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Influence of Feed Rate, Moisture and Mixture Composition from Composites Containing Rice (*Oryza sativa*), Sorghum [*Sorghum bicolor* (L.) Moench] and Bamboo (*Yushania alpina*) Shoots on Physical Properties of Extruded Flour and Mass Transfer

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Abstract

Raw material composition, loading rate and moisture level in extrusion processing have a direct bearing on physical properties of the product besides other extruder operational parameters. These properties greatly influence the consumer appeal, package design and shelflife of the product. This study aimed at evaluating the effect of sorghum and rice flour containing bamboo shoot flour (BSF) and other ingredients on resultant flour and product throughput. A commercial single screw extruder with a constant barrel temperature of 250˚C and screw speed of 1480 rpm was used. Five different blends (100:0:0, 70:30:0, 60:30:10, 55:30:15 and 50:27:23 for rice, sorghum and BSF respectively, on dry weight basis) were extruded at three levels of water addition (15, 20 and 25 kg/h) and two feed rates (1800 and 2100 kg/h). Extrudates were analyzed for expansion ratio (ER). Extrudates were then milled to particle size of 2 mm and flour samples were analyzed for hydration properties, colour, bulk density (BD) and oil holding capacity (OHC). Product throughput was calculated using mass balance equation based on dry matter content of the raw materials and the corresponding extruded product. Mixture composition significantly affected all physico-chemical properties analyzed for the products except water solubility index (WSI). Feed rate significantly affected all physico-chemical of the product properties except WSI and colour lightness (L^*). Water addition significantly affected product mass transfer, ER, BD, colour and swelling capacity (SC). Therefore, BSF can be blended with other ingredients and extrusion parameters be manipulated to give forth a product with desirable properties.

Keywords

Bamboo Shoots, Extrusion, Physical Properties, Mass Transfer

1. Introduction

Extrusion cooking has been defined as the thermomechanical process in which heat transfer, mass transfer, pressure changes and shear are combined to produce unit operations such as cooking, sterilization, drying, melting, cooling, texturizing, conveying, puffing, mixing, kneading, conching (chocolate), freezing, and forming [1]. Due to its versatility nature, extrusion processing has been used extensively in the production of convenience foods owing to its ease of operation and ability to produce a variety of physical properties which are both appealing to consumers and nutritious [2] [3]. Predominant physical properties that influence consumer appeal for a product include colour, structure, density, viscosity shape, size and texture [4]. Many studies have looked at how manipulation of extruder operational parameters such as barrel temperature, screw speed, screw configuration and die dimensions affects physical properties of different types of extruded foods [5] [6] [7] [8] [9]. Manipulation of extruder ingredients variables: Feed rate, moisture level, mixture composition and particle size remains to be of interest to researchers.

Blending of different food ingredients to be extruded has recently gained popularity among food processors and researchers. The main purpose of blending is to enrich extruded products so as to address nutrient deficiencies and use of natural substances having high nutritional value as additives makes the product more acceptable [2]. According to [10] besides the nutritional aspects, there is an emergent interest in polysaccharide-protein systems, as they can function as gelling agents, thickeners, emulsifiers, texture modifiers or stabilizers in foods. This is derived from knowledge on capability of proteins which have on the behaviour of flours. When elaborating starchy products, the hydration, pasting, thermal, rheological and gelling properties of flours are important parameters that will influence the behaviour of flours when they are applied to products. Sometimes, these properties are not optimal in native starch and therefore need to be modified by various techniques to better suit the relevant end product.

Rice is one of the major cereal crops that act as an attractive material for the manufacture of ready-to-cook (RTC) products like pasta, noodles, ready-to-eat (RTE) breakfast cereals, modified starch, weaning foods, snack foods, pet foods, and dried soup, because of its colour, bland taste, flavour as well as good processing characteristics. Due to low nutritional value, many studies have been carried out to enrich rice with proteins, minerals and fibre from eggs, vegetables, legumes, fruit wastes and other cereals like sorghum and wheat [2] [11] [12] [13] However, very little information is available on effect of incorporating bamboo shoots into rice and sorghum on the physical properties of extruded products.

Bamboo shoots consumption is gaining popularity globally due to increasing awareness about it being rich in main nutrients, such as proteins, carbohydrates, minerals and fibre and is low in fat. Beyond nutritional, bamboo shoots have been found to confer other health benefits attributed to its components exhibiting prebiotic capability, nutraceutical capacity, free radical scavenging ability and other functional properties [14] [15]. So as to increase consumption of bamboo shoots, there is concerted effort by researchers to incorporate it in major staple foods. Besides blending with other ingredients, different processing methods are being used such fermentation, pickling, baking, roasting and canning [16] to increase bamboo shoot consumption. As a result of exploiting bamboo shoots in different formulations with staple foods, it is expected that the impact will not be only nutritional but also of physico-chemical nature of the blends.

However, very little information is available on impact of incorporating bamboo shoots in rice and sorghum coupled with extrusion processing on physico-chemical properties. Rice and sorghum are among the key cereal crops that are staple food among many communities around the world. Therefore, the aim of this study was to evaluate the influence of raw material containing bamboo shoot flour, sorghum and rice at different moisture level and feed rate in a single screw extruder on physical-chemical properties of resultant flour. We theorized that formulating the ingredients at different ratios and extruding these ratios at different moisture level and feed rate will not only affect the hydration properties, colour, density and expansion but also mass transfer during extrusion. Mass balance equations were employed in estimating the rate of product throughput and flashed steam. Extruder barrel temperature, screw speed and die dimensions were held constant.

2. Materials and Method

2.1. Materials

Long grain white Rice (*Oryza sativa*), red Sorghum [*Sorghum bicolor* (L.) Moench] were purchased from a cereal dealer in Nairobi, Kenya. Bamboo shoots of *Alpina* spp. were obtained from Mt. Elgon National Reserve. The fresh bamboo shoots were harvested at 4 - 6 weeks old after emergence from the soils after onset of rain season of April. Immediately after harvesting, the shoots were washed and 2 - 3 layers of husk as well as the hardened base removed using a knife. These shoots were then dried on a fire stand to a moisture content of about 10%. All the ingredients: Rice, Sorghum and bamboo shoots were milled using a hammer mill to flour of particle sizes of 800 µm. The study was carried between May to November.

2.2. Experimental Deign

This study employed a factorial experiment with 3 variables: Feed mixture composition of rice flour, sorghum and BSF (100:0:0, 70:30:0, 50:27:23, 60:30:10 and 55:35:15), feed moisture (15, 20 and 25 kg/h) and feed rate (1800 and 2100 kg/h) were used. Feed mixture composition were developed aiming at optimizing protein, dietary fibre and minerals in the blend. Feed rate levels and moisture to be added were established during the pre-trials. Experiment was conducted in triplicates.

2.3. Extrusion Cooking and Milling

A single screw commercial extruder (InstaPro Model 2000R, Chelworth, UK) was used in processing the pre-formulated mixtures. The extruder barrel was 1120 mm long divided into three sections: feeding section 480 mm, metering section 380 mm and cooking section 260 mm. Barrel temperatures for each section were 100˚C, 180˚C and 250˚C for feeding section, metering and cooking, respectively. Screw speed was constant at 1480 rpm while die diameter was 8.55 mm. The exit at the die had a cutter that chopped the extrudates into very small pieces. Extrudates dried immediately upon exit at the die after losing water through steam flash. The chopped dried extrudates were conveyed to a disk mill (FFC-45, Zhengzhou Muchnang, Henan, china) to be mill and sieve flour to particle of size of 2 mm. The mill rotor diameter was 450 mm and speed of rotation was 3000 rpm.

2.4. Physical Properties Analysis

2.4.1. Expansion Ratio

Expansion ratio (ER) was determined by dividing the average cross-sectional diameter of the extrudates with the cross-sectional diameter of the extruder die which was 8.55 ± 0.01 mm. The cross-sectional diameters were measured in millimetres with a Vernier calliper (Mituyoto, Japan).

$$\text{ER} = \frac{\text{Diameter of extrudate}}{\text{Diameter of die}} \tag{1}$$

2.4.2. Flour Hydration Properties

1) Water Absorption Index (WAI) and Water Solubility Index (WSI)

Water absorption index (WAI) and Water solubility index (WSI) were determined as described by [17]. One gram of a ground sample was accurately weighed, put into test tubes and 20 ml of distilled water added. The tubes were shaken on a vortexer and left to stand for 15 min. The tubes were then shaken and centrifuged at 1000 g for 10 min. The supernatant portion was decanted into an evaporating dish of known weight and dried at 105˚C for 12 hours. The weight of the remaining gel in the tube was taken as the WAI.

$$\text{WAI (g/g)} = \frac{\text{Weight of wet residue} - \text{Weight of dried residue}}{\text{Weight of the sample}} \tag{2}$$

$$\text{WSI}\,(\text{g/g}) = \frac{\text{Weight of soluble}}{\text{Weight of sample}} \tag{3}$$

2) Swelling Capacity (SC)

The swelling capacity (SC) was determined according to the method described by [18] with small modifications. Accurately 10.0 g of the sample was weighed and gradually mixed with 100 ml of distilled water. The suspension was held at room temperature (22˚C ± 2˚C) for 24 hours. Volume of the absorbent treated sample was recorded and then dried in an oven at 105˚C for 12 hours. Each test was carried out in triplicate and the readings reported as means. Swelling capacity (SC) was expressed as ml of water per gram of dry sample as given in equation below;

$$\text{SC}\,(\text{g/ml}) = \frac{\text{Volume of absorbent treated sample} - \text{Volume of dry sample}}{\text{Weight of dry sample}} \tag{4}$$

3) Water Holding Capacity (WHC)

The water holding capacity (WHC) was determined according to the method described by [19]. Accurately 1.0 g of sample was weighed and mixed with 25 ml of distilled water at room temperature (22˚C ± 2˚C) and left to stand for 24 hours. Centrifugation at 4000 g for 15 min was done and the residue collected, weighed and dried at 105˚C. Each test was carried out in triplicate and the readings reported as the mean. The WHC was expressed as grams of water per gram of dry sample as given in equation below:

$$\text{WHC}\,(\text{g/g}) = \frac{\text{Weight of wet residue} - \text{Weight of dry residue}}{\text{Weight of dry residue}} \tag{5}$$

2.4.3. Oil Holding Capacity

The oil holding capacity (OHC) was determined according to the method described by [19]. Accurately 1.0 g of sample was weighed and mixed with 25 ml of distilled water at room temperature (22˚C ± 2˚C) and left to stand for 24 hours. Centrifugation at 4000 g for 15 min was done and the residue collected, weighed and dried at 105˚C. Each test was carried out in triplicates and the readings reported as the mean. The OHC was expressed as g of oil per mg of dry sample as given in the following equation;

$$\text{OHC}\,(\text{g/g}) = \frac{\text{Weight of sample with oil} - \text{Weight of dry sample}}{\text{Weight of dry sample}} \tag{6}$$

2.4.4. Bulk Density (BD)

The oil holding capacity (OHC) was determined according to the method described by [19]. Accurately 1.0 g of sample was weighed and mixed with 25 ml of distilled water at room temperature (22˚C ± 2˚C) and left to stand for 24 hours. Centrifugation at 4000 g for 15 min was done and the residue collected, weighed and dried at 105˚C. Each test was carried out in triplicates and the readings reported as the mean. The OHC was expressed as g of oil per mg of dry sample as given in the following equation;

$$\text{Bulk density}\left(\text{g/cm}^3\right)=\frac{\text{Mass of the flour sample}}{\text{Volume of the flour sample}} \tag{7}$$

2.4.5. Colour Determination

Colour properties of samples were measured using a HunterLab Colour Difference Meter (Minolta, Tokyo, Japan). The results were expressed using the $L^* a^* b^*$ system, where L^* values range from black (0) to white (100), a^* values range from green (−60) to red (+60), and b^* values range from blue (−60) to yellow (+60). The hue angle and Chroma values were calculated according to [20]:

$$\text{Chroma},\left(C^*\right)=\sqrt{\left(a^{*2}\right)+\left(b^{*2}\right)} \tag{8}$$

$$\text{Hue angle}\left(h^*\right)=\tan^{-1}\left(\frac{b^*}{a^*}\right) \tag{9}$$

2.4.6. Mass Transfer Calculations

1) Rate of Product Throughput and Flash Steam Evaporation

Estimation of the rate of product throughput and flash steam being evaporated at the die was done in two steps. Stem one was to determine the dry matter content of the five feed mixture and the extruded flour samples. The oven method [21] Method 950.46 was used. About 2.0 g of samples was accurately weighed and transferred into aluminium dishes. The samples were dried in a dry air oven at 105˚C for 24 hours and cooled in a desiccator before weighing.

The second step was to use mass balance equation to determine the rate of mass transfer as follows:

$$\textbf{TMB}:\quad F+W=S+P \tag{10}$$

$$\textbf{DMB}:\quad FX_f+WX_w=SX_s+PX_P \tag{11}$$

The assumption made was that water being added to the feed and steam being liberated does not contain any dry matter component, therefore:

$$\textbf{DMB}:\quad FX_f=PX_P \tag{12}$$

where: F = Extruder feed rate at kg/h; W = Rate of water addition to the extruder at kg/h; S = Rate of flash steam being liberated at kg/h; P = Rate of product throughput at kg/h; X_f = Dry matter content in the feed; X_w = Dry matter content in water; X_s = Dry matter content in steam; X_p = Dry matter content of the product; TMB = Total mass balance and DMB = Dry matter balance.

2) Specific Mechanical Energy (SME)

Specific Mechanical Energy (SME) was calculated using the equation below according to [22] [23]:

$$\text{SME}=\frac{T\times\omega}{M_f}\quad(\text{W·h/kg}) \tag{13}$$

where: T = Torque of the extruder (N·M); ω = Angular velocity (radians/s) and M_f = Extruder feed rate (Kg/h). Given that:

$$\omega = \frac{2\pi N}{60} \quad \text{(radians/s)} \tag{14}$$

$$T = \frac{60P}{2\pi N} \quad \text{(N·m)} \tag{15}$$

where N = Screw speed of the extruder which was 1480 rpm; P = Power rating of the extruder in kW which was 75 kW.

Assumption made was that torque remained constant due to constant screw speed while SME changed based on changing feed rate of the extruder.

2.5. Data Analysis

Data obtained was tested for normality using PROC UNIVARIATE using SAS software version 9.1 (SAS Institute and Cary, NC). Analysis of variance (ANOVA) was carried out to investigate the effect of feed rate, moisture and mixture ratios on physical properties using PROC GLM. HOVTEST = LEVENE option was used to test for homogeneity of variance among the observations. Means separations were done using Scheffe method at $p \leq 0.05$.

3. Results

3.1. Effect of Extruder Mixture Composition on Hydration Properties of Flour

Effect of extruder feed composition on hydration properties of flour is shown in Figure 1. Feed composition had a significant effect on WHC, WAI and SC of extruded flour. Flour from feed ratio with 60:30:10 for rice, sorghum and bamboo shoots respectively had significantly highest values for WHC, WAI and SC. Flour from feed ratios with 55:35:15 and 50:27:23 for rice, sorghum and bamboo shoots respectively were not significantly different but had the least values compared to other feed ratios. On other hand, WSI was not significantly affected by feed composition, though flour from feed ratio of 60:30:10 had the highest solubility while flour from 55:35:15 and 50:27:23 had the least.

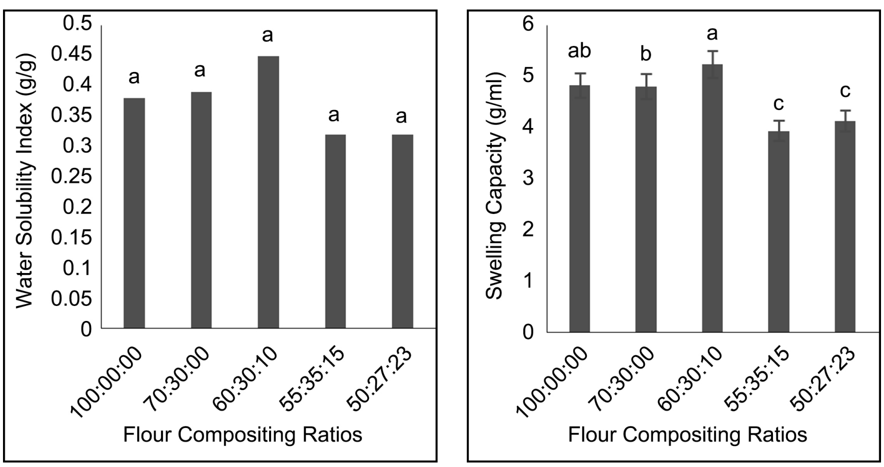

Figure 1. Effect of extruder feed composition on flour hydration properties. Mean error bars with same letter not significantly different at $p < 0.05$.

3.2. Effect of Water Addition to the Feed on Hydration Properties of the Flour

Effect of extruder rate of water addition on hydration properties of the flour is shown in Figure 2. Rate of water addition to the extruder had a significant effect on only SC of extruded flour. Water addition at a rate of 20 kg/h had significantly highest values of SC. While WHC, WAI and WSI were not significantly affected by rate of water addition, 20 kg/h had the highest values for WHC and WAI.

3.3. Effect of Feed Rate on Hydration Properties of Flour

Effect of extruder feed rate on hydration properties of flour is shown in Figure 3. Extruder feed rate had a significant effect on WHC, WAI and SC of extruded flour. Feed rate of 2100 kg/h had significantly highest values for all water hydration properties except WSI.

3.4. Effect of Ingredient Variables on Physical Properties of Extrudates and the Resultant Flour

Effect of extruder feed composition, feed rate and water addition rate on other physical properties of extrudates and the flour is shown in Table 1. Feed composition significantly affected all physical properties with the control having the

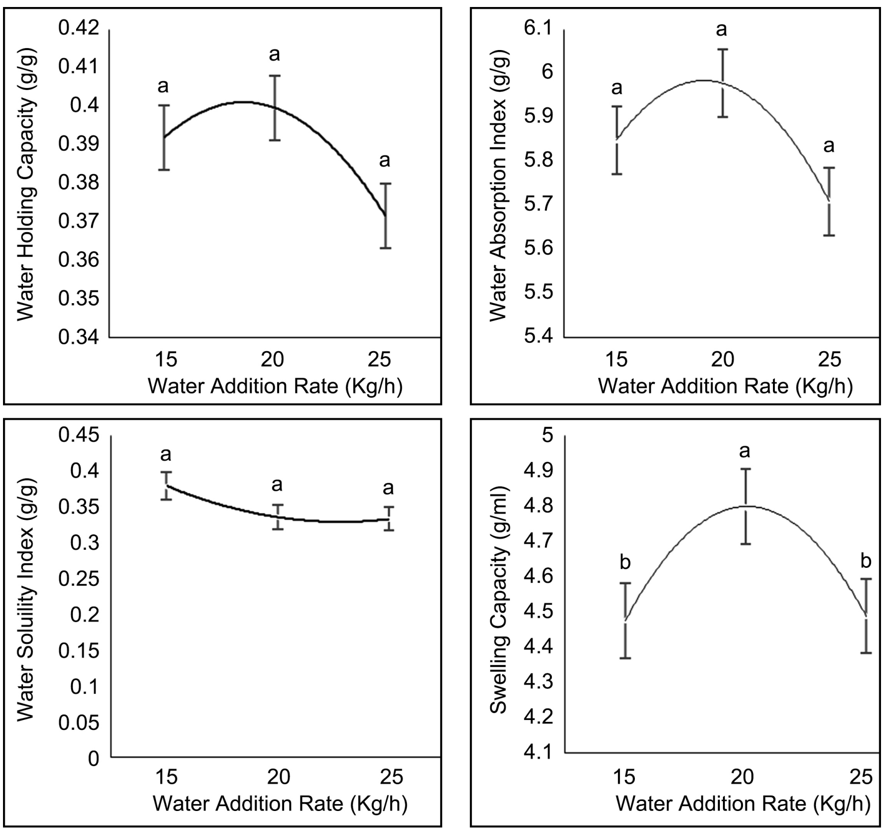

Figure 2. Effect of extruder water addition rate on flour hydration properties. Mean error bars with same letter not significantly different at $p < 0.05$.

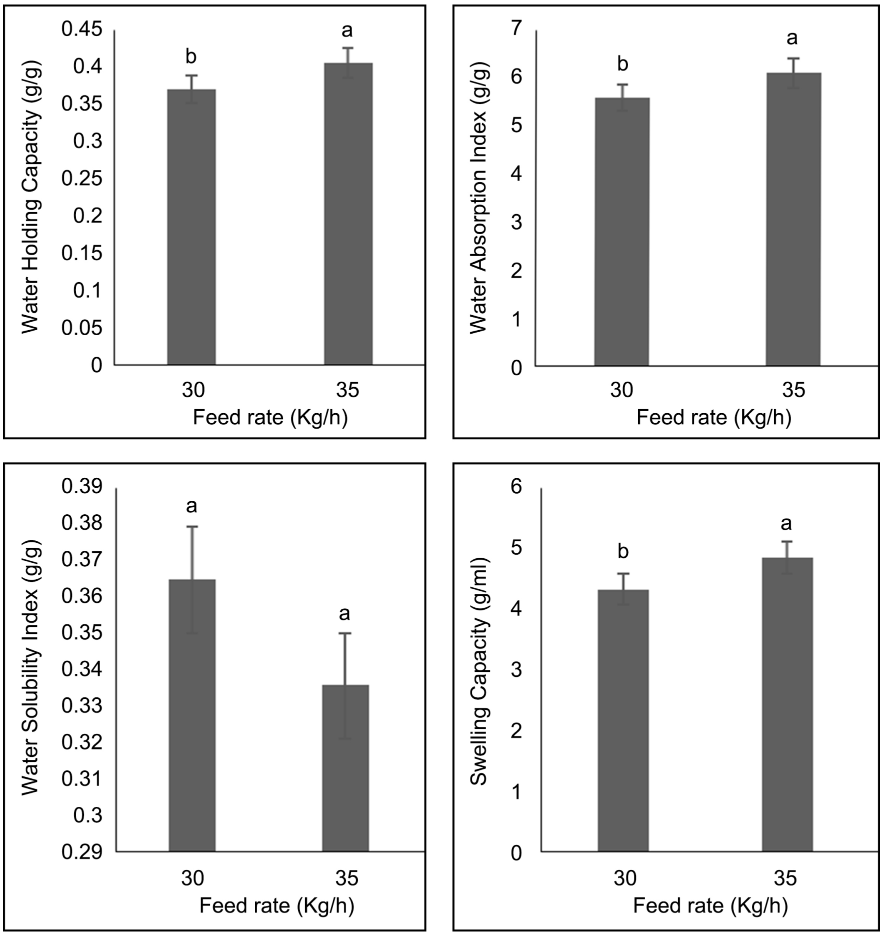

Figure 3. Effect of extruder feed rate on hydration properties of the flour. Mean error bars with same letter not significantly different at $p < 0.05$.

Table 1. Physical and mass transfer propeeties of extrudates.

Factor	Level	ER	OHC	BD	PR	SR
Feed ratio	100:00:00	4.21 ± 0.21^a	2.51 ± 0.10^a	0.56 ± 0.02^a	1782.0 ± 32.4^c	22.80 ± 1.07^a
	70:30:00	2.37 ± 0.12^b	2.21 ± 0.10^b	0.42 ± 0.03^e	1848.0 ± 35.4^b	21.70 ± 0.92^b
	60:30:10	2.09 ± 0.06^c	2.01 ± 0.08^{bc}	0.45 ± 0.01^d	1844.4 ± 31.2^b	21.76 ± 0.97^b
	55:35:15	1.94 ± 0.06^c	2.15 ± 0.12^b	0.47 ± 0.04^c	1876.2 ± 40.2^a	21.23 ± 1.14^c
	50:27:23	1.57 ± 0.11^d	1.92 ± 0.03^c	0.52 ± 0.02^b	1842.6 ± 31.2^b	21.80 ± 1.05^b
Added water	15 kg/h	2.37 ± 0.15^b	2.16 ± 0.07^a	0.48 ± 0.02^a	1843.2 ± 26.4^a	16.78 ± 0.14^c
	20 kg/h	2.20 ± 0.18^c	2.19 ± 0.08^a	0.48 ± 0.02^a	1848.6 ± 27.6^a	21.69 ± 0.15^b
	25 kg/h	2.73 ± 0.24^a	2.13 ± 0.08^a	0.49 ± 0.02^a	1823.4 ± 26.4^b	27.11 ± 0.14^a
Feed rate	1800 kg/h	2.31 ± 0.17^b	2.25 ± 0.07^a	0.46 ± 0.02^b	1701.6 ± 6.0^b	21.64 ± 0.65^b
	2100 kg/h	2.56 ± 0.15^a	2.07 ± 0.06^b	0.51 ± 0.02^a	1975.8 ± 7.8^a	22.07 ± 0.65^a

Means with same letter within a factor are not significantly different at $p < 0.05$. Key: ER = Expansion Ratio; OHC = Oil Holding Capacity; BD = Bulk Density; PR = Product Throughput rate; SR = Flashed Steam Evaporation rate.

highest values for ER, OHC, BD and SR. The rate of water addition significantly affected physical properties except OHC and BD with water addition at 25 kg/h having the values expect for PR. Extruder feed rate significantly affected all physical properties except with feed rate of 2100 kg/h having the highest values except for OHC.

3.5. Effect of Feed Rate on Specific Mechanical Energy

Effect of feed rate on SME is shown in **Figure 4**. Feed rate of 1800 kg/h had significantly higher mean for SME, 150.0 (W·h/kg) compared to feed rate at 2100 kg/h, 128.6 (W·h/kg).

3.6. Effect of Extruder Ingredient Variables on Colour of the Resultant Flour

Effect of extruder feed composition, feed rate and water addition rate on calorimetric properties of extrudates and the flour is shown in **Table 2**. The feed mixture ratio significantly affected all calorimetric parameters. Rice had the least mean values for a^*, b^* and chroma while the highest for L^* and hue angle. Amount of water added to the extruder significantly affected L^* and a^*. Water addition at 20 kg/h had the highest L^* mean values while 15 kg/h had the least. The feed rate to the extruder significantly affected all calorimetric parameters except L^*. Feed rate 1800 kg/h had significantly highest mean values for b^*, chroma and hue angle and least for a^*.

The pictorial representation of the products: extrudates and resultant instant flour is shown in **Figure 5**.

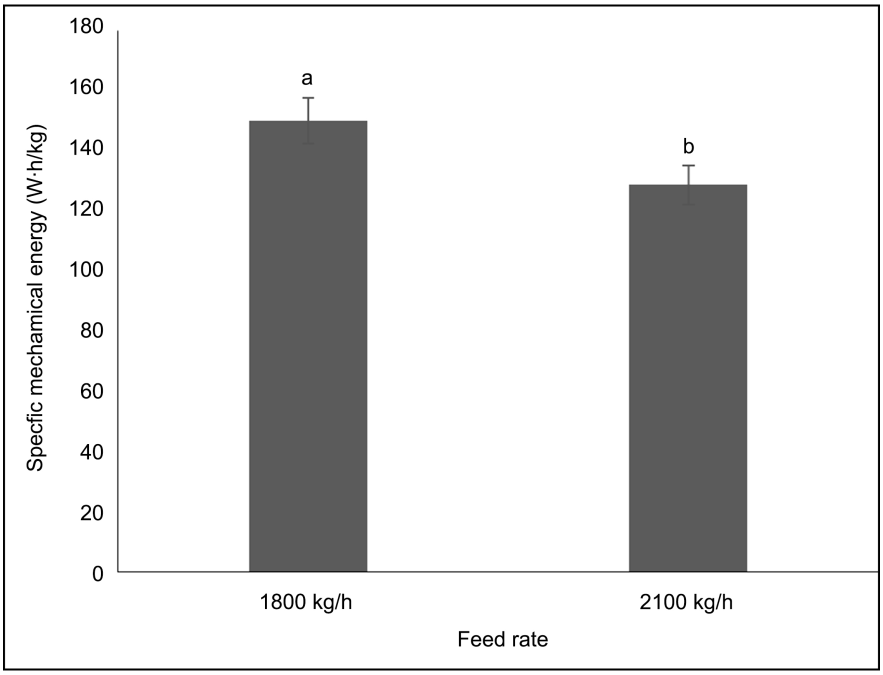

Figure 4. Effect of extruder feed rate on specific mechanical energy. Mean error bars with same letter not significantly different at $p < 0.05$.

Figure 5. Photos of extrudates and resultant instant flour.

Table 2. Calorimetric properties the extruded flour.

Factor	Level	L^*	a^*	b^*	Chroma	Hue angle
Feed ratio	100:00:00	69.53 ± 1.40^a	1.93 ± 0.25^d	16.33 ± 0.44^c	16.47 ± 0.44^c	83.34 ± 0.87^a
	70:30:00	46.95 ± 1.60^b	9.05 ± 0.15^a	19.37 ± 0.08^b	21.39 ± 0.12^a	64.98 ± 0.30^d
	60:30:10	44.51 ± 1.01^b	6.88 ± 0.14^c	19.21 ± 0.29^b	20.42 ± 0.29^b	70.26 ± 0.42^c
	55:35:15	43.86 ± 1.02^b	6.98 ± 0.15^{bc}	20.76 ± 0.26^a	21.91 ± 0.25^a	71.38 ± 0.43^b
	50:27:23	37.87 ± 1.48^c	7.27 ± 0.10^b	19.54 ± 0.38^b	20.86 ± 0.36^{ab}	69.54 ± 0.45^c
Added water	15 kg/h	47.13 ± 1.68^b	6.43 ± 0.36^{ab}	19.38 ± 0.34^a	20.49 ± 0.39^a	71.90 ± 0.88^a
	20 kg/h	50.32 ± 2.41^a	6.27 ± 0.50^b	18.80 ± 0.34^a	19.95 ± 0.41^a	72.18 ± 1.35^a
	25 kg/h	48.17 ± 2.56^b	6.57 ± 0.51^a	18.95 ± 0.40^a	20.19 ± 0.48^a	71.59 ± 1.34^a
Feed rate	1800 kg/h	48.46 ± 1.63^a	6.29 ± 0.34^b	19.55 ± 0.22^a	20.64 ± 0.26^a	72.43 ± 0.90^a
	2100 kg/h	48.62 ± 2.03^a	6.56 ± 0.41^a	18.53 ± 0.33^b	19.78 ± 0.41^b	71.35 ± 1.05^b

Means with same letter within a factor are not significantly different at $p < 0.05$. L = Lightness scale of colour where black is 0 and white is 100; a^* = (+) is red and (−) is green; b^* = (+) is yellow and (−) blue.

4. Discussion

4.1. Influence of Mixture Composition, Added Water and Feed Rate on Hydration Properties of Extruded Flour

On composition of the ingredients used, rice is about 78.87% - 82.94% carbohydrates, 6.87% - 9.51% protein, 0.48% - 0.85% crude fibre and 0.06% - 0.92% crude fat on dry weight basis [24]. Sorghum is about 6.23% - 13.81% protein, 65.57% - 76.28% carbohydrates, 3.60% - 10.54% crude fat and 1.65% - 7.94% crude fibre [25]. Bamboo shoots from A. alpina contain 26.0% - 31.33% protein, 12.17% - 18.9% crude fibre, 1.6% - 5.5% crude fat and 18% - 19% carbohydrates [26] [27]. Therefore, increasing the proportion of bamboo shoots in the blend subsequently increases protein and crude fibre content while at the same time reducing the carbohydrates. Carbohydrate in these three ingredients is starch.

WHC, WAI and SC mean values for the extruded flour significantly increased from the control with only rice to an optimum in feed blend with 60:30:10 for rice, sorghum and bamboo shoot, respectively, as shown in **Figure 1**. Beyond the feed blend of 10% bamboo shoots, WHC, WAI and SC of extruded flour mean values significantly reduced. Feed blends with 15 and 23 % bamboo shoot had the least mean values for WHC and WAI which did not differ significantly from the control. WSI was not significantly affected probably due to hydrophobic nature. Unlike feed mixture composition, SC of the extruded flour was the only hydration property significantly affected by rate of water addition as shown in **Figure 2**. However, water addition at a rate of 20 kg/h still had higher mean values for WHC and WAI but the least for WSI. Total amount of water in the feed (inherent and added water) has a direct influence on the rate of bioreaction that happens in the extruder. The increasing moisture content induces plasticizing effect which retards shearing and lowers starch gelatinization and degradation, thereby, increasing the hydration of rice-based extrudates [10]. Effect of extruder feed rate had a similar effect on hydration properties flour. Flour from an extruder fed at 2100 kg/h had significantly highest mean values for WHC, WAI and SC as compared to 1800 kg/h. The rate of loading the extruder affects the residence time of a product in the extruder and consequently the extent of cooking. Slower the feeding rate results in longer the residence time and higher biochemical reactions such as gelatinization, caramelization and maillard reactions.

WHC, WAI and SC can be defined as the ability of flour to absorb water and swell for thus improving consistency in food. It is a desirable property in food systems to improve yield and consistency and give body to the food. There is a direct relationship between WAI of the flour with amylose and amylopectin in the native granules of starch and weaker associative forces maintaining the granules structure. Usually used as a measure of the strength of starch inter-granular bond where low water binding is a characteristic to fit tightly while high water binding capacity is to specify the slack association of starch polymers or low lipid content [28] [29].

4.2. Influence of Mixture Composition, Added Water and Feed Rate on Other Physical Properties of Extrudates and Resultant Flour

Expansion ratio of the extrudates was significantly affected by the feed mixture ratio, rate of water addition to the extruder and the feed rate as shown in **Table 1**. Increasing proportion of bamboo shoots in the feed mixture significantly reduced the expansion rate. This could be attributed to the decreasing content of carbohydrates. With increase in rate of water addition, expansion ratio of extrudates significantly reduced and the increased. Also, higher feed rate resulted in higher expansion ratio. Increase in rate of gelatinization has been found to reduce expansion ratio.

OHC of the extruded flour was significantly only affected by feed mixture ratio and feed rate as shown in **Table 1**. Similar to expansion ratio, progressive increase in proportion of bamboo shoots in the mixture caused significant decrease in OHC. Increase in feed rate resulted in decrease in OHC of the extruded flour. OHC could be attributed to the lipophilic nature of the constituents of the flour. Flours which have high OAC can retain the flavour, improve the palatability, and extend the shelf life of bakery products [30]. According to [31], OHC depend upon the intrinsic factors like amino acid composition, protein conformation and surface polarity or hydrophobicity. The ability of the proteins of these flours to bind with oil makes it useful in food system where optimum oil absorption is desired. This makes flour to have potential functional uses in foods such as sausage, whipped toppings, chiffon dessert, angel and sponge cakes.

BD of the extruded flour was also significantly affected by feed mixture ratio and feed rate as shown in **Table 1**. Bilk density (BD) significantly reduced with increase in proportion of bamboo shoots in the mixture up to 10% level, after which it then increase. On the other hand, slower feed rate of the extruder resulted in higher bulk density of the extruded flour. Increase in BD has been postulated to the alteration of the structure of amylopectin which reduces the melt viscosity and elasticity of dough through plasticizing effect. Bulk density indicates the porosity of a product which influences package design and type of packaging material.

4.3. Influence of Mixture Composition, Added Water and Feed Rate on Mass Transfer Properties

Rate of product throughput and flash steam evaporated at the exit of the extruder was significantly affected by the feed mixture ratio, rate of water addition and feed rate as shown in **Table 1**. Increase in proportion of bamboo shoots in the mixture up to 15% level caused an increase in product throughput, after which it started to decrease. On contrary, rate of steam evaporated decreased with increase in bamboo shoot proportion in the feed mixture up to 15% and then it increased. Also, increase in rate of water addition caused an increase in product throughput but decreased afterwards. Conversely, increase in rate of water addition resulted in increase in rate of steam evaporation at the die. A higher feed rate caused higher product throughput and rate of steam evaporation. Lower feed rate had a significantly higher SME and vice versa as shown in **Figure 4**. This could be credited to the lower product throughput that required more time and definitely energy, to mix ingredients in the metering section of the extruder. According to [22], SME is the indication of the viscous dissipation of mechanical energy provided by the screw drive shaft, into the dough due to frictional resistance.

4.4. Influence of Mixture Composition, Added Water and Feed Rate on Colorimetric Properties of Extruded Flour

Feed mixture ratio significantly affected all aspects of extruded flour colour as shown in **Table 2**. Lightness of the product reduced with reduction of rice proportion in the mixture. Rate of water addition only affected L^* and b^* aspects of colour. Feed rate affected all aspects of colour of the extruded flour except L^*. Increase in feed rate had caused lower mean values for b^*, chroma and hue angle. Many reactions occur during extrusion that affects the colour of the extrudate. The most common reactions are non-enzymatic browning such as Maillard reaction and caramelization and pigment degradation [32]. According to [33] colour is three dimensional, and any colour-order system will need to address hue, what we instinctively think of as colour (e.g., red, blue, green), value, which represents lightness and darkness, and chroma or saturation which indicates intensity. Chroma (C^*) is considered the quantitative attribute of colourfulness, is used to determine the degree of difference of a hue in comparison to a grey colour with the same lightness. The higher the chroma values, the higher the colour intensity of samples perceived by humans. Hue angle (h^*), considered the qualitative attribute of colour, is the attribute according to which colours have been traditionally defined as reddish, greenish, etc., and it is used to define the difference of a certain colour with reference to grey colour with the same lightness. An angle of 0˚ or 360˚ represents red hue, whilst angles of 90˚, 180˚ and 270˚ represent yellow, green and blue hues, respectively [20].

5. Conclusion

Extruder ingredient variables have a significant effect on the resultant products as well as mass transfer within the extruder during cooking. More energy per kg is required when extruding blends at lower feed rate of 1800 kg/h than at 2100 kg/h. Extrusion cooking of blends made from BSF, sorghum and rice could possess a wide range of applications in the food industry. A blend that had 60:30:10 for rice, sorghum and BSF respectively, had the optimal hydration properties which indicated that it has the potential to be used in baking, soup thickening and sausage making. We therefore, recommend more studies on exploitation of bamboo as a functional ingredient in food product development.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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