



# Extrusion Temperature Influence on the Chemical and Functional Properties of Plantain, Jack-Bean and Maize Based Flakes

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## Abstract

The study evaluated the effect of extrusion temperature on the chemical and functional properties of the flour blends extruded into flakes to determine their impact on its nutritional quality. The raw plantain was peeled, sliced, air oven-dried at 60°C until constant weight was achieved, milled and sieved to obtain plantain flour, while maize was also processed to obtain maize flour. Similarly, jack-bean was washed, soaked for 4 hours, germinated for 3 days, oven dried at 60°C until constant weight, and milled to obtain jack-bean flour. The flour samples were mixed at different proportions to obtain different flour blends of low glycemic profile using design mixture of Response Surface Methodology (RSM) software applications. The glycemic profile of the generated runs from the RSM was evaluated. The selected flour blend on the basis of low glycemic profile and high resistant starch - Sample A (60% maize flour, 15.5% plantain and 24.5% jack bean flour) and Sample B (75% maize flour, 10% plantain flour and 15% jack bean flour) were extruded at various temperatures (100, 120 and 140°C). Within the experimental temperature range, higher extrusion temperatures typically resulted in lower levels of moisture and carbohydrates as well as increased levels of protein, ash and crude fiber. This shows that the chemical properties of the flakes are generally impacted by extrusion temperatures. The range of the bulk density was 0.801 g/ml (A140) to 0.625g/ml (B100). Increased bulk densities were generally the result of higher extrusion temperatures indicative of more compaction and reduced porosity in the extrudates. It is recommended that the intended use of the finished product be taken into consideration and extrusion temperature be carefully optimized to produce composite flakes of high nutritional quality. In selecting the processing conditions, moderate extrusion temperatures (120°C) are needed to balance the chemical and functional properties of the samples.

**Keywords:** Jackbean, Plantain, Maize, Extrusion, nutritional composition

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## 1. Introduction

After rice, wheat, and maize, plantains rank as the fourth most important food crop worldwide. Based on volume, they are also the most often grown fruit worldwide. Plantains are a key staple crop in Sub-Saharan Africa and are quite important for maintaining food security since they constitute around one-third of Worldwide yearly production of 100 million metric tonnes. Leading producers of plantains in West Africa are Ghana, Nigeria, Côte d'Ivoire, and Guinea (Adi, 2024). Many nations across the world recognize *Musa paradisiaca*, a medicinal plant thought to have several health advantages. It is a dependable crop that grows well in Asia, Africa, Central America, and South America. Though it has numerous therapeutic uses, most people eat it for energy. It is used to treat and control diabetes mellitus, inflammation, bacterial infections, parasitic infections, kidney and liver failure (Oguntibeju 2019). Like other edible legumes, Jack beans have outstanding qualities including low fat content, high fiber

levels, carbohydrates and a substantial amount of protein (Munjali *et al.*, 2024). *Canavalia ensiformis* L., known as jack bean is generally an underutilized crop. Raw jack bean seeds are not extensively used as a food source due to their anti-nutrient content. Heat treatment and alkali extraction have successfully reduced the anti-nutrient factors in Jackbean (Jirarat *et al.*, 2025).

Fruits and vegetables contain phytochemicals, which have been linked to a range of health benefits, including anti-inflammatory and anti-proliferative properties (Jadhav *et al.*, 2022). Celiac disease is an immune system-driven illness that results in people eating gluten-containing meals. The only proven therapy for celiac disease is to follow a gluten-free (GF) diet for life. To address the problem and meet the needs of the population impacted by this disorder, one strategy has been to produce a wide variety of cereal-based goods (Mazzola *et al.*, 2024).

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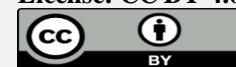
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Currently, composite flours are becoming more popular due to their proven ability to lower various lifestyle-related health issues when consumed consistently over a long duration. Consequently, they are capturing a considerable share of the commercial food and nutrition sector because individuals are increasingly aware of their health benefits. (Banua *et al.*, 2021).

The majority of the nutritional content and antinutrients found in foods are affected by the high barrel temperature of the extruder. A high barrel temperature and low moisture content in the feed enhance the water solubility index and expansion ratio of the extruded snack, while decreasing its bulk density and hardness (Ali *et al.*, 2024). Extrusion minimizes fat oxidation, alters proteins, transforms starch into a gel-like form, and mitigates anti-nutritional factors. Extruded items are safe from microbes, have an extended shelf life, improve nutrient availability, and possess lower moisture content (Pathak and Kochhar 2018). Numerous studies indicate that the quality of extruded products, such as bulk density, water absorption index, and sensory characteristics, is affected by factors including the extrusion temperature, moisture content of the feed, and the feed composition (Sadik *et al.*, 2024).

This study was carried out to investigate how extrusion temperature affects the chemical and functional properties of composite flour from this underutilized crop with the intent of enhancing its utilization.

## 2. Materials and Methods

### Plantain and Maize Flour Preparation:

The raw plantains were peeled, sliced (2 mm), air oven-dried at 60°C till constant weight, milled and sieved to obtain plantain flour, while maize grains were oven-dried, milled using a hammer mill (FUTA 2023 model) and sieved to obtain maize flour, packed into a cellophane bag and stored for further analysis (Oduro *et al.*, 2015). The sieve aperture used for the flours is 80 µm

### Jackbean Flour Preparation:

Jack-bean was washed, soaked for 4 hours, germinated for 3 days, oven dried at 60°C till constant weight, and milled using a FUTA hammer mill and sieved to obtain jack-bean flour, packed into a cellophane bag and stored for further analysis (Oduro *et al.*, 2015)

### Mixture Design of Composite Flour

Response Surface Methodology (RSM) was employed to create a blended flour mixture, and the experimental design framework is presented in Table 1. The primary components of the formulation are maize flour, plantain flour, and jackbean flour. The aim of the RSM is to optimize the flour mixture to attain preferred characteristics such as high protein and fiber levels.

The optimal RSM design adheres to the guidelines set by the American Diabetes Association (ADA), stating that adults with diabetes should have a macronutrient distribution comprising 45 to 60% carbohydrates, 15 to 20% protein, and 20 to 35% fat, based on total energy intake. This enables personalized dietary therapy tailored to treatment goals and personal preferences.

**Table 1:** Optimal Mixture Design of Composite Flour

S/N	Maize flour	Plantain flour	Jackbean flour
1	60	10	30
2	67.5	10	22.5
3	62.5	12.5	25
4	60	17.5	22.5
5	70	15	15
6	62.5	20	17.5
7	60	15.5	24.5
8	65	15	20
9	60	25	15
10	67.5	17.5	15
11	75	10	15
12	65	20	15

### Extrusion Processing

Extrusion experiments were performed using a table top single screw extruder (FUTA 2024 model) which was powered by a 10 hp motor with an operating screw speed of 300 rpm. The extruder had a barrel length-to-diameter ratio of 5:1 and a barrel diameter of 19 mm. A uniform 19.05 mm pitch screw with compression ratio of 3:1. The screw had a variable flute depth, with a depth at the feed portion of 19.05 mm, and near the die of 3.81 mm (Plate 1). The raw materials were fed to the extruder in constant feed rate; 80 g/min. Experiments were conducted at 3 barrel temperatures (100, 120, 140°C). During the experiment, the screw speed of extruder was maintained at 300 rpm.

### Determination of the Proximate Composition of the Samples

Proximate composition of the composite flour sample was determined according to AOAC (2012).

### Determination of the Mineral Contents of the Samples

The minerals (magnesium, iron, zinc, potassium, calcium) content was determined on the ash by atomic absorption spectrophotometry. The ash samples were from the product of the ash content determination (AOAC, 2014).

### Determination of Amino Acid Compositions of the Samples

The amino acid profiles of the flour blends and extruded samples was determined using the modified method of Malomo *et al.* (2020). About 2.0 g of sample was oven dried and loaded into the Technicon Sequential Multi-Sample Amino Acid Analyser (TSM-1) (Technicon Instruments Corporation, New York, USA). About 40 mg of the defatted sample was separately weighed into glass ampoules while 6 N HCl (7 ml) was added and put into an oven (105°C) to hydrolyze. About 10 µL of each hydrolysate was dispensed into the cartridge of the analyser, which then separated and analysed free acidic, neutral and basic amines, with Norleucine as the internal standard.

### Determination of Bulk Density

50 g of samples was weighed into 100-ml measuring cylinder and tapped continuously on a laboratory table to reach a constant volume according to Oladele & Aina (2007).

$$\text{Bulk Density (g/ml)} = \frac{\text{weight of sample (g)}}{\text{Weight of Sample after tapping (ml)}}$$

### Determination of Water and Oil Absorption Capacity

The sample (1.00 g) was poured into centrifuge tube containing distilled water (15 ml) and centrifuged (2500 rpm; 30 min). The supernatant was decanted and the residue weighed. In the case of oil absorption capacity (OAC), oil was accordingly used in the replacement for water as previously described by (Nwosu *et al.*, 2010).

### Determination of Samples Swelling Capacities

The sample (10 g) was put in a clean and dried calibrated measuring cylinder (initial volume is then taken) while 50 ml of distilled water was poured and allowed to stand (4 h) as described (Ukpabi & Ndimiele, 2001).

### Statistical Analysis

All determinations were obtained in triplicates values and the experimental errors were obtained as mean standard deviation and subjected to analysis of variance (ANOVA) using the Statistical Package for Social Science (SPSS) of version 21 (SPSS Inc., USA). The means were separated using the procedures of New Duncan Multiple Range Test (NDMRT) at 5% significance level. Results were obtained in triplicate and subjected to statistical analysis.

## 3. Results and Discussion

### Proximate Analysis of the Flour

The proximate analysis of the raw flour materials is shown in Table 2. There was not much difference in the ash contents of the raw material samples, which ranges from  $1.39 \pm 0.04\%$  for maize flour to  $1.75 \pm 0.02\%$  for plantain flour, showing the total mineral amount. Jackbean flour at  $6.33 \pm 0.04\%$  has the highest fat content, which is much more than that in plantain flour at  $0.18 \pm 0.02\%$  and maize flour at  $2.92 \pm 0.16\%$ . For recipes requiring low fat, plantain flour is suitable because of its low fat amount. Jackbean flour had the highest crude fiber at  $12.02 \pm 0.08\%$ , followed by maize flour at  $1.64 \pm 0.01\%$  and plantain flour at  $0.54 \pm 0.03\%$ . Jackbean flour had the highest protein content at  $30.00 \pm 0.10\%$ , while plantain flour had  $2.98 \pm 0.02\%$ , and maize flour had  $10.06 \pm 0.10\%$ . The very high protein content in jackbean flour indicates that it can be used as a protein boost in mixed flours and food recipes. The largest amount of carbohydrates at  $84.84 \pm 0.02\%$  was in plantain flour. The protein level in jackbeans aligns with findings of Fiametta *et al.*, (2023), which showed it was between 28 to 39% of the dry weight. Dietary proteins provide amino acids, which help the body strengthen and grow lean muscle. Many amino acids serve specific functions (Moughan *et al.*, 2024). Oko *et al.*, (2025) stated that the carbohydrate amount in different plantain types varied greatly in the average results, ranging from 69 to 81%. These results back up earlier studies showing that plantains have a lot of carbohydrates. High carbohydrate levels can replace fiber in meals and can be an important energy source when included in the diet.

### Proximate Analysis of Composite Flours

Table 3 displays the various compositions of the raw materials used in the different mixtures obtained from RSM. The ash content varies between 1.85% for Sample 5 and 2.31% for Sample 1. Greater ash content is linked to increased levels of minerals. This indicates that an increased amount of plantain flour improves the mineral content. The amount of crude fiber

in each formulation varied from 2.55% (Sample 9) to 4.05% (Sample 1). Sample 1, which contains 22.5% jackbean, exhibits the highest fiber content at  $4.05 \pm 0.09\%$ , and this is considerably greater than that of the other samples. Jackbean, as a type of legume that provides a considerable amount of fiber, appears to be a beneficial option for improving the fiber content in flours made from mixtures of cereals and legumes. Along with being high in fiber, samples 4 and 7 contained protein levels of 3.5% and 2.95%, respectively, which indicates a favorable balance between fiber and protein. Sample 2 has a protein content of  $12.95 \pm 0.09\%$ , which is notably lower than that of the other samples. In contrast, sample 11 possesses the highest protein content at  $15.50 \pm 0.00\%$ , significantly surpassing the other samples. Sample 1 is significant because it has a lot of protein and fiber. Sample 11 contains the most protein and fat while having the least amount of carbohydrates, making it ideal for products that focus on being high in protein and energy. Although Sample 2 contained more carbohydrates, it had the least amount of protein, which suggests that the low amount of jackbean affected its dilution. The five chosen samples were examined for their glycemic index characteristics. Enhancing blood sugar regulation, decreasing glucose fluctuations, reducing high insulin levels, lowering fat concentrations in the blood, and assisting individuals with type 2 diabetes in controlling their weight are objectives for managing this condition. Increasing fiber intake, preferably through food or dietary supplements, may be advantageous (Banshi *et al.*, 2022).

### Glycemic Index of Flour Samples

Table 4 shows the glycemic index (pGI), resistant starch (RS), slowly digestible starch (SDS) rapidly digestible starch (RDS), and total starch (TS).

With a glycemic index of 64.62, Sample 1 had the highest GI indicating that the food had a medium GI, Sample 5 had the lowest GI ( $44.75 \pm 0.02$ ) falling into the low-GI category. With significantly lower pGI values, samples 3, 4 and 5 are suitable for diabetics and other individuals requiring glycemic control. The RDS content was highest in sample 1, ( $39.15 \pm 0.37\%$ ) and Sample 2 (26.73%) while Sample 5 had the lowest RDS percentage ( $17.05 \pm 0.10\%$ ). Lower Rapidly Digestible Starch (RDS) in Samples 4 and 5 supports lower glycemic responses. Slowly Digestible Starch which was present in samples 4 and 5 are significantly lower compared to other samples (18.63 and 17.04% respectively). Samples 2 and 5 showed a moderate to low GI value as indicated by their significant RS content ( $22.10 \pm 0.18\%$  and  $21.21 \pm 0.60\%$  respectively). When resistant starch (RS) is not broken down in the small intestine and enters the colon unchanged is fermented by resident microorganisms short-chain fatty acids (SCFAs) are created (Bojarczuk *et al.*, 2022). A daily intake of 15–60 g of resistant starch may reduce energy intake while improving insulin sensitivity and satiety in healthy adults (ADA 2013). Samples 4 and 5 designated A and B were extruded at different temperatures (100, 120 and 140°C).

### Proximate Analysis of Extruded Samples

The samples (A and B) extruded at various temperatures were examined for proximate analysis as seen in Table 5. As the temperature rose, the amount of protein increased. Xuxuan (2022), claims that following extrusion protein solubility

increased at temperatures ranging from 90 to 150°C. Perhaps as a result of less protein leaching and denaturation higher extrusion temperatures appeared to improve protein retention. Protein values in Sample A are typically higher than those in Sample B at the same temperature. The samples have varying moisture contents ranging from 8.47% (A120) to 6.37% (B140). Moisture generally dropped as the extrusion temperature increased most likely due to better water evaporation at higher heat settings. Extruded products should contain less moisture for longer shelf life and microbial stability. With the lowest moisture content sample B140 is probably the most shelf-stable. In general, the percentage of ash content rose as the temperature increased. The least amount of ash was found in A100 (0.83%) and A140 had the highest (1.80%) which represents the overall amount of minerals. Higher temperatures have the potential to break down cell walls thermally producing more ash and making minerals easier to extract. The fat content was between 8.02% (A120) and 10.96% (B100). Notably the B samples usually have a higher fat content than the A samples at the same temperatures. Variations in the composition of the flour blends may account for this. At lower temperatures there was a slight increase in fat content which could have been brought on by less fat degradation or volatilization. A100 had the lowest crude fiber content. Conversely the B100 and B120 samples displayed a contrasting decline which may indicate that after prolonged exposure, fiber structural deterioration happens even at lower temperatures. In the extruded samples, the flour formulation and extrusion temperature had a significant effect on the nutritional composition. Higher extrusion temperatures led to higher levels of protein ash and crude fiber and lower levels of moisture and carbohydrates. According to Gutiérrez Román *et al.*, (2022) the extruded barley-corn mix increased protein digestibility by about 5%. These findings are in line with those of Omana *et al.*, (2010) who investigated the composition and quality of extruded products made from rice flour and fish mince with a focus on the thermal properties of rice flour. As the barrel temperature rose they discovered that the protein, fat and ash content increased in all treatments. Claudia *et al.*, (2019) discovered that higher extrusion temperatures increase the amounts of protein and soluble dietary fiber while also improving protein digestibility.

### Functional Properties of the Extruded Samples

The functional properties of the extruded samples are as presented in Table 6. The range of the bulk density was 0.801 g/ml (A140) to 0.625g/ml (B100). Increased bulk densities were generally the result of higher extrusion temperatures. Higher bulk densities in A140 are indicative of more compaction and reduced porosity in the extrudates. The enhanced molecular bonding and starch gelatinization caused by the high extrusion temperature and pressure may be the cause of this. Lower bulk densities like those found in B100 and A100 are generally linked to more expanded and airy structures which may be preferred in snack applications (Sean 2018). The samples capacities to absorb water (WAC) varied significantly with B140 being the lowest. Water absorption shows the extrudates ability to interact with water and expand which is crucial for applications like baby food and snacks. The oil absorption capacity ranged from 0.96 (A120) to 1.71g/ml (A140) in samples. Samples A140 and B140 displayed noticeably higher OAC values indicating that higher

extrusion temperatures improve the flours ability to bind fat. One possible explanation for this problem is the denaturation of proteins and the exposure of hydrophobic groups that encourage oil interaction. OAC plays a critical role in assessing the food items taste and flavor preservation.

As the temperature rose, the samples capacity to swell increased-A140 (17.00g/ml) and B140 (16.00g/ml). For extruded food products, a high swelling capacity is frequently linked to improved mouthfeel, textural qualities and increased product volume. A140 exhibited the highest degree of swelling which was consistent with its higher level of gelatinization and starch modification. Lower temperature treatments improve water absorption capacity (WAC) which may make these formulations better suited for food systems that require moist textures or rehydration. At lower temperatures, formulation B demonstrated superior water absorption, however in terms of bulk density and oil absorption capacity (OAC) formulation A generally outperformed formulation B.

According to Boakye Sharma and Gujral (2023). The increase in WAC and oil absorption capacity was attributed to the creation of porous structures that could absorb more water or oil. An excess of water causes gelatinization, the irreversible melting phase transition of starch granules from an ordered to a disordered state. Water absorption and swelling destabilize the amorphous portion of a starch granule during the gelatinization process while the crystalline portion melts simultaneously with gradually increasing hydration (Song *et al.*, 2020).

### Mineral Analysis of Extruded Samples

The mineral analysis of the extruded samples is as presented in table 7. The sodium (Na) ranges from 91.80 ± 0.07 mg/kg (B100) to 114.50 ± 0.01 mg/kg (B120). In general, and especially in formulation B, a trend of rising sodium content with rising extrusion temperature was noted, this might be explained by concentration effects brought on by moisture loss. Sodium is beneficial because it helps with nerve function and electrolyte balance. The sodium content of the sample is comparable to that of breakfast cereal extruded from maize-based composite flours which was reported by Adepeju *et al.*, 2024. Their findings ranged from 108.8 mg/kg to 186.7 mg/kg for Sodium content. The American Diabetes Association (ADA) on nutrition therapy for the treatment of adults with diabetes suggested that most patients with diabetes should aim for 230 mg/kg per day with lower goals only for specific patients depending on other health factors. (ADA 2013).

The element potassium (K), in the samples analysed was the most abundant. It was lowest in B120 (144.90 ± 1.00 mg/kg) and highest in A140 (173.00 ± 1.00 mg/kg). Dietary K is positively associated with reduced cardiovascular risk. In the sample A, the higher levels at 140°C imply that high-temperature extrusion promotes potassium retention. Potassium is necessary for both muscle contraction and blood coagulation. It mostly exists as an intracellular cation with a sizable fraction of this cation attached to proteins. A slightly increased potassium to a product could be beneficial particularly for breakfast cereals where potassium is a crucial macronutrient among other minerals (Olugbuyi 2022).

Calcium (Ca) levels in samples extruded at 120 °C were significantly higher (A120: 82. 80 ± 0. 80 mg/kg) and B140 (81. 00 ± 1. 01 mg/kg) was not far behind. There were lower values in B100 (70-80 ± 0-06 mg/kg). Calcium plays a crucial role in bone formation and cellular signaling making this a nutritionally significant item. Energy metabolism neuromuscular function and enzymatic reactions all depend on magnesium. Magnesium, Zinc significantly reduced fasting plasma glucose (Zahra *et al.*, 2020) and helps in the reduction of oxidative stress. The iron content varied slightly but was consistent across most samples. A120 had the lowest concentration (0. 977 ± 0. 09 mg/kg) while B140 and B100 had the highest (1. 10 ± 0. 01 mg/kg). Hemoglobin synthesis and oxygen transport depend on iron. B100 had the highest zinc levels (0. 118 ± 0. 01 mg/kg) which ranged from 0. 100 to 0. 118 mg/kg. Immune system and enzymatic functions depend on zinc. The minor variations could result from different ingredient sources or from the bioavailability of zinc being impacted by heat exposure. The manganese content varied moderately peaking at B140 (0. 110 ± 0. 00 mg/kg) and falling to its lowest in A120 (0. 075 ± 0. 00 mg/kg). A140 had the lowest Se level (0. 020 ± 0. 01 mg/kg) while B100 had the highest (0. 080 ± 0. 02 mg/kg). Despite being necessary in trace amounts, Selenium is essential for thyroid hormone metabolism and antioxidant defense. Higher Se concentrations at lower temperatures imply that this element might be heat-sensitive and undergo partial volatilization or degradation when extruded at high temperatures. The element phosphorus (P). The majority of the samples had trace levels of phosphorus with A140 and B140 having 0.06 ± 0. 01 mg/kg. The absence

of phosphorus in A100 and B100 indicates that there is substantial thermal degradation or binding at lower temperatures. Both bone mineralization and energy metabolism (ATP) depend on phosphorus. Iron and potassium were more likely to be retained by high-temperature extrusion (140 °C) whereas magnesium and selenium were preserved by lower temperatures. The mineral content of the formulations varied as well in general formulation B had somewhat higher levels of Fe, Zn and Se. These results are helpful for optimizing extruded flour products that are designed to satisfy particular micronutrient requirements particularly for fortified or functional foods.

Table 7b shows the mineral analysis ratio. The significance of the mineral analysis ratio is to ascertain a proper balance between minerals in a biological system. The extruded samples show a Na/K ratio that is less than 1, which is desirable even in anti-diabetics as recommended by the World Health Organisation (WHO 2012). For most of the food samples, the calcium-to-potassium (Ca/K) ratio is almost 1:1, within a normal advantageous range and has favorable effects on human nutrition. The extruded samples showed a Ca/Mg ratio lesser than the optimal 2:1, this parameter is essential for anti-inflammation. The risk of metabolic inflammatory and cardiovascular disorders has been linked to a serum Ca/Mg ratio greater than 2:1. Some clinical or experimental studies also show that the effect of Mg on vascular calcification should be analyzed together with the Ca levels. As T2DM is a chronic inflammatory disease, it has been associated with increased Ca/Mg ratio and hypomagnesemia (Yücel *et al* 2023).

**Table 2:** Proximate Analysis of the Flour

Samples	%MC	%Ash	%Fat	%Crude	%Protein	%CHO
Jackbean flour	8.53 ± 0.46 <sup>c</sup>	1.57 ± 0.02 <sup>a</sup>	6.33 ± 0.04 <sup>a</sup>	12.02 ± 0.08 <sup>a</sup>	30.00 ± 0.1 <sup>a</sup>	47.68 ± 0.7 <sup>b</sup>
Plantain flour	9.72 ± 0.15 <sup>ab</sup>	1.75 ± 0.02 <sup>a</sup>	0.18 ± 0.02 <sup>c</sup>	0.54 ± 0.03 <sup>c</sup>	2.98 ± 0.02 <sup>c</sup>	84.84 ± 0.02 <sup>a</sup>
Maize flour	10.52 ± 0.05 <sup>a</sup>	1.39 ± 0.04 <sup>a</sup>	2.92 ± 0.16 <sup>b</sup>	1.64 ± 0.01 <sup>b</sup>	10.06 ± 0.1 <sup>b</sup>	73.47 ± 0.07 <sup>a</sup>

**Table 3:** Proximate Analysis of Composite Flours

	%MC	%Ash	%Fat	%Crude fibre	%Protein	%CHO
1	9.87 ± 0.01 <sup>b</sup>	2.31 ± 0.01 <sup>a</sup>	9.08 ± 0.2 <sup>d</sup>	4.05 ± 0.09 <sup>a</sup>	15.21 ± 0.07 <sup>b</sup>	59.49 ± 0.33 <sup>f</sup>
2	9.67 ± 0.02 <sup>bc</sup>	1.96 ± 0.00 <sup>fg</sup>	9.69 ± 0.00 <sup>b</sup>	3.13 ± 0.03 <sup>bcd</sup>	12.95 ± 0.09 <sup>b</sup>	62.61 ± 0.09 <sup>ab</sup>
3	9.70 ± 0.01 <sup>bc</sup>	2.17 ± 0.03 <sup>b</sup>	9.04 ± 0.00 <sup>d</sup>	3.48 ± 0.00 <sup>abc</sup>	13.46 ± 0.00 <sup>g</sup>	62.16 ± 0.04 <sup>bc</sup>
4	9.45 ± 0.00 <sup>d</sup>	2.00 ± 0.00 <sup>def</sup>	9.61 ± 0.00 <sup>b</sup>	3.50 ± 0.00 <sup>bc</sup>	14.45 ± 0.00 <sup>e</sup>	60.99 ± 0.00 <sup>de</sup>
5	9.10 ± 0.02 <sup>f</sup>	1.85 ± 0.00 <sup>h</sup>	9.05 ± 0.00 <sup>d</sup>	3.12 ± 0.00 <sup>bcd</sup>	13.93 ± 0.00 <sup>f</sup>	62.91 ± 0.02 <sup>a</sup>
6	9.33 ± 0.00 <sup>e</sup>	1.93 ± 0.04 <sup>g</sup>	9.03 ± 0.00 <sup>d</sup>	3.33 ± 0.00 <sup>abc</sup>	13.66 ± 0.11 <sup>g</sup>	62.72 ± 0.00 <sup>ab</sup>
7	9.73 ± 0.10 <sup>bc</sup>	2.03 ± 0.01 <sup>cde</sup>	9.22 ± 0.02 <sup>cd</sup>	2.95 ± 0.13 <sup>bcd</sup>	14.49 ± 0.01 <sup>de</sup>	61.60 ± 0.04 <sup>cd</sup>
8	8.99 ± 0.05 <sup>f</sup>	2.14 ± 0.04 <sup>b</sup>	9.45 ± 0.00 <sup>bc</sup>	3.43 ± 0.00 <sup>abc</sup>	14.72 ± 0.04 <sup>cd</sup>	61.28 ± 0.03 <sup>de</sup>
9	9.63 ± 0.00 <sup>cd</sup>	2.07 ± 0.02 <sup>c</sup>	8.97 ± 0.01 <sup>d</sup>	2.55 ± 0.19 <sup>d</sup>	14.64 ± 0.00 <sup>cde</sup>	62.14 ± 0.02 <sup>bc</sup>
10	10.10 ± 0.00 <sup>a</sup>	2.04 ± 0.00 <sup>cd</sup>	9.56 ± 0.00 <sup>b</sup>	2.76 ± 0.14 <sup>cd</sup>	14.85 ± 0.00 <sup>c</sup>	60.69 ± 0.10 <sup>e</sup>
11	9.82 ± 0.02 <sup>bc</sup>	2.02 ± 0.01 <sup>cde</sup>	10.20 ± 0.00 <sup>a</sup>	3.33 ± 0.00 <sup>abc</sup>	15.50 ± 0.00 <sup>a</sup>	59.14 ± 0.02 <sup>f</sup>
12	9.64 ± 0.00 <sup>cd</sup>	1.98 ± 0.03 <sup>efg</sup>	10.02 ± 0.04 <sup>a</sup>	3.30 ± 0.03 <sup>bc</sup>	14.02 ± 0.12 <sup>f</sup>	61.35 ± 0.20 <sup>de</sup>

5 samples highlighted above were selected and the glycemic index determined based on their fibre and protein levels

**Table 4:** Glycemic Index Table for the Selected Flour Samples

	pGI %	RDS	SDS	RS	TS
1	64.62 ± 0.50 <sup>a</sup>	39.15 ± 0.37 <sup>a</sup>	31.42 ± 0.23 <sup>a</sup>	16.98 ± 0.06 <sup>d</sup>	87.55 ± 0.06 <sup>a</sup>
2	52.28 ± 0.33 <sup>b</sup>	26.72 ± 0.88 <sup>b</sup>	28.69 ± 0.80 <sup>b</sup>	22.09 ± 0.18 <sup>b</sup>	77.52 ± 0.71 <sup>b</sup>
3	49.97 ± 0.14 <sup>bc</sup>	20.79 ± 0.13 <sup>c</sup>	19.67 ± 0.13 <sup>c</sup>	24.22 ± 0.32 <sup>a</sup>	64.68 ± 0.07 <sup>c</sup>
4	47.08 ± 0.88 <sup>cd</sup>	18.66 ± 0.47 <sup>cd</sup>	14.88 ± 0.04 <sup>d</sup>	19.46 ± 0.79 <sup>c</sup>	53.00 ± 0.81 <sup>d</sup>
5	44.75 ± 0.02 <sup>d</sup>	17.04 ± 0.10 <sup>d</sup>	13.32 ± 0.10 <sup>d</sup>	21.21 ± 0.60 <sup>bc</sup>	51.59 ± 0.85 <sup>d</sup>

Sample 4&5 (A&B) were extruded at various temperatures (100, 120 and 140°C) and their proximate and functional properties determined.

The composition of sample 4 is 60% maize flour, 15.5% plantain flour and 24.5% jack bean flour

The composition of sample 5 is 75% maize flour, 10% maize flour and 15% jack bean flour

**Table 5:** Proximate Analysis of Extruded Samples

	%MC	%Ash	%Fat	%Crude fibre	%Protein	%CHO
A140	7.02 ± 0.00 <sup>b</sup>	1.80 ± 0.03 <sup>a</sup>	10.14 ± 0.07 <sup>a</sup>	3.80 ± 0.13 <sup>a</sup>	21.03 ± 0.00 <sup>a</sup>	56.21 ± 0.09 <sup>b</sup>
A120	8.46 ± 0.14 <sup>a</sup>	1.52 ± 0.00 <sup>b</sup>	8.02 ± 0.10 <sup>c</sup>	4.11 ± 0.53 <sup>a</sup>	15.74 ± 0.00 <sup>e</sup>	62.15 ± 0.00 <sup>a</sup>
A100	7.08 ± 0.09 <sup>b</sup>	0.83 ± 0.02 <sup>d</sup>	9.66 ± 0.11 <sup>ab</sup>	2.30 ± 0.10 <sup>b</sup>	17.46 ± 0.00 <sup>c</sup>	62.67 ± 0.00 <sup>a</sup>
B140	6.37 ± 0.00 <sup>c</sup>	1.73 ± 0.14 <sup>a</sup>	10.80 ± 0.30 <sup>a</sup>	4.24 ± 0.06 <sup>a</sup>	20.00 ± 0.00 <sup>b</sup>	56.86 ± 0.20 <sup>b</sup>
B120	7.36 ± 0.11 <sup>b</sup>	1.54 ± 0.02 <sup>b</sup>	10.43 ± 0.07 <sup>a</sup>	2.67 ± 0.11 <sup>b</sup>	17.12 ± 0.00 <sup>d</sup>	60.88 ± 0.30 <sup>ab</sup>
B100	8.37 ± 0.00 <sup>a</sup>	1.39 ± 0.01 <sup>c</sup>	10.96 ± 0.07 <sup>a</sup>	2.58 ± 0.00 <sup>b</sup>	20.06 ± 0.00 <sup>b</sup>	56.64 ± 0.07 <sup>b</sup>

**Table 6:** Functional Properties of Extruded Samples

	Bulk density (G/ML)	WAC (G/ML)	OAC (G/ML)	Swelling capacity (ML)
A140	0.801 ± 0.01 <sup>a</sup>	2.00 ± 0.00 <sup>cd</sup>	1.71 ± 0.06 <sup>a</sup>	17.00 ± 0.00 <sup>a</sup>
A120	0.787 ± 0.01 <sup>a</sup>	2.20 ± 0.00 <sup>c</sup>	0.96 ± 0.00 <sup>c</sup>	10.00 ± 0.00 <sup>c</sup>
A100	0.674 ± 0.01 <sup>b</sup>	2.45 ± 0.07 <sup>b</sup>	1.10 ± 0.00 <sup>c</sup>	15.00 ± 0.00 <sup>b</sup>
B140	0.707 ± 0.01 <sup>b</sup>	1.45 ± 0.07 <sup>e</sup>	1.27 ± 0.05 <sup>b</sup>	16.00 ± 0.00 <sup>ab</sup>
B120	0.771 ± 0.02 <sup>a</sup>	1.95 ± 0.07 <sup>d</sup>	1.01 ± 0.06 <sup>c</sup>	13.50 ± 0.70 <sup>c</sup>
B100	0.625 ± 0.00 <sup>c</sup>	2.75 ± 0.07 <sup>a</sup>	1.40 ± 0.00 <sup>b</sup>	12.00 ± 0.00 <sup>c</sup>

Means with different letters in the column are significantly different ( $p < 0.05$ )

**KEY**

**A140** = 60% maize flour + 15.5% plantain flour + 24.5% jack bean flour extruded at 140°C

**B140** = 75% maize flour, 10% plantain flour + 15% jack bean flour extruded at 140°C

**A120** = 60% maize flour + 15.5% plantain flour + 24.5% jack bean flour extruded at 120°C

**B120** = 75% maize flour, 10% plantain flour and 15% jack bean flour extruded at 120°C

**A100** = 60% maize flour + 15.5% plantain flour + 24.5% jack bean flour extruded at 100°C

**B100** = 75% maize flour, 10% plantain flour and 15% jack bean flour extruded at 100°C

**Table 7:** Mineral Analysis of Extruded Samples

	Metals (mg/kg)								
	Na	K	Ca	Mg	Fe	Zn	Mn	Se	P
<b>A140</b>	105.00 ± 0.04 <sup>d</sup>	173.00 ± 1.00 <sup>a</sup>	78.50 ± 0.01 <sup>b</sup>	92.10 ± 0.01 <sup>ab</sup>	1.095 ± 0.01 <sup>a</sup>	0.110 ± 0.01 <sup>a</sup>	0.100 ± 0.01 <sup>ab</sup>	0.020 ± 0.01 <sup>b</sup>	0.06 ± 0.01 <sup>a</sup>
<b>A120</b>	110.00 ± 0.04 <sup>b</sup>	148.00 ± 0.01 <sup>d</sup>	82.80 ± 0.80 <sup>a</sup>	83.60 ± 0.80 <sup>c</sup>	0.977 ± 0.09 <sup>b</sup>	0.100 ± 0.00 <sup>a</sup>	0.075 ± 0.00 <sup>b</sup>	0.030 ± 0.01 <sup>ab</sup>	0.02 ± 0.00 <sup>b</sup>
<b>A100</b>	95.30 ± 0.01 <sup>e</sup>	153.50 ± 0.70 <sup>c</sup>	74.20 ± 0.01 <sup>c</sup>	92.50 ± 1.10 <sup>a</sup>	1.02 ± 0.00 <sup>b</sup>	0.115 ± 0.00 <sup>a</sup>	0.086 ± 0.00 <sup>ab</sup>	0.050 ± 0.01 <sup>ab</sup>	0.00 ± 0.00 <sup>b</sup>
<b>B140</b>	107.00 ± 0.02 <sup>c</sup>	169.70 ± 0.14 <sup>a</sup>	81.00 ± 1.01 <sup>ab</sup>	88.60 ± 0.80 <sup>b</sup>	1.10 ± 0.01 <sup>a</sup>	0.114 ± 0.01 <sup>a</sup>	0.110 ± 0.00 <sup>a</sup>	0.040 ± 0.01 <sup>ab</sup>	0.06 ± 0.01 <sup>a</sup>
<b>B120</b>	114.50 ± 0.01 <sup>a</sup>	144.90 ± 1.00 <sup>d</sup>	80.50 ± 0.70 <sup>ab</sup>	83.90 ± 1.01 <sup>c</sup>	0.982 ± 0.02 <sup>b</sup>	0.113 ± 0.00 <sup>a</sup>	0.091 ± 0.00 <sup>ab</sup>	0.050 ± 0.01 <sup>ab</sup>	0.02 ± 0.00 <sup>b</sup>
<b>B100</b>	91.80 ± 0.07 <sup>f</sup>	157.10 ± 0.14 <sup>b</sup>	70.80 ± 0.06 <sup>c</sup>	95.00 ± 1.02 <sup>a</sup>	1.10 ± 0.01 <sup>a</sup>	0.118 ± 0.01 <sup>a</sup>	0.100 ± 0.00 <sup>ab</sup>	0.080 ± 0.02 <sup>a</sup>	0.00 ± 0.00 <sup>b</sup>

Means with different letters in the column are significantly different ( $p < 0.05$ )

**Table 7b:** Mineral Analysis Ratio

	Na/K	Ca/k	Ca/Mg
<b>A140</b>	0.61 ± 0.01 <sup>b</sup>	0.45 ± 0.10 <sup>b</sup>	0.84 ± 0.10 <sup>b</sup>
<b>A120</b>	0.74 ± 0.02 <sup>a</sup>	0.56 ± 0.10 <sup>a</sup>	0.99 ± 0.20 <sup>a</sup>
<b>A100</b>	0.62 ± 0.01 <sup>b</sup>	0.48 ± 0.01 <sup>b</sup>	0.80 ± 0.00 <sup>b</sup>
<b>B140</b>	0.60 ± 0.01 <sup>b</sup>	0.48 ± 0.02 <sup>b</sup>	0.91 ± 0.00 <sup>a</sup>
<b>B120</b>	0.79 ± 0.03 <sup>a</sup>	0.56 ± 0.02 <sup>a</sup>	0.95 ± 0.10 <sup>a</sup>
<b>B100</b>	0.58 ± 0.02 <sup>bc</sup>	0.45 ± 0.00 <sup>b</sup>	0.74 ± 0.10 <sup>c</sup>

Means with different letters in the column are significantly different ( $p < 0.05$ )

**4. Conclusion**

This study shows the impact of extrusion on key parameters of the extruded flakes. The nutritional composition of the extruded samples was greatly impacted by the extrusion temperature and flour formulation. In general, samples with higher extrusion temperatures had higher levels of protein, ash and crude fiber as well as lower levels of moisture and carbohydrates. In terms of bulk density, and Oil Absorption Capacity, samples A generally performed better than samples B even though samples B showed superior water absorption at lower temperatures. The intended use of the finished product should therefore be taken into consideration when selecting the processing conditions. The study indicates that the retention and bioavailability of essential minerals are significantly influenced by the extrusion temperature and blend formulation. Lower temperatures preserved magnesium and selenium while at 140°C, Iron and Potassium were more retained in samples.

**Conflict of Interest**

The Authors declare no conflict of Interest

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