contents. The industry is focused on high starch yielding cultivars, and thus dry matter content is the basis of selecting cassava on a variety basis.

3.6. Moisture content

The moisture content ranged between 10.43 and 11.76% (Table 5), and varied ($p < 0.05$) among the varieties. The local variety was not significantly different from the improved varieties. Manano et al. [43] reported moisture contents of cassava varieties in Uganda in the average range 5.43–10.87%. The differences in moisture contents could be attributed to differences in chemical constituents. Moisture correlated positively with protein ($r = 0.36$, $p < 0.01$), lipid ($r = 0.45$, $p < 0.05$), and negatively with fibre contents ($r = -0.32$, $p < 0.01$). This suggests that high lipid and possibly protein contents can contribute to higher moisture contents. The inverse relationship between moisture and fibre implies that increased fibre contents depletes lipids ($r = -0.13$, $p < 0.001$) and carbohydrates ($r = -0.08$, $p < 0.001$), and thus depressing the hydration sites which can result into decreased moisture contents. Moisture content is one of the most common tests in foods since the water content in foods has an important relationship between preservation and the chemical, physical and microbiological changes during the storage [44].

3.7. Protein content

The protein contents were in the range 1.21–1.87%. The highest protein contents were recorded in *Bangweulu*, and lowest in *Chila*. The protein in varieties were not significantly different ($p > 0.05$). Manano et al. [43] reported protein in the range 0.74–1.52%. Emmanuel et al. [7] reported in the range 1.76–3.46% protein. Other authors have reported lower protein values in the range 0.3–0.6% protein [45,46], and 0.72% protein [47]. The differences in protein contents can be accounted for in terms of environmental conditions such as soil fertility environmental conditions [2,3]. Nitrogen rich fertilizer contributed to increased protein contents in cassava varieties from the range of 4.3–19.30% in unfertilized cassava varieties to the range 9.6–20.9% in fertilized varieties [48]. However, these results are alarmingly too high levels for protein in cassava flours. The high levels, however, could be due to additional nitrogen from cyanides during alkaline distillation of acid-digested samples. While it is not certainly clearly understood, the nitrogen in cyanide compounds can contribute to the crude content of nitrogen levels attributed to proteins. Moreover, in the current study, the proteins showed a weak positive correlation ($r = 0.12$, $p < 0.001$) with cyanide contents in the roots. Nevertheless, protein in cassava flours can influence pasting properties as shown in the positive correlation with moisture content ($r = 0.36$, $p < 0.01$). The entanglement of protein and starch is responsible for viscosity changes during gelation and the resulting matrix could restrict swelling of starch granules. Proteins can bind water and can limit starch granule swelling [6] at low heating temperature. Protein correlated negatively with carbohydrates (r = −0.70, $p < 0.05$). This follows the ‘dilution hypothesis’ which explains the reduction of molecular interactions between protein molecules (aggregation) by increased saccharide contents [49]. During drying saccharides replaces water molecules bonded to proteins. The elimination of water may alter the binding sites of proteins which affect their activities, and presumably decreasing the protein contents.

3.8. Lipid content

The crude lipid contents were in the range 0.15–0.63%, and varied ($p < 0.05$) among the varieties. Previous studies have reported lipids in the range 0.1–0.3% [45,46] 0.74–1.49 [7], and 0.41 [47]. Lipids exhibited negative correlation with carbohydrates (r = −0.56, $p < 0.05$) and dry matter contents (r = −0.39, $p < 0.01$). This suggests that lower lipids had decreased moisture contents (r = 0.45, $p < 0.01$), which proximately increases dry matter contents, and subsequently total carbohydrates. Lipid such as monoglycerides and phospholipids can form liquid-crystalline phase with water through hydrophilic (polar heads) or hydrophobic (methyl) groups. The polar lipid, due to their surface-active nature, accumulate at the interface [50] and have a tendency to absorb water, which justifies their positive correlation with moisture contents in flours. The formation of amylose-lipid complexes is reported to increase the viscosities [51,52] during starches pasting.

3.9. Ash content

The ash contents were in the average range of 1.21–1.78%, and varied ($p < 0.05$) among the varieties. Ash has been reported in previous studies, 1.46–2.71 [53], 1.90–2.84 [7] and 1.44–2.35 [54]. The differences in reported ash contents could be attributed to differences in dry matter contents and their proximate composition. Ash contents correlated negatively with dry matter (r = −0.73, $p < 0.05$). Higher dry matter contents were associated with lower ash contents as shown in *Bangweulu*. This could be attributed to higher fibre contents in *Bangweulu*. Fibre was a major contributor to ash contents in varieties. In a related study, wheat flour varieties with higher fibre content had higher ash contents [55]. Ash content is an indicator of mineral contents and is used as measurement of quality of flours in the food industry. The redness-greenness (a^*) correlated positively with ash content in wheat flours [56], which suggests high ash contents can impact the whiteness of flours and bread. Increased mineral content may promote metal chelating activities to form metal ion-pigment complexes [57] which can confer greenness/redness or yellowness colour on the final flour product. Nevertheless, in the current study ash negatively correlated with a* and b*, which is justified as starchy vascular ground tissue of cassava do not contain pigments, and formation metal ion-pigment complexes are prominent in the cassava peels [58].

3.10. Fibre contents

The fibre contents ranged from 0.03 to 0.60%. *Bangweulu* differed significantly ($p < 0.05$) from other varieties. The highest fibre contents were recorded in *Bangweulu*, and lowest in *Kampolombo*. Fibre correlated negatively with smaller particle size D10 (r = −0.24, $p < 0.01$), D30 (r = −0.25, $p < 0.01$), D50 (r = −0.22, $p < 0.01$), and positively with larger particle size D60 (r = 0.04, $p < 0.001$), and D90 (r = 0.05, $p < 0.001$). It follows that high fibrous cassava would be characteristically coarse while less fibrous is likely to be finer. This was further reflected in the positive correlation with dry matter (r = 0.40, $p < 0.05$), which suggests that higher dry matter contents are likely to be associated with high amounts of fibre and larger flour particle size. The negative correlation between fibre and ash contents (r = −0.35, $p < 0.05$) could be an indicator of loss of mineral content in high fibrous cassava roots during dewatering (pressing). There could be increased rate of nutrients release (loss) in highly permeable fibres during processing [59]. Furthermore, the negative correlation between fibre and moisture content (r = −0.35, $p < 0.01$) could suggest that the high fibre cassava had lower moisture content. Edible fibres are mainly composed of polysaccharides such as cellulose, hemicellulose and pectin. The combination of cellulose microfibrils and cross-linking hemicelluloses with an inter-penetrating pectin network provides strength and rigidity to the cell wall. In cellulose, a network of micro fibrils formed by close packing of unbranched β-1,4-glucan chains, which are stabilised by intra- and inter-molecular hydrogen bonds, makes this polymer impermeable and water insoluble [59,60]. Fibre might be quicker to take up water like a wick, however, this water is loosely bound in the fibre structure, and can be easily lost during drying resulting in decreased moisture contents. When fibre is present along with starch, it competes for the limited amount of water available in food system. The partial solubilisation of fibre present in mixtures can affect the initial viscosity. Pectin function as a plasticiser and control porosity [61], and depending on porosity, there could be differential moisture responses among the varieties. Fibre correlated negatively with protein (r = −0.19, $p < 0.001$) and lipid (r = −0.18, $p < 0.001$). The proximate increase in fibre resulted in decreased protein and lipid contents of flours. Fibre contents in cassava flours were observed to increase while protein and lipids decreased with increase in the age of the plant [62]. Since age was not the factor in the current study, the variation in fibre can be alluded to differential genetic responses of varieties.

3.11. Total carbohydrates

The total carbohydrates content on dry matter basis were in the range 84.32–86.57%. The total carbohydrate contents were high in *Chila*, and was significantly similar ($p > 0.05$) with *Kampolombo*, and different ($p < 0.05$) from other varieties. Similar was reported by in the range 80.1–86.3% carbohydrate [4]. Carbohydrates correlated negatively with other proximate contents, protein (r= −0.70, $p < 0.05$), lipid (r = −0.56, $p < 0.05$), fibre (r = 0.08, $p < 0.001$), ash (r = −0.2, $p < 0.01$) and moisture (r = −0.83, $p < 0.05$) contents. This implies that protein, lipid and moisture contents were the major components impacting carbohydrates, and decrease in these molecules would lead to significant increase in total carbohydrates. Carbohydrates binds proteins through hydrogen bonding via hydroxyl group on saccharides and amine group on proteins [63], which may result in highly carbonyl substituted carbohydrate, and subsequently loss of protein activity and availability. Carbohydrate interact with lipids to form glycolipids through glycosidic bond [64] which reduces free lipids. The carbohydrates binds water molecules through hydrogen bonding [65], hence limiting water mobility which justifies the inverse relationship between moisture and carbohydrates. The carbohydrates correlated positively with dry matter (r = 0.39, $p < 0.01$), implying that higher dry matter were associated with higher carbohydrate contents. The negative correlation with bulk density (r = −0.58, $p < 0.05$) suggests that reduced bulk density had higher carbohydrates contents. The carbohydrates correlated positively with flour particle sizes, D10 (r = 0.60, $p < 0.05$), D30 (r = 0.62, $p < 0.05$), D50 (r = 0.31, $p < 0.05$), D60 (r = 0.39, $p < 0.01$), and D90 (r = 0.28, $p < 0.01$). The strong correlation with D10 and D30 suggests that the smaller flour particle size were associated with reduced fibre contents and increased carbohydrates.

3.12. *Cyanide contents in roots*

The cyanides were in the range 23.60 to 238.12 ppm (Table 8), and varied significantly ($p < 0.05$) among varieties. The lowest cyanide contents were recorded in the local variety *Katobamputa*, and highest in *Bangweulu* among the improved varieties. Mtunguja et al. [8] reported average cyanide contents in the range 133.30–346.70 ppm in six cassava varieties of the Tanzanian cultivars, and varied with genotype and environment. The author observed that the variety *Kiroba* recorded 800, 200, and 40 mg ppm from three separate regional sites (Chambezi, Amani and Magadu), respectively, at 15 months after planting. In the current study the varieties were cultivated on the same site and were rain fed. Thus, the differences in cyanides among varieties might be alluded to variations in genotype and water stress. The dry spell experienced during rainy season of the cassava plant growth may have caused a variation in cyanides. Ndubuisi and Chidiebere [66] reported that cyanide content of cassava increases during period of drought due to water stress on the plant. The root cyanide contents exhibited positive correlations with genetic traits, protein (r = 0.12, $p < 0.001$), lipid (r = 0.12, $p < 0.001$), and fibre (r = 0.35, $p < 0.01$). The xylem and phloem are fibrous nature [67], and can retain higher cyanides after harvest. This suggests that higher fibre contents would produce higher cyanides. Cassava roots contain cyanides in different forms. The glycosides essentially linamarin and lotaustraline are considered bound [68]. The non-glycosides which are hydrogen cyanide (HCN) and cyanohydride are considered free [69]. This cyanide can lead to human toxicity problems and would require that cassava for food is processed to remove cyanide-containing substances to safe levels [10].

Table 5. Percentage (%) dry matter, starch yield and proximate analysis of cassava flours from six varieties grown in Zambia.

Variety	Dry matter	Starch yield	Moisture	Protein	Lipid	Ash	Fibre	Total Carbohydrates
Bangweulu	47.25(2.80) ^{a}	25.98(1.44)^{a}	11.02(1.00)^{ab}	1.87(0.78) ^{a}	0.39(0.04) ^{a}	1.16(0.05) ^{a}	0.60(0.49) ^{b}	84.95(1.04) ^{ab}
Katobamputa	40.27(4.31) ^{b}	26.8(1.83)^{a}	11.05(1.46) ^{ab}	1.45(0.03) ^{a}	0.41(0.05) ^{ab}	1.78(0.32) ^{d}	0.15(0.15) ^{a}	85.16(0.18) ^{ab}
Mweru	40.31(1.34) ^{b}	28.31(4.12)^{a}	11.76(1.61)^{b}	1.78(0.28) ^{a}	0.59(0.18) ^{bc}	1.51(0.08) ^{c}	0.05(0.06) ^{a}	84.32(0.32) ^{a}
Kariba	40.04(1.62) ^{b}	20.76(0.59)^{b}	11.18(0.72) ^{ab}	1.43(0.41) ^{a}	0.63(0.06) ^{bc}	1.48(0.06) ^{c}	0.04(0.02) ^{a}	85.24(1.08)^{ab}
Kampolombo	46.59(1.61) ^{a}	26.92(3.37)^{a}	10.69(0.62) ^{a}	1.58(0.15) ^{a}	0.32(0.19) ^{cd}	1.21(0.09) ^{ab}	0.03(0.02) ^{a}	86.17(0.58) ^{bc}
Chila	43.01(1.27) ^{ab}	28.11(1.01)^{a}	10.43(0.37) ^{a}	1.21(0.09)^{a}	0.15(0.04)^{d}	1.48(0.07) ^{bc}	0.15(0.05) ^{a}	86.57(0.41) ^{c}
Significance level								
Variety	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$

Note: All values are means of three replications. Data in the parenthesis are the standard deviations. Within the same column, the values with different letters are significantly different at $p < 0.05$ by LSD test.

Table 6. Correlation coefficients proximate, particle size distribution and cyanides content.

Parameters	Bulk density	Protein	Lipid	Fibre	Ash	Moisture	Carbs	Dry matter	D10	D30	D50	D60	D90	Cyanides roots	Cyanides flours
Bulk density	1														
Protein	0.31	1													
Lipid	0.42	0.20	1												
Fibre	−0.17	0.29	−0.13	1											
Ash	0.26	−0.22	0.14	−0.35	1										
Moisture	0.56	0.36	0.45	−0.32	0.19	1									
Carbohydrates	−0.58	−0.70	−0.56	−0.08	−0.21	−0.83	1								
Dry matter	−0.34	−0.02	−0.39	0.40	−0.73	−0.36	0.39	1							
D10	−0.62	−0.32	−0.31	−0.24	−0.33	−0.40	0.60	0.17	1						
D30	−0.46	−0.23	−0.41	−0.25	−0.44	−0.41	0.62	0.33	0.93	1					
D50	−0.16	−0.02	−0.10	−0.22	−0.55	−0.13	0.31	0.28	0.80	0.88	1				
D60	−0.53	0.00	−0.20	0.04	−0.72	−0.29	0.39	0.52	0.82	0.85	0.88	1			
D90	−0.71	−0.02	0.01	0.05	−0.45	−0.28	0.28	0.39	0.44	0.38	0.26	0.59	1		
Cyanides roots	−0.30	0.12	0.12	0.35	−0.50	0.03	−0.07	0.18	0.48	0.32	0.56	0.67	0.21	1	
Cyanides flours	0.21	−0.01	0.12	−0.23	−0.22	0.29	−0.08	0.22	−0.23	−0.19	0.02	0.03	−0.01	0.07	1

Table 7. Correlation coefficients of colour parameters, and proximate and cyanide contents.

Parameter	L	a	b	Whiteness	Chroma	Dry matter	Protein	Lipid	Fibre	Cyanides flours	Cyanides Varieties
L	1										
a	0.16	1									
b	−0.06	0.74	1								
Whiteness	0.51	−0.56	−0.89	1							
Chroma	−0.06	0.75	1.00	−0.89	1						
Dry matter	−0.21	0.33	0.49	−0.51	0.49	1					
Protein	−0.20	−0.27	−0.29	0.16	−0.29	−0.02	1				
Lipid	0.23	−0.34	−0.77	0.77	−0.77	−0.39	0.21	1			
Fibre	−0.47	0.29	0.26	−0.44	0.26	0.58	−0.19	−0.18	1		
Cyanides flours	0.24	−0.09	−0.12	0.21	−0.11	0.08	0.82	0.16	−0.16	1	
Cyanides Varieties	0.44	0.39	0.19	0.04	0.19	0.23	0.02	0.13	0.35	0.47	1

Table 8. Cyanide content (ppm) of six cassava varieties at 18 months after planting.

Variety	Cassava root	Cassava flour	Cyanide reduction (%)
Bangweulu	238.12(31.11)^{d}	15.48(4.78)^{b}	93.27(2.93)^{b}
Katobamputa	23.60(6.87)^{a}	8.62(0.58)^{a}	60.76(13.82)^{a}
Mweru	167.33(8.92)^{c}	15.16(1.98)^{b}	90.94(1.00)^{b}
Kariba	229.00(24.25)^{d}	13.69(3.55)^{b}	93.86(2.29)^{b}
Kampolombo	113.50(7.15)^{b}	13.59(0.84)^{b}	88.03(0.03)^{b}
Chila	190.61(7.18)^{c}	11.97(0.72)^{ab}	93.71(0.60)^{b}
Significance level			
Variety	$p < 0.05$	$p < 0.05$	$p < 0.05$

Note: All values are means of three replications. Data in the parenthesis are the standard deviations. Within the same column, the values with different letters are significantly different at $p < 0.05$ by LSD test. Units: ppm = mg HCN/kg.

3.13. Cyanide contents in cassava flours

The cyanide contents ranged between 8.62 and 15.48 ppm and differed insignificantly ($p > 0.05$) among the varieties. The lowest cyanide contents were recorded in *Katobamputa* and differed significantly ($p < 0.05$) from the improved varieties. Compared to the cassava roots, cyanide in flours significantly reduced. Percentage cyanide reduction in flours were 93.27, 60.76, 90.94, 93.86, 88.03, and 93.71%, in *Bangweulu, Katobamputa, Mweru, Kariba, Kampolombo,* and *Chila*, respectively. This is attributed to the method of processing. Cyanide is largely removed by the traditional processing methods of grating, dewatering (pressing), fermenting, and drying [10]. The highest cyanide retention was in local variety *Katobamputa,* suggesting presence of glycoside linamalin chemically bound. The improved varieties had lower cyanide retention levels which could indicate the presence of free cyanides such as hydrogen cyanide and cyanohydride. Cyanide is soluble in water and volatile (25 ℃ boiling point) and can removed soaking and air drying temperatures (28–40 ℃) [70]. Cassava varieties are classified as sweet variety when cyanide values are in the range 15-50 ppm, and bitter variety when values are from 15–400 ppm of fresh cassava [66]. The recommended safe levels in a final food products is 10 ppm [71]. Since cassava flour is a raw material, the cyanides are expected to reduce further down the processing stream. The temperatures for proofing (30–32 ℃) and baking (178–193 ℃) for bread making can significantly reduce cyanides in the final product.

3.14. Colour of cassava flours

3.14.1. Lightness (L*)

The lightness (L^*) ranged between 93.65 and 94.69 (Table 9) across varieties and were significantly different ($p < 0.05$). Omolola et al. [72] reported in the range L* 88.30–93.57 of cassava flour, which were dried at temperatures 60–72 ℃ for 15–20 h. The differences in L* could be attributed to drying temperatures. In the current study cassava flours were sun-dried followed by oven dried at 40 ± 5 ℃ for 12 h. Drying of flours at elevated oven temperatures causes scorching and discolorations (personal observation) leading to reduced lightness. Depending on the moisture content of flours, higher temperatures as reported in Omolola et al. [72] may gelatinize the flours starch granules leading to loss of birefringence properties and thus affecting the quality of raw flours.

3.14.2. Redness-greenness (a*)

The redness-greenness (a^*) ranged between −0.03 (green) and 0.44 (red), and significance differences were observed between *Mweru* and *Chila*. The source of greenness could be due to residue of cassava peels. Nevertheless, the a* values were lower compared to −0.22 to −0.31 reported by Eriksson et al. [73].

3.14.3. Yellowness (b*)

The yellowness (b^*) ranged from 6.52 to 8.14, and varied ($p < 0.05$) among varieties. Similar results were reported in the range 5.00–5.15 [73]. The differences could be attributed to varied contents of oxidants in cassava varieties. In the present study, variation in yellowness can be caused by inadequate dewatering of grated cassava. The water in the fresh cassava is the medium of reactive oxygen species (oxidants) [74] and can taint the flours yellowish during drying. It requires that the water is expressed out from the grated cassava followed by granulating of mass before drying. Granulation with use of pulveriser or hands is critical to crumble the mass into smaller particles for increased surface area during drying.

Table 9. Colour, whiteness, and chroma of flour from six cassava varieties grown in Zambia.

	Colour parameters				
Variety	L	a	b	Whiteness	Chroma
Bangweulu	94.05(0.02)^{b}	0.27(0.02)^{ab}	7.48(0.28)^{c}	90.46(0.09)^{b}	7.48(0.09)^{c}
Katobamputa	93.65(0.27)^{a}	0.19(0.04)^{ab}	7.29(0.42)^{c}	90.33(0.69)^{b}	7.29(0.59)^{c}
Mweru	94.49(0.16)^{c}	−0.03(0.05)^{a}	6.52(0.20)^{a}	91.46(0.14)^{c}	6.52(0.16)^{a}
Kariba	94.69(0.08)^{d}	0.01(0.01)^{a}	6.74(0.05)^{ab}	91.38(0.21)^{c}	6.79(0.21)^{ab}
Kampolombo	94.55(0.09)^{cd}	0.15(0.03)^{ab}	6.97(0.09)^{b}	91.15(0.19)^{c}	6.97(0.19)^{b}
Chila	94.05(0.36)^{b}	0.44(0.12)^{b}	8.15(0.58)^{d}	89.90(0.49)^{a}	8.16(0.49)^{d}

Note: All values are means of three replications. Data in the parenthesis are the standard deviations. Within the same column, the values with different letters are significantly different at $p < 0.05$ by LSD test.

3.14.4. Whiteness index

The whiteness was in the average range of 89.90–91.46 (Table 9) and varied ($p < 0.05$) among varieties. Similar study reported whiteness in the range 82.88–89.42 [72]. The differences in whiteness could be attributed to differences in drying temperature and time. Higher temperatures and longer times could impact scorching effect on flours which may result in their increased a* (redness) and b* (yellowish) values, and hence decreasing the whiteness. The whiteness correlated positively with L* ($r = 0.51$, $p < 0.05$), negatively with a* ($r = -0.56$, $p < 0.05$) and b* ($r = -0.89$, $p < 0.05$). This implies that the higher whiteness index values could be attributed to lower a* and b* values, and higher L* values. The fibre contents impacted negatively on whiteness ($r = -0.44$, $p < 0.01$), suggesting that higher fibre in flours decreases whiteness. The negative correlation between whiteness and dry matter content ($r = -0.51$, $p < 0.05$) further supports the fact that decrease in fibre increased whiteness. Varieties *Mweru* and *Kariba* had lower dry matter and fibre contents, and they gave higher whiteness index.

3.14.5. Chroma

The Chroma were in the range of 6.52–8.16, and varied ($p < 0.05$) among varieties. Chroma correlated positively with dry matter ($r = 0.49$, $p < 0.01$) and fibre ($r = 0.26$, $p < 0.01$). This suggests that increased dry matter and fibre content increased chroma. *Bangweulu* had highest chroma, and exhibited highest dry matter and fibre content.

Colour is the consumer preference quality attribute, and it is perceived as a measure of quality. The desired colour quality criteria for selection of cassava flours for industrial applications are a high value for lightness (L*) and low value for chroma [75,76]. Nevertheless, the small degree shifts in yellowness and greenness impacted on the whiteness. The low whiteness value of *Chila* were due to high Chroma value. The high whiteness value of *Kariba* exhibited low Chroma value. In general factors affecting colour of flours include variety, maturity stage [77], and processing procedure [78]. Cassava flour prepared from unpeeled or not properly peeled roots develops a grey colour during wet storage [79] and develop a purple colour during drying (personal observations). The retained colour lowers the quality and thus affecting its value. The production of flour with increased lightness (L^*) and hence whiteness would require processes characterized with controlled sorting, peeling, enhanced washing through use of potable water, thorough grating and high press dewatering.

4. Conclusions

The variety effect on the quality traits was significant which suggests that variety can be targeted as the basis of selecting cassava with potential to produce required quality characteristics. The particle size distribution at 90 percent, were within the acceptable size limits for application in the baking industry. The varieties were characterized with high dry matter contents and starch extraction yields. *Kariba* exhibited lowest dry matter and starch extraction yields. The protein, lipids, fibre and ash contents indicates poor nutrition quality and were within acceptable ranges and in agreement with reported values in the previous works. Also, the study confirmed the effect of variety on cyanide content of cassava roots. The local variety *Katobamputa* exhibited lowest cyanide in cassava roots, and flours within the recommended safe levels, however, this variety had highest cyanide retention. The higher reduction of cyanides in flours are attributed to grating and dewatering. The two operation steps can be considered as critical control points in the primary processing of transforming cassava roots into shelf stable. The high whiteness index combined with low ash contents are some of the primary desirable quality traits for application of cassava flours in the food and non-food industry.

Acknowledgements

The authors are grateful to Dr Martin Chiona, Plant Breeding, Mansa Root and Tuber research station, Zambia Agriculture Research Institute (ZARI), for cassava experimental fields. The authors would like to thank the National Institute for Scientific and Industrial research (NISIR) for financial support.

Conflicts of interest

No competing conflicts of interest expressed among authors.

References

1. Uchechukwu-Agua AD, Caleb OJ, Opara UL (2015) Postharvest handling and storage of fresh cassava root and products: a review. *Food Bioprocess Technol* 8: 729–748.
2. Burns AE, Gleadow RM, Zacarias AM, et al. (2012) Variations in the chemical composition of cassava (Manihot esculenta Crantz) leaves and roots as affected by genotypic and environmental variation. *J Agric Food Chem* 60: 4946–4956.
3. Agiriga A, Iwe M (2016) Optimization of Chemical Properties of Cassava Varieties Harvested at Different Times using Response Surface Methodology. *Am J Adv Food Sci Technol* 4: 10–21.

4. Charles AL, Sriroth K, Huang T-c (2005) Proximate composition, mineral contents, hydrogen cyanide and phytic acid of 5 cassava genotypes. *Food Chem* 92: 615–620.
5. Chiwona-Karltun L, Nyirenda D, Mwansa CN, et al. (2015) Farmer preference, utilisation, and biochemical composition of improved cassava (Manihot esculenta Crantz) varieties in southeastern Africa. *Econ Bot* 69: 42–56.
6. Lu D, Lu W (2012) Effects of protein removal on the physicochemical properties of waxy maize flours. *Starch-Stärke* 64: 874–881.
7. Emmanuel O, Clement A, Agnes S, et al. (2012) Chemical composition and cyanogenic potential of traditional and high yielding CMD resistant cassava (Manihot esculenta Crantz) varieties. *Int Food Res J* 19: 175–181.
8. Mtunguja MK, Laswai HS, Kanju E, et al. (2016) Effect of genotype and genotype by environment interaction on total cyanide content, fresh root, and starch yield in farmer-preferred cassava landraces in Tanzania. *Food Sci Nutr* 4: 791–801.
9. Kashala-Abotnes E, Okitundu D, Mumba D, et al. (2018) Konzo: a distinct neurological disease associated with food (cassava) cyanogenic poisoning. *Brain Res Bull* 145: 87–91.
10. Montagnac JA, Davis CR, Tanumihardjo SA (2009) Processing techniques to reduce toxicity and antinutrients of cassava for use as a staple food. *Compr Rev Food Sci Food Saf* 8: 17–27.
11. Mlingi NL, Bainbridge Z (1994) Reduction of cyanogen levels during sun-drying of cassava in Tanzania. *Acta Hortic* 375: 233–240.
12. Dixon AG, Asiedu R, Bokanga M (1994) Breeding of cassava for low cyanogenic potential: problems, progress and prospects. *Acta Hortic* 375: 153–162.
13. Sarkiyayi S, Agar T (2010) Comparative analysis on the nutritional and anti-nutritional contents of the sweet and bitter cassava varieties. *Adv J Food Sci Technol* 2: 328–334.
14. Barbosa-Cánovas GV, Harte F, Yan HH (2012) Particle size distribution in food powders. *Food Eng* 1: 303–328.
15. Roa DF, Baeza RI, Tolaba MP (2015) Effect of ball milling energy on rheological and thermal properties of amaranth flour. *J Food Sci Technol* 52: 8389–8394.
16. Scientific H (2012) A guidebook to particle size analysis. Horiba Instruments, Inc., 1–29.
17. Numfor F, Walter W (1996) Cohesiveness of native cassava starch pastes: effect of fermentation. *Afr J Root Tuber Crops* 1: 29–32.
18. Eriksson E, Koch K, Tortoe C, et al. (2014) Evaluation of the physical and sensory characteristics of bread produced from three varieties of cassava and wheat composite flours. *Food Pub Health* 4: 214–222.
19. Benesi IR, Labuschagne MT, Dixon AG, et al. (2004) Stability of native starch quality parameters, starch extraction and root dry matter of cassava genotypes in different environments. *J Sci Food Agric* 84: 1381–1388.
20. Nuwamanya E, Baguma Y, Rubaihayo P (2010) Physicochemical and functional characteristics of cassava starch in Ugandan varieties and their progenies. *J Plant Breed Crop Sci* 2: 001–011.
21. AOAC (2012) Official Methods of Analysis of AOAC international. Gaithersburg, Maryland, USA: 19th edition, AOAC International.
22. Orjiekwe C, Solola A, Iyen E, et al. (2013) Determination of cyanogenic glucosides in cassava products sold in Okada, Edo State, Nigeria. *Afr J Food Sci* 7: 468–472.
23. Zhu F, Sakulnak R, Wang S (2016) Effect of black tea on antioxidant, textural, and sensory properties of Chinese steamed bread. *Food Chem* 194: 1217–1223.

24. Sonaye S, Baxi R (2012) Particle size measurement and analysis of flour. *Int J Eng Res Appl* 2: 1839–1842.
25. Ahmed J, Thomas L, Arfat YA (2018) Functional, rheological, microstructural and antioxidant properties of quinoa flour in dispersions as influenced by particle size. *Food Res Int* 116: 302–311.
26. Oladunmoye OO, Aworh OC, Maziya-Dixon B, et al. (2014) Chemical and functional properties of cassava starch, durum wheat semolina flour, and their blends. *Food Sci Nutr* 2: 132–138.
27. Lazaridou A, Marinopoulou A, Biliaderis CG (2019) Impact of flour particle size and hydrothermal treatment on dough rheology and quality of barley rusks. *Food Hydrocolloids* 87: 561–569.
28. Farooq AM, Li C, Chen S, et al. (2018) Particle size affects structural and in vitro digestion properties of cooked rice flours. *Int J Biol Macromol* 118: 160–167.
29. Etuk BR, Akpan I (2003) Optimum size distribution of sorghum grist for brewing purposes. *Global J Pure Appl Sci* 9: 259–264.
30. Hossen MS, Sotome I, Takenaka M, et al. (2011) Effect of particle size of different crop starches and their flours on pasting properties. *Jpn J Food Eng* 12: 29–35.
31. Oladunmoye O, Akinoso R, Olapade A (2010) Evaluation of some physical–chemical properties of wheat, cassava, maize and cowpea flours for bread making. *J Food Qual* 33: 693–708.
32. Eleazu OC, Eleazu KC, Kolawole S (2014) Use of indigenous technology for the production of high quality cassava flour with similar food qualities as wheat flour. *Acta Sci Pol, Technol Aliment* 13: 249–256.
33. Raigar R, Mishra H (2015) Effect of moisture content and particle sizes on physical and thermal properties of roasted B engal gram flour. *J Food Process Preserv* 39: 1839–1844.
34. Sharma A, Jana AH, Chavan RS (2012) Functionality of milk powders and milk-based powders for end use applications—a review. *Compr Rev Food Sci Food Saf* 11: 518–528.
35. Iwe M, Onyeukwu U, Agiriga A, et al. (2016) Proximate, functional and pasting properties of FARO 44 rice, African yam bean and brown cowpea seeds composite flour. *Cogent Food Agric* 2: 1142409.
36. Abdullah EC, Geldart D (1999) The use of bulk density measurements as flowability indicators. *Powder Technol* 102: 151–165.
37. Van Toan N (2018) Preparation and Improved Quality Production of Flour and the Made Biscuits from Purple Sweet Potato. *J Food Nutr* 4: 1–14.
38. Teye E, Asare A, Amoah R, et al. (2011) Determination of the dry matter content of cassava (Manihot esculenta, Crantz) tubers using specific gravity method. *ARPN J Agric Biol Sci* 6: 23–28.
39. Beyene G, Solomon FR, Chauhan RD, et al. (2018) Provitamin A biofortification of cassava enhances shelf life but reduces dry matter content of storage roots due to altered carbon partitioning into starch. *Plant Biotechnol J* 16: 1186–1200.
40. Buddhakulsomsiri J, Parthanadee P, Pannakkong W (2018) Prediction models of starch content in fresh cassava roots for a tapioca starch manufacturer in Thailand. *Comput Electron Agric* 154: 296–303.
41. Abera S, Rakshit SK (2003) Processing technology comparison of physicochemical and functional properties of cassava starch extracted from fresh root and dry chips. *Starch-Stärke* 55: 287–296.
42. Pérez JC, Lenis JI, Calle F, et al. (2011) Genetic variability of root peel thickness and its influence in extractable starch from cassava (Manihot esculenta Crantz) roots. *Plant Breed* 130: 688–693.
43. Manano J, Ogwok P, Byarugaba-Bazirake GW (2017) Chemical composition of major cassava varieties in Uganda, targeted for industrialisation. *J Food Res* 7: 1.

44. Passos MEAd, Moreira CFF, Pacheco MTB, et al. (2013) Proximate and mineral composition of industrialized biscuits. *Food Sci Technol* 33: 323–331.
45. Charles AL, Chang YH, Ko WC, et al. (2004) Some physical and chemical properties of starch isolates of cassava genotypes. *Starch-Stärke* 56: 413–418.
46. Montagnac JA, Davis CR, Tanumihardjo SA (2009) Nutritional value of cassava for use as a staple food and recent advances for improvement. *Compr Rev Food Sci Food Saf* 8: 181–194.
47. Somendrika M, Wickramasinghe I, Wansapala M, et al. (2016) Analysing proximate composition of macro nutrients of Sri Lankan cassava variety 'Kirikawadi'. *Pak J Nutr* 15: 283.
48. Shittu T, Dixon A, Awonorin S, et al. (2008) Bread from composite cassava–wheat flour. II: Effect of cassava genotype and nitrogen fertilizer on bread quality. *Food Res Int* 41: 569–578.
49. Costantino HR, Curley JG, Wu S, et al. (1998) Water sorption behavior of lyophilized protein—sugar systems and implications for solid-state interactions. *Int J Pharm* 166: 211–221.
50. Larsson K (1982) Some effects of lipids on the structure of foods. *Food Struct* 1: 6.
51. Nwokocha LM, Aviara NA, Senan C, et al. (2009) A comparative study of some properties of cassava (Manihot esculenta, Crantz) and cocoyam (Colocasia esculenta, Linn) starches. *Carbohydr Polym* 76: 362–367.
52. Peroni F, Rocha T, Franco C (2006) Some structural and physicochemical characteristics of tuber and root starches. *Food Sci Technol Int* 12: 505–513.
53. Rojas CC, Nair B, Herbas A, et al. (2007) Proximal composition and mineral contents of six varieties of cassava (Mannihot esculenta Crantz), from Bolivia. *Rev Boliv Quim* 24: 71–77.
54. Eleazu C, Eleazu K (2012) Determination of the proximate composition, total carotenoid, reducing sugars and residual cyanide levels of flours of 6 new yellow and white cassava (Manihot esculenta Crantz) varieties. *Am J Food Technol* 7: 642–649.
55. Pavlovich-Abril A, Rouzaud-Sández O, Romero-Baranzini AL, et al. (2015) Relationships between chemical composition and quality-related characteristics in bread making with wheat flour—fine bran blends. *J Food Qual* 38: 30–39.
56. Katyal M, Virdi AS, Kaur A, et al. (2016) Diversity in quality traits amongst Indian wheat varieties I: Flour and protein characteristics. *Food Chem* 194: 337–344.
57. Yu L, Nanguet AL (2013) Comparison of antioxidant properties of refined and whole wheat flour and bread. *Antioxidants* 2: 370–383.
58. Schwantes D, Gonçalves AC, Coelho GF, et al. (2016) Chemical modifications of cassava peel as adsorbent material for metals ions from wastewater. *J Chem* 2016: 3694174.
59. Grundy MML, Edwards CH, Mackie AR, et al. (2016) Re-evaluation of the mechanisms of dietary fibre and implications for macronutrient bioaccessibility, digestion and postprandial metabolism. *Br J Nutr* 116: 816–833.
60. Brett CT, Waldron KW (1996) Physiology and biochemistry of plant cell walls. Vol. 2, Springer Science & Business Media.
61. Do DT, Singh J, Oey I, et al. (2018) Biomimetic plant foods: Structural design and functionality. *Trends Food Sci Technol* 82: 46–59.
62. Oluwaniyi OO, Oladipo JO (2017) Comparative studies on the phytochemicals, nutrients and antinutrients content of cassava varieties. *J Turk Chem Soc* 4: 661–674.
63. Del Carmen Fernández-Alonso M, Díaz D, Alvaro Berbis M, et al. (2012) Protein-carbohydrate interactions studied by NMR: from molecular recognition to drug design. *Curr Protein Pept Sci* 13: 816–830.

64. Pomeranz Y, Chung O (1978) Interaction of lipids with proteins and carbohydrates in breadmaking. *J Am Oil Chem Soc* 55: 285–289.
65. Li L, Wang N, Ma S, et al. (2018) Relationship of moisture status and quality characteristics of fresh wet noodles prepared from different grade wheat flours from flour milling streams. *J Chem* 2018: 1–8.
66. Ndubuisi N, Chidiebere A (2018) Cyanide in cassava: a review. *Int J Genomics Data Min* 10: 1–10.
67. Figueiredo PG, de Moraes-Dallaqua MA, Bicudo SJ, et al. (2015) Development of tuberous cassava roots under different tillage systems: descriptive anatomy. *Plant Prod Sci* 18: 241–245.
68. Zidenga T, Siritunga D, Sayre RT (2017) Cyanogen metabolism in Cassava roots: Impact on protein synthesis and root development. *Front Recent Dev Plant Sci* 8: 1–12.
69. Samson SO, Akomolafe O, FK O (2017) Fermentation: A means of treating and improving the nutrition content of cassava (manihot esculenta C.) peels and reducing its cyanide content. *Genomics Appl Biol* 8: 17–25.
70. Akande SA, Onyegbula AF, Salawu RA, et al. (2017) Effects of post-harvest handling on hydrogen cyanide content of cassava products obtained from Ilorin-West urban markets, Nigeria. *Afr J Food Sci* 11: 362–368.
71. FAO/WHO (1991) Joint FAO/WHO food standards programme. Codex Alimentarius Commission, XII (Suppl. 4), Rome : FAO.
72. Omolola AO, Kapila PF, Anyasi TA, et al. (2017) Optimization of colour and thermal properties of sweet cassava (Manihot esculenta Crantz Var. UVLNR 0005) flour using response surface methodology. *Asian J Agric Res* 11: 57–65.
73. Eriksson E, Koch K, Tortoe C, et al. (2014) Physicochemical, functional and pasting characteristics of three varieties of cassava in wheat composite flours. *Br J Appl Sci Technol* 4: 1069–1073.
74. Hu W, Tie W, Ou W, et al. (2018) Crosstalk between calcium and melatonin affects postharvest physiological deterioration and quality loss in cassava. *Postharvest Biol Technol* 140: 42–49.
75. Sankhon A, Amadou I, Yao WR, et al. (2014) Comparison of physicochemical and functional properties of flour and starch extract in different methods from africa locust bean (Parkia Biglobosa) Seeds. *Afr J Tradit, Complementary Altern Med* 11: 264–272.
76. Vasconcelos L, Brito A, Carmo C, et al. (2017) Phenotypic diversity of starch granules in cassava germplasm. *Genet Mol Res: GMR* 16: 1–10.
77. McClements DJ, Chung C, Wu B (2017) Structural design approaches for creating fat droplet and starch granule mimetics. *Food Funct* 8: 498–510.
78. Rodriguez-Sandoval E, Prasca-Sierra I, Hernandez V (2017) Effect of modified cassava starch as a fat replacer on the texture and quality characteristics of muffins. *J Food Meas Charact* 11: 1630–1639.
79. Jyothi AN, Kiran KS, Wilson B, et al. (2007) Wet storage of cassava starch: Use of sodium metabisulphite and acetic acid and the effect on starch properties. *Starch-Stärke* 59: 141–148.

AIMS Press