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Effect of Extrusion on the Functional and Pasting Properties of High-quality Cassava Flour (HQCF)

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Abstract

Cassava is a rich source of starch and is used as a food ingredient and additive. In its natural state, cassava flour or starch cannot meet all functional requirements in food processing. This necessitates the modification of starch to meet specific functional requirements for products and processes. This study investigated the effect of different extrusion conditions, such as moisture content, screw speed, and temperature on the functional and pasting properties of high-quality cassava flour (HQCF). Particle size distribution, functional and pasting properties of the HQCF were determined. Moisture content (MC) had a significant effect on the properties of HQCF. Water absorption capacity (WAC) increased from 245% to 732%, swelling power (SP) increased from 3.4 g/g to 7.2 g/g, and water absorption index (WAI) increased from 3.0% to 3.3% after extrusion at 40% MC. While at lower MC levels, bulk density (BD) increased from 0.7g/ml to 0.8g/ml for the non-extruded and 30% MC; oil absorption capacity (OAC) from 215% to 253% for the non-extruded and 10% MC; water solubility index (WSI) from 6.0% to 56% for the non-extruded and 20% MC respectively. A positive correlation was observed between extrusion parameters and functional properties. The results suggest that manipulation of extrusion conditions can be used to modify HQCF for varied food applications.

Keywords: cassava, extrusion, flour, functional properties, modification

1. Introduction

Cassava (*Manihot esculenta* Crantz) is a substantial source of revenue for small-scale farmers and plays an important role in food security (Aristizábal, García, & Ospina, 2017; Kacou, Elvis, Ekissi, Ebbah, Djedji, N'zué, & Kouamé, 2018). Cassava is a rich source of starch and is used as a food ingredient and additive (Dini, Doporto, Vina, & García, 2014). In its natural state, however, starch is unable to provide all of the desired functions in food processing (Leonel, Zhang, Ying, & Fang, 2009). This demands starch modification to fulfill specific functional requirements for products and processes (Olusegun, Francis, & Ainamensa, 2017).

Different ways have been used to modify starches, including physical, chemical, and biological methods (Leonel et al., 2009). Chemical modification entails inserting functional groups into starch molecules which results in significantly altered physicochemical properties. Acetylation of starch, for example, has been shown to boost the swelling power and solubility of starch from various sources (Kushwaha & Kaur, 2019). Studies on acetylated maize, potato, and rice starches by several authors revealed a considerable increase in swelling strength and solubility (Kushwaha & Kaur, 2019).

Physical modifications such as heat-moisture, steam-pressure treatments, annealing, and other non-thermal procedures are all used to modify starches physically (Kushwaha & Kaur, 2019). Physical treatments entail treating native starch under a variety of temperature-moisture and pressure conditions. Starch can be physically modified to increase its water solubility (Alcázar-Alay & Meireles, 2015; Kushwaha & Kaur, 2019). The use of drum drying, spray drying, and extrusion to pre-gelatinized starch increases water absorption and water solubility index (Alcázar-Alay & Meireles, 2015; Kushwaha & Kaur, 2019). Current works are investigating new ways of starch modification, such as superheating of starch (Kushwaha and Kaur, 2019) thermally inhibited treatment (dry heating) (Kushwaha and Kaur, 2019), and osmotic pressure treatment (Kushwaha & Kaur, 2019).

The functional qualities of gluten-free loaves of bread were improved by pre-treating cassava roots with a citric acid solution before milling into flour, using 30% cassava flour substitution, and resulted in satisfactory loaves of bread (Aristizábal et al., 2017).

Extrusion is a process that uses high temperature and short time (HTST) to cook food products (Byaruhanga, Kassozi, Wafoyo, Mugoya, & Masiga, 2014; Alcázar-Alay & Meireles, 2015). Extrusion is a multipurpose, effective, and low-cost way of producing food with very little waste accumulated during the process (Alam, Kaur, Khaira, & Gupta, 2016; Atukuri, Odong, & Muyonga, 2019). It can be used to manufacture low bulk density instant flours with higher nutrient density which are better than the raw flours (Atukuri et al., 2019).

The primary goal of flours extrusion is to modify their functional properties (Martínez, Oliete, Román, & Gómez, 2014). Cereals are the main raw materials used for extrusion cooking because of their good expansion characteristics (Pasqualone, Costantini, Coldea, & Summo, 2020). Extrusion cooking of cereals is a critical process in the food industry because it affects a wide range of products (Oladiran & Emmambux, 2018) such as snack foods, baby foods, breakfast cereals, noodles, pasta, and cereal-based blends (Planini, Pavokovi, & Blazi., 2012; Zhu, Adedeji, & Alavi, 2017; Forsido, Duguma, Lema, Sturm, & Hensel, 2019). Extruded foods attract consumers because of their appearance, texture, and convenience (Pasqualone et al., 2020). Extrusion cooking is used to make better use of food waste, and to introduce and manufacture foods rich in dietary fiber (Oladiran & Emmambux, 2018).

Extrusion technology has been used to improve the structure of cereals, as well as their solubility, swelling power, water hydration viscosity, and water holding capacity (Alam et al., 2016). It has been demonstrated to alter the functional properties of cassava starch, including water absorption (Shittu, Alimi, Wahab, Sanni, and Abass, 2016), water retaining (Akinwale et al., 2017), swelling power (Shittu et al., 2016), and pasting qualities (Shittu et al., 2016). It has the potential to generate greater alterations to starch than typical cooking methods (Martinez et al., 2014). Additionally, it can be used to modify cereal flavor with desirable textural attributes for consumer acceptability (Zhu et al., 2017).

The effects of extrusion cooking on the physio-chemical characteristics and microstructure of cell walls on onion waste were evaluated by Alam et al. (2016). The results show that extrusion cooking increases the solubility of pectin polymers and hemicelluloses accompanied by an increase in swelling of the cell-wall material (Alam et al., 2016). Extrusion has also proven to increase the content of soluble fiber of fibrous materials such as plant cell walls, brans, and hulls of several cereals and legumes (Alam et al., 2016). Most work done on the extrusion of cassava has been with the blend for product formulation. Little extrusion work has investigated high-quality cassava flour as a modified ingredient for food applications. This work investigated the effect of varying extrusion conditions on the functional and pasting properties of High-Quality Cassava Flour.

2. Materials and Methods

2.1 Preparation of Cassava Flour

Cassava flour was made according to the methods of Oladiran and Emmambux (2018) with few modifications. Fresh roots of the NAROCASS1 cassava variety were obtained from National Crop Resources Research Institute (NaCRRI), Namulonge Kampala, Uganda. The cassava was peeled, washed, and grated. The grated cassava was transferred to a tray and dried in a hot air oven (LTD-5D MULTI-LAYER DRYER, SHANDONG LIGHT M&E Co. Ltd, Shandong, China) for 3 hours 40 minutes at 50 ^{o}C. After drying, the cassava flakes were milled into flour and packaged in air-tight bags awaiting further treatment and analysis.

2.2 Extrusion Process

Extrusion was carried out using a twin-screw extruder (LT70-L Twin Screw Extruder, Shandong Light M&E Co. Ltd, Shandon, China). Extrusion was operated at conditions: temperature (60 ^{o}C) and screw speed (40 rpm). For each run, cassava flour was fed into the extruder at 20 kg/hr. After extrusion, the extrudates were dried in a hot air oven (LTD-5D Multi-Layer Dryer Shandong Light M&E Co. Ltd, Shandong, China) at 50 ^{o}C for 5 hours. After drying, the extrudates were cooled to 25 ^{o}C, then milled into flour and stored in air-tight bags until further analysis.

2.3 Treatments

The treatments in this experiment were varying amounts of water added to the HQCF before extrusion. The added amounts of water were: 10, 20, 30, and 40% (w/w). The control was HQCF that was not extruded.

2.4 Proximate Composition

Proximate composition, namely crude protein, carbohydrate, fat, moisture content, dietary fiber and ash content of the cassava flour was determined using standard AOAC (2016) methods.

2.5 Functional Properties

2.5.1 Pasting Properties

Pasting properties were determined using Rapid Visco Analyzer (RVA 4500 Perten) (Newport Pty. Ltd. Warriewood, Australia) as described by Atukuri et al. (2019). Cassava flours (3.5 g) of each sample were weighed and added to 25 ml of distilled water in a canister and mixed, the mixture was loaded to the RVA and ran. Test runs were carried out using standard profile. Stirring and warming up were done in 1 minute at 50 ^{o}C, heating for 3.7 minutes at 11.16 ^{o}C/minutes up to 95 ^{o}C; 2.5 minutes of holding at 95 ^{o}C; 3.8 minutes of cooling down to 50 ^{o}C at 11.84 ^{o}C /minutes, and 2 minutes of holding at 50 ^{o}C. Stirrer speed (160 rpm) was used throughout the analysis and the entire process lasted approximately 13 minutes. The following parameters were measured: Peak viscosity, trough, breakdown, final viscosity, setback, peak time, and pasting temperature.

2.5.2 Bulk Density

The bulk density (BD) was determined using a method described by Atukuri et al. (2019). About 4 g of Cassava flour was weighed into a 10 ml cylinder in triplicates. The cylinder was gently tapped on a laboratory bench until no further diminution and flour filled to the volume mark. This was done to eliminate air spaces. The volume was recorded after taping, and the results were calculated and expressed as a weight-to-volume ratio using equation (1).

$$Bulk\ density\ \left(\frac{g}{ml}\right) = weightof\ sample\ (g) \div Volume\ of\ sample\ (ml) \tag{1}$$

2.5.3 Water Absorption Capacity

The water absorption capacity (WAC) was determined by the method described by Chandla, Saxena, & Singh (2017). About 2.5 g of cassava flour was measured and placed in a 50 ml falcon tube, 30 ml distilled water was added to the tube and mixed. The sample was agitated for 10 minutes and centrifuged (Thermo Scientific, Megafuge 8) at 3,000 rpm for 10 minutes. The free water recovered from the sentimental flour sample was removed and the tube was drained for 10 minutes to separate the surface water, and water absorption capacity was calculated using equation (2).

$$WAC = weight\ of\ sediment \div weight\ of\ sample \times 100 \tag{2}$$

2.5.4 Oil Absorption Capacity

The oil absorption capacity (OAC) was determined using the method of Chandla et al. (2017). About 2.5 g of cassava flour was measured and placed in a 50 ml falcon tube, and 30ml of vegetable oil was added to the tube and mixed. The sample was then agitated for 10 minutes and centrifuged (Thermo Scientific, Megafuge 8) at 3,000 rpm for 10 minutes. The free oil recovered from the sentimental flour sample was removed and the tube was drained for 10 minutes to separate the surface oil, and oil absorption capacity was calculated using equation (3)

$$OAC = weight\ of\ sediment \div weight\ of\ sample \times 100 \tag{3}$$

2.5.5 Water Absorption and Solubility Index

Water absorption and solubility index (WAI and WSI respectively) were determined using the method of Atukuri et al. (2019). A portion (3 g) of cassava flour was measured and mixed with 25 ml of distilled water in a 50 ml falcon tube and heated in a water bath (Grant, Sub Aqua 18) for 15 minutes at 90 ℃. The cooked paste was cool at room temperature and centrifuged (Thermo Scientific, Megafuge 8) at 1,500 rpm for 20 minutes. Afterward, the supernatant was decanted into a pre-weighed moisture dish to determine the solid content and the sediment weight. The weight of dry solids was obtained by evaporating the supernatant overnight at 105 ℃, and the Water absorption Index and Water solubility were calculated using equations (4) and (5) respectively.

$$\mathrm{WAI} = \text{weight of sediment} \div \text{weight of sample} \tag{4}$$

$$\mathrm{WSI} = \text{weight of dissolved solid in supernatant} \div \text{weight of the sample} \tag{5}$$

2.5.6 Swelling Power

Swelling power was analyzed following the method described by Chandla et al. (2017). Cassava flour (0.5 g) of each sample was placed in a 50 ml falcon tube, mixed with 25ml of distilled water, and heated in a water bath (Grant, SUB Aqua 18) at 60 ^{o}C for 30 minutes, with gentle shaking. Afterward, the samples were centrifuged (Thermo Scientific, Megafuge 8) at 1600 rpm for 15 minutes. The precipitated part was weighed and calculated using equation (6).

$$\text{SP} = \text{sediment weight(wet mass)} \div \text{weight of the sample} \tag{6}$$

2.6 Particle Size Distribution

Particle size distribution was determined according to the methods described by Sonaye and Baxi (2012). Approximately 100 g of the flour sample was weighed and poured into the top sieve containing the screen opening of 0.35 mm. Each lower sieve in the column had a smaller opening than the one above and a receiver at the base. The column was then placed in a mechanical shaker (MRC Laboratory Equipment, model TSS-200, Hz 50; Serial No. 108041502) and shaken for 10 minutes at 3 rpm. After the shaking was completed, the material on each sieve was weighed, calculated, and reported as particle size distribution using equation (7).

$$\% = \text{sample retained} \div \text{sample weight measured} \times 100 \tag{7}$$

2.7 Data Analysis

Mean effects of treatments on functional and pasting properties were subjected to a one-way analysis of variance (ANOVA) at a 95% confidence interval using SPSS software version 20. The comparison of means was performed by the Tukey test at a 5% significant level. The same data used for means and standards deviation were subjected to Principal Component Analysis (PCA) using XLSTAT (2022 Version) to generate a biplot for functional and pasting properties.

3. Results

Table 1. Proximate composition of non-extruded and extruded cassava flour

Sample	Moisture Content (%)	Ash (%)	Protein (%)	Fat (%)	Dietary Fiber (%)	Carbohydrate (%)
NE	9.7 ± 0.3^{b}	2.4 ± 0.1^{a}	13.3 ± 1.7^{a}	0.5 ± 0.0^{b}	2.9 ± 0.2^{b}	74.7 ± 3.0^{a}
10%	9.8 ± 0.2^{b}	2.6 ± 0.1^{a}	13.4 ± 1.6^{a}	0.1 ± 0.1^{a}	2.2 ± 0.0^{a}	73.1 ± 1.7^{a}
20%	8.4 ± 0.3^{a}	2.5 ± 0.1^{a}	14.8 ± 2.3^{a}	0.0 ± 0.0^{a}	2.5 ± 0.3^{ab}	80.6 ± 0.5^{b}
30%	10.3 ± 0.6^{b}	2.4 ± 0.0^{a}	16.8 ± 3.5^{a}	0.1 ± 0.1^{a}	2.3 ± 0.3^{a}	77.9 ± 2.6^{ab}
40%	11.9 ± 0.3^{c}	2.5 ± 0.1^{a}	16.8 ± 4.4^{a}	0.1 ± 0.0^{a}	2.2 ± 0.1^{a}	78.0 ± 0.6^{ab}

Values are means ± SD of samples; mean values in the same column with different superscript letters are significantly different ($P < 0.05$). NE= Non-extruded, 10%=10% moisture content, 20%=20% moisture content, 30%=30% moisture content, 40%=40% moisture content.

Table 2. Functional properties of Extruded Cassava flour

Sample	Bulk density (g/ml)	Oil Absorption Capacity (%)	Water Absorption Capacity (%)	Swelling Power (g/g)	Water Absorption Index (%)	Water Solubility Index (%)
NE	0.7 ± 0.0^{b}	215.5 ± 1.5^{ab}	245.7 ± 2.1^{b}	3.4 ± 0.2^{a}	3.0 ± 0.0^{abc}	6.0 ± 0.1^{a}
10%	0.5 ± 0.0^{a}	253.2 ± 0.7^{b}	224.3 ± 14.6^{ab}	3.1 ± 1.2^{a}	2.7 ± 0.2^{ab}	55.1 ± 4.5^{b}
20%	0.8 ± 0.0^{c}	202.6 ± 11.5^{a}	461.0 ± 36.4^{c}	5.9 ± 0.1^{b}	2.6 ± 0.1^{a}	56.5 ± 8.3^{b}
30%	0.8 ± 0.0^{c}	$190.\ 5 \pm 1.7^{a}$	505.7 ± 25.7^{c}	6.0 ± 0.0^{b}	3.2 ± 0.4^{bc}	49.1 ± 7.6^{b}
40%	0.7 ± 0.0^{b}	206.3 ± 1.7^{a}	732.9 ± 30.7^{d}	7.2 ± 0.3^{b}	3.3 ± 0.2^{c}	49.3 ± 4.2^{b}

Values are means ± SD of samples; mean values in the same column with different superscript letters are significantly different ($P < 0.05$). NE= Non-extruded, 10%=10% moisture content, 20%=20% moisture content, 30%=30% moisture content, 40%=40% moisture content.

Table 3. Pasting Properties of control and extruded cassava flours

Sample	**Peak viscosity (RVU)**	**Trough (RVU)**	**Breakdown (RVU)**	**Final viscosity (RVU)**	**Setback (RVU)**	**Peak time (min)**	**Pasting Temperature (^{o}C)**
NE	309.0±13.7^{c}	171.3±67.3^{c}	138.7±62.7^{c}	251.7±59.5^{c}	798.3±22.1^{b}	5.2±0.4^{c}	71.5±0.5^{bc}
10%	233.7±67.4^{a}	60.3±15.9^{a}	173.3±51.8^{a}	129.7±36.9^{ab}	69.3±24.5^{a}	2.1±0.6^{b}	59.6±8.7^{bc}
20%	275.3±34.4^{a}	76.0±41.7^{a}	199.3±38.6^{a}	131.3±82.8^{ab}	55.3±41.5^{a}	1.1±0.1^{a}	83.4±15.3^{c}
30%	549.0±24.1^{ab}	146.7±26.0^{ab}	402.3±21.8^{ab}	361.7±18.9^{ab}	215.0±18.1^{c}	1.4±0.5^{ab}	54.7±6.9^{b}
40%	966.3±38.8^{b}	227.3±74.0^{b}	739.0±31.1^{b}	434.3±18.9^{b}	207.0±11.4^{c}	1.2±0.1^{ab}	56.3±10.5^{b}

Values are means ± SD of samples; mean values in the same column with different superscript letters are significantly different ($P < 0.05$). NE= Non-extruded, 10%=10% moisture content, 20%=20% moisture content, 30%=30% moisture content, 40%=40% moisture content.

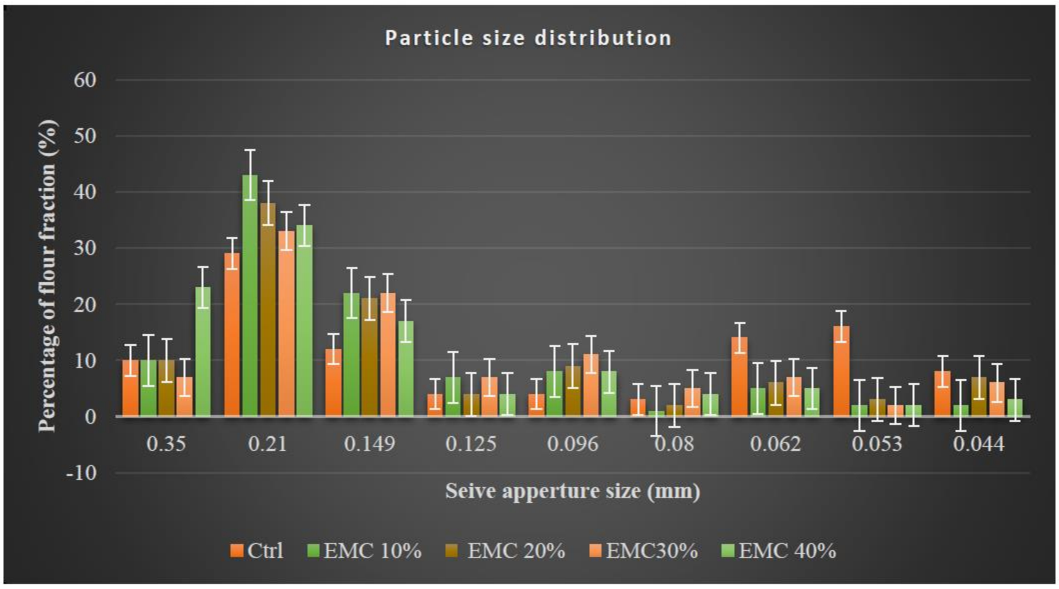

Figure 1. Particle size distribution of the high quality cassava flours extruded at different moisture content. Ctrl=control, EMC10%=Extrusion moisture content 10%, EMC20%=Extrusion moisture content 20%, EMC30%=Extrusion moisture content 30%, EMC40%=Extrusion moisture content 40%

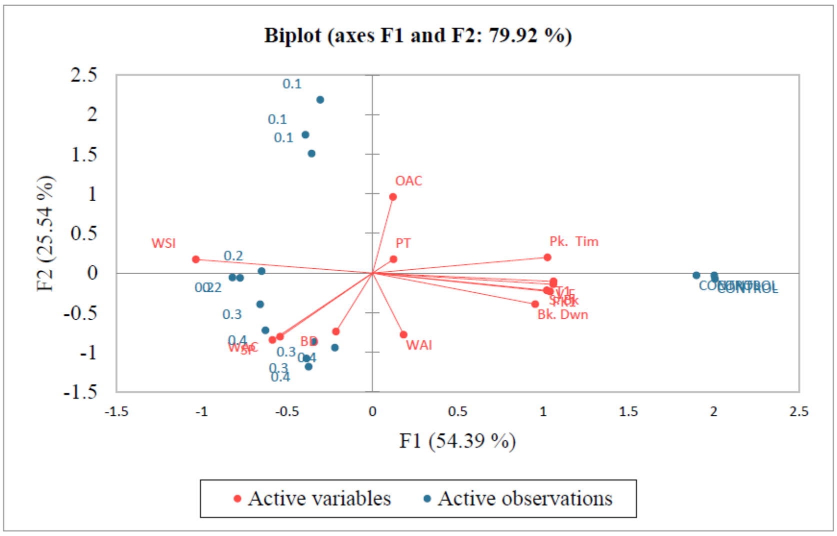

Figure 2. Bi-plot of functional and pasting properties and loadings for processing variables

BD, Bulk density; WAI, Water absorption index; WSI, Water solubility index; WAC, Water absorption capacity; OAC, Oil absorption capacity; SP, Swelling power; PT, Pasting temperature; Pk.Tim, Peak time; Bk. Down, Breakdown; Pk, Peak viscosity; S. bk, setback; T1, Trough; F.V, Final viscosity

4. Discussion

4.1 Proximate Composition

The proximate composition for the differently treated cassava flours is shown in Table 1. In general, the results show that different extrusion conditions did not affect the proximate composition of the cassava flour. MC in this study agreed with the findings of Agbemafle (2019) for cassava flour dried using sun and solar. Ash content ranged from 2.4-2.6% and showed no significant difference among all samples. Ash content in this study was higher than the range 1.0-2.0% reported by Nilusha et al. (2021) for five cassava varieties. Protein content ranged from 13.3-16.8g; all samples exhibited no significant difference. Protein content in this study was higher than that reported by Chisenga et al. (2019) for cassava flour from six different varieties. Fat content ranged from 0.0-0.5% with the non-extruded flour having the highest fat content. Except for the control, the fat content for all the samples showed no significant difference. The lower fat content in the extruded flours can be attributed to the complexation of lipids with proteins and or carbohydrates induced by the extrusion process. Nilusha et al. (2021) found a similar effect and attributed it to extrusion induced reactions between lipids and protein or carbohydrates. Dietary fiber ranged from 2.2-2.9% with the non-extruded recording the highest amount of dietary fiber. Except for the control, all dietary fiber was not significantly different. The slight decrease in the fiber can be attributed to the breakdown and solubilizing effects of extrusion processes. Extrusion have the ability to increase the content of soluble fiber of fibrous materials like plant cell walls, brans and hulls of several cereals and legumes (Alam et al., 2016). Carbohydrate content ranged from 73.1-80.6%; except for 20%, all samples were not significantly different. The range for carbohydrate in this study was lower than what was reported by Agbemafle (2019) for cassava flour (83-86%).

4.2 Bulk Density

The functional properties of the control and extrudates of cassava flours are presented in Table 2. Bulk density measures the amount of load a sample can carry when resting on each other and it is used as a criterion to select its packaging (Kacou et al., 2018; Hasmadi et al., 2020; Otondi, Nduko, & Omwamba, 2020). The Bulk density for the flours ranged from 0.5-0.8 g/ml; Bulk density increased with the increase in moisture content. There were significant differences among the flours extruded at 30% and 20% and the control with the latter exhibiting the highest bulk density. Extrudates from flour with 10% moisture content expressed the lowest bulk density. Due to plasticization during extrusion, increased feed moisture is the main factor affecting extrudate density (Otondi et al., 2020). Moisture and bulk density has a strong positive relationship (Oladunmoye, Akinoso, & Olapade 2010; Gulati et al., 2016). A similar trend was reported by Pasha et al. (2015). The high Bulk density reported for flour extruded at 30% and 20% moisture content could be due to increased particle size (Figure 1) (Oladunmoye et al., 2010; Ngoma, Mashau, & Silungwe, 2019). This is because the density of particulates depends solely on moisture content and particle size (Chandra, Singh, & Kumari, 2015; Ngoma et al., 2019). The high bulk density of the flours indicates that they are suitable for food preparations such as liquids, semi-solids, and solids (Hasmadi et al., 2020); whereas low BD is suitable for the formulation of supplementary foods (Akubor & Ukwuru, 2003).

4.3 Oil Absorption Capacity

Oil absorption capacity (OAC) measures the physical entrapment of oil in a food product (Kacou et al., 2018; Hasmadi et al., 2020). OAC is an important aspect to consider in food processing because fats act as flavor retainers and improve the mouth feel of foods (Wang, 2018; Hasmadi et al., 2020; MO et al., 2017). Oil absorption capacity ranged from 190 to 253%. OAC decreased as moisture content increased. Extrudates from flours with 40%, 30%, and 20% moisture contents had lower OACs compared to the control. Extrudates of cassava flour with 10% moisture content had the highest OAC of 253.2%. There was no significant difference between extrudates from flours with 40%, 30%, and 20% moisture content whereas the control and extrudates from flour at 10% moisture content exhibited a significant difference. This means that gelatinized starches have a lower capacity for oil absorption; a similar observation was reported by Guerra-Oliveira et al. (2022). A lower range (80-108) of oil absorption was reported by (Kacou et al., 2018) for seven different cassava varieties. Higher oil absorption capacity is needed in foods such as bread (Kacou et al., 2018) because it aids in flavour retention and mouthfeel of food (Hasmadi et al., 2020). High OAC flours have potential use in food, especially in flavor retention, improvement of palatability, and extend shelf-life of bakery products (Chandra et al., 2015).

4.4 Water Absorption Capacity

The ability of flour to absorb water is a major quality required for all flours in the food industry (Akinwale et al., 2017; Kacou et al., 2018). Water Absorption Capacity (WAC) is the ability of flour to associate with water under limited water conditions such as dough and paste (Hasmadi et al., 2020). Water absorption capacities for the flours range from 224 to 732%. An increase in WAC as the moisture content increased was observed. A similar trend was observed by Oladunmoye et al. (2014) for cassava starch, durum wheat semolina flours, and their blends. Extrudates from flours with 30% and 20% were not significantly different from control. The high WAC observed in this study indicates that the flour may have extra hydrophilic elements such as polysaccharides (Chandra et al., 2015). Increased WAC is also linked to an increase in amylose discharge, solubility, and damage to crystalline structure (Hasmadi et al., 2020). High water absorption capacity suggests that the flour can be used in the formulation of bakery, dairy, and meat products (Chandra et al., 2015; Ngoma et al., 2019).

4.5 Swelling Power

Swelling power is the capacity of starch to absorb water and allowed the size of starch granules to increase when the internal structure is exposed to water (Otondi et al., 2020). The swelling power of the flours ranges from 3.1 to 7.2 g/g. Swelling power in the extruded flours increased with an increase in moisture content. Extrudates from flours at 40%, 30%, and 20% moisture content showed high swelling power compared to the control. Extrudates of flour extruded at 10% and the control were not significantly different and exhibited low swelling power. A slightly higher range (2.4 g/g - 8.8 g/g) of swelling power was reported by Otondi et al. (2020) for extruded cassava-chia seed instant flour. Low extrusion temperatures (60 ^{o}C) can increase the swelling power of certain cassava varieties; this is in agreement with the findings of Chisenga, Workneh, Bultosa, & Alimi (2019) for starches from improved cassava varieties in Zambia. This indicated that there is a positive correlation between extrusion, flour moisture content, and swelling power (Shittu et al., 2016). According to Kusumayanti, Handayani, & Santosa (2015), greater swelling power is an indication of higher solubility which is apparent in Table 2. High swelling is also linked to better digestibility which is desirable in the brewing and starch liquefaction industry (Chisenga et al., 2019). This means that the flours in this study have suitable applications in the brewing industry, local liquefied beverages, and other local traditional drinks.

4.6 Water Absorption Index

The water Absorption Index (WAI) measures the volume starch occupies after swelling in excess water and is the true representation of starch integrity (Atukuri et al., 2019). The water absorption index ranged from 2.6 to 3.3%. Flour extruded at 40% and 30% had a higher water absorption index compared to the control. This observation is an indication that the WAI increases with an increase in moisture content during extrusion (Carvalho, Takeiti, Onwulata, & Pordesimo, 2010; Pardhi, Singh, Ahmad, & Dar, 2019). A similar trend was observed by Pardhi et al. (2019) and Otondi et al. (2020). WAI for 40% MC extrudate was significantly higher than that of the other treatments. This can be attributed to variations in starch granule, crystallinity, viscosity patterns, and internal interaction of starch after extrusion at high MC (Naiker, Gerrano, & Mellem, 2019). Extrudates from flours of 20 and 10% moisture content exhibited similar WAI reported for extruded Cassava-soy composite flour by Oladiran

& Emmambux (2018). The increase in Water Absorption Index could be due to starch gelatinization and depolymerization which give rise to an increase in the availability of hydrophilic groups in the food system after extrusion cooking (Byaruhanga et al., 2014; Oladiran & Emmambux, 2018).

4.7 Water Solubility Index

Water Solubility Index (WSI) accounts for components that starch released after extrusion (Otondi et al., 2020). The water solubility index ranged from 6 to 56%. The WSI for all the extruded flours was higher than the control. This is an indication that extrusion, irrespective of the MC, can increase the water solubility index of cassava flour. All WSI for extruded cassava flour in this study were higher than those reported by Leonel et al. (2009) for extruded cassava starch. The high Water Solubility Index reported in this study could be due to high starch degradation which gives rise to more soluble molecules in the flour (Ngoma et al., 2019).

4.8 Pasting Temperature

The pasting properties of the flours are presented in Table 3. Flour’s pasting properties are important in determining its cooking and baking qualities (Zhang et al., 2020). Save for 20% MC extrusion and the different extrusion MC decreased the pasting temperatures of the cassava flour as compared to the control. A similar effect was observed by Andriansyah et al. (2017) for cassava flour modified by autoclaving.

4.8.1 Peak Viscosity

The Peak Viscosity ranges from 233 to 966 RVU. Flours extruded at 40% and 30% exhibited high peak viscosity compared to the control and were significantly different from each other. Extruded flours with 20% and 10% moisture exhibited low peak viscosity compared to the control and were not significantly different. Peak viscosity was also reported to increase with an increase in flour moisture content (Planini, Pavokovi, & Blazi, 2012; Lm- & Huan, 2013); this means that there is a correlation between extrusion, flour moisture content, and peak viscosity. It can be postulated that at high extrusion moisture content and relatively low screw speed (used in this study) the starch granules are conserved and gelatinized resulting in a starch that absorbs more water and thus exhibits high peak viscosity. On the other hand lower extrusion MC seemed to support depolymerization of the starch polymer resulting small units that do not hold much water thus resulting in lower peak viscosities.

4.8.2 Trough viscosity

The Trough measures a paste's ability to resist breakdown in hot and constant shear conditions (Kisambira et al., 2015). Trough viscosity for the flours ranged from 60 to 227 RVU. Flour extruded at 40% moisture content reported a higher trough compared to the control and was significantly different from the rest of the flours. Flours extruded at 30%, 20%, and 10% reported a lower trough compared to the control; 20% and 10% were not significantly different. Trough viscosity showed an increasing trend when the moisture content was increased. A similar trend was reported by Lm- & Huan (2013) for cassava flour and Ocheme et al. (2018) for wheat-groundnut concentrate flour. The difference in pasting behavior among the flours could be due to changes in amylose, and crystallinity (MO et al., 2017).

4.8.3 Breakdown Viscosity

Breakdown viscosity determines the stability of starch when heated (Andriansyah et al., 2017). Breakdown of the differently treated cassava flours in work varied from 138 to 739 RVU. Breakdown in all extruded flours was high compared to the control and showed an increasing trend with an increase in flour moisture content. A similar trend was reported by Ocheme et al. (2018) for wheat-groundnut concentrate flour. Flours extruded at 20% and 10% were not significantly different while the rest of the flours were significantly different. This indicates that there is a correlation between flour moisture content and breakdown. Higher moisture content gives rise to higher breakdown (Leonard, Zhang, Ying, & Fang, 2020) and vice versa. High breakdown viscosity is an indication of reduced starch stability (Akinwale et al., 2017) and reduces flour’s ability to withstand heat and shear stress during cooking (Ocheme et al., 2018).

4.8.4 Final Viscosity

Final viscosity is the ability of starch to form gel during cooling (Andriansyah et al., 2017; MO et al., 2017). The final viscosity of the differently treated flours varied from 129 to 434 RVU. Flours extruded at 30%, 20%, and 10% were not significantly different while 40% and the control were significantly different. Flours extruded at 40% and 30% reported high final viscosities compared to the control. It was observed that the final viscosity in the extruded flours increased with an increase in moisture content. A similar trend was reported by Lm- & Huan (2013) for extruded cassava flour and Ocheme et al. (2018) for wheat-groundnut concentrate flour. Flour moisture, screw speed, and temperature can also affect the pasting profile of extrudates (Leonard et al., 2009).

Low final viscosity flours find suitable application in infant food because of the less thick paste viscosity as in the case of 10% and 20% extruded flours (Akinwale et al., 2017).

4.8.5 Setback Viscosity

Setback Viscosity provides information about starch retrogradation (Andriansyah et al., 2017; Afoakwa et al., 2021). The setback Viscosity for the flours ranged from 55-798 RVU. Extrudates of cassava flours exhibited lower setback viscosities compared to the control. Setback for the extrudates increased with an increase in moisture content. The low setback viscosity observed among the extruded flours could be attributed to high starch swelling power and water absorption capacity of the extruded cassava flours (Leonard et al., 2020). A low setback value suggests lower starch retrogradation and shows that flour can be used in products that require a high level of starch stability (Zhang et al., 2020).

4.8.6 Peak Time

Peak time provides information on the amount of energy and time required to cook a flour suspension (Shittu et al., 2016). The peak time for the flours ranges from 1.1 to 5.2 minutes. The Peak time for all the extrudates was lower than that for the control. Peak times for extrudates from flours at 40% and 30% were not significantly different. The peak time for the control in this study was similar to that reported for composite cassava-citrus flour by Imoisi et al. (2020). The low peak times observed among the extrudates from the cassava flours in this study mean less energy is needed to cook (Ajatta et al., 2016; Imoisi et al., 2020) the flour and retrogradation and hardening would not occur (Awolu, 2017).

4.9 Particle Size Distribution

The particle size distribution for the control and the cassava flour extrudates is shown in Figure 1. The results show that most of the flour particles were below 0.2 mm. The control exhibited about 61% of flour below 0.2 mm followed by 30% moisture content extruded flour (60%), 20% moisture content extruded flour (52%), 10% moisture content extruded flour (47%) and 40% moisture content extruded flour (43%) respectively. The results suggest that both extrusion and extrusion MC affects particle size distribution of high-quality cassava flour. Extrudates of flours with the lowest moisture contents exhibited relatively low particle size. A similar observation was reported by Nguyen et al. (2021). It can be postulated that in extrusion at low moisture content flour particles are unable to gelatinize completely hence, making it possible for the flour particles to disintegrate into smaller sizes during milling compared to the completely gelatinized ones at high moisture contents.

4.10 Principle Component Analysis:

The Principle component analysis is presented in Figure 2. The principal component analysis was conducted to determine the relationship between extrusion parameters and functional properties. The first two PCs explained 79.92% of the variation in the data. PC2 was a contrast between samples with low moisture content with positive loadings and high moisture content with negative loadings. Samples with low moisture content were associated with higher WSI, and OAC while those with high moisture content were associated with high BD, SP, WAI, and WAC. PC1 showed a contrast between BD, SP, WSI, and WAC with negative loadings, while WAI, OAC, and pasting properties with positive loadings. SP and WAC were observed to be highly correlated; greater swelling power is an indication of higher solubility (Table 2) and higher solubility means the flour can absorb water and dissolve easily (Byaruhanga et al., 2014). This correlation is related to the fact that extrusion at high moisture content increases the water absorption capacity of the flours; this was similarly observed by Martinez et al. (2014) while extruding rice flour. There was a strong correlation between pasting properties (peak 1, trough 1, breakdown, final viscosity, setback, and peak time). This is in agreement with the findings of Ocheme et al. (2018). A negative relationship between BD and WSI was observed; Gulati et al. (2016) reported a similar finding while extruding proso millet. It was also observed that WAI and OAC had a negative relationship. This is because flours with smaller particle sizes can easily absorb water, while flours with high water absorption have a lower capacity for oil absorption (Guerra-Oliveira et al., 2022).

5. Conclusion

Varying extrusion conditions like moisture content, screw speed and temperature modify the functional and pasting properties of high-quality cassava flour. However, moisture content seems to have a predominant effect on functional and pasting properties. This work underscores the potential of extrusion in modifying starches for different food and non-food applications.

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References

Afoakwa, E. O., Sampson, G. O., Nyirenda, D., Mwansa, C. N., Brimer, L., & Chiwona-Karltun, L. (2021). Physico-Functional and Starch Pasting Properties of Cassava (Manihot Esculenta Cruntz) Flours as Influenced by Processing Technique and Varietal Variations. *Asian Journal of Agriculture and Food Sciences, 9*(2), 71-82. https://doi.org/10.24203/ajafs.v9i2.6556

Agbemafle, R. (2019). Proximate , Starch , Sugar Compositions and Functional Properties of Cassava Flour. *Journal of Food Security, 7*(2), 40-46. https://doi.org/10.12691/jfs-7-2-3

Ajatta, M. A., Akinola, S. A., & Osundahunsi, O. F. (2016). Proximate, Functional, and Pasting Properties of Composite Flours Made from Wheat, Breadfruit, and Cassava Starch. *Applied Tropical Agriculture, 21*(3), 158-165.

Akinwale, T. E., Shittu, T. A., Adebowale, A. razaq A., Adewuyi, S., & Abass, A. B. (2017). Effect of soy protein isolates on the functional, pasting, and sensory acceptability of cassava starch-based custard. *Food Science and Nutrition, 5*(6), 1163-1169. https://doi.org/10.1002/fsn3.507

Alam, M. S., Kaur, J., Khaira, H., & Gupta, K. (2016). Extrusion and Extruded Products: Changes in Quality Attributes as Affected by Extrusion Process Parameters: A Review. *Critical Reviews in Food Science and Nutrition, 56*(3), 445-473. https://doi.org/10.1080/10408398.2013.779568

Andriansyah, R. C. E., Rahman, T., Herminiati, A., Rahman, N., & Luthfiyanti, R. (2017). Characteristics of Chemical and Functional Properties of Modified Cassava Flour (Manihot esculenta) by Autoclaving-Cooling Cycles Method. *IOP Conference Series: Earth and Environmental Science, 101*(1). https://doi.org/10.1088/1755-1315/101/1/012023

AOAC International. (2016). Official methods of analysis of AOAC International. *Association of Official Analysis Chemists International*. pp. 3172.

Aristizábal, J., García, J. A., & Ospina, B. (2017). Refined cassava flour in bread making: A review. *Ingenieria e Investigacion, 37*(1), 25-33. https://doi.org/10.15446/ing.investig.v37n1.57306

Atukuri, J., Odong, B. B., & Muyonga, J. H. (2019). Multi-response optimization of extrusion conditions of grain amaranth flour by response surface methodology. *Food Science and Nutrition, 7*(12), 4147-4162. https://doi.org/10.1002/fsn3.1284

Awolu, O. O. (2017). Optimization of the functional characteristics, pasting, and rheological properties of pearl millet-based composite flour. *Heliyon, 3*(2), e00240. https://doi.org/10.1016/j.heliyon.2017.e00240

Byaruhanga, Y. B., Kassozi, V., Wafoyo, R., Mugoya, C., & Masiga, C. (2014). *PROPERTIES OF EXTRUDATES FROM SORGHUM VARIETIES*. *African Crop Science Journal, 22*, 829-836.

Carvalho, C. W. P., Takeiti, C. Y., Onwulata, C. I., & Pordesimo, L. O. (2010). The relative effect of particle size on the physical properties of corn meal extrudates: Effect of particle size on the extrusion of corn meal. *Journal of Food Engineering, 98*(1), 103-109. https://doi.org/10.1016/j.jfoodeng.2009.12.015

Chandla, N. K., Saxena, D. C., & Singh, S. (2017). Amaranth (Amaranthus spp.) starch isolation, characterization, and utilization in the development of clear edible films. *Journal of Food Processing and Preservation, 41*(6). https://doi.org/10.1111/jfpp.13217

Chisenga, S. M., Workneh, T. S., Bultosa, G., & Alimi, B. A. (2019). Progress in research and applications of cassava flour and starch: a review. *Journal of Food Science and Technology, 56*(6), 2799-2813. https://doi.org/10.1007/s13197-019-03814-6

Chandra, S., Singh, S., & Kumari, D. (2015). Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. *Journal of Food Science and Technology, 52*(6), 3681-3688. https://doi.org/10.1007/s13197-014-1427-2

Dini, C., Doporto, M. C., Vina, S. Z., & García, M. A. (2014). Cassava flour and starch as differentiated ingredients for gluten-free products. *Cassava: Production, Nutritional Properties, and Health Effects, July 2017*, 87-114.

Gulati, P., Weier, S. A., Santra, D., Subbiah, J., & Rose, D. J. (2016). Effects of feed moisture and extruder screw speed and temperature on physical characteristics and antioxidant activity of extruded proso millet

(Panicum miliaceum) flour. *International Journal of Food Science and Technology, 51*(1), 114-122. https://doi.org/10.1111/ijfs.12974

Guerra-Oliveira, P., Fernández-Peláez, J., Gallego, C., & Gómez, M. (2022). Effects of particle size in wasted bread flour properties. *International Journal of Food Science and Technology*, 1-10. https://doi.org/10.1111/ijfs.15656

Hasmadi, M., Noorfarahzilah, M., Noraidah, H., Zainol, M. K., & Jahurul, M. H. A. (2020). Functional properties of composite flour: A review. *Food Research*, *4*(6), 1820-1831. https://doi.org/10.26656/fr.2017.4(6).419

Imoisi, C., Iyasele, J. U., Imhontu, E. E., Ikpahwore, D. O., & Okpebho, A. O. (2020). Pasting Properties of Composite of Cassava and Wheat Flours. *Journal of Chemical Society of Nigeria, 45*(6). https://doi.org/10.46602/jcsn.v45i6.540

Julianti, E., Rusmarilin, H., Ridwansyah, & Yusraini, E. (2016). Effect of soybean flour on physico-chemical, functional, and rheological properties of composite flour from rice, sweet potato, and potato. *Tropical Life Sciences Research, 27*(November), 133-138. https://doi.org/10.21315/tlsr2016.27.3.18

Kacou, M. A., Elvis Ekissi, G. S., Ebbah Djedji, B. C., N’zué, B., & Kouamé, P. L. (2018). Assessment of Functional Properties Flours from Seven Local Varieties of Cassava (Manihot esculenta Crantz) Consumed in Côte d’Ivoire. *International Journal of Current Microbiology and Applied Sciences*, *7*(10), 815-826. https://doi.org/10.20546/ijcmas.2018.710.090

Kisambira, A., Muyonga, J. H., Byaruhanga, Y. B., Tukamuhabwa, P., Tumwegamire, S., & Grüneberg, W. J. (2015). Composition and Functional Properties of Yam Bean (*Pachyrhizus spp.*) Seed Flour. *Food and Nutrition Sciences, 06*(08), 736-746. https://doi.org/10.4236/fns.2015.68076

Kusumayanti, H., Handayani, N. A., & Santosa, H. (2015). Swelling Power and Water Solubility of Cassava and Sweet Potatoes Flour. *Procedia Environmental Sciences, 23*(Ictcred 2014), 164-167. https://doi.org/10.1016/j.proenv.2015.01.025

Leonel, M., de Freitas, T. S., & Mischan, M. M. (2009). Physical characteristics of extruded cassava starch. *Scientia Agricola, 66*(4), 486-493. https://doi.org/10.1590/s0103-90162009000400009

Leonard, W., Zhang, P., Ying, D., & Fang, Z. (2020). Application of extrusion technology in plant food processing byproducts : An overview. *COMPREHENSIVE REVIEWS IN FOOD SCIENCE AND FOOD SAFETY, October 2019*, 218-246. https://doi.org/10.1111/1541-4337.12514

Lm-, F. T. F., & Huan, Z. (2013). *Pasting Characteristics of Cassava at Different Extrusion Conditions*.

Martínez, M. M., Oliete, B., Román, L., & Gómez, M. (2014). Influence of the Addition of Extruded Flours on Rice Bread Quality. *Journal of Food Quality, 37*(2), 83-94. https://doi.org/10.1111/jfq.12071

MO, I., N, M., NE, M., NE, O., GI, O., TU, N., & JO, O. (2017). Physicochemical and Pasting Properties High-Quality Cassava Flour (HQCF) and Wheat Flour Blends. *Agrotechnology, 06*(03). https://doi.org/10.4172/2168-9881.1000167

Naiker, T. S., Gerrano, A., & Mellem, J. (2019). Physicochemical properties of flour produced from different cowpea (Vigna unguiculata) cultivars of Southern African origin. *Journal of Food Science and Technology, 56*(3), 1541-1550. https://doi.org/10.1007/s13197-019-03649-1

Nilusha, R. A. T., Jayasinghe, J. M. J. K., Perera, O. D. A. N., Perera, P. I. P., & Jayasinghe, C. V. L. (2021). Proximate Composition, Physicochemical, Functional, and Antioxidant Properties of Flours from Selected Cassava (Manihot esculenta Crantz) Varieties. *International Journal of Food Science, 2021*. https://doi.org/10.1155/2021/6064545

Ngoma, K., Mashau, M. E., & Silungwe, H. (2019). Physicochemical and Functional Properties of Chemically Pretreated Ndou Sweet Potato Flour. *International Journal of Food Science, 2019*. https://doi.org/10.1155/2019/4158213

Nguyen, T. C., Fillaudeau, L., Anne-Archard, D., Chu-Ky, S., Luong, H. N., Vu, T. T., Nguyen, T. H. D., & Nguyen, V. H. (2021). Impact of particle size on the rheological properties and amylolysis kinetics of ungelatinized cassava flour suspensions. *Processes, 9*(6). https://doi.org/10.3390/pr9060989

Ocheme, O. B., Adedeji, O. E., Chinma, C. E., Yakubu, C. M., & Ajibo, U. H. (2018). Proximate composition, functional, and pasting properties of wheat and groundnut protein concentrate flour blends. *Food Science and Nutrition, 6*(5), 1173-1178. https://doi.org/10.1002/fsn3.670

Oladiran, D. A., & Emmambux, N. M. (2018). Nutritional and Functional Properties of Extruded Cassava-Soy Composite with Grape Pomace. *Starch/Starke, 70*(7-8), 1-11. https://doi.org/10.1002/star.201700298

Oladunmoye, O. O., Akinoso, R., & Olapade, A. A. (2010). Evaluation of some physical-chemical properties of wheat, cassava, maize, and cowpea flours for bread making. *Journal of Food Quality, 33*(6), 693-708. https://doi.org/10.1111/j.1745-4557.2010.00351.x

Otondi, E. A., Nduko, J. M., & Omwamba, M. (2020). Physico-chemical properties of extruded cassava-chia seed instant flour. *Journal of Agriculture and Food Research*, *2*(July), 100058. https://doi.org/10.1016/j.jafr.2020.100058

Pardhi, S. D., Singh, B., Ahmad, G., & Dar, B. N. (2019). Journal of the Saudi Society of Agricultural Sciences Evaluation of functional properties of extruded snacks developed from brown rice grits by using response surface methodology. *Journal of the Saudi Society of Agricultural Sciences, 18*(1), 7-16. https://doi.org/10.1016/j.jssas.2016.11.006

Planini, M., Pavokovi, M., & Blazi, M. (2012). Effect of Screw Configuration, Moisture Content, and Particle Size of Corn Grits on Properties of Extrudates. *Croatian Journal of Food Science and Technology, 4*(2), 95-101.

Kushwaha, R., & Kaur, D. (2019). *Recent techniques used in the modification of starches : A review*. Food Technology from Health to Wealth & Future Challenges. pp. 1-15.

Shittu, T. A., Alimi, B. A., Wahab, B., Sanni, L. O., & Abass, A. B. (2016). Cassava Flour and Starch: Processing Technology and Utilization. *Tropical Roots and Tubers: Production, Processing, and Technology*. https://doi.org/10.1002/9781118992739.ch10a

Sonaye, S. Y., & Baxi, R. N. (2012). Particle size measurement and analysis of flour. *International Journal of Engineering Research and Applications*, *2*(3), 1839-1842.

Zhang, Y., Nie, L., Sun, J., Hong, Y., Yan, H., Li, M., You, X., Zhu, L., & Fang, F. (2020). Impacts of Environmental Factors on Pasting Properties of Cassava Flour Mediated by Its Macronutrients. *Frontiers in Nutrition, 7*(November), 1-9. https://doi.org/10.3389/fnut.2020.598960

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