Hindawi
Journal of Food Processing and Preservation
Volume 2023, Article ID 1775604, 11 pages
https://doi.org/10.1155/2023/1775604

Research Article

Effect of Different Drying Techniques on the Functionality and Digestibility of Yellow-Fleshed Cassava Flour and Its Performance in Food Application

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Received 14 July 2023; Revised 19 September 2023; Accepted 4 October 2023; Published 15 November 2023

Academic Editor: Yogesh Kumar

The impact of different drying techniques on the properties of yellow cassava flour and its food application was investigated in this study. Flour was made from three cultivars of yellow cassava by solar-, hot air oven-, or drum- drying. Their functionality was determined by standard methods, and their digestibility was evaluated *in vitro*. The flours were used in the preparation of *fufu*, which was evaluated by sensorial and instrumental methods. The digestibility of drum-dried flours was higher (69.4–79.7%) than solar- (60.4–70.7%) or air oven-dried flours (60.3–70.4%), whereas β-carotene concentration was higher in air oven-dried samples compared to the others. Significant differences ($p < 0.05$) due to cultivar and/or drying technique were observed in the hydration and pasting properties of the flours. Instrumental texture analysis of *fufu* made from yellow cassava flours showed both drying technique and cultivar to affect the hardness, adhesiveness, and cohesiveness of the product. Acceptability scores for the *fufu* ranged from 4 to 6, with a decisive preference for samples produced from drum-dried flours. The study has shown the successful utilization of different drying techniques in the production of flour from yellow cassava variants for the preparation of *fufu*.

1. Introduction

Globally, cassava is a major root and tuber crop and raw material for a rich diversity of food and industrial applications. It is an important source of carbohydrates and is heavily relied on for many local diets where it is cultivated. Cassava roots begin to deteriorate a few days after harvest and therefore must be processed into shelf-stable forms. Processing of cassava roots mainly employs boiling, roasting, fermenting, and drying, as summarized in a number of studies [1–3]. This presents a useful opportunity of converting raw cassava roots into products such as cassava flour, which is widely used in the production of *fufu*, as a hygienic and convenient alternative to the traditional cuisine [3]. Primarily, cassava flour for *fufu* is produced by drying precooked cassava roots.

Drying describes the process of thermally removing moisture, and it involves simultaneous heat and mass transfer [4]. It is an important process in preserving agricultural produce. The use of a particular drying technique is critical in determining flour functionality, and selection is influenced by the end use of the dried product. For instance, whereas drum drying may be used to produce instant swelling flours or powders, a solar or air oven method may be used for making flours for use in bakery applications. Different dying methods have varied effects on the functionality of flours [5, 6]. Recent studies by Buzera et al. [7] and Badiora et al. [8] demonstrated the impact of drying methods on both chemical and functional properties of potato flour and orange sweet potato flour.

Solar drying and air oven drying are less expensive and commonly preferred in cassava flour production. Yet, these require long drying periods, which may negatively affect coloured products such as yellow cassava. Studies involving yellow-fleshed cassava and other pigmented crops have catalogued the detrimental effects of drying conditions and methods such as sun, solar, and oven drying on the final product quality [9–12]. Chavez et al. [13] found a higher retention of carotenoids in oven-dried yellow cassava flour (72%), compared to shade drying (59%) and open sun drying (38%). To overcome these challenges, drum drying may be explored in the processing of yellow cassava flour.

Drum drying is a conductive drying technique in which a food material, in the form of a slurry or mash, adhered to a drum, is dried by heat from condensed steam within the drum [14]. It has the advantage of short heat exposure time and simultaneous cooking and drying, leading to end products with unique features such as instant swelling, high porosity, low bulk density, and high digestibility [15]. Additionally, because of the short exposure time, drum drying may also be useful in preserving the carotenoid levels and impact the quality of the final product. The objective of this study was therefore to compare the effect of different drying methods on the physicochemical and functional behaviour of yellow cassava flour.

2. Materials and Methods

2.1. Raw Material. Three cultivars of yellow-fleshed cassava with β-carotene contents 7.21 μg/g (1082264 designated as S1), 4.56 μg/g (1083774 designated as S2), and 6.93 μg/g (1083594 designated as S3) were obtained from demonstration plots of the CSIR-Savanna Agriculture Research Institute, Nyankpala. The roots were manually peeled and washed before slicing (3 mm) and steam blanching at 110°C for 5 min in a pressure cooker, based on an initial optimization step. For drum drying, the blanched slices were mashed while still hot and allowed to cool to room temperature before use.

2.2. Drum Drying. Drum drying was performed on a single drum dryer (ANDRITZ, Gouda, the Netherlands) preheated to 120°C before introducing the yellow cassava mash onto the drum surface, while rotating at 10 rpm. These conditions were obtained from a preliminary trials. The dry flakes were allowed to cool to room temperature before milling into flour (300 μm) with a laboratory mill (Waring 8420, Torrington, USA). The flour was sealed in transparent polypropylene bags before packing into cardboard boxes and stored for further analyses.

2.3. Air Oven Drying. Blanched slices, spread thinly on stainless steel drying trays, were dried in a forced convection oven at 65 °C for 7 h. Thereafter, the dried slices were allowed to cool to room temperature, milled, and packaged similarly as the drum-dried flour.

2.4. Solar Drying. A solar tunnel dryer was used in this experiment. The blanched slices were spread thinly on a drying mesh and dried at an average temperature of 52 °C, for 40 h. After that, the dried slices were allowed to cool and processed further as described in the previous sections.

2.5. Analyses of Yellow Cassava Fufu Flour

2.5.1. Chemical Composition

(1) β-Carotene Determination. A slightly modified version of Dutta et al. [16] was used in determining the β-carotene content of the cassava flours. Five grams of sample was macerated in a mixture of 15 mL isopropyl alcohol and 5 mL hexane and stirred for 1 min. The volume of the mixture was adjusted with distilled water in a 125 mL amber separation funnel and allowed to stand for 30 min before filtering (Whatman No. 4). Absorbance of the filtrate was determined at 450 nm with UV-Vis spectrophotometer (T80, PG Instruments, Leicestershire, UK).

2.6. Functional Properties

2.6.1. Water Solubility Index and Swelling Power. Swelling power (SP) and water solubility index (WSI) were determined according to the method described elsewhere [17]. Distilled water (10 mL) was added to 100 mg of flour (W_0) and the suspension thoroughly vortexed for 10 s. The mixture was incubated in a water bath at 85°C for 30 min with continuous shaking and cooled before centrifuging at 2000 rpm for 35 min (Hermle Z206A, Hermle Labortechnik GmbH, Germany). The supernatant was carefully decanted and dried to constant weight (W_1). The sediment in the centrifuge tube was weighed (W_s), and WSI (%) and SP (g/g) were calculated using

$$\begin{aligned} \text{WSI} &= \frac{W_1}{W_0} \times 100, \\ \text{SP} &= \frac{W_s}{W_0 \times (1 - \text{WSI}/100)}. \end{aligned} \quad (1)$$

2.6.2. Water-Binding Capacity. Five hundred milligrams of sample was suspended in 10 mL water in a 15 mL centrifuge tube according to Eriksson et al. [17]. The suspension was agitated for 1 h at room temperature on a shaker (Grant Instruments, England) before centrifuging at 2200 rpm for 10 min. The sediment was weighed, and water-binding capacity of the sample was calculated using

$$\text{WBC} = \frac{W_{\text{bound water}}}{W_{\text{sample}}} \times 100, \quad (2)$$

where $W_{\text{bound water}}$ is the weight of the pellet after centrifugation − weight of the initial sample and W_{sample} is the weight of the initial sample.

2.6.3. Bulk Density and Flour Flowability. Ten grams (10 g) of flour in a measuring cylinder was gently tapped for 5 min, and the final volume was used to calculate the bulk density of flour samples. Flow properties of the yellow cassava flour, based on the Carr index (CI) and Hausner ratio (HR), were determined as described by Asokapandian et al. [18]. CI and HR were calculated using

$$\begin{aligned} CI &= \frac{\rho_t - \rho_l}{\rho_t} \times 100, \\ HR &= \frac{\rho_t}{\rho_l}, \end{aligned} \quad (3)$$

where ρ_t and ρ_l correspondingly represent the tapped bulk density and loose bulk density.

2.6.4. Particle Size Analysis. The sieve method described in ASABE Standard S219.4 (ASABE, 2008) was used for particle size determination. Yellow cassava flour was weighed (100 g) into the topmost sieve of a stack of sieves with successively decreasing apertures with the collecting pan at the bottom of the stack. Using a shaker (ROTAP RX30, USA), the stack of sieves was shaken for 15 min, and the percent of retention was plotted against the sieve aperture size.

2.7. Microstructure. Scanning electron microscopy (SEM) was used to characterize the microstructure of yellow cassava flour. Before imaging, a speck of flour was sputter-coated with gold before mounting on sample stubs [19].

2.8. Digestibility of Yellow Cassava Flour. Digestibility was determined *in vitro* according to Zhang et al. [20]. Cassava flour (500 mg) was mixed with 15 mL phosphate buffer (0.15 M, pH 6.5) and 30 mg each of gelatin, $CaCl_2$, and amylase (Sigma-Aldrich, St. Louis, USA). The mixture was incubated at 37°C for 6 h before adding 5 mL of 1% H_2SO_4. The mixture was centrifuged at $5000 \times g$ for 15 min and gently decanted, and the sediment was resuspended in 15 mL of 80% ethanol. The suspension was centrifuged for 5 min, and the sediment was dried to constant weight at 70°C. Flour digestibility was expressed as a percentage of weight loss after digestion.

2.9. Pasting Properties. Pasting characteristics of the flour were determined with a Brabender Viscoamylograph (Viscograph E, Brabender, Duisburg, Germany). Peak viscosity, pasting temperature, hot paste viscosity, cool paste viscosity, breakdown, and setback viscosity were recorded using the Viscograph Software, 2.3 (Brabender GmbH, Duisburg, Germany) [21].

2.10. Analyses on Fufu

2.10.1. Preparation of Fufu Using Yellow Cassava Flour. Fifty grams (50 g) of flour from each of the drying methods was reconstituted in 170 mL of water and stirred into a uniform consistency. The slurry was cooked by stirring into a stiff pasty mass of *fufu*, before moulding into 35 g morsels each using a plastic mould. The morsels were placed in a bowl, allowed to cool to room temperature, and covered with an aluminium foil to prevent moisture loss prior to analyses.

2.11. Texture Analysis. Texture profile analysis (TPA) was conducted on the *fufu* samples at room temperature using a texture analyzer (TA.XT2 Plus, Stable Micro Systems, UK) equipped with a 5 kg load cell. A double-bite compression was conducted to 50% strain with a P35 acrylic probe using the following conditions: trigger force of 0.05 N; pretest, test speed, and posttest speeds of 5.0 mm/s, 1.0 mm/s, and 5.0 mm/s, respectively; and stopping time of 5 s between first and second bites. Hardness (N), adhesiveness (N·s), and cohesiveness were calculated using the Exponent Lite 6.1 software (Stable Microsystems, UK).

2.12. Sensory Evaluation of Fufu Made from Yellow Cassava Flour. A panel of 25 untrained assessors was used to evaluate the sensory attributes of *fufu*. Participants were selected based on regular consumption of *fufu*, previous experience in sensory evaluation, willingness, and availability to participate. They assessed the product based on appearance, softness, stickiness, and cohesiveness and overall likeness using a seven-point hedonic scale (1-dislike extremely, 3-neither like nor dislike, and 7-like extremely). The evaluations were done during two sessions where five and four samples were presented randomly to panelists for the first and second sessions, respectively. The panelists were asked to touch and evaluate each sample between the fingers and score their perception of each sample.

2.13. Experimental Design and Statistical Analyses. The drying experiment was set up using a 3×3 categorical factorial design (STATGRAPHICS Centurion XIV). Each of the principal factors had three levels as follows:

(1) Drying method: drum drying, hot air oven drying, and solar drying

(2) Yellow cassava varieties: cultivars S1, S3, and S2

Data obtained were analyzed using multifactor ANOVA in which the drying method and yellow cassava cultivar represented the independent variables. Statistical significance was set at a 95% confidence level. Principal component analysis (PCA) was performed on the functional properties of the flours and sensory attributes of *fufu*, using XLSTAT software for Microsoft Excel (version 2014).

3. Results and Discussions

3.1. Particle Size Distribution of the Flours. Flour particle size, generally represented as the geometric particle diameter, is an important property in determining their functionality and utilization in food processing and influences the quality properties of the final product [22, 23]. In this study, the predominant proportion of particle size of all flours was less than 250 μm, accounting for nearly 54–59% of the particles, whereas 7-10% was held on the 300 μm sieve and 2-4% was less than 100 μm (Figure 1). Flours produced by drum drying were finer, with about 32% of its particles being smaller than 150 μm, compared to 29% for the air oven and 24% for solar-dried samples. A plausible explanation is that the particles of flour produced by drum drying are

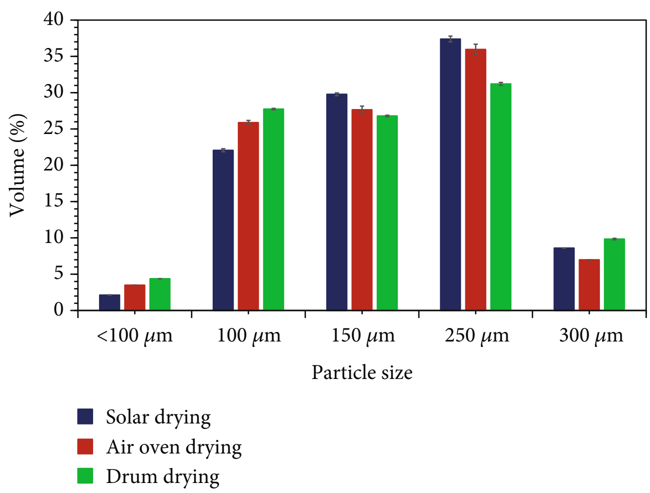

FIGURE 1: Particle size distribution of yellow cassava flour.

friable and can easily be milled into fine particles owing to their flat geometry and voids in their microstructure [15]. Solar-dried flour samples had the coarsest of particles compared to samples produced by air oven and drum drying techniques. Smaller particles have been shown to provide finer texture, smoother consistency/mouthfeel, and higher hydration ability [23], but lower viscosity [24] compared to bigger particles of the same flour samples.

3.2. Microstructure of Yellow-Fleshed Cassava Flour. SEM imaging of the flours dried using solar drying (Figure 2(a)), air oven drying (Figure 2(b)), and drum drying (Figure 2(c)) revealed obvious differences between flours produced by using the various drying techniques. Flour produced by solar drying or air oven drying showed a few intact starch granules, an indication that the steam blanching pretreatment was short enough to not fully gelatinize all starch granules present. On the contrary, no intact starch granule was seen in the flour produced by drum drying. Furthermore, conspicuous pores were present in the drum-dried flours, clearly due to the simultaneous boiling/cooking and moisture evaporation that occurs during drum drying.

3.3. β-Carotene Content and Digestibility of Yellow-Fleshed Cassava Flour. β-Carotene, the main carotenoid in yellow cassava, is an important micronutrient known to be a major precursor of vitamin A in the human body. The levels of β-carotene in the yellow cassava flours ranged from 0.7 to 4.1 mg/kg (Table 1), but these levels were significantly dependent on both drying method ($p = 0.008$) and cultivar ($p < 0.001$). Hot air drying was the best technique to preserve β-carotene in the yellow cassava cultivars examined. Flours produced by this method recorded a mean β-carotene content of 2.8 mg/kg, whereas those produced by solar drying and drum drying correspondingly had a mean of 2.2 mg/kg and 1.5 mg/kg.

This emphasizes the detrimental effect of intense heat on β-carotene stability, as in the case of drum drying. Abonyi et al. [25] suggest that the degradation of carotenoids during drum drying heightens after most of the moisture is evaporated from the food. In the case of solar drying, the degradation of β-carotene would have been facilitated by exposure to light during the long drying periods. However, the results seem to suggest that heat had a more profound effect on the carotenoid, compared to light. Results of the present study contrast the findings of Ruttarattanamongkol et al. [12] who reported lower degradation of β-carotene in drum-dried orange-fleshed sweet potato flour compared to hot air-dried flour.

3.4. In Vitro Starch Digestibility. Starch digestibility is important for estimating the postprandial glucose response to starchy foods [26]. *In vitro* digestibility of the processed yellow cassava flours varied widely (60.3 to 79.7%), highlighting the influence of cultivar, drying method, or both factors. Regardless of cultivar, flours produced by drum drying showed better digestibility (69.4–79.7%). This is because complete cooking and gelatinization occurred during the drum drying, making these flours more susceptible to enzymatic attack and enhancing the rate of hydrolysis [27], compared to sun- and oven-dried flours, in which partial cooking was induced by steam blanching pretreatment. Aside from complete cooking, it is also possible that the simultaneous kneading and shearing occurring at the applicator roller-drum interface may have caused massive rapture to starch granules and other components, making them more sensitive to the digestive enzymes. Another reason for the higher digestibility in drum-dried samples might be its particle size distribution (Figure 1). These flours had finer particles (<250 μm), providing a wider surface area and enzyme accessibility [28, 29]. Avula [30] also reported a higher digestibility for drum-dried potato flour compared to hot air-dried potato flour.

These observations affirm the inevitable influence of food microstructure on the digestibility and glycaemic response of food. Evidently, the drum-dried flours were more porous than the others, as indicated in their SEM micrographs (Figure 2(c)). The digestibility of flours produced by hot air drying was slightly higher than those produced by solar drying. Multifactor ANOVA showed a significant effect of cultivar on the digestibility of yellow cassava flours. Zhang et al. [20] explain that because starch is the predominant biomolecule in cassava flour, its amylase sensitivity strongly influences the digestibility of the flours. The influence of cassava cultivars may therefore be explained by intrinsic differences in amylose and amylopectin content, starch structure, crystallinity, and granule size, among others. In rice, for instance, Chung et al. [31] showed, among different cultivars, that digestibility is directly associated with amylose content. The levels of other nonstarch components, such as proteins, fat, and fibre, may account for some of these differences, as these limit the accessibility of the substrate to amylases.

3.5. Functional Properties. Bulk density is a key determinant of flour flowability [32] and is directly associated with the economic dynamics of transportation and storage. Drying method had a significant effect on bulk density (Table 2). Drum-dried flours had the lowest bulk density (about

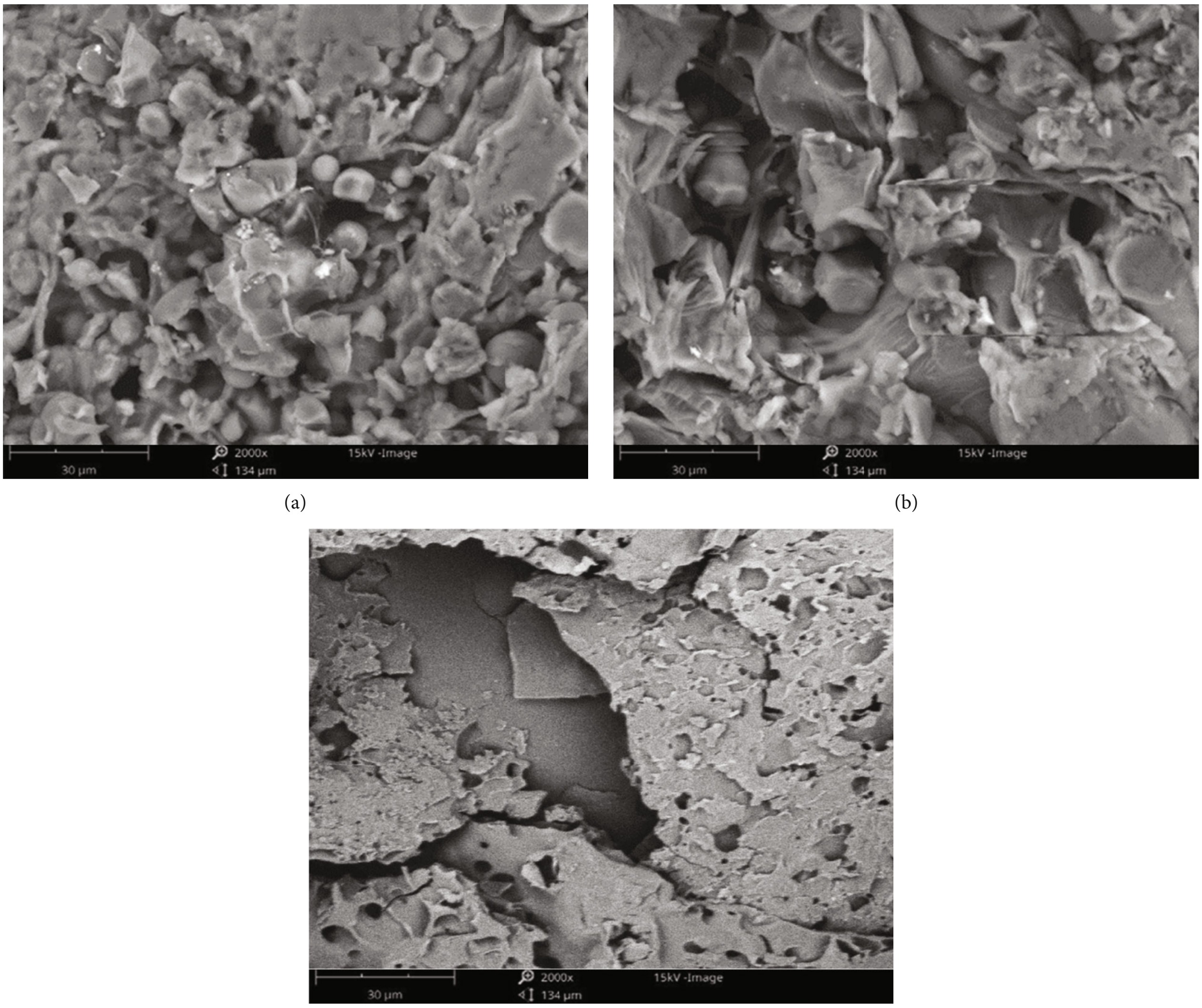

Figure 2: Electron micrographs (×2000) of yellow cassava flour produced by (a) solar, (b) air oven, and (c) drum drying. Micrographs of sample S1 were used to represent the microstructure of the flours since flours (from different cultivars) dried by the same drying method had similar microstructure.

Table 1: Carotene and digestibility of yellow cassava flour from different drying methods.

Cultivar	Drying method	β-Carotene (mg/kg)	Digestibility (%)
S1	S	2.46 ± 0.03	60.38 ± 0.31
	AO	4.10 ± 0.01	60.25 ± 0.18
	D	2.47 ± 0.04	69.42 ± 0.12
S2	S	0.65 ± 0.01	65.21 ± 0.23
	AO	0.70 ± 0.01	68.08 ± 0.15
	D	0.65 ± 0.01	79.68 ± 0.47
S3	S	1.47 ± 0.01	70.73 ± 0.54
	AO	3.59 ± 0.02	70.35 ± 0.21
	D	3.47 ± 0.01	73.18 ± 0.66

S: solar drying; AO: air oven drying; D: drum drying. Values shown are means and standard deviations.

0.7 g/cm^3) because of their high porosity resulting from rapid moisture evaporation rates, leaving conspicuous air spaces within the flour matrix (Figure 2). Their relatively smaller particle size also resulted in better particle compaction [33]. Flours made by solar drying and air oven drying were heavier and exhibited no air space within their matrices. Tapped bulk density results from this study were comparable to the bulk density of orange-fleshed sweet potato of the drum-dried flours and compared well with some wheat varieties but were higher than 497.5 and 327.4 kg/m^3 reported by Oladunmoye et al. [34] for wheat flour and cassava flour.

Flowability is a critical consideration in many flour applications, with better flowing flours being easier to spread smoothly and tightly. Yellow cassava flour flowability was expressed by the Carr index and Hausner ratio (Table 2), and these two indices also reflect their packability [35]. Values obtained in this study indicate that all flours had

Table 2: Functional properties of yellow cassava flour.

Genotype	Drying method	BD (g/cm^3)	Carr index %	Hausner ratio	SP (g/g)	WSI (%)	WBC (%)
S1	S	0.80 ± 0.04	13.21 ± 0.21	1.16 ± 0.01	19.1 ± 0.2	9.8 ± 0.2	550.1 ± 5.6
	AO	0.76 ± 0.01	12.86 ± 0.10	1.15 ± 0.02	19.3 ± 0.2	10.2 ± 0.4	548.8 ± 4.8
	D	0.59 ± 0.01	12.75 ± 0.54	1.15 ± 0.01	22.9 ± 0.1	16.6 ± 0.2	842.3 ± 11.2
S2	S	0.86 ± 0.02	12.74 ± 0.81	1.18 ± 0.01	19.0 ± 0.1	9.1 ± 0.1	528.2 ± 7.1
	AO	0.86 ± 0.03	12.74 ± 0.25	1.18 ± 0.01	18.8 ± 0.2	9.8 ± 0.5	546.9 ± 5.3
	D	0.58 ± 0.03	11.56 ± 0.25	1.12 ± 0.01	22.7 ± 0.3	18.8 ± 0.4	836.4 ± 8.9
S3	S	0.80 ± 0.01	12.86 ± 0.40	1.16 ± 0.02	17.3 ± 0.2	7.1 ± 0.3	513.6 ± 7.4
	AO	0.80 ± 0.01	12.53 ± 0.23	1.16 ± 0.01	16.2 ± 0.2	8.8 ± 0.3	521.1 ± 4.9
	D	0.60 ± 0.01	12.14 ± 0.20	1.12 ± 0.01	20.1 ± 0.2	15.9 ± 0.1	828.9 ± 9.7

S: solar drying; AO: air oven drying; D: drum drying; BD: bulk density; WSI: water solubility index; SP: swelling power. Values shown are means and standard deviations.

good flowability since their Carr index ranged from 11 to 15 and Hausner ratio between 1.12 and 1.18 [18]. These two indices were unaffected by cultivar ($p > 0.05$). However, the drying methods seem to have had an influence, with the drum-dried flour obtaining a higher Carr index and Hausner ratio compared to flours produced by hot air oven or solar drying. This suggests higher cohesiveness among its particles compared to flours produced by hot air oven and solar drying. One explanation for this observation is that drum-dried flour generally had finer particle sizes and distribution, compared to the others (Figure 1). Another could be that particles of the drum-dried samples generally had a flat geometry compared to flours dried using other methods (Figure 2), thus agreeing with the findings of previous studies that the further away the particles deviate from a spherical shape, the higher the ratio of tapped to loose bulk density [35].

Swelling power and water solubility of the flours correspondingly ranged between 16 and 23 g/g and 7 and 19%, respectively (Table 2), while the water-binding capacity was more than 500% of their initial weight. Swelling power in the present study was higher than the swelling power values for native and pregelatinized cassava flour reported by Murayama et al. [36] for five Philippine cassava varieties. The flour from the different varieties had similar water-binding capacity, but this was affected by the drying method. Drum-dried flours recorded higher values compared to flours dried by other techniques. This is because drum drying involves an appreciable extent of shearing and kneading, resulting in extensive molecular rearrangement or damage. Moreover, due to the extensive gelatinization that occurs during drum drying (refer to pasting properties), these flours easily hydrate, swell, and have a remarkable capacity to absorb water. Rapid boiling and moisture evaporation during drum drying makes these flours highly porous, contributing to their high water absorption behaviour. The highly porous nature of drum-dried flours has been reported by Jittanit et al. [37] and more recently by Akonor et al. [15]. It is possible that porosity had a greater influence on water-binding capacity than molecular rearrangement.

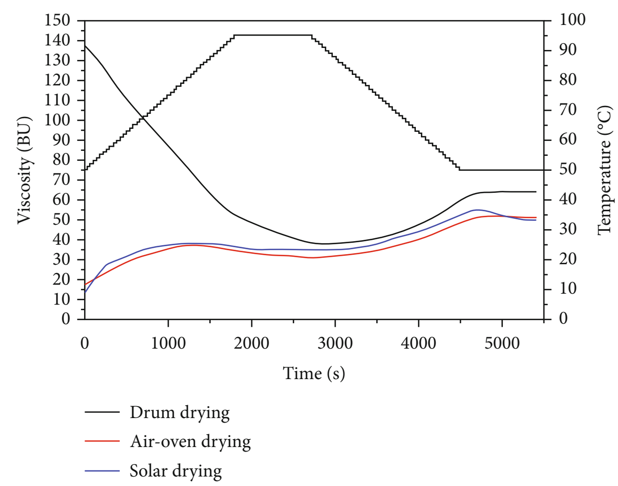

Figure 3: Pasting profile of yellow cassava flour produced by different drying methods.

3.6. Pasting Properties of Cassava Flour. Pasting characteristics of flours are important because they provide useful rheological insights to guide their food application. In this study, the pasting profile of the dried flours deviated from the classical starch pasting profile in which the viscosity begins at zero. Rather, the profile depicted the flours' instantaneous swelling and increase in viscosity after reconstituting in water (Figure 3). The pasting curve of the drum-dried flours began with a high viscosity (peak viscosity), which was reduced during the heating and shearing cycle. This is because, for these flours, the blanching and subsequent drum drying gelatinized all starch granules (Figure 2(c)), making them cold water-soluble and exhibiting a high viscosity when reconstituted in water, even without heating.

The results confirm drum drying as a good method for processing flours for applications that require instant cold water swelling ability. It may also be suitable in *fufu* production, in which extensive swelling is required for an acceptable final product texture. Ruttarattanamongkol et al. [12] also reported a complete gelatinization of both orange and purple sweet potato flours during drum drying. The pasting

Table 3: Pasting properties of yellow cassava flour produced by different drying methods.

Genotype	Drying method	Pasting temperature (°C)	Peak viscosity (BU)	Cold paste viscosity (BU)	Breakdown viscosity (BU)	Setback viscosity (BU)
S1	S	62.0 ± 0.1	113.0 ± 0.2	64.3 ± 0.2	74.1 ± 0.3	25.0 ± 0.1
	AO	64.8 ± 0.3	120.9 ± 0.2	77.2 ± 0.3	67.2 ± 0.2	23.3 ± 0.1
	D	50.0 ± 0.3	137.3 ± 0.4	60.0 ± 0.3	99.0 ± 0.5	22.3 ± 0.1
S2	S	62.5 ± 0.4	110.1 ± 0.1	86.0 ± 0.4	56.0 ± 0.3	30.1 ± 0.1
	AO	62.0 ± 0.3	102.7 ± 0.2	69.3 ± 0.1	60.0 ± 0.3	26.0 ± 0.2
	D	50.0 ± 0.1	174.3 ± 0.6	64.9 ± 0.1	131.6 ± 0.8	23.0 ± 0.1
S3	S	59.1 ± 0.1	38.0 ± 0.1	49.0 ± 0.3	6.0 ± 0.1	17.0 ± 0.1
	AO	60.0 ± 0.2	40.1 ± 0.1	30.1 ± 0.3	28.2 ± 0.2	18.3 ± 0.1
	D	50.0 ± 0.1	108.1 ± 0.4	69.0 ± 0.1	53.0 ± 0.3	13.7 ± 0.1

S: solar drying; AO: air oven drying; D: drum drying. Values shown are means and standard deviations.

pattern for the drum-dried flours in this study is consistent with reports by Srikaeo and Sopade [38] for instant jasmine rice porridges and Yadav et al. [39] for drum-dried sweet potato flour. The pasting profile of the air oven- and solar-dried flours also did not begin from zero, due to the steam blanching pretreatment. Compared to the drum-dried flours, however, their initial viscosity was much lower. Apart from the high starting viscosity (>0 BU), the profile of these samples resembled the typical pasting curve. Both air oven- and solar-dried flours showed a significant increase in viscosity during heating and a peak viscosity located within the heating phase. The reason is that the steam blanching alone was insufficient to fully gelatinize all the starch granules in these flours since the blanching time was short. In these flours, complete gelatinization occurred during the heating phase of the pasting profile.

The solar- and oven-dried flours had comparable peak viscosities, but these, together with the drum-dried flours, had lower peak viscosity compared with flour from some white cassava varieties (299–482 BU) reported by Oduro-Yeboah et al. [3]. The high swelling power of drum-dried flours, which is due to its ability to readily absorb water, contributed to its high peak viscosity. Indeed, peak viscosity of the flours correlated well ($r = 0.891$) with their swelling power. Breakdown viscosity, which characterizes the shear stability of pastes during heating, was lower in drum-dried flours compared to flours dried using solar and air oven methods. A breakdown viscosity of 99, 132, and 53 BU were recorded in the drum-dried flours, and these were higher compared to flours produced by solar or air oven drying (Table 3). Higher breakdown viscosity (55-118 BU) was reported for five varieties of white-fleshed cassava by Oduro-Yeboah et al. [3]. All flours exhibited a marginal increase in viscosity by the end of final cooling, depicting the generally low tendency of all yellow cassava flours to retrograde. Awoyale et al. [40] have argued that this is an important parameter in determining the cooking quality of starchy foods such as *fufu*. The results, for instance, suggest that cultivar S2, dried by solar drying, would readily set into a firm mass compared to S3 produced using the drum drying technique. The pasting index of the flours was lower than the values reported for cassava flour by Oladunmoye et al. [34].

3.7. Texture Analysis and Sensory Evaluation of *Fufu* Samples

3.7.1. Texture Profile Analysis (TPA). The texture of *fufu* samples was described by the hardness, adhesiveness, and cohesiveness obtained from the texture profile analyses. Hardness, adhesiveness, and cohesiveness ranged between 3.2 and 7.5 N, 1.0 and 2.0 N·s, and 0.3 and 0.7, respectively, for the three properties of texture (Table 4).

Both cultivar and drying method affected the texture of *fufu* made from yellow cassava. *Fufu* made from cultivar S2 was generally the hardest (mean of 6.2 N), followed by S1 (5.1 N) and S3 (4.4 N). Two-way ANOVA also showed a significant interaction ($p < 0.001$) between cultivar and drying method on *fufu* hardness. Differences in sample hardness could be explained by the presence of other components such as fibre, ash, and β-carotene, which may have interfered to different extents with starch retrogradation in the final product depending on their levels. Incidentally, fibre, ash, and carotene were higher for this sample compared to the others (results not shown). The hardness of samples obtained in this study was higher than the range of 1.4–1.7 N reported by Oduro-Yeboah et al. [41], who studied the texture of *fufu* made from white cassava and plantain flour.

As characteristic of pasty cassava products, all the *fufu* samples were adhesive. Their adhesiveness ranged from -2.0 to -1.0 N·s. There was a significant ($p < 0.001$) cultivar × drying method effect on the adhesiveness of the product. Differences in adhesiveness of the samples may be directly influenced by flour chemical properties, pasting characteristics, and functional properties such as swelling power [40]. Adhesiveness of the samples was slightly higher than the range of 0.3–1.1 N·s reported by Oduro-Yeboah et al. [41].

Cohesiveness is a desirable attribute in *fufu* and is described by Friedman et al. [42] as "a direct function of the work needed to overcome the internal bonds of

Table 4: Texture properties of fufu made from yellow cassava flour made by different drying methods.

Genotype	Drying method	Hardness (N)	Adhesiveness (N·s)	Cohesiveness
S1	S	4.67 ± 0.34	−1.43 ± 0.32	0.55 ± 0.01
	AO	7.40 ± 0.32	−1.95 ± 0.30	0.51 ± 0.03
	D	3.16 ± 0.18	−1.09 ± 0.06	0.67 ± 0.01
S2	S	6.13 ± 0.23	−1.20 ± 0.08	0.60 ± 0.02
	AO	7.46 ± 0.35	−1.43 ± 0.12	0.59 ± 0.02
	D	5.14 ± 0.10	−1.58 ± 0.31	0.63 ± 0.01
S3	S	3.51 ± 0.21	−1.31 ± 0.04	0.30 ± 0.01
	AO	6.33 ± 0.06	−1.21 ± 0.10	0.30 ± 0.01
	D	3.23 ± 0.11	−1.00 ± 0.12	0.41 ± 0.01

S: solar drying; AO: air oven drying; D: drum drying. Values shown are means and standard deviations.

Table 5: Sensory scores for *fufu* made from yellow cassava flour produced by different drying methods.

Genotype	Drying method	Appearance	Elasticity	Stickiness	Softness	Overall likeness
S1	S	5.9 ± 0.3	4.2 ± 0.2	5.6 ± 0.2	4.8 ± 0.3	5.6 ± 1.2
	AO	6.3 ± 0.4	6.6 ± 0.4	5.6 ± 0.8	4.6 ± 0.8	5.9 ± 1.0
	D	6.5 ± 0.5	6.5 ± 0.8	5.6 ± 0.4	6.1 ± 0.4	6.1 ± 1.2
S2	S	5.4 ± 0.4	2.4 ± 0.8	5.1 ± 0.2	5.1 ± 0.6	4.6 ± 0.8
	AO	4.3 ± 0.8	3.2 ± 0.5	5.0 ± 0.6	4.1 ± 0.2	4.8 ± 0.4
	D	5.6 ± 1.1	2.6 ± 0.8	4.6 ± 0.8	5.2 ± 0.4	5.2 ± 1.0
S3	S	4.9 ± 0.5	4.5 ± 0.5	3.8 ± 0.4	4.6 ± 0.3	4.2 ± 0.8
	AO	6.2 ± 0.7	4.4 ± 0.7	3.8 ± 0.5	5.4 ± 1.0	4.1 ± 0.7
	D	5.3 ± 0.4	5.2 ± 1.2	3.6 ± 0.2	5.7 ± 0.5	5.7 ± 1.2

S: solar drying; AO: air oven drying; D: drum drying. Values shown are means and standard deviations.

the material." Results for cohesiveness ranged from 0.3 to 0.7 and showed differences between the samples tested. ANOVA showed cultivar ($p < 0.001$) and drying method independently ($p = 0.004$) influenced the cohesiveness of the *fufu* samples. Samples made from hot air-dried flours were also the most adhesive and the least cohesive, whereas drum-dried flours were the least adhesive but the most cohesive.

3.8. Sensory Evaluation. Sensory evaluation showed differences in the scoring of all attributes assessed in the *fufu* samples. Scores for appearance ranged between 4.3 and 6.5 (Table 5). Generally, the scoring was influenced by the colour and surface sheen of the *fufu* samples.

While some appeared dull, others, especially samples made by drum drying, had a smooth, glossy surface. ANOVA revealed a significant dependence of appearance on cultivar ($p = 0.021$). Samples that appeared more yellowish (S1) were rated higher, possibly because of their striking resemblance to *fufu* made from a combination of cassava and plantain, which is relatively popular and widely acceptable. Irrespective of the drying method ($p = 0.562$), samples from S3, which was the paler of the three cultivars, obtained the lowest scores for appearance.

Stickiness is due to the combination of cohesive and adhesive forces, with the latter being higher in sticky foods [43]. Moderate stickiness is a desirable trait in *amala* [44], a similar product made from yam flour. The panelist scored product stickiness between 4 and 6 correspondingly for samples made from S3 and S1. Stickiness of *fufu* samples was significantly affected by cultivar ($p < 0.001$), with S1 having the most desirable stickiness (5.6) and S3 the worst (3.8). Sample S3 had the least setback viscosity and, therefore, was predicted to have an undesirably softer texture. Sensory stickiness has been linked to starch functional and thermal properties, as observed by Akissoe et al. [45] for *amala*. Their results also suggested the stickiness to be highly temperature and time-dependent, as hot *amala* formed a strong bond and adhered firmly to the bowl and stirring pellet compared to when it is cooled to 40°C. Elasticity was scored between 2.4 and 6.6 for samples made from cultivars S2 and S1 and was influenced by both cultivar ($p < 0.001$), drying method ($p = 0.015$), and their interaction ($p = 0.019$). This was not surprising since S1 recorded the highest cohesiveness in the instrumental texture analyses. Duncan's multiple range tests revealed *fufu* samples made from drum- or air-dried flours to be equally elastic compared to the flours made by solar drying. Although no direct reason could be

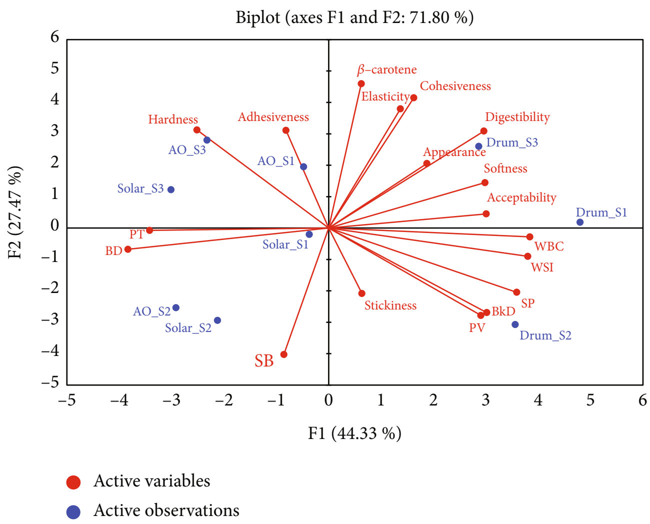

Figure 4: PCA biplots of yellow cassava flour dried by different methods and their physicochemical properties. AO: hot air oven; PT: pasting temperature; BD: breakdown viscosity; SB: setback viscosity; PV: peak viscosity; BkD: bulk density; SP: swelling power; WSI: water solubility index; WBC: water-binding capacity.

ascribed to this observation, the contribution of particle size and water hydration properties of the flours to this outcome cannot be overlooked.

There was a cultivar × drying method interaction on the softness of the *fufu* ($p = 0.001$), with *post hoc* analyses showing a lower softness score for cultivar S3, and a tendency for *fufu* made from drum-dried flour to be rated better than the other methods. This agrees with the instrumental texture analyses and setback viscosity results which showed *fufu* made from drum-dried flours as having the lowest affinity to retrograde and therefore the softer of the samples. As observed in the attributes, the acceptability scores for the samples also varied considerably. A significant interaction between the cultivar and drying method suggested that flour from cultivar S1 dried using drum drying or hot air drying produced the most desirable *fufu*. Regression analysis of the sensory results indicated the dependence of the overall acceptability of yellow cassava *fufu* samples on elasticity, stickiness, and softness ($R^2 = 0.742$).

3.9. Principal Component Analysis (PCA). To reduce the amount of variability in the dataset with the most influential variables and reveal their interrelationships, PCA was performed using chemical, functional, pasting, and texture properties of the yellow cassava flours (Figure 4). The first two principal components, F1 and F2, accounted for 71.8% of the accumulated variance in the dataset. The first component (F1) was mainly related to flour functional properties, while the second (F2) was associated with the instrumental texture properties of *fufu* made from these flours. The plot further revealed that all drum-dried flours aggregated into principal component 1 and were associated by their physicochemical properties, digestibility, and sensory attributes of *fufu* made from them. Flours produced using the hot air oven method or solar drying mainly appeared in principal component 2. These were similar in terms of flour pasting properties and instrumental texture attributes of *fufu*, including hardness and adhesiveness. Others (AO_S2 and Solar_S2) resembled each other in their setback viscosity. Unsurprisingly, the latter were derived from the same cultivar.

4. Conclusion

This study showed differences in the physical, chemical, and functional characteristics of yellow cassava flour, due to the cultivar and or drying method used. β-Carotene concentrations in the flours were affected by both cultivar and drying methods, with hot air drying giving the best results (2.8 mg/kg). Flour digestibility and hydration properties were significantly higher among flours produced using drum drying, and this positively impacted the softness of *fufu* produced. *Fufu* produced from drum-dried flours were the most acceptable by the sensory panel, and their preference was particularly influenced by elasticity, stickiness, and softness of the final product. Principal component analysis showed that drum-dried samples were more associated with their digestibility, hydration properties, and sensory attributes of *fufu*. Although the study did not consider the bioavailability of β-carotene in the flours and *fufu*, it would be useful in estimating this in future studies.

Data Availability

The data used to support the findings of this study are in the article.

Conflicts of Interest

The authors declare no conflict of interest in submitting this article for publication.

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