





Phytochemical Properties and in Vitro Anti-Diabetic Potential of Extruded Composite Flakes: Influence of Flakes Composition and Extrusion Temperature

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Abstract	Article History
<p>The study aimed to understand the impact of flakes composition and extrusion temperature on the phytochemical properties and in Vitro Anti-Diabetic Potential of Extruded Flakes. Jackbean flour was produced from washed jackbean, soaked (4 hours), germinated (3 days), oven dried (60°C until constant weight). Maize and plantain flours were prepared following recommended method. Different flour blends were obtained using design mixture of Response Surface Methodology (RSM) software applications and the glycemic index of selected runs were evaluated. The selected samples were extruded at various temperatures (100, 120 and 140°C) and evaluated for their phytochemical properties, in vitro anti diabetic potential, phenolic and amino profile.</p> <p>Results showed that the most significant decrease across the sample formulation was in sample B with values decreasing with increased temperature ranging from 0.025 ± 0.00 mg/g (A140) to 0.009 ± 0.00 mg/g, (B140). Tannins and flavonoids were generally reduced more when the extrusion temperature was raised for formulation B although phenols and oxalates behaved differently depending on the sample formulation. However, In Sample A generally, high-temperature extrusion (140 °C) seems to preserve or even concentrate both tannin and oxalate levels. Aside sample B100 with an ABTS value of 6.740 ± 0.21, the majority of samples (A140, B140, A120 and A100) did not differ statistically significantly (p 0.05), with the sample A120 showing the best DPPH, Fe²⁺, OH⁻ anti-oxidant activities among samples.</p> <p>Better protein retention or digestibility may be favored by B100's formulation or extrusion conditions as indicated by its higher total amino acid content. In comparison to A120, B100 has a higher concentration of both non-essential amino acids and essential amino acids (EAAs) which suggests better nutritional completeness. The retention and degradation of anti-nutritional compounds are significantly influenced by the extrusion temperature and blend composition.</p>	<p>Received: 15 Jan 2026 Accepted: 12 Feb 2026 Published: 17 Feb 2026</p>  <p>Scan QR Code to view¹</p> <p>License: CC BY 4.0</p>  <p>Open Access article.</p>
<p>Keywords: Jackbean, Plantain, Maize, Extrusion, Phytochemical, Anti-oxidants, Amino acid</p> <p>How to cite this paper: Ilara, O. A., Olumurewa, J. A. V., & Ijarotimi, O. S. (2026). Phytochemical properties and in vitro anti-diabetic potential of extruded composite flakes: Influence of flakes composition and extrusion temperature. <i>IPS Journal of Nutrition and Food Science</i>, 6(1), 746–754. https://doi.org/10.54117/kssfb051</p>	

1. Introduction

Extrusion cooking is a high-temperature, high-pressure, short-duration processing method used all over the world that enables the creation and modification of a wide range of goods. The quality of the extruded food products is highly influenced by the screw speed, feed moisture content, barrel temperature, feed material composition and other extrusion system parameters. Extrusion is a complicated multi-variable process that necessitates careful process control and working parameter optimization, if the goal is to produce a high-quality product (Kosutic et al. 2023). In foods, the high barrel temperature of the extruder affects the majority of the nutritional composition and anti-nutritional elements. Elevated barrel temperatures reduce the extrudate anti-nutritional characteristics. While lowering bulk density and hardness, high barrel temperature and low feed moisture content raise the extruded snacks water solubility index and

expansion ratio (Ali et al., 2024). Extrusion cooking modifies the foods physical attributes, chemical makeup and sensory profile. Minerals pH and dietary fiber are a few of the raw material components that affect the extrusion process even at low concentrations (Merillon et al., 2019).

Consuming maize and other whole grain products has been associated with better digestive health and a lower risk of long-term health issues such as heart disease, Type 2 diabetes, obesity and several cancers. Anti-inflammatory and anti-proliferative qualities are among the many health advantages associated with phytochemicals found in fruits and vegetables (Jadhav et al. 2022). People with celiac disease, an immune system-driven condition must avoid gluten-containing foods. Living a lifelong gluten-free (GF) diet is a viable treatment for celiac disease that has been proven to work. The production of a broad range of cereal-based products has been one tactic

used to address the issue and satisfy the needs of the population affected by this disorder. Diabetes mellitus (DM) is characterized by chronic hyperglycemia that damages vital organs and tissues such as the kidneys retina heart blood vessels and nerves. An estimated 589 million adults aged 20 to 79 have diabetes. By 2050 it is anticipated that there will be 853 million diabetics worldwide. The International Diabetes Federation (2025) reports that 81% of adults with diabetes reside in low- and middle-income nations.

This paper seeks to investigate how extrusion temperature and formulation affects the food product's phytochemical properties and in-vitro antidiabetic potentials while making use of underutilized crops.

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).

Design Matrix for Composite flour

Table 1: Optimal Mixture Design On 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

Optimizing the flour mixture to achieve desired properties like high protein and fiber levels is the goal of the RSM while adhering to the American Diabetes Associations (ADA) recommendations for macronutrient distribution in adult diabetics having a macronutrient distribution of 45–60% carbohydrates 15–20% protein and 20–35% fat.

Extrusion

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 manually to the extruder in constant feed rate; 80 g/min quantities. Experiments were conducted at 3 barrel temperatures (100, 120, 140°C). During the experiment, the screw speed of extruder was maintained at 300 rpm.

Phytochemical Properties Analysis

Determination of tannin

Finely ground sample (0.2g) was weighed into a 50 ml sample bottle. Aqueous acetone (10 ml of 70%) was added and properly covered. The bottle was put in an ice bath shaker and shaken for 2 h at 30 °C. Each mixture was then centrifuge and the supernatant stored in ice. Each solution (0.2 ml) was pipetted into the test tube and 0.8 ml of distilled water was added. Standard tannin acid solutions were prepared from a 0.5 mg/ml of the stock and the solution made up to 1ml with distilled water. 0.5ml of Folin ciocateau reagent was added to both sample and standard followed by 2.5 ml of 20% Na₂CO₃, the solution was then vortexed, Incubated at room temperature and absorbance then read (725 nm) using reagent as blank concentration (Makkar 1996).

Determination of oxalate

Oxalate determination was carried out as previously described by (Kasimala et al 2018). One gram of the sample was soaked in 75 ml of 1.5N H₂SO₄, for 1 h and then filter through a No 1 Whatman filter paper. 25 ml was taking out of the filtrate and placed in inside a conical flask and this was titrated hot at about (80-90°C) against 0.1 M KMnO₄, until a pink colour that persisted for 15 s. The soluble oxalate was subtracted from total oxalate to obtain insoluble oxalate.

Determination of total phenolic content

The total phenolic content was determined according to the methods of Singleton *et al.* (1999) using the Folin Ciocalteu's phenol reagent as an oxidizing reagent. 0.2 ml of Folin-Ciocalteu's phenol reagent was added to a mixture of 0.1ml of sample and 0.9ml of water while the mixture was immediately vortexed. After 5 min of standing, 1.0 ml of 7% (w/w) Na₂CO₃ solution then added and the solution was then distilled to 2.5 ml before incubated for 90min at room temperature. The absorbance against a negative control containing 1ml of water in place of the sample was then taken at 750 nm. The standard used was the Gallic acid at 0.1 mg/ml in order determine the Gallic acid Equivalent (GAE) of sample, after preparing a calibration curve with the distilled water serving as blank.

Determination of Flavonoids

Total flavonoid content was measured using the colorimetric method (John *et al.*, 2014). 10 mg of sample was dissolved with methanol p.a to 10 ml. Next, 1 mL and 3 mL of pure methanol were added, then 0.2 mL of 10% aluminium chloride and 0.2 mL of 1 M potassium acetate were also added. Distilled water was added to make 10 mL. The mixture was incubated for 30 mins. Then, the absorbance was measured using a UV-Vis spectrophotometer at a wavelength of 439 nm.

Antioxidants Potentials Assays

Determination of hydroxyl radical scavenging activity

The deoxyribose assay was used to determine the hydroxyl radical scavenging activity in an aqueous medium according to Malomo et al. (2020). The reaction mixture containing FeCl₃ (100 μM), EDTA (104 μM), H₂O₂ (1 mM) and 2-deoxy- D-ribose (2.8 mM) at various concentrations of samples in 1 ml final reaction volume made with potassium phosphate buffer (20mM, pH 7.4) and incubated for 1 hr at 37°C. The mixture was heated at 95 °C in water bath for 15 min followed by the addition of 1 ml each of TCA (2.8%) and TBA (0.5% TBA in 0.025 M NaOH containing 0.02% BHA). Finally, the reaction mixture was cooled on ice and centrifuged at 5000 rpm for 15 min. The absorbance of supernatant was measured at 532 nm while ascorbic acid was used as the positive control.

$$\% \text{ Hydroxyl Scavenging Activity} = \frac{A_c - A_s}{A_c} \times \frac{100}{1}$$

Where A_c is the absorbance of control and A, the absorbance of the extract.

Determination of DPPH scavenging radical activity

The radical scavenging activities of the cookies were determined using the stable radical DPPH(2,2-diphenyl-1-picrylhydrazyl hydrate) as previously described (Malomo et al,2020).The reaction of DPPH with an antioxidant compound which can donate hydrogen, leads to its reduction. The change in colour from deep violet to light yellow was measured spectrophotometrically at 517 nm. To 1ml of different concentrations of the sample or standard (ascorbic acid) in a test tube was added 1ml of 0.3 mM DPPH in methanol.

The mixture was mixed and incubated in the dark for 30min after which the absorbance was read at 517 nm.

$$\% \text{ Radical Scavenging Activity} = \frac{A_{\text{blank}} - A_{\text{sample}}}{A_{\text{blank}}} \times \frac{100}{1}$$

Determination of ferric reducing antioxidant power

Ferric reducing or antioxidant power was determined as describe by Malomo et al. (2020). 10 u lof the extract were mixed with 2.5ml of 200 mmol/l phosphate buffer (ph 6.6) and 2.5ml of 1% potassium ferricyanide and incubated at 50 °C for 20min. then, 2.5 mlof 10% Trichloroacetic acid was added, and the tubes were centrifuged at 10,00 rpm for 10min. after this, 5 ml of the upper layer were mixed and 1 ml of 0.1% ferric chloride, and the absorbance of the reaction mixtures was measured at 700 nm while ascorbic acid was used as a positive control.

Determination of Iron chelating activity

Metal chelating activity was measured as described by Malomo et al. (2020). 0.1 mM FeSO₄(0.2 ml) and 0.25 mM ferrozine (0.4 ml) were subsequently added into 0.2 ml of flour sample and dough meal, After incubating at room temperature for 10 min, absorbance of the mixture was recorded at 562 nm. Chelating activity was calculated using the following formula:

$$\text{Metal chelating Activity} = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times \frac{100}{1}$$

Determination of inhibition of α-amylase activity

The in-vitro α-amylase activity was done according to the previously described method (Sheikhetal., 2008). The 10 μL of a-amylase solution (0.025 mg/ml) was mixed with 390 ul of phosphate buffer (0.02 M containing 0.006 M NaCl, pH 7.0) containing different concentration of extracts. After incubation at 37 °C for 10 min, 100 ul of starch solution (1%) was added, and the mixture was re-incubated for 1 h. Next, 0.1 ml of 1% iodine solution was added, and after adding 5 ml distilled water, the absorbance was taken at 565 nm. Sample substrate and α-amylase blank determinations were carried out under the same reaction conditions. The inhibition of enzyme activity was calculated as:

$$\% = \frac{A-C}{B-C} \times \frac{100}{1}$$

Where A=absorbance of the sample, B=absorbance of blank (without a-amylase) and C=absorbance of control.

Determination of inhibition of α-glucosidase activity

The α-glucosidase inhibition activity was done using the described method (Sheikh *er al.*,2008) The final volume of the reaction mixture was 100 ul, which contained 70 ul of phosphate buffer saline (50 mM, pH 6.8), 10μl of test extracts, and 10 μl (0.057 U) enzyme. The content was mixed pre-incubated at 37°C for 10 min, and pre-read against the blank reagent at 400 nm. The reaction was initiated using 10 ul of 0.5 mM substrate (i.e.,p-nitrophenol glucopyranoside) while Acarbose was used as a positive control. The enzyme inhibition is given as:

$$\% \text{inhibition} = \frac{A_{\text{control}} - A_{\text{sample}}}{A_{\text{control}}} \times \frac{100}{1}$$

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 triplicates and subjected to statistical analysis.

3. Results and Discussion

Phytochemical Composition of Extruded Samples

Table 2 shows the phytochemical composition of extruded samples. Oxalate levels in B120 is 1.755 ± 0. 06 mg/g whereas they were 3.195 ± 0. 06 mg/g in A140. The highest oxalate content was found in A140 while the lowest was in B120. It appears that oxalate levels are concentrated by high-temperature extrusion (140°C). The increase in the oxalate content in Sample B formulation with increased extrusion cooking is comparable to the result of Savage et al., 2017 in the cooking of taro stems where oxalates was converted to insoluble forms leading to increased oxalates at increased cooking temperature. A140 had the highest phenolic content (0. 067 ± 0. 00 mg/g) while B120 had the lowest (0. 0235 ± 0. 00 mg/g). The tannin levels in the B140 sample showed the biggest decline among all the samples at 0.0095 mg/g. They exhibit a favorable decrease with increasing extrusion temperature indicating that thermal processing effectively breaks down tannin structures especially for the Sample B. Flavonoids such as phenols can function as anti-nutrients and antioxidants. A120 had the highest flavonoid content due to

its optimal release from cell matrices at moderate extrusion temperatures. The lower levels at 140°C suggest that these thermolabile compounds may degrade at higher temperatures. This result indicates that the retention and degradation of anti-nutritional compounds are significantly influenced by the extrusion temperature and blend composition. This result is similar to the result of Nooshim *et al.*, 2017 where there was a reduction in phytochemical - phytate, tannins as a result of thermos-mechanical treatment and extrusion. This is also similar to the result of Eze *et al.*, 2020 on extruded snacks from sorghum as a result of increased extrusion temperature where there is a reduction in the phytate, tannin and oxalate content. There were formulation-specific differences in the behavior of phenols and oxalates.

In Vitro Glycemic Profile of Extruded Samples

Figure 1 and 2 shows the glycemic profile of extruded samples. The glycemic index of the samples falls in the middle range from (B100) 52.105 ± 0.08 to 76.11 ± 0.34 (A120). A120 showed the highest GI and GL values (GI = 76.11 GL = 35.065) indicating a fast blood glucose response after meals.

The reason for this could be that the matrix has less fiber interaction and more rapidly digested starch at 120°C. The lowest glycemic profile was seen in Sample B100 that has a glycemic index of 52.105 and Glycemic load of 11.115. This is better suited for individuals requiring low-glycemic foods and for the treatment of diabetes mellitus. The comparatively lower GL values of B100 and B120 indicate that the amount of carbohydrates also significantly affects the expected glycemic response. The low glycemic profile can be associated with the presence of bioactive compounds in jackbean, plantain flour which may help inhibit alpha-glucosidase and alpha-amylase action as corroborated by Sutedja *et al.*, 2020 and Alya 2023.

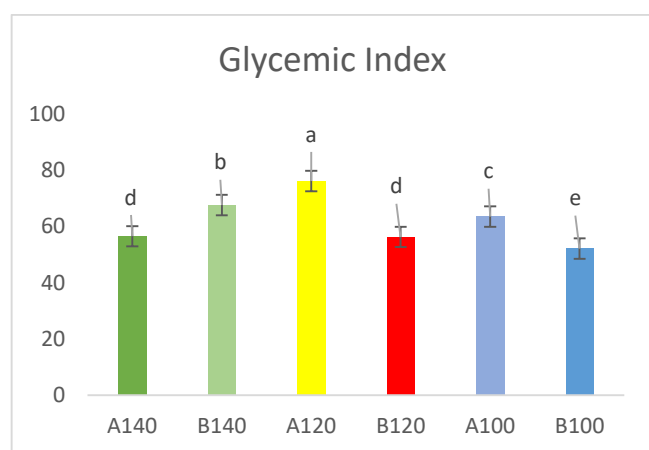


Figure 1: In Vitro Glycemic Index of Extruded Samples

Means with different letter 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

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

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

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

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

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

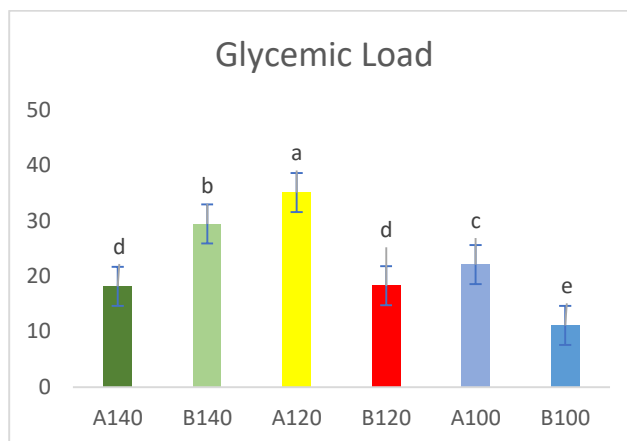


Figure 2: In Vitro Glycemic Load of Extruded Samples

Means with different letter 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

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

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

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

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

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

3.3 In Vitro Anti-Oxidants Activities of Extruded Samples

Figure 3 and 4 shows the alpha amylase and alpha glucosidase of extruded samples. Alpha-amylase inhibition was highest in A120 (40.727 ± 0.07 %) indicating that this sample may be able to effectively reduce postprandial glucose surges and starch hydrolysis. Due to its lower GI and OH percent values, B100 was found to have the lowest inhibition for both alpha-glucosidase (7.8225 ± 0.07 percent) and alpha-amylase (13.7825 ± 0.02 percent). Given this inverse relationship, it is possible that factors other than enzyme inhibition, such as a higher content of resistant starch or fiber could affect the formulation's glycemic control.

Alpha-glucosidase and alpha-amylase enzyme inhibition is essential for delaying the breakdown of carbohydrates and the absorption of glucose. Alpha-glucosidase inhibition was highest in A120 suggesting a strong potential for glucose moderation. Strong potential for glucose moderation was indicated by the highest alpha-glucosidase inhibition which was observed in A120 (17.5861 ± 0.00 %) closely followed by B140 (14.1389 ± 0.19 percent).

The in vitro analysis indicates that the glycemic and enzyme-inhibitory behavior of the samples are significantly influenced by the extrusion temperature and blend. The increased availability of digestible starches may be the reason why A120 appears metabolically active in terms of enzyme inhibition but ironically it exhibits high glycemic responses. Although B100 shows less enzyme inhibition, its low glycemic profile indicates that it may be more appropriate for the creation of functional foods targeted at diabetic or pre-diabetic populations.

Due to extremely high shear stress temperature and pressure during the extrusion cooking process, the moistened expandable starch physically swells modifying starch profile (Li *et al.*, 2022).

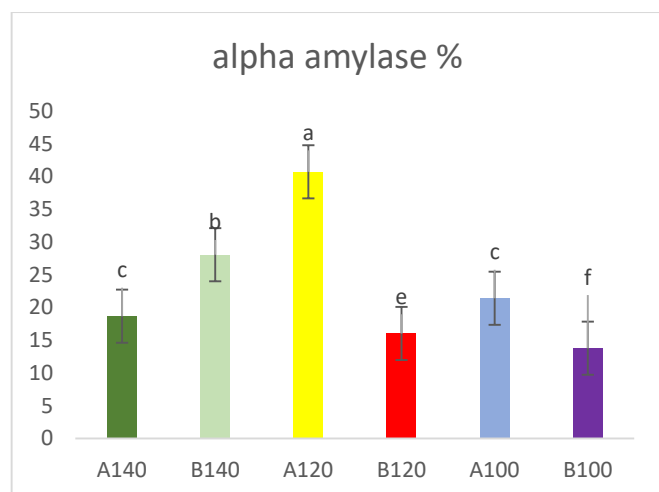


Figure 3: Alpha amylase activities of extruded samples

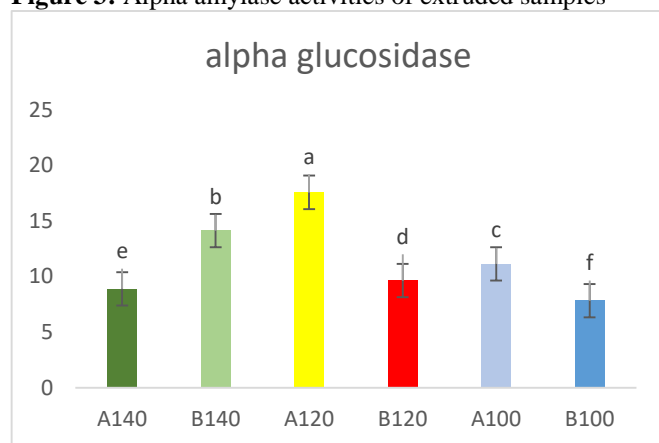


Figure 4: Alpha glucosidase activities of extruded samples
Means with different letter in the column are significantly different ($p < 0.05$)

KEY

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

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

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

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

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

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

The ability of antioxidants to scavenge the ABTS is assessed by the ABTS assay as presented in fig 5. Aside sample B100 with an ABTS value of 6.74025 ± 0.21 , the majority of samples (A140, B140, A120 and A100) did not differ statistically significantly ($p > 0.05$) with the exception of B100 which had a noticeably lower ABTS value indicating that this formulations antioxidant potential was reduced. With the exception of B100, the constant ABTS activity across formulations suggests that the antioxidant compounds that scavenge ABTS radicals are generally stable across extrusion conditions and blends. More variation was seen in the FRAP values with B120 showing the highest activity ($24.7299 \pm 0.$

20 mg/ml) and A140 coming in second (20.0823 ± 0.01 mg/ml). It was found that A120 had the lowest FRAP value (9.09817 ± 0.01 mg/ml).

The high value in B120 points to a high concentration of antioxidants that donate electrons which may have been impacted by the extrusion temperature and ingredient composition. This is comparable to a study by Ashrafi *et al* 2022 investigated the changes in fat soluble nutraceuticals, phenolics and antioxidant activity in extrudates of whole maize flour processed at 20 %, 25 % and 30 % feed moisture. Extrusion resulted in a significant reduction in the content of components and antioxidant activity. On the other hand, the reduced FRAP in A120 might be explained by the phenolic compounds oxidative breakdown at 120 °C or their change into less active forms. With the exception of A120 which displayed a noticeably higher value (0.00935 ± 0.00 mg/ml) than the others (all around 0.00106–0.00132 mg/ml) the Fe^{2+} chelation capacity was comparatively constant across samples as seen in figure 7.

A120 may contain compounds that can bind ferrous ions and prevent the catalysis of oxidative reactions (Fenton-type reactions) due to its strong chelating ability. A120s metal-chelating potential may provide an alternative antioxidant mechanism highlighting the samples complex antioxidant profile despite its moderate DPPH and lower FRAP. A120 once again stood out with the highest DPPH activity as shown in figure 12, because certain phenolic compounds are either preserved or enhanced at 120°C and are highly reactive with DPPH radicals. Due to increased lipid oxidation caused by its higher fat content, B100 may have a general decline in antioxidant potency due to its low ABTS value and relatively lower DPPH activity. Higher concentrations of flavonoids and hydroxycinnamic acids which are known for their metal chelation and free radical scavenging capabilities may account for B100s relatively higher antioxidant capacity in the DPPH and FRAP tests.

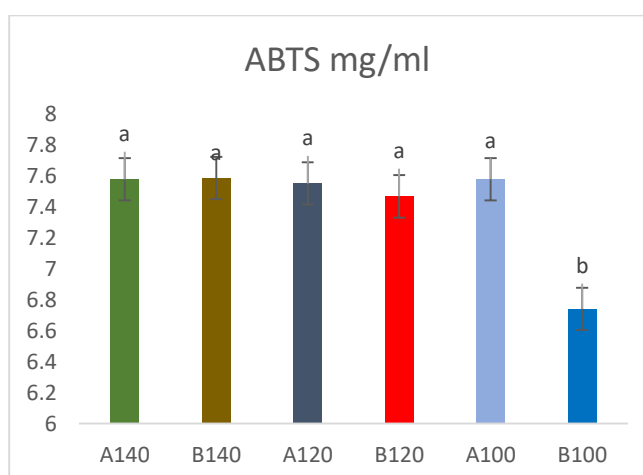


Figure 5: ABTS activities of extruded samples

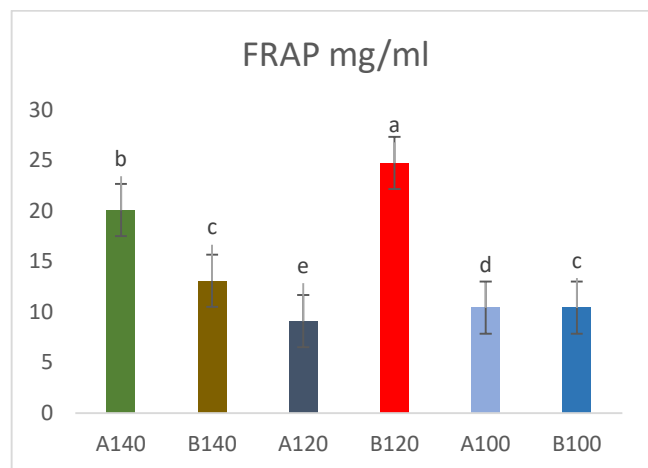


Figure 6: FRAP activities of extruded samples
Means with different letter in the column are significantly different ($p < 0.05$)

KEY

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

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

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

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

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

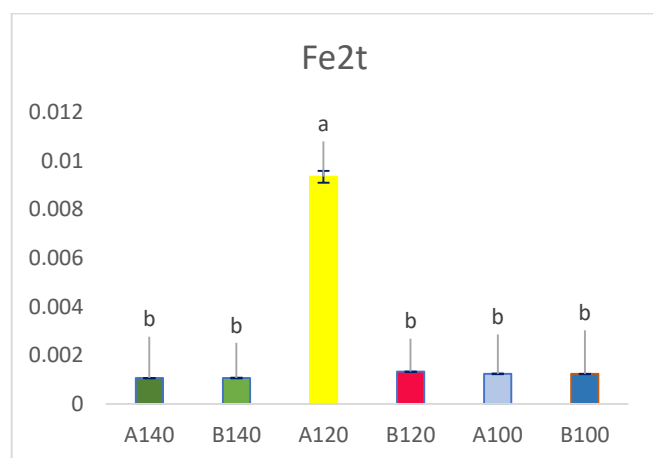


Figure 7: Iron chelating activities of extruded samples
Means with different letter in the column are significantly different ($p < 0.05$)

KEY

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

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

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

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

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

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

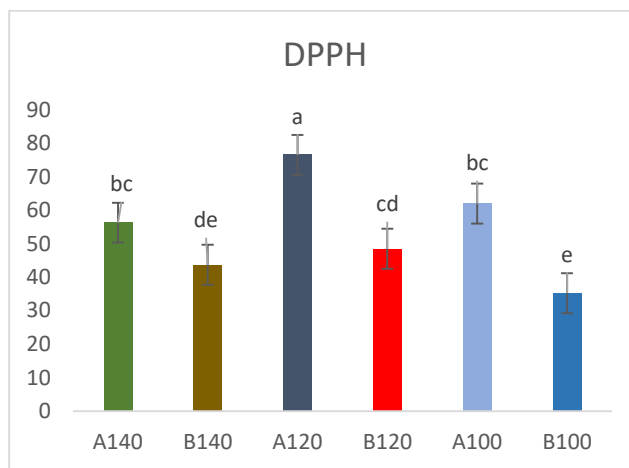


Figure 8: DPPH activities of extruded samples

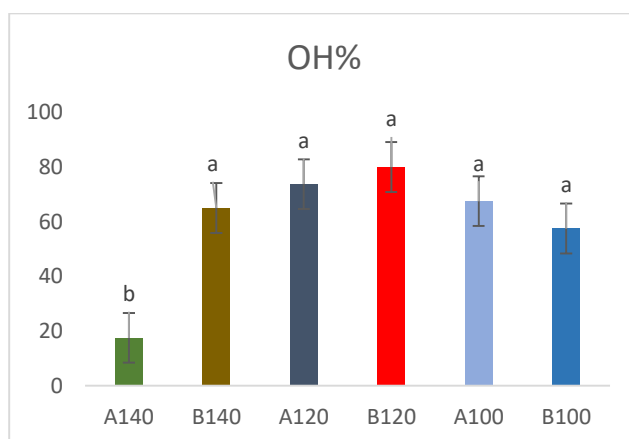


Figure 9: OH⁻ activities of extruded samples

Means with different letter 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

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

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

Phenolic Profile of Samples

The individual polyphenolic compounds in extruded samples B100 and A120 is shown in Table 3. The impact of extrusion temperature and formulation on the retention and composition of bioactive phenolics was evaluated. The total quantified polyphenolic compounds in the B100 formulation was higher showing a higher composition of bioactive compounds (127.804 mg/100g) while sample A120 has 111.777 mg/100g. This discrepancy shows that B100s compositional variation and lower extrusion temperature (100°C) may improve or preserve the extractability of phenolics especially flavonoids and hydroxycinnamic acids. Phenolic acids with 86.9 mg/100g of ferulic acid in B100 and 77.6 mg/100g in A120, ferulic acid was the most prevalent phenolic acid in both samples and accounted for more than 65% of the total polyphenolic content. B100 had significantly higher levels of kaempferol (2.98 mg/100g) and quercetin (2.39 mg/100g)

than A120 (2.05 and 2.14 mg/100g respectively). The polyphenolic composition of B100 may contribute to the observed inhibitory effects on digestive enzymes (e.g. α -glucosidase and α -amylase) suggesting that it could be applied to glycemic control applications. Zeng et al (2016) observed that the content of various phenolic acids changed noticeably following extrusion processing.

Amino Acid Profile of Samples

Table 4a displays the amino profiles of the extruded samples. Given its higher total amino acid content, B100s formulation and extrusion conditions may favor better protein retention or digestibility. Both essential and non-essential amino acids (EAAs) are more abundant in B100 than in A120 indicating greater nutritional completeness. EAAs are an acronym for essential amino acids. The most common EAA in both samples is leucine and a statistically significant difference was verified with B100 having a higher value (8.65) than in A120 (6.72 g/100g) at LSD (0.123).

Higher amounts of tryptophan and methionine which are commonly limiting in plant-based proteins were noted in B100 (1.471 and 2.18mg/100g protein respectively). B100 showed a slight increase in lysine which is necessary for protein synthesis and often deficient in foods based on cereals. 2.345 g/100g in

B100 as against A120 (2.20 g/100g) which was not statistically significant. Glutamate was the most common amino acid in both samples. Glutamine is the most abundant amino acid in the circulation. Glutamate converted from glutamine is an essential mediator that enhances calcium signaling in the glutamine-amplifying effect on insulin secretion (Han et al 2021).

Alanine and glycine levels were consistently higher in B100 (5.63 and 5.54mg/100g respectively). B100 also had higher levels of tyrosine and cystine (2.87, 1.34mg/100g) which are essential for the production of neurotransmitters, and their antioxidant properties. Higher levels of crucial EAAs like leucine methionine tryptophan and isoleucine are found in B100s amino acid composition which suggests a more nutritionally complete and balanced protein source. A necessary component of human nutrition and health are amino acids. A diet high in amino acids is essential for the healthy operation of tissues and organic systems while a diet low in them is associated with several diseases. During processing, the amount and quality of raw materials used determine the protein content of extruded products which varies significantly (Ruiz-Armenta et al. 2024). While jack bean protein contains all of the essential amino acids (EAAs), leucine makes up the largest percentage and methionine which contains sulfur the smallest. Jack bean protein is considered incomplete due to its low cysteine and methionine levels (Jirarat et al. 2023).

Table 2: Phytochemical Composition of Extruded Samples

	Oxalate (mg/g)	Phenol (mg/g)	Tannin (mg/g)	Flavonoids (%)
A140	3.195±0.06 ^a	0.067±0.00 ^a	0.025±0.00 ^a	3.90±0.14 ^b
A120	2.25±0.00 ^c	0.0275±0.00 ^b	0.017±0.00 ^b	5.10±0.14 ^a
A100	3.105±0.06 ^a	0.023±0.00 ^b	0.014±0.00 ^b	2.90±0.14 ^c
B140	2.7±0.00 ^b	0.024±0.00 ^b	0.0095±0.00 ^c	2.300.14 ^d
B120	1.755±0.06 ^d	0.0235±0.00 ^b	0.011±0.00 ^c	3.30±0.14 ^c
B100	2.7±0.00 ^b	0.023±0.01 ^b	0.015±0.00 ^b	4.00±0.00 ^b

Means with different letter 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

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

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

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

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

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

Table 3: Phenolic Profile of Samples

Name	B100	A120	Average	Std	LSD
	Amount [mg/100g]	Amount [mg/100g]			
p-coumaric Acid	12.3	11.33	11.815	0.68589	0.136
Vanillic Acid	1.18	1.13	1.155	0.03536	0.096
o-coumaric Acid	3.93	2.8	3.365	0.79903	0.043
p-hydroxybenzoic Acid	4.04	4.19	4.115	0.10607	0.122
Catechin	3.85	2.76	3.305	0.77075	0.215
Epicatechin	1.46	1.4	1.43	0.04243	0.043
Caffeic Acid	2.02	1.9	1.96	0.08485	0.061
Ferulic Acid	86.9	77.6	82.25	6.57609	0.431
Syringic Acid	1.68	1.09	1.385	0.41719	0.061
Apigenin	0.15	0.01	0.08	0.09899	0.048
Luteolin	1.46	1.31	1.385	0.10607	0.043
Kaempferol	2.98	2.05	2.515	0.65761	0.043
Epigallocatechin	0.02	0.01	0.015	0.00707	0.03
Quercetin	2.39	2.14	2.265	0.17678	0.061
Isorhamnetin	0.47	0.07	0.27	0.28284	0.061
Myricetin	2.2	1.88	2.04	0.22627	0.061
Rutin	0.76	0.1	0.43	0.46669	0.043
	127.804	111.777			

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

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

Table 4a: Amino Acid Profile of Samples

Name	A120	B100	Average	STD	LSD
	Amount g/100gProtein				
Glycine	4.38224	5.54298	4.96261	0.820767	1.055
Alanine	4.27317	5.631	4.952085	0.960131	1.126
Serine	5.34439	6.11491	5.72965	0.54484	1.267
Proline	5.63124	4.87823	5.254735	0.532458	0.788
Valine	4.88321	4.88295	4.88308	0.000184	0.653
Threonine	3.91332	4.1565	4.03491	0.171954	0.166
Isoleucine	3.66411	4.42615	4.04513	0.538844	0.074
Leucine	6.72277	8.65787	7.69032	1.368322	0.123
Aspartate	7.21403	7.34922	7.281625	0.095594	0.102
Lysine	2.20534	2.34573	2.275535	0.099271	0.093
Methionine	1.83495	2.18587	2.01041	0.248138	0.067
Glutamate	17.56091	17.66292	17.611915	0.072132	0.07
Phenylalanine	3.61963	3.79536	3.707495	0.12426	0.106
Histidine	2.72401	2.52675	2.62538	0.139484	0.093
Arginine	2.55438	2.42982	2.4921	0.088077	0.073
Tyrosine	2.6042	2.87159	2.737895	0.189073	0.061
Tryptophan	1.1878	1.47176	1.32978	0.20079	0.059
Cystine	1.15405	1.34338	1.248715	0.133877	0.062
	81.47375	88.27299			

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

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

Table 4b: Amino Acid Ratios

	A120	B100
TAA	81.474	88.273
HAA	36.269	41.465
PCAA	7.483	7.325
NCAA	24.775	25.011
SCAA	2.990	3.528
TEAA	30.455	34.448
TNEAA	51.018	53.824
BCAA	15.270	17.969
AAA	7.416	8.128
FISCHER RATIO	2.060	2.207

Conflict of Interest

The Authors declare no conflict of Interest

4. Conclusion

This study assessed the impact of flakes composition and Extrusion Temperature on the phytochemical properties and in Vitro Anti-Diabetic Potential of Extruded Flakes. Phytochemicals were impacted by extrusion temperatures and sample formulations as tannin structures became concentrated with increased extrusion temperature and formulation A having phytochemical compositions that are statistically more improved than formulation B. The in-vitro anti-oxidants of the samples showed that various formulations of the Sample and extrusion temperature have no significant impact on the ability to scavenge ABTS, with Sample A120 showing the most potency to scavenge for DPPH, OH- and metal chelating. The ability to inhibit alpha-amylase and alpha-glucosidase is highest in sample A120 thus inferring that it has the most ability within the sample formulations and temperature range to delay post-prandial surges. Sample B100 has the lowest glycemic index and glycemic load of the samples and falling in the middle range of glycemic index, indicating it might be most suited of the samples in

management of diabetes mellitus. Sample B100 has the most phenolic content of the two tested samples for phenolic profile, having p-coumaric acid as the most abundant phenolic content- which is essential for insulin sensitivity, regulating blood glucose and reducing oxidative stress. Sample B100 has the most amino acids suggesting more nutritional completeness with glutamic acid as the most abundant helping in insulin secretion.

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