Chapter

Primary Quality Control Parameters of Cassava Raw Materials

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Abstract

Fresh cassava roots are transformed into shelf stable raw materials (flours and extracted starches). Chemical composition (moisture, protein, lipid, fibre and amylose content, cyanide contents), dry matter, starch extraction yields, particle size distribution and whiteness index are some of the quality characteristic requirements for selection of varieties in breeding programs, and raw materials for industrial processes. Starch yields ranges 20–35%, and vary with genotype. The crude protein (1–2%) and crude fat (~1%) are considered minor components of cassava and are indicative of the poor nutritional quality. The cumulative of particles passing finer than sieve (D90) is commonly selected for industrial applications because it yields a large proportion of flour in the range 90–96% finer particle than sieve size. The amylose is the main genetic trait for categorising starches into waxy, semi-waxy, normal/regular and high amylose types when amylose content is 0–2, 3–15, 16–35, and > 35% of the total starch, respectively. Additionally, amylose is basic criteria for blending flours of different botanical sources. Cassava varieties are classified as sweet and bitter varieties when cyanide values are in the range 15–50 and 50–400 ppm, respectively. The a* (redness-greenness) and b* (yellowish) are considered as impurities in white fleshed cassava.

Keywords: Cassava, *Manihot esculenta* Crantz, Flour, Particle Size, Chemical composition, Starch yields, Amylose Cyanides

1. Introduction

Cassava (*Manihot esculenta* Crantz) is a staple food for over 800 million people in the tropics, and second highest dietary source of calories in sub-Saharan Africa where the crop is mainly produced for human consumption [1]. The cassava leaves are consumed as vegetable. In countries such as Democratic Republic of the Congo, Zambia, Tanzania, Sierra Leone, Liberia and Guinea, younger and tender cassava leaves are a major component of the diet. Nigeria is the largest producer of cassava worldwide. Thailand and Indonesia account for the largest share (75%) of cassava production in Asia. Thailand is the largest cassava exporter with 60% of global markets [2]. In the Americas, 40% of produced cassava is used as human food, and 30% for livestock feed. Cassava provides income, employment, and play a role as major food security crop. Cassava root is typically a carbohydrate material predominantly comprising of starch. Among the starches, including main cereal crops,

cassava is the highest producer of carbohydrates per hectare and is very tolerant to drought, heat stress and can thrives well on marginal soils. Cassava has gained tremendous use in food and beverages. It is added to wheat flour to form composite flour for making bread and other bakery products. In Nigeria, where the policy of cassava flour inclusion is mandatory, flour mills are required to partially substitute wheat flour with minimum of 10% cassava flour for bread making and other bakery products [3, 4].

Commercially, cassava flour and starch find application in bakery, brewing and pharmaceuticals industries. These industries have a number of specific quality requirements in raw materials. Proximate contents (moisture, crude protein, crude lipids, crude fibre and ash), colour, dry matter, starch yield, amylose contents, flour particle size and cyanide contents are some of the primary quality indicators for selection of cassava root raw materials in the industry. This chapter focused on production of cassava raw materials and criteria parameters for primary selection.

2. Cassava varieties

The cassava bulking roots are source of dietary calories. The cassava leaves serve as vegetable and contains significant levels of leucine, lysine, phenylalanine, valine and threonine, and crude protein content of ~26% per 100 g [5]. There are a number of cultivated cassava varieties. The breeding objective of most cassava program is to produce high yielding, early bulking, pests and disease resistant varieties [6]. Other breeding objectives include reduced cyanide content in cassava to produce sweet varieties. The bio-fortified cassava is yellow or orange fleshed and is the most recent genotype which has been bred for improved nutrition to supply pro-vitamin A carotenoids. The micronutrients, mainly of provitamin A, and dry matter content traits are among the primary selection objectives in cassava breeding. The yellow-fleshed cassava has other advantages such as delayed postharvest deterioration due to anti-oxidant carotenoids contained in the root [7].

3. Cassava primary products

The rapid physiological postharvest deterioration (PPD) and high amounts of cyanide content are the main factors limiting utilisation of fresh cassava [8]. Fresh cassava roots undergo PPD after harvest resulting in poor shelf life. The PPD decreases starch content resulting in poor functional properties. Preventing PPD requires that fresh cassava roots are processed into shelf-stable dried products immediately after harvest. Processing of cassava roots leads to decreased cyanide content and improved shelf life stability. The cassava primary products include flours and starches and serve as raw materials to the growing industrial utilisation of cassava. The fresh cassava roots can be processed into chips, and the dried chips can be milled into flour or starch at the later stage in the value chain.

3.1 Processing of cassava chips

Cassava chipping is the first primary step of processing peeled cassava into raw dried chips. The production of cassava chips is mainly a two steps process involving chipping and drying. Manually or motorised chipping machines are used. The peeled and cleaned fresh cassava roots are fed into the hopper of a chipping machine, and the chipped materials are collected at the bottom using cleaned receptacles such as trays, buckets or woven sacks. The collected fresh chips are

spread on the drying mats or trays. For large scale production, the chipper is mounted on the wheels to facilitate the spreading of chips on the drying mats. The chipping machine has an inbuilt rotating circular steel plate with chipping blades. The peeled cassava is chipped or sliced into finger-like strips of ~3 mm diameter. Thinly chipped materials are recommended for increased surface area for enhanced drying and release of volatile cyanides. The methods of drying include sun-drying, and hot air circulation using commercial ovens. The drying temperature ranges of 45–60°C are commonly applied. It is recommended to dry to a moisture content of 8 to l0%, after which the chips are cooled and packed.

3.2 Processing of cassava flour

Cassava roots are processed into unfermented flour as described by Chisenga et al. [9]. The harvested fresh cassava is sorted to select healthy and marketable roots which are cleaned to remove soil and debris. The cleaned roots are peeled and chopped into small pieces by hand with a knife, and washed 2x in potable water. Also, peeling can be conducted using motorised or engine driven peeler machine. The chopped cassava is grated using a motorised or engine driven grating machine with an inbuilt spiked stainless-steel sheet mounted on the wooden roller. The grating roller rotates against the clearance space of the adjustable wooden board at the bottom of the hopper, and can be adjusted according to the desired fineness of cassava pulp. The fine grated cassava pulp is then put into clean polypropylene woven sacks and dewatered to remove excess water by pressing using a manually operated vertical screw press. Alternatively, industrial electric motor or engine driven dewatering machines are used. The dewatered pulp is then granulated by crumbling by hand or using pulverising machine into small particles (grits) and spread on mats (polyethylene plastic sheet) placed on raised platforms. The grits are then sun-dried, and can also be dried using a hot air circulation oven drier at 35°C for 12 h. The dried grits are stored until milling into flour.

3.3 Production of starch

Wet milling of cassava is the primary step toward extraction of starch from fresh cassava. Subsequent steps include dilution, filtration, sedimentation, and decantation. Centrifugation of the filtrate can replace a batch step of sedimentation. The sedimented starch can carry impurities. Therefore, after decantation, it is essential to wash the surface of sedimented starch with potable water. The extracted wet starch can be dried through sun drying or oven drying at 35–40°C. Thorough peeling of fresh cassava roots before wet milling is a critical step. Cassava starch extracted from unproperly peeled roots can form a grey colour during wet storage and purple colour during drying (personal observations). Also, starch extracted from bitter cassava varieties are subject to purple colourations during drying (personal observations). The retained colour decreases the quality, and thus affecting the market value. The extraction methods are not standardised, to the extent that workers applied different amount of water for extraction. The ratio of water to cassava slurry of 2:1 was used by Abera and Rakshit [10], while Nand et al. [11] used ratio 10:1 of water to cassava slurry, respectively. In some procedures, grating was performed with sulphur-containing water for detoxification of hydrocyanic acids (HCN). The fresh starch can be stored in sodium meta-bisulphite solution to prevent the microbial growth.

Extracted starch is expressed in terms of percentage starch yield. The fresh cassava roots are washed, peeled, chopped into small pieces and then pulverising in a blender. The pulp is suspended in potable water in the ration 1:10 (the volume of

water 10x the volume of pulp), and the well-stirred mixture is filtered using double cheesecloth. The collected filtrate is allowed to sediment, and after decanting of the supernatant, the sediment is washed six times. The resultant starch is washed using distilled water, and after decanting, the starch is oven-dried at less than 35°C for 24 h. The starch yield is determined based on original weight of peeled and blended cassava.

$$Starch\ yield, \% = \frac{S_f - S_d}{W_o} \times 100 \quad (1)$$

Where, S_f = weight of fresh starch, S_d = weight of dried starch, W_o = original weight of peeled and blended cassava.

Starch is the main component of cassava. The values of starch extraction yield are expressed as fresh weight of peeled cassava and usually reported based on wet weight. Literature showed cassava starch yields in range of 20–35% [12]. On dry weight, the starch content from fresh cassava root is estimated at 80% [13]. Cassava genotype is the major factor influencing starch yields. Mtunguja et al. [14] reported that genotype had huge influence on variability of starch contents and yields, while environmental factors yielded insignificant variations. Similarly, Mejía-Agüero et al. [13] screened and compared starch content among cassava cultivars planted and harvested simultaneously in a single plantation. The authors observed that significant differences in starch contents due to differences in cassava varieties. Therefore, diversity of cassava genotypes accounts for differences in starch extraction rates (yields) and contents. The cassava industry is focused on growing cassava cultivars with high starch yields.

4. Cassava flour particle size distribution

The particle size can affect the pasting and functional characteristics of flours and starches. Ahmed et al. [15] reported that the onset gelatinization temperature decreased from 70 to 60°C with decreasing particle size, which suggested that the smallest particle fraction had a lower initiation temperature of gelatinization because of high water absorption for smaller particle size. Oladunmoye et al. [16] reported that the particle size of flours affects the rate of water absorption during processing as fine particles resulted in faster absorption of water. Lazaridou et al. [17] reported that coarse flour doughs exhibited increased stiffness and resistance to deformation and flow. A study on rice reported that coarse particles had lower solubility compared with fine and medium particles, and large particle size retarded digestion [18]. The reduced digestibility in large particle could suggest application in the formulation of resistant starch products. When wheat flour was fractioned by sieving into finer fractions (<75 and 75–118 μm) and coarser fractions (118–150 and > 150 μm), the finer fractions were reported to produce high-quality bread [19]. Reducing the particle size can strengthen gluten network of dough resulting in shorter development time and longer mixing stability of dough because of fast and high-water absorption [20]. The reduced particle size of cassava flours from 15 to 5 μm were reported to result in a decreased peak, trough and final viscosities [21].

The fractionation of cassava flour from the Zambian varieties was shown in the work of Chisenga et al. [22]. Flour particle size distribution was determined by sieving ~500 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 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 weight on each sieve was measured. The weight of the materials on each sieve was then divided by sample weight to obtain the 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%.

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

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

where: W_{sieve} = weight of fraction retained on the sieve, W_{sample} = weight of the sample.

The weight of sieve and total weight (sieve and flour sample) retained on sieve after sieving is shown in **Table 1**. To obtain weight of sample retained on sieve (**Table 2**), the weight of sieve is subtracted from the total weight. For example, amount retained on sieve 425 μm for Bangweulu is obtained by subtracting 473.99 g from 484.14 g. The difference (10.15 g) is expressed as percentage of total weight of retained samples (**Table 3**). Percentage cumulative for Bangweulu of sieve 425 μm is 4.97% (**Table 4**). The %cumulative on sieve 300 μm is obtained by adding % weight retained on sieve 425 μm (4.97%) and %weight retained on sieve 300 μm (5.57%). Therefore %cumulative on sieve 300 is 10.53% which is then added to % weight retained on sieve 180 μm to obtain 25.10% cumulative on sieve 180 μm, and so forth. The percentage cumulative of flour particles passing finer than sieve size (**Table 5**) is obtained using Eq. (3).

The percent passing (finer than size) was plotted as the function of sieve sizes (**Figure 1**). The limits of D10, D30, D50, D60, and D90 were selected as they are commonly used in the 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. The D10, D30, D50, D60 and D90 were obtained from the plot by performing particle size trend analysis using Excel. For example, particle

Sieve Size (μm)	Weight of Sieve	Total weight of sieve and retained flour sample (g)					
		Ban	Kat	Mwe	Kar	Kam	Chi
425	473.99	484.14	482.4	480.64	485.6	485.94	483
300	325.05	336.43	333.9	332.68	337.94	339.45	334
180	303.96	333.72	323.14	319.7	328.01	334.09	325
150	310.25	325.16	318.6	323.87	318.8	324.92	318
106	310.63	355.5	342.64	371.99	392.07	417.4	432.46
90	280.79	302.98	305.15	313.42	293.55	284.94	292.3
38	442.66	495.13	518.4	493.03	489.13	465.48	462.09
Receiver pan	414.23	432.03	437.34	433.63	427.64	426.72	425.46

Cassava varieties: Ban = Bangweulu, Kat = Katobamputa, Mwe = Mweru, Kar = Kariba, Kam = Kampolombo, Chi = Chila.

Table 1.
Weight of sieve, total weight of sieve and flour samples retained on sieves after sieving.

Sieve Size (μm)	Amount retained on sieve (g)					
	Ban	Kat	Mwe	Kar	Kam	Chi
425	10.15	8.41	6.65	11.61	11.95	9.01
300	11.38	8.85	7.63	12.89	14.4	8.95
180	29.76	19.18	15.74	24.05	30.13	21.04
150	14.91	8.35	13.62	8.55	14.67	7.75
106	44.87	32.01	61.36	81.44	106.77	121.83
90	22.19	24.36	32.63	12.76	4.15	11.51
38	52.47	75.74	50.37	46.47	22.82	19.43
Receiver pan	17.8	23.11	19.4	13.41	12.49	11.23
Total weight retained	203.53	200.01	207.4	211.18	217.38	210.75

Cassava varieties: Ban = Bangweulu, Kat = Katobamputa, Mwe = Mweru, Kar = Kariba, Kam = Kampolombo, Chi = Chila.

Table 2.
Weight of cassava flour samples retained on sieve after sieving.

Sieve Size (μm)	%Weight retained					
	Ban	Kat	Mwe	Kar	Kam	Chi
425	4.97	4.19	3.20	5.49	5.34	4.15
300	5.57	4.41	3.67	6.10	6.43	4.12
180	14.56	9.57	7.57	11.37	13.46	9.68
150	7.30	4.16	6.55	4.04	6.55	3.57
106	21.96	15.97	29.53	38.52	47.70	56.06
90	10.86	12.15	15.70	6.03	1.85	5.30
38	25.67	37.78	24.24	21.98	10.19	8.94
Fines <38	8.71	11.53	9.34	6.34	5.58	5.17

Cassava varieties: Ban = Bangweulu, Kat = Katobamputa, Mwe = Mweru, Kar = Kariba, Kam = Kampolombo, Chi = Chila.

Table 3.
Percentage of weight of cassava flour samples retained on sieve after sieving.

size of Bangweulu flour (312 μm) at D90 was obtained by performing trend formula using Excel (Please see **Figure 2**) on %cumulative finer particles: TREND (B3:B4, C3:C4,90), where B3 = 425 μm mesh, B3 = 300 μm mesh, C3 = 95.03% finer particles passing through 425 μm mesh, C4 = 89.46% finer particles passing through 300 μm mesh.

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 varied with variety. 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 (**Table 6**). The particle size distribution curve on each variety suggested that flours were a mixture of various particle sizes. The variety Kampolombo recorded the largest particle size across the distribution levels

Sieve Size (μm)	% Cumulative retained					
	Ban	**Kat**	**Mwe**	**Kar**	**Kam**	**Chi**
425	4.97	4.19	3.20	5.49	5.34	4.15
300	10.53	8.61	6.87	11.59	11.77	8.26
180	25.10	18.17	14.45	22.96	25.23	17.95
150	32.39	22.34	21.00	27.00	31.79	21.51
106	54.35	38.30	50.53	65.52	79.49	77.57
90	65.21	50.45	66.24	71.55	81.34	82.87
38	90.88	88.23	90.48	93.53	91.53	91.81

Cassava varieties: Ban = Bangweulu, Kat = Katobamputa, Mwe = Mweru, Kar = Kariba, Kam = Kampolombo, Chi = Chila.

Table 4.
Percentage cumulative of cassava flour samples retained after sieving.

Sieve Size (μm)	%Finer particles					
	Ban	**Kat**	**Mwe**	**Kar**	**Kam**	**Chi**
425	95.03	95.81	96.80	94.51	94.66	95.85
300	89.47	91.39	93.13	88.41	88.23	91.74
180	74.90	81.83	85.55	77.04	74.77	82.05
150	67.61	77.66	79.00	73.00	68.21	78.49
106	45.65	61.70	49.47	34.48	20.51	22.43
90	34.79	49.55	33.76	28.45	18.66	17.13
38	9.12	11.77	9.52	6.47	8.47	8.19

Cassava varieties: Ban = Bangweulu, Kat = Katobamputa, Mwe = Mweru, Kar = Kariba, Kam = Kampolombo, Chi = Chila.

Table 5.
Percentage cassava flour sample particles passing through finer than sieve.

except at D10 and exhibited a smaller amount of flour passing at all sieve sizes except at lowest aperture sieve (38 μm). Particle size can be a differentiating genetic trait among cassava varieties. In this study, cassava genotypes were cultivated simultaneously on a single plantation and harvested at the same time, with the same milling conditions. Thus, the variation in flour particle size was attributed to genetic differences among the cassava varieties [23]. The selection of sieve is guided by product nature because decreasing cumulative of particles passing finer than sieve results in reduced proportion amount of flour. In this study, D90 was selected for bread baking since it yielded a large proportion amount of flour in the range 90–96% finer particle at sieve size 300–425 μm, respectively.

4.1 Bulk density

The bulk density (g/cm^3) of flour is the density measured without the influence of any compression. The bulk densities of cassava flours are reported in the range 0.40–0.50 g/cm^3 [22] and 0.60–0.70 g/cm^3 [24]. These values are lower than 0.80 g/cm^3 reported in wheat flour. The bulk density is reported to associate positively with moisture, protein and lipid content, and negatively with fibre.

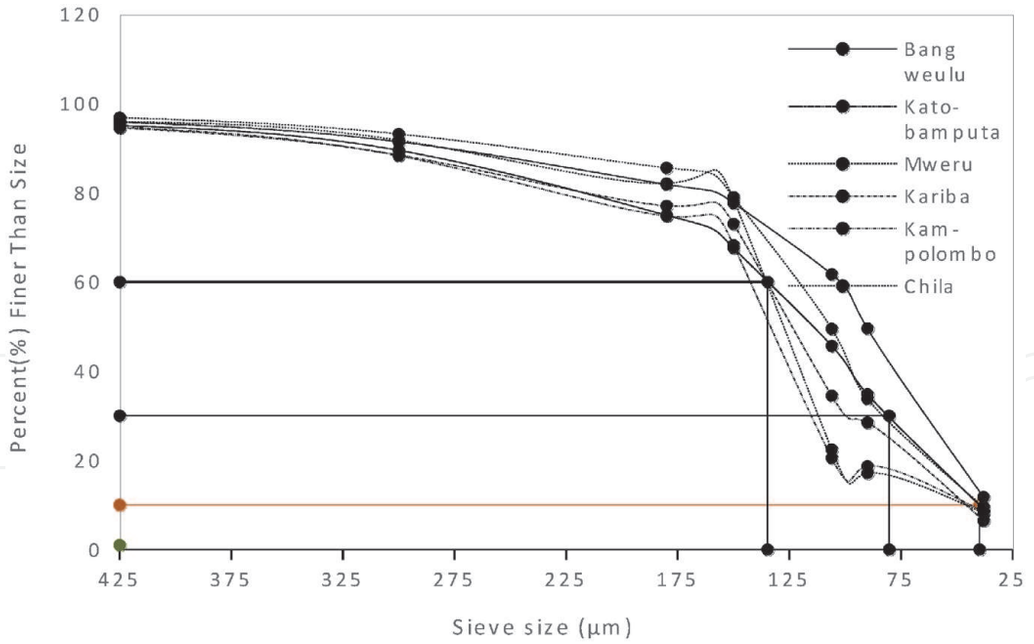

Figure 1.
Particle size distribution curves for cassava flours from six different varieties at selected percentage cumulative of particles passing finer than standard sieve size at 5% significance level LSD test (Variety = 0.055, Sieve size = 0.059). Classification and uniformity criteria of D10, D30, and D60 for the particle size distribution of flours derived from Bangweulu variety using TREND in Excel. Adapted from the work on Zambian cassava varieties [22].

	A	B	C	D	E	F	G	H
1	Sieve		%Finer particles than sieve size					
2	Sieve size (mm)	Sieve Size (µm)	Ban	Kat	Mwe	Kar	Kam	Chi
3	0.425	425	95.03	95.81	96.80	94.51	94.66	95.85
4	0.3	300	89.47	91.39	93.13	88.41	88.23	91.74
5	0.18	180	74.90	81.83	85.55	77.04	74.77	82.05
6	0.15	150	67.61	77.66	79.00	73.00	68.21	78.49
7	0.106	106	45.65	61.70	49.47	34.48	20.51	22.43
8	0.09	90	34.79	49.55	33.76	28.45	18.66	17.13
9	0.038	38	9.12	11.77	9.52	6.47	8.47	8.19

Figure 2.
Excel sheet used for performing TREND Analysis. Cassava varieties: Ban = Bangweulu, Kat = Katobamputa, Mwe = Mweru, Kar = Kariba, Kam = Kampolombo, Chi = Chila.

	Percentage cumulative				
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}

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 6.
Flour particle size at selected percentage cumulative of particles passing finer than sieve size.

This suggests that flour with high bulk density contains high protein and lipid contents. Oladunmoye et al. [25] ascribed low bulk density in cassava flour to low protein and fat content of cassava flour. Flours with high bulk density exhibit low fibre content, implying that decreased fibre content results in finer flour particle size. Chandra et al. [26] revealed that bulk density depends on the particle size and initial moisture content of flours. The study on roasted Bengal gram flour showed that an increase in moisture content resulted in an increase in bulk density [27]. This means that bulk density increases with increase in moisture content. The strong negative correlation between bulk density and particle size [22] suggests that flours with smaller particle size at specified mesh size can yield higher bulk density. The bulk density values can find application in packaging, handling, and processing requirements.

4.2 Packed density

The packing of powder is the indication of the maximum packing density of flours attained under the influence of defined externally applied forces. The packed densities are 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, compactable, properly tapped/vibrated and with suitable packaging material. Bulk density influences flowability of flours, package design and can be used in determining the requirements of packaging material [28]. The denser packaging materials are required for packing flours with higher bulk densities. The increase in packed density is desirable as it offers greater packaging advantage as a greater quantity may be packed within a constant unit volume.

The methods to determine bulk density and packed density have been reported [22, 24]. The bulk density is determined by adding 50 g of flour sample to a graduated cylinder, and the volume recorded.

$$Bulk\ density,\ g/cm^3 = \frac{V_b}{Weight\ of\ sample} \tag{4}$$

where: V_b = volume of flour.

The tapped density is determined by mechanically tapping (100x) a graduated cylinder containing flour sample (V_b) until no further volume change was observed. The final volume [29] recorded.

$$Packed\ density\ g/cm^3 = \frac{V_b - V_f}{Weight\ of\ sample} \tag{5}$$

where: V_f = final volume.

4.3 Root dry matter content

The dry matter content is used as a basis for accepting raw materials in the food industry. In addition, dry matter content is often used by breeders as a proxy for starch content when selecting cassava varieties. Dry matter content levels of above 30% are considered to be high. The differences in dry matter content among the varieties can be associated with months after planting. Teye et al. [30] reported dry matter content in the range of 30–40% for cassava root that were harvested at 13 months after planting, which are lower than the values (40 and 50%) for cassava roots harvested 18 months after planting [22]. The factors influencing dry matter

content include harvest age, seasons and growing locations. Beyene et al. [31] reported that bio-fortification of nutrients in cassava reduced dry matter contents.

The dry matter content can be determined by taking 200 ± 05 g fresh peeled cassava roots from undamaged roots selected randomly from 3 plants after medial sections are chipped into strips, mixed thoroughly and dried at 65°C, 72 h until constant weight. The dry matter content is estimated as the difference between the mass before drying and the mass loss on drying.

$$Drymatter\ content, \% = \frac{W_f - W_d}{W_f} \times 100 \quad (6)$$

where: W_f = weight of fresh cassava strips, W_d = weight of dried cassava strips.

4.4 Cyanide glucoside content

Cyanide glucosides content in cassava is a limiting quality trait for both human and animal consumption. The level of cyanides in roots and flours is an important trait for selecting cassava varieties in breeding programs. Consumption of high dietary cyanides causes konzo, a permanent neurological condition, causing spasticity. 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 elderly people, a progressive myeloneuropathy that was first described in Nigeria and is characterised by a progressive onset of ataxia [32]. Cassava roots have been reported with high levels of cyanides (1090–1550 ppm) [33]. Other studies reported low levels of cyanides (23–350 ppm) [22]. The cyanides can vary with genotype and environment. The variation due to environmental was demonstrated in Tanzania by Mtunguja et al. [14], and the authors observed that the variety Kiroba recorded 800, 200, and 40 ppm of extracted cyanides from three separate regional sites (Chambezi, Amani and Magadu), respectively, at 15 months after planting. The variations due to genotype was shown in Chisenga et al. [22] the study in which the varieties were cultivated at the same site and were rain fed. The differences in cyanide levels among varieties were assumed to relate with genotype and water stress. Water stress experienced during the rainy season may cause a variation in cyanide levels [34]. The root cyanide levels were associated with genetic traits, protein and fibre content. The xylem and phloem are fibrous nature [35], and can retain higher cyanides after harvest. Cassava roots contain cyanides in different forms. The glycosides linamarin and lotaustratin are considered bound [36]. The non-glycosides which are hydrogen cyanide (HCN) and cyanohydride are considered free [37] and would be leached during processing. The cyanogens can lead to human toxicity problems and would require that cassava for food is processed to reduce cyanide-containing substances to safe levels. There are many cultivars of cassava and are classified as bitter and sweet varieties depending on the cyanogenic glucoside levels. The bitter and sweet varieties have high (≥ 100/mg/kg) and low (≤ 50 mg/kg) HCN content respectively. Cassava is consumed in various forms which may vary across countries. Generally, one target of cassava processing is to reduce its cyanogenic glucoside content to the lowest level possible.

Primary techniques of processing cassava are developed with a common goal of reducing cyanogens to safe levels in shelf-stable products such as cassava flour, chips, and starch. The processed cassava flours showed cyanide reduction levels of 60–90% compared to the levels in fresh cassava roots [22]. The method of processing is vital for reduction of cyanogens. Cyanides are largely removed by the traditional processing methods such as grating, dewatering (pressing), fermenting,

and drying. The highest level of cyanides retention in some cassava derived products could suggest that the cyanogens are chemically bound. The improved varieties referred to as sweet varieties have lower cyanides retention levels, which could indicate the higher levels of free cyanides such hydrogen cyanide and cyanohydride are readily extracted, or have higher levels of linamarase, which degrades cyanogenic glycosides. Hydrogen cyanide and cyanohydride are soluble in water and volatile (25°C boiling point). The total cyanide content can be reduced by soaking and air drying at low temperatures (28–40°C), which combines the enzymic action of linamarase with water extraction and volatilisation. Cassava varieties are classified as sweet varieties when their extracted cyanide values are in the range 15–50 ppm, and as bitter variety when their values are from 50 to 400 ppm of fresh cassava [34]. The recommended safe level of cyanides in a final food product is 10 ppm (FAO/WHO). Since cassava flour is a raw material, the total cyanide level is expected to reduce further down the processing stream. The temperatures for proofing (30–32°C) and baking (178–193°C) for bread making can significantly reduce cyanide levels in the final product.

4.5 Fungal contamination

Cassava raw materials (chips and flours) are subject to attacks by fungi such as Aspergillus, Fusarium and Penicillium during storage and distribution. These fungal contaminations can lead to mouldy taste, discolouration, and production off odours. In addition, the contamination can lead to production of mycotoxins of serious safety and health concerns. Some of the mycotoxins of public health importance include aflatoxins, fumonisins, ochratoxin A, zearalenone and deoxynivanelol [38] and harmful to animals and humans. The mycotoxins can act as nephrotoxins, hepatotoxins, immunotoxins, neurotoxins, teratogens, or carcinogens, however, the kidney is the primary target for toxicity. The quantity of mycotoxins in food and feed is strictly monitored and regulated by the bureau of standards in most of member states of World Trade Organisation. It is the common practice for food companies to inspect raw materials for presence of fungal and mould growth on receipt and during storage of raw materials. However, this method is limited to detecting fungal at visible growth level. Nevertheless, the recent advances in detection techniques accounts for the use of electronic nose system capable of early detection and identification of fungal [39]. The electronic nose technique involves analysing air in the vicinity of fungal and records of which are analysed using Principal Component Analysis.

4.6 Proximate composition

The chemical composition is cultivar dependent, and varies according to geographical location, maturity stage of the plant, and environmental conditions. On the wet basis, fresh cassava root is composed of 56–60% moisture, 0.3–0.6% protein, 30–35% carbohydrate, and 0.1–0.3% fat (**Table 7**). Moisture content is one of the most common tests in foods because the water content in food products influences the interaction between preservation and chemical-, physical- and microbiological- changes during storage. On the dry basis, 8–12% moisture levels are recommended for shelf stability. It is difficult to compare chemical constituents based on data derived from literature because analyses were based on different cassava varieties, variation in harvest time, and lack of complete description of sample materials in terms of genotypic traits, and insufficient information about the colour of the flesh (yellow or white fleshed cassava). Cassava is rich in carbohydrates and deficient in proteins and fats. On a dry matter basis, cassava root has

Cassava source, Country	Number of variety	White/yellow fleshed	Harvest time	Moisture (%)	Ash (%)	Protein (%)	Lipids (%)	Fiber (%)	Reference
Gannoruwa, SriLanka	1	-	-	62.92	-	0.72	0.41	0.92	[40]
Mansa, Zambia	6	White	18	10-11	1.16-1.80	1.21-1.87	0.15-0.63	0.03-0.60	[22]
Umudike, Nigeria	3	-	10	61.05-69.95	-	-	-	-	[41]
Umudike, Nigeria	3	-	13	62.85-70.21	-	-	-	-	[41]
Umudike, Nigeria	3	-	16	49.96-62.02	-	-	-	-	[41]
Pokuase, Ghana	6	-	12	33.14-45.86	-	1.76-3.48	0.74-1.49	1.38-3.20	[42]
Nassau, Bahamas	6	-	9	56.50-68.80	2.27-3.24	1.20-2.10	0.20-041	-	-
Chapare, Bolivia	6	-	-	-	1.46-2.71	1.46-2.49	0.58-1.4	7.40-8.50	[43]
IITA Ibadan, Nigeria	2	-	-	55.44-58.79	1.90-2.84	0.90-1.43	-	3.62-5.45	[44]
Nokornratchasrima, Thailand	1	-	10	-	2.41	1.83	0.14	1.79	[45]
Nokornratchasrima, Thailand	1	white	12	-	2.52	1.41	0.08	2.59	[45]
Umudike, Nigeria	1	white	-	12.28	1.92	-	0.95	1.78	[24]
Umudike, Nigeria	5	yellow	-	8.40-9.85	1.44-2.35	-	0.80-2.75	1.65-2.32	[24]

MAP = months after planting, hyphen (-) implies value or information not found. Dry matter basis, analysis based on dried cassava samples. Wet basis, analysis based on fresh cassava samples.

Table 7.
Proximate composition of different cassava varieties.

carbohydrate content of 70–82%, which is made up of starch containing amylopectin and amylose. Nevertheless, carbohydrate contents are season depenedent, and converts into sugars during hot and rainy season. These changes results in decreased starch yields, and this necessitate the need for optimal harvest time depending on genotype and geographical location.

The differences in proteins among the varieties can be accounted for in terms of environmental conditions such as soil fertility levels and environmental conditions. Nitrogen rich fertiliser contributed to increased protein contents in cassava varieties from the range of 4.3% unfertilized to 9.6% in fertilised varieties [46]. However, these results reported levels of protein in cassava flour that are far higher than other studies. The high levels, however, could have been due to the measurement of additional nitrogen from cyanogens 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, which may be attributed to proteins. Moreover, the study Chisenga et al. [22] showed that proteins correlated positively with cyanogen contents in the roots. Nevertheless, protein in cassava flours can influence pasting properties. The entanglement of protein and starch is responsible for viscosity changes during gelation, and the resulting matrix can restrict swelling of starch granules. Proteins can bind water and limit starch swelling at low heating temperature. The negative association between protein and carbohydrates follows the 'dilution hypothesis', which explains the reduction of molecular interactions between protein molecules (aggregation) by increased saccharide contents [47]. During drying, saccharide replaces water molecules bonded to proteins. The elimination of water may alter the binding sites of proteins, which affects their activities, and presumably decreases the protein content.

Lipid such as monoglycerides and phospholipids can form a liquid-crystalline phase with water through hydrophilic (polar heads) or hydrophobic (methyl) groups. The polar lipid, due to their surface-active nature, accumulates at interfaces [48], and have a tendency to absorb water, which justifies their positive association with moisture in flours. The formation of amylose-lipid complexes is reported to increase viscosity levels achieved during starch pasting.

Ash content is an indicator of mineral content, and is used as measurement of the quality of flours in the food industry. The ash content of cassava varies 1–2%. Fibre is a major contributor to ash contents in varieties. Related studies showed that wheat flour varieties with higher fibre content had a higher ash content [49]. The objective of milling and fractionation is to separate the fibrous residue from the flour. The determination of ash content involves incinerating a known weight of flour under controlled conditions, weighing the residue, and calculating the percentage of ash based upon the original sample weight [50].

Studies showed that fibre contents associated negatively with smaller particle size, and positively with larger particle size and dry matter content of cassava flour. This suggests that high fibrous cassava flour would be characteristically coarse, while less fibrous flour would be finer. In addition, higher dry matter contents are likely to be associated with high levels of fibre and larger flour particle size. The negative interaction between fibre and ash content is indicative of the loss of mineral content in high fibrous cassava roots during dewatering (pressing). There could be a high level of nutrients release (loss) from highly permeable fibre during processing [51]. Furthermore, the negative correlation between fibre content and moisture content confirms that the high fibre cassava have lower moisture content. Edible fibres are mainly composed of polysaccharides such as cellulose, hemicellulose and pectin. The matrix combining cross-linking hemicelluloses and cellulose microfibrils with an inter-penetrating pectin network gives strength and rigidity to the cell wall. In cellulose, a system of micro fibrils composed of close packing of

unbranched β-1,4-glucan chains through intra- and inter-molecular hydrogen bonds, makes this polymer impermeable and water-insoluble [51]. Fibre is quick 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 functions as a plasticiser and controls porosity [52], and depending on porosity, there could be differential moisture responses among the varietal genetics. In addition the fibre content in cassava flours have been observed to increase while protein and lipids decreased with increases in the age of the plant [52].

The total carbohydrate contents on dry matter basis associates negatively with other proximate contents (protein, lipid, fibre, ash and moisture). Carbohydrates bind proteins through hydrogen bonding via hydroxyl group on saccharides and amine group on proteins, which may result in highly carbonyl-substituted carbohydrates, and subsequently loss of protein activity and availability. Carbohydrates also interact with lipids to form glycolipids through glycosidic bonds, and this reduces the levels of free lipids. Carbohydrates binds water molecules through hydrogen bonding [53], hence limiting water mobility, which explains the inverse relationship between moisture and carbohydrates.

4.7 Amylose content

The extracted starch is a biopolymer of two major polysaccharides, namely amylose and amylopectin. The amylose is the principal molecule for classifying starches into waxy, semi-waxy, normal/regular and high amylose types when amylose content is 0–2, 3–15, 16–35, and > 35% of the total starch, respectively [54]. Waxy cassava varieties containing zero amylose content by weight was reported [55]. The common cassava varieties are mostly normal/regular starches. High amylose starches are reported in maize varieties [56], which implies that these corn varieties contained high content of amylose by weight, while wheat and potato are commonly regular starches. Amylose content can be suggested as a basis for selecting flours/starches from different botanical sources for blending application. Starches with similar amylose contents can exhibit similar functionalities. Amylose content is the basis of ascertaining *in vitro* enzyme susceptibility of cassava starch to α-amylases. Amylose content was reported to relate negatively with cassava starch digestibility [57]. This relationship suggests that amylose resist α-amylases digestibility. The resistance of a starch material to digestion is related with the extent of starch availability to enzymatic hydrolysis in the human digestive system [58]. The resistant starch (RS) and inclusion in human diets have elicited interest because it restricts calorie load for individuals such as diabetic patients [59]. RS is a dietary fibre that does not get digested in the small intestine and has the potential for human health benefits [59]. The RS concept could be utilised as the basis of describing nutrition quality and potentially as a criterion parameter for classification of cassava varieties in slowly and fast digestible starches.

4.8 Colour

The colour of cassava flour and extracted starch is commonly described using whiteness index and chroma. The whiteness of flours can be analysed using a HunterLab ColorFlex instrument (Hunter Associate Laboratories Inc., Reston, CA, USA). The colour parameters of flours regarding 'L' (degree of lightness), 'a' (redness to greenness) and 'b' (yellowness to blueness) are measured after being

standardised using Hunter Lab Colour Standards of Hunter L^*, a^*, and b^*. The whiteness index can be calculated using the equation:

$$Whiteness\ index = 100 - \left[(100 - L)^2 + a^2 + b^2\right]^{\frac{1}{2}} \quad (7)$$

$$Chroma = \left(a^2 + b^2\right]^{\frac{1}{2}} \quad (8)$$

where: L* = lightness, a* = redness to greenness, b* = yellowness to blueness.

The whiteness index values of the cassava flours were reported, 90–92 [22] and 80–90 [60]. The whiteness of flour is influenced by drying temperature and time. Higher temperatures and longer times can impact scorching effect on flours, and may show increased a* (redness) and b* (yellowish) values, which contributes to decreased whiteness. The whiteness of flour exhibits positive association with L*, and negative with a* and b*. The high whiteness index values are indicative of low a* and b* values, and high L* values. Elevated oven drying temperatures can cause scorching and discolorations leading to reduced lightness. Moreover, high temperatures combined with high moisture content of flours, can gelatinize the flours leading to loss of birefringence properties which can affect the pasting quality of cassava flours. The redness-greenness (a^*) and yellowness (b*) are considered impurities in white flours. The source of impurities redness/greenness in cassava flours are possibly due to the residue of cassava peels. The yellowness (b^*) of the cassava flours can be due to inadequate dewatering of grated cassava. The a* and b* are reported to associate positively with ash content in wheat flours [61], which implies that high ash contents can influence the whiteness of flours and subsequent products such as bread. Additionally, high mineral content can accelerate metal chelating activities to form metal ion-pigment complexes, which can confer greenness/redness or yellowness (b*) colour on the final flour product. The negative relationship of whiteness index with ash content along with a* and b* as shown in Chisenga et al. [22] is consistent with the above theories because starchy vascular ground tissue of white fleshed cassava do not contain pigments, whereas the formation metal ion-pigment complexes are prominent in the cassava peels. The dewatering stage is the critical quality control point. The water in the fresh cassava is the medium of reactive oxygen species (oxidants) [62], and can taint the flours yellowish during drying. In addition, the yellowness may be due to residual procarotenoids compounds or minor Maillard and/or caramelization reaction products formed on drying. During processing toward flours, it requires that the available water is expressed out from the grated cassava followed by granulating of pulp before drying. Granulation with use of pulverizer or hands is critical to crumble the mass into smaller particles for an increased surface area during drying.

5. Influence of chemical composition on physicochemical properties

The presence of non-starch compounds (lipids and proteins) are reported to have negative influence on swelling power of starches. The protein compounds can restrict swelling of starch granules in plasticizing water [63] due to increased hydrophobicity which limits uptake of water [64]. However, lipids and proteins are minor components of cassava starch, and may not limit swelling of starches. This could explain the highest swelling power and solubility values for cassava starches when compared to those reported for corn, wheat and potato starches [65, 66]. It is worth noting that swelling power and solubility of starches are in function of amylose contents. The negative correlation between swelling power and amylose

content was reported [57]. In addition, Sanchez et al. [67] reported that waxy cassava starches (containing less amylose) showed highest swelling powers. Swelling of starches in water results in release of soluble matters including amylose. However, presence of lipid can influence formation of lipid-amylose complex, and can restrict exudation of amylose [66] which could yield lower swelling power. The presence of amylose-lipid complex lowers gelatinization of starches. Lipids may impact diffusion of water into the starch granules, and their presence on starch granules was reported to reduce gelatinization. Li et al. [68] showed that defatted starch yielded lower gelatinization temperatures. The protein and starch granules compete for water molecules [69] which probably leads to inhibited swelling resulting in delayed gelatinization, and hence higher gelatinization temperatures.

Amylose contents influences pasting behaviour of starches in a food system. The lower amylose cassava starches (waxy) exhibited a narrow range of viscosities [70]. This implies that waxy starches are likely to limit exudation of amylose which could probably lead to decreased solubility, and hence reduced viscosity. The higher contents of proteins and lipids, and subsequent formation of lipid-amylose complex could be the reason for higher pasting temperatures in cereal and potato starches. At higher gelatinization temperatures, cassava starches form a clear paste with high starch paste viscosity. The chemical components such as amylose may affect light transmittance of starch gels. Paste clarity tend to relate negatively with amylose content. The waxy cassava starches are associated with high paste clarity and high swelling power [70].

6. Conclusion

Dry matter content, starch yields, particle size, and composition (protein, lipid, ash, fibre, moisture) including cyanide contents are some of the primary quality traits for selecting cassava raw materials. Flour particle size distribution can influence uniformity and efficiency of processing systems. Grating and dewatering are two operation steps considered as critical quality control points in the primary processing of transforming cassava roots into safe shelf-stable product. Reduction of cyanide contents in fresh cassava roots can be achieved through grating and dewatering. To achieve good shelf stability of raw materials, moisture levels <12% are recommended during storage. The high whiteness index and low ash content are some of the primary desirable quality traits for application of cassava flours in the food and non-food industry. Amylose content is basis of classifying flours into regular, waxy and high-amylose, and can be used as primary criteria for blending flours of same or different botanical sources. Amylose content influences starch digestibility and resistant starch content. The concept of resistant starch can be criterion parameter for describing nutrition quality and classification of cassava varieties in slowly and fast digestible starches.

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