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Pasting Properties, Digestibility, and Nutritional Enhancement of Cassava, Yam, and Maize-Based Composite Flours Enriched with Potato Peel Powder

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Abstract

Potato peels represent a significant proportion of food processing waste, often discarded despite their rich nutritional and functional composition. This study investigated the effects of potato peel powder incorporation on the proximate composition, functional properties, pasting characteristics, and digestibility of cassava-, yam-, and maize-based composite flours.

Composite blends with the cassava, yam and maize flour were formulated at varying substitution levels (0%, 5%, 10%, and 15%) and evaluated using standard analytical methods.

Results showed a progressive increase in moisture, protein, ash, and resistant starch contents with increasing levels of potato peel substitution, while carbohydrate content and total energy value decreased across all flour bases. Maize-based blends exhibited the highest improvement in resistant starch, whereas cassava blends showed higher swelling capacity and setback viscosity, indicating greater retrogradation tendencies. Yam-based blends demonstrated relatively stable thermal properties and lower setback viscosity, suggesting improved storage stability. Functional analyses revealed that potato peel incorporation influenced gelatinization and pasting behaviour, with variations in peak, breakdown, and setback viscosities reflecting differences in starch–fibre interactions among flour types. Overall, potato peel powder enhanced the nutritional profile and modified functional properties without significantly compromising the intrinsic starch characteristics of the base flours. The study concludes that

potato peel powder is a promising functional ingredient for developing nutrient-enriched composite flours with improved digestibility and potential health benefits, particularly in reducing glycaemic load and enhancing dietary fibre intake. These findings highlight the valorisation of potato processing waste and its potential application in sustainable food product development systems.

Keywords

Cassava; Yam; Maize; Potato peel powder; Composite flour; Resistant starch

STATEMENTS AND DECLARATIONS

Ethics Approval and Consent to Participate

Not applicable. This manuscript does not involve human participants, human-derived samples, or experimental animals.

Consent for Publication

Not applicable. This manuscript does not contain identifiable individual-level data or images requiring consent for publication.

Competing Interests

The authors declare that they have no competing interests.

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Authors' Contributions

ALO conceived and designed the study. ODT and ALO conducted the study, collect data and drafted the manuscript. AAF supervised and review the draft manuscript. All authors critically revised the manuscript for important intellectual content, approved the final version, and agreed to be accountable for all aspects of the work

Data Availability

The datasets used in this study will be made available upon request.

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Use of Artificial Intelligence

During the preparation of this manuscript, the authors may have used artificial intelligence-assisted tools for language editing, organization, and/or refinement of the manuscript. The authors reviewed and critically evaluated all AI-assisted content and take full responsibility for the accuracy, originality, and integrity of the final manuscript

1.0 Introduction

The increasing global demand for sustainable food systems owing to continuously growing world population has intensified interest in agro-industrial by-products. Among these, potato peels represent a significant proportion of food processing waste, often discarded despite their rich nutritional and functional composition. Potato is the fourth most common crop cultivated globally annually (Kumar *et al.*, 2024). Potato peel is the major waste released by potato-processing industries and poses a global environmental threat. Potato peels are known to contain appreciable levels of dietary fiber, phenolic compounds, minerals, and bioactive constituents with antioxidant properties, making them a promising candidate for functional food development.

In sub-Saharan Africa, staple flours derived from cassava, yam, and maize (corn) constitute a major component of daily dietary intake (Valdez *et al.*, 2024; Ndhlovu and Tagutanazvo, 2025). While these flours are energy-dense, they are generally limited in micronutrients, dietary fiber, and certain phytochemicals (Mensah *et al.*, 2021). This nutritional limitation presents an opportunity for fortification using underutilized plant-based resources. The incorporation of such bioactive-rich materials into commonly consumed flours could enhance their nutritional profile and contribute to improved public health outcomes (Amoah *et al.*, 2022).

Previous studies have explored the use of plant-based by-products in food fortification; however, there remains limited comparative evaluation of potato peel incorporation across multiple indigenous flour systems. Additionally, the impact of varying inclusion levels of potato peel on the physicochemical properties, functional characteristics, and overall quality attributes of cassava, yam, and corn flours has not been comprehensively elucidated.

Therefore, this study aims to investigate the effects of graded concentrations of potato peel powder on selected properties of cassava flour, yam flour, and corn flour. Specifically, the study evaluates the proximate composition, functional properties (such as water absorption capacity, bulk density, and swelling index), and potential improvements in nutritional quality.

By doing so, this research seeks to provide a scientific basis for the utilization of potato peel as a value-added ingredient in staple flour systems, thereby contributing to waste reduction, food sustainability, and nutritional enhancement.

2.0 Methods

2.1 Raw Material Procurement

2.1.1 Potato Peel Powder (PPP) Production

Dried maize, fresh sweet potato, cassava and yam tubers were gotten from local farm in Ogbomoso. The fresh potato tubers obtained from local farm market in Ogbomoso were washed in clean water and were peeled with knife. The fresh potato peels were obtained immediately after manual peeling of wholesome potato tubers. The peels were sorted to remove extraneous materials such as dirt, stones, and damaged tissues, and subsequently washed thoroughly under running tap water to eliminate adhering impurities.

The cleaned potato peels were then reduced to uniform sizes to ensure even heat transfer during blanching. Blanching was carried out using the hot water method. Briefly, water was heated to a temperature range of 85–100°C, and the potato peels were completely immersed in the hot water for 3 minutes. To minimize enzymatic browning and preserve the natural color, 0.2% (w/v) citric acid solution was incorporated into the blanching medium.

At the end of the blanching period, the peels were rapidly cooled by transferring them into cold water ($\approx 4^{\circ}\text{C}$) to halt further thermal action. The cooled samples were drained using a sieve to remove excess surface water.

The blanched potato peels were subsequently subjected to drying in a hot air oven at 50–60°C until a constant weight was achieved. The dried samples were then milled into fine flour and stored in airtight containers at ambient temperature.

2.1.2 Flour Production

For the cassava and yam flour, the fresh cassava was peeled, washed and dried using hot air oven at 50–60°C until constant weight was achieved. The dried samples were then milled into fine flour and stored in airtight containers at ambient temperature.

For the maize flour, the dried maize were cleaned to ensure they are free from dirt, milled and then sieved and the flour sample were kept in airtight plastic containers.

2.1.3 Formulations of Composite Flour Blends

Composite flours were formulated by incorporating potato peel powder (PPP) into three different base flours viz: cassava, yam, and maize at graded substitution levels. The substitution was carried out on a weight-by-weight (w/w) basis to ensure uniformity across all samples.

Four formulation levels were prepared for each base flour, consisting of a control (0% PPP) and three experimental blends containing increasing proportions of potato peel powder (5%, 10%, and 15%) (Table 1). The formulations were thoroughly mixed to achieve homogeneity and subsequently stored in airtight containers at ambient conditions prior to analysis.

Table 1: Formulation Ratios

Sample Code	Composition (%)	Description
F0	100:0	100% base flour (no PPP)
F5	95:5	95% base flour + 5% PPP
F10	90:10	90% base flour + 10% PPP
F15	85:15	85% base flour + 15% PPP

2.1.4 Sample Coding System

To ensure clarity and traceability, samples were coded based on the type of base flour and the level of PPP inclusion as in Table 2, 3 and 4:

Table 2: Cassava Flour-Based Blends (CF)

Sample Code	Description
CF0	100% cassava flour (control)
CF5	Cassava flour + 5% PPP
CF10	Cassava flour + 10% PPP
CF15	Cassava flour + 15% PPP

Table 3: Yam Flour-Based Blends (YF)

Sample Code	Description
YF0	100% yam flour (control)
YF5	Yam flour + 5% PPP
YF10	Yam flour + 10% PPP
YF15	Yam flour + 15% PPP

Table 4: Maize Flour-Based Blends (MF)

Sample Code	Description
MF0	100% maize flour (control)
MF5	Maize flour + 5% PPP
MF10	Maize flour + 10% PPP

2.2 Blending Procedure

Each formulation was prepared by accurately weighing the required proportions of base flour and potato peel powder using a digital analytical balance. The components were mixed using a laboratory mixer to ensure uniform distribution of PPP within the flour matrix. The blended samples were sieved to improve homogeneity and eliminate agglomerates.

All composite flour samples were packaged in airtight polyethylene bags and stored under dry conditions at room temperature labeled as in table 2, 3 and 4 until further analyses (proximate composition, functional properties, pasting characteristics, and digestibility studies) were conducted.

2.3 Analytical Determinations

2.3.1 Proximate Composition

Determination of moisture content

For each sample, a clean, dried glass petri dish was weighed (W_1). 5g of sample was weighed in to each of the dish (W_2). The dish was shake gently to ensure uniform distribution of sample. The dish containing sample was placed in the oven at 105°C for 2 hours then, the dish was moved to desiccator and allowed to cool. The dish containing a dried sample was weighed (W_3).The weight was done continuously until constant weight was obtained.

Calculation

The percentage moisture was calculated as follows:

$$\% M/C = \left(\frac{W_2 - W_3}{W_2 - W_1} \right) \times 100$$

Where:

W_1 = *Weight of empty dish*

W_2 = *Weight of empty dish + weight of sample before dry*

W_3 = *Weight of dish + weight of sample after dried at 105°C*

Determination of Crude Protein (Kjeldahl Method, AOAC 978.04)

Crude protein content was determined via the Kjeldahl method following standard AOAC procedures. Approximately 1.0 g of each sample was weighed into a Kjeldahl digestion flask, and a digestion mixture containing 7.0 g potassium sulphate (K_2SO_4), 0.8 g copper sulphate ($CuSO_4$), and 20 mL concentrated sulphuric acid (H_2SO_4) was added. The mixture was gently swirled and heated initially at low temperature until frothing subsided, then at elevated

temperature until a clear digest was obtained, followed by continued boiling for 6 h to ensure complete digestion.

After cooling, the digest was diluted to 100 mL with distilled water. An aliquot (10 mL) of the digest was transferred into a distillation unit, and 50 mL of 40% NaOH along with 50 mL distilled water was added to liberate ammonia. The released ammonia was distilled into 30 mL of 2% boric acid solution containing mixed indicator for 10–15 min.

The distillate was titrated against 0.1 N HCl to a pink endpoint, and the titre value recorded. Nitrogen content was calculated using standard Kjeldahl equations, and crude protein was obtained by multiplying the nitrogen value by a conversion factor of 6.25.

Calculation:

$$\% N = \frac{V_1 \times n_1 \times F_1 \times MW_n}{W_s \times 10}$$

$$\text{Crude Protein} = \% N \times \text{Factor (6.25)} \times F_2$$

V_1 =Volume of titre value

n_1 = Normality of acid

F_1 =Acid Factor

MW_n =Molar mass of Nitrogen

W_s =Weight of sample

F_2 =Dilution factor (6.25)

Determination of Crude Fat Content (Soxhlet Extraction Method)

Crude fat content was determined using the Soxhlet extraction method. Filter paper was folded into a thimble and pre-weighed to obtain a zeroed mass. Approximately 2.0 g of sample was accurately weighed and placed into the thimble, which was then inserted into the Soxhlet extractor.

A volume of 250 mL n-hexane (petroleum ether) was added via a glass funnel into the extraction flask through the condenser assembly. The system was assembled, and the heating mantle, main power supply, and condenser cooling water were switched on. Extraction was carried out for a minimum of 4 h at a condensation rate of 5–6 drops per second.

After extraction, the heating unit and water supply were turned off, and the solvent containing the extracted fat was carefully transferred into a pre-weighed beaker (W_1). The thimble was rinsed with additional petroleum ether to ensure complete recovery of lipids. The solvent was evaporated in a hot-air oven at 70°C for 30 min, after which it was allowed to cool. Residual solvent was removed, and the beaker containing the extracted fat was weighed (W_2).

Crude fat content was then calculated based on the difference in mass between W_2 and W_1 relative to the original sample weight.

Calculation:

$$\% \text{ Crude Fat} = \frac{(W_2 - W_1)}{W_1} \times 100$$

W_1 = Weight of beaker

W_2 = Weight of beaker (g) + Fat extract (g)

Determination of Ash Content (Dry Ashing Method)

Ash content was determined by the dry ashing method. Clean crucibles were first dried in an oven at 105°C for at least 2 h, cooled in a desiccator, and weighed to obtain the empty crucible weight (W_1). Approximately 5.0 g of sample was accurately weighed into the crucible and recorded as (W_2).

The samples were then incinerated in a muffle furnace (Carbolite) at 550°C for 6 h until complete ashing was achieved. After ashing, the crucibles were carefully removed, cooled in a desiccator to prevent moisture uptake, and reweighed to obtain the final weight (W_3). Heating, cooling, and weighing were repeated where necessary until a constant ash weight was obtained.

Calculation

$$\% \text{ Ash Content} = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100$$

Where:

W_1 = Weight of empty crucible

W_2 = Weight of crucible + sample before ashing

W_3 = Weight of crucible + ash after incineration

2.3.2 Determination of Carbohydrate Content and Total Energy Value

Carbohydrate Content

Carbohydrate content was determined by difference, based on the proximate composition of the sample. It was calculated as the remaining fraction after accounting for moisture, crude protein, crude fat, and ash contents:

$$\% \text{ Carbohydrate} = 100 - (\% \text{ Protein} + \% \text{ Fat} + \% \text{ Ash} + \% \text{ Moisture})$$

Total Energy Value (Kcal)

The total energy value of the samples was calculated using the Atwater conversion factors as follows:

$$\text{Energy (Kcal)} = (\text{Protein} \times 2.44) + (\text{Lipids} \times 8.37) + (\text{Carbohydrate} \times 3.57)$$

Where:

Protein, Lipids, and Carbohydrate are expressed as percentages (%) or g/100 g sample
Energy is expressed in kilocalories (Kcal)

2.3.3 Physicochemical and Functional Characterization

Gelatinization Temperature

Gelatinization temperature was determined in triplicate. Precisely 1.0 g of flour sample was weighed into 20 mL screw-capped tubes, and 10 mL of distilled water was added to each tube. The samples were heated gradually in a water bath with continuous monitoring until complete gel formation was observed. The temperature at which full gelatinization occurred confirmed by the formation of a firm gel was recorded as the gelatinization temperature.

Pasting Properties and Resistant Starch Estimation (Rapid Visco Analyzer)

Pasting characteristics and resistant starch estimation were carried out using Rapid Visco Analyzer (RVA). Approximately 2.5 g of starch/flour sample was weighed into a dry RVA canister, followed by the addition of 25 mL distilled water. The slurry was manually stirred to ensure uniform dispersion before being mounted in the RVA.

The heating profile was programmed to increase from 50°C to 95°C, held for 2 min, and subsequently cooled back to 50°C with a 2 min holding period. Heating and cooling were maintained at a constant rate of 11.25°C/min. However, for the resistant starch estimation, the slurry was thoroughly mixed and analysed using the RVA under a standard temperature profile involving heating to 95°C, holding, and subsequent cooling

The RVA thermo-gram was used to obtain key pasting parameters, including peak viscosity (indicator for starch granule swelling), breakdown viscosity, setback viscosity, and pasting temperature which collectively provide indirect evidence of resistant starch behaviour.

Amylose Content Determination

The amylose content of the flour blends was determined using the iodine-binding colorimetric method. Briefly, 100 mg of each sample was dispersed in ethanol and treated with 1 N sodium hydroxide to achieve complete solubilization. The resulting mixture was diluted with distilled water, acidified with acetic acid, and subsequently reacted with iodine solution. Absorbance was measured at 620 nm using a spectrophotometer, while amylose concentration was estimated from a standard calibration curve

Amylopectin Content Determination

Amylopectin content was determined indirectly by calculating the difference between total starch and amylose content for each sample. Total starch was quantified enzymatically, after which amylopectin content was expressed as:

$$\text{Amylopectin (\%)} = \text{Total starch (\%)} - \text{Amylose (\%)}$$

3.0 Results

3.1 Proximate Composition of the Flours Blend

Figure 1 presents the moisture content (%) of cassava-, yam-, and maize-based composite flours at varying inclusion levels (F0, F5, F10, and F15). A consistent increase in moisture content was observed across all flour types with increasing substitution levels. The control samples (F0) recorded the lowest moisture values, approximately 6.1%, 5.9%, and 5.9% for cassava, yam, and maize, respectively.

A significant increase ($p < 0.05$) in moisture content was observed at F5 in the cassava blend relative to the control. Furthermore, across all flour types, the F10 and F15 samples exhibited significantly higher moisture contents compared to both F0 and F5 (Figure 1).

At the 5% inclusion level (F5), yam and maize blends showed a significant reduction in moisture content compared to the cassava blend. However, at higher inclusion levels (F10 and F15), the trend reversed, with yam and maize blends exhibiting significantly higher moisture contents than the cassava-based blend (Figure 1).

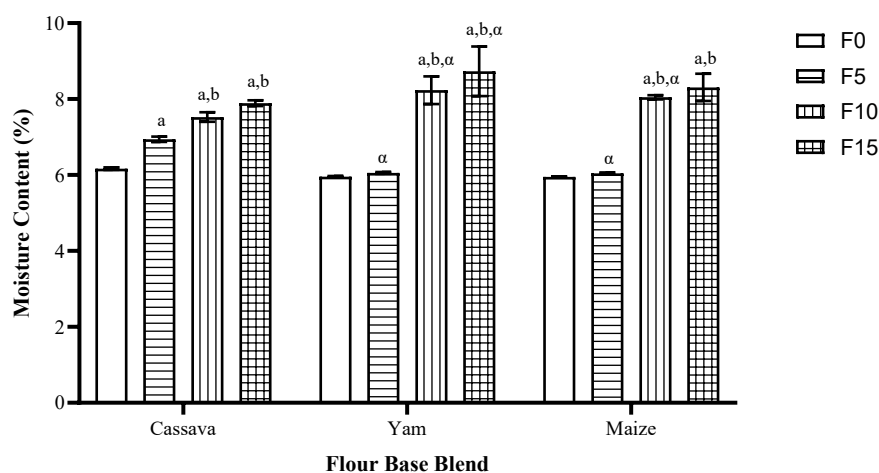


Figure 1: Percentage moisture content of the flour base blend. Bars are means $\pm$ SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a, vs. F0, – b, vs. F5, – α, vs. Cassava.

Figure 2 shows the crude protein (%) of cassava-, yam-, and maize-based potato blend flours at varying inclusion levels (F0, F5, F10, and F15). No significant difference was observed across all the cassava and yam blends. There was significant increase in the crude protein percentage of the F5, F10, and F15 compared to the F0 (Figure 2). The percentage crude protein of the yam F10 blend was significantly increased compared to the cassava F10 blend (Figure

2). The crude protein percentage of the maize flour was significantly low compared to that of the cassava and Yam flour (Figure 2).

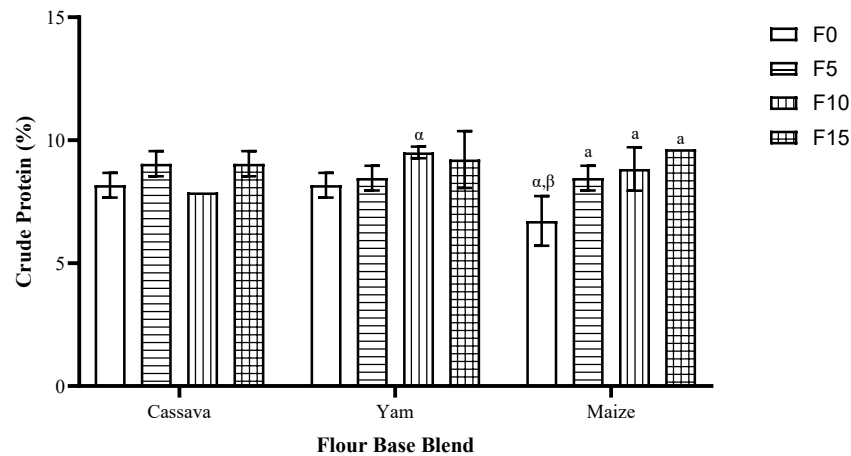


Figure 2: Percentage crude protein of the flour base blend. Bars are means $\pm$ SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a , vs. F_0 ; – α , vs. Cassava; β , vs. Yam.

Figure 3 shows the crude fat (%) of cassava-, yam-, and maize-based potato blend flours at varying inclusion levels (F_0 , F_5 , F_{10} , and F_{15}). In the cassava flour base blend, there was significant decrease in F_5 and F_{15} of compared to the F_0 . No significant difference was observed across all the yam base blend. However, there was significant increase in the crude fat percentage of the F_5 compared to the F_0 (Figure 3) and the significant decrease was observed in the F_{10} and F_{15} maize blends when compared to the F_5 blend (Figure 3). Meanwhile, significant decrease in percentage crude fat of the maize flour base blend F_0 and F_{10} compared to the F_0 and F_{10} cassava and yam flour base blends (Figure 3). Meanwhile, a significant increase in the percentage crude fat of the F_5 and F_{15} of the maize flour base blend compared to the F_5 and F_{15} of cassava and yam flour base blends (Figure 3).

In figure 4, there was significant increase in the ash content (%) for the F_5 and F_{15} cassava blend compared to the F_0 while the ash content in the F_{10} and F_{15} of both the yam and maize flour blend was significantly decrease compare to the respective F_0 of each of the flour blend (Figure 4). The ash content in the F_5 maize flour blend was significantly lower compared to that of the F_0 of the maize blend and in the maize flour blend, the ash content of the F_{15} blend was significantly low compared to the F_5 blend (Figure 4). However, the F_0 yam flour blend shows significant increase in ash content compared to F_0 of either of cassava and maize blend, while there was significant decrease in the Ash content of the F_5 and F_{10} of the maize flour

blend when compare to the respective concentration of flour blend of cassava and yam (Figure 4).

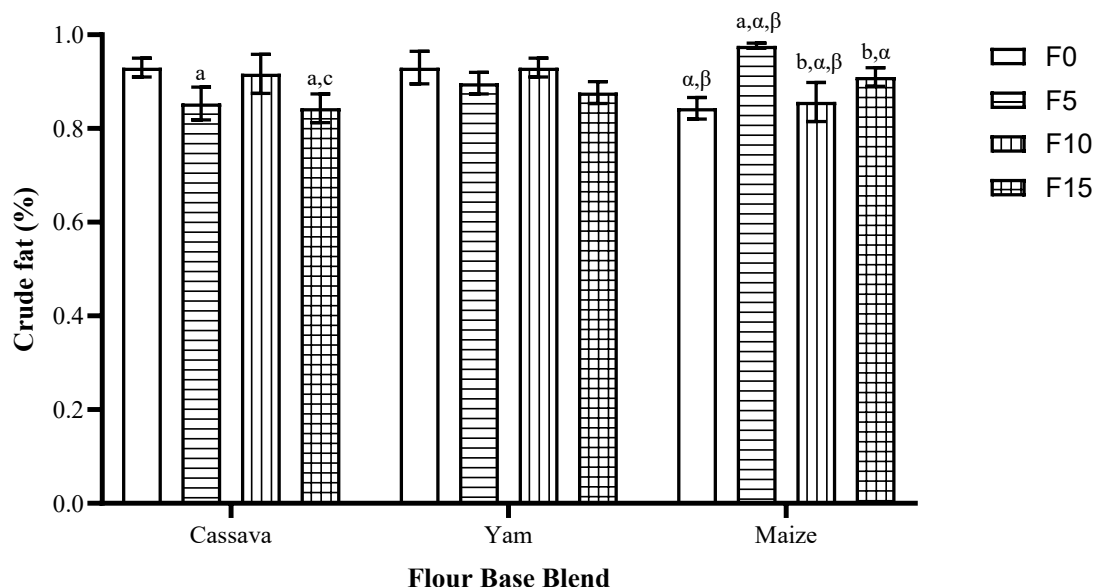


Figure 3: Percentage crude fat of the flour base blend. Bars are means $\pm$ SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a, vs. F0, – b, vs. F5, – c, vs. F10, – α , vs. Cassava, β , vs. Yam.

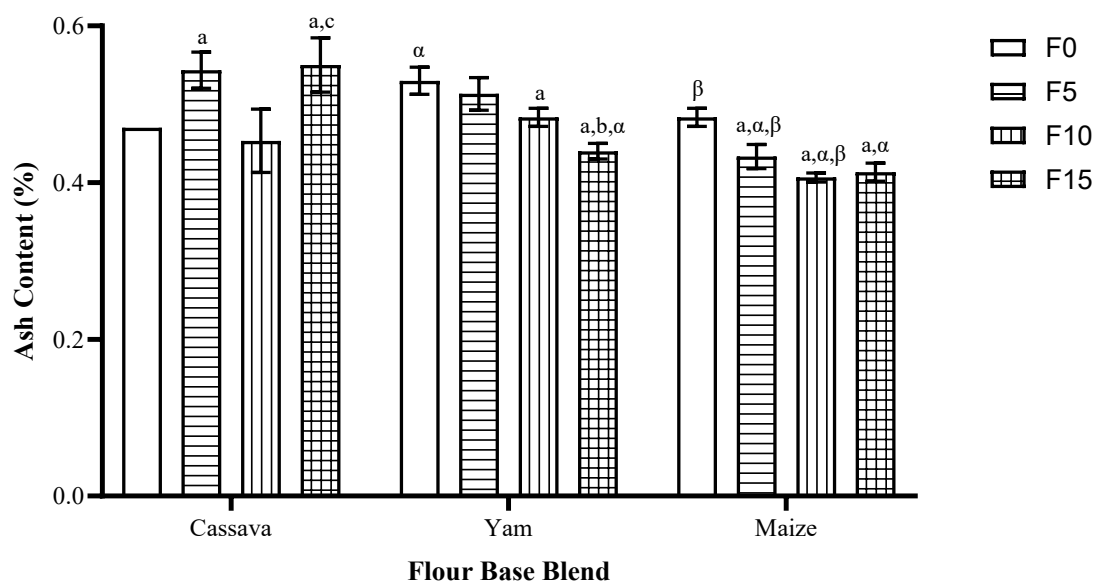


Figure 4: Percentage ash content of the flour base blend. Bars are means $\pm$ SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a, vs. F0, – b, vs. F5, – α , vs. Cassava, β , vs. Yam

There was significant decrease in the carbohydrate content (%) for the F15 cassava blend compared to the F0, the carbohydrate content (%) for the F10 yam blend compared to the F0 and F5 yam blend, while the cassava content in the F10 and F15 of the maize flour blend was significantly decrease compare to the F0 of the maize flour blend (Figure 5).

In respect of total energy value, there was significant decrease in the total energy value of cassava flour blend at F5, F10 and F15 compared to the F0 cassava flour blend (Figure 6). Also there was significant decrease in the total energy value of both yam and maize flour blend at F10 and F15 compared to the F0 and F5 of their respective flour blend (Figure 6). At F10, the yam and maize flour blend was significantly lower in total energy value compared to the F10 cassava flour blend (Figure 6).

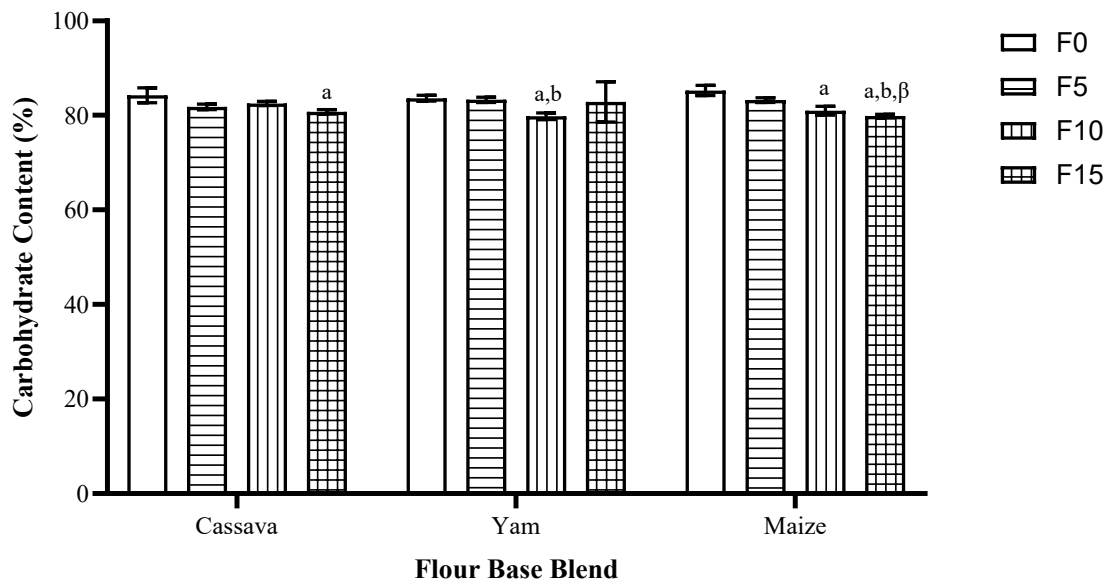


Figure 5: Percentage carbohydrate content of the flour base blend. Bars are means $\pm$ SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a, vs. F0, – b, vs. F5, – β , vs. Yam

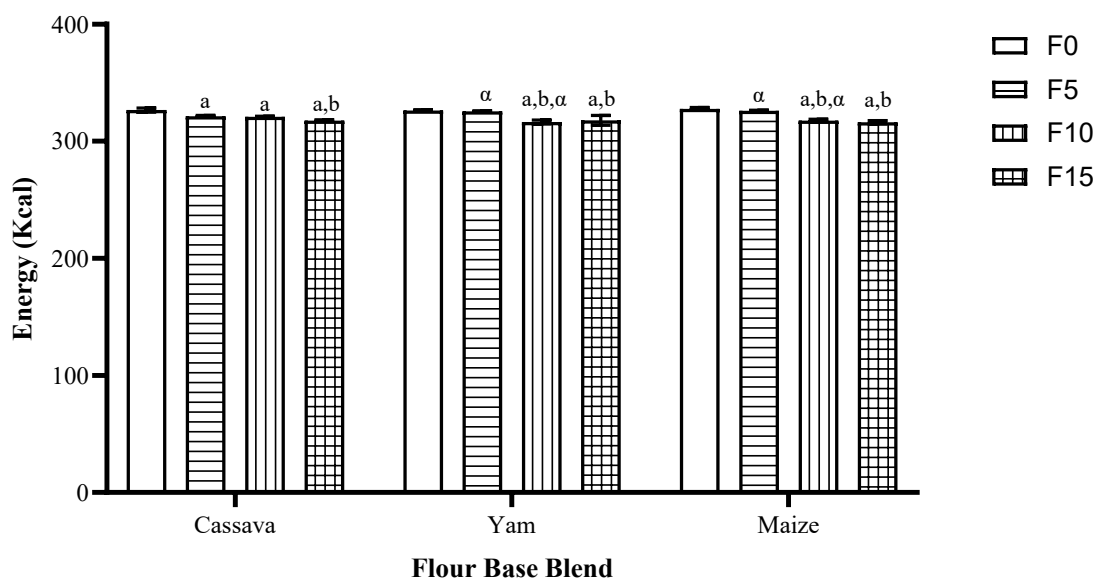


Figure 6: The total energy value of the flour base blend. Bars are means $\pm$ SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a, vs. F0, – b, vs. F5, – α , vs. cassava.

3.2 Physicochemical and Functional Characteristics of Blend

3.2.1 Gelatinization Temperature

Figure 7 presents the gelatinization temperature of cassava-, yam-, and maize-based flour blends formulated with varying substitution levels (F0, F5, F10, and F15). Among the cassava-based blends, the F5 blend exhibited the highest gelatinization temperature (about 91–92 °C) and significantly higher compared to the F0, F10, and F15 (Figure 7).

For yam-based blends, gelatinization temperatures remained relatively stable across treatments, with values close to 90–91 °C. However, F15 showed a significantly higher value compared with F10 and also increased significantly from cassava-based blends (Figure 7).

In maize-based blends, F0 recorded slightly higher gelatinization temperatures than F10 and F15. Significant increase in the 100% maize flour and the 100% of other flour bases (Figure 7).

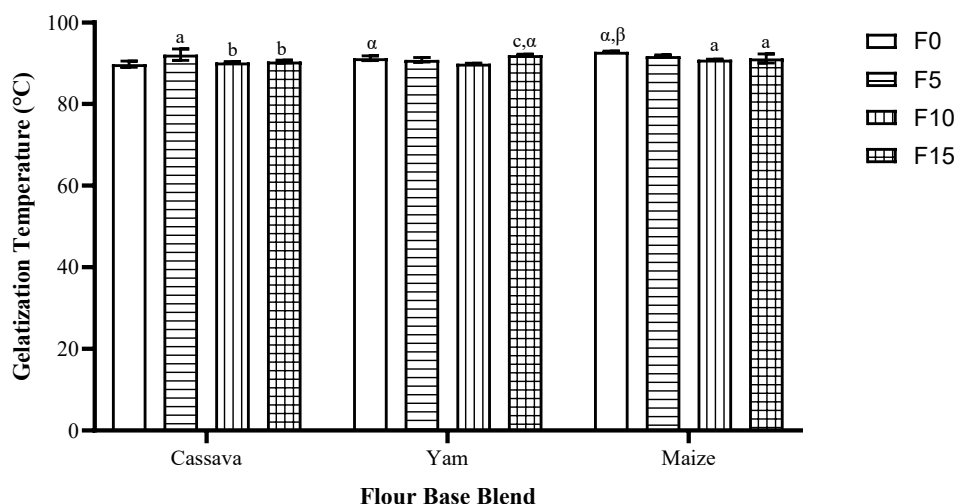


Figure 7: The gelatinization temperature of the flour base blend. Bars are means $\pm$ SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a, vs. F0, – b, vs. F5, – c, vs. F10, – α , vs. cassava, – β , vs. yam.

3.2.2 Pasting Properties and Percentage of Resistant Starch of Flour Blends

Table 5 presents the pasting properties of cassava-, yam-, and maize-based flour blends formulated at different substitution levels (F0, F5, F10, and F15). The parameters evaluated include peak viscosity, breakdown viscosity, setback viscosity, and pasting temperature, which are important indicators of starch functionality, cooking behavior, and stability of flour during processing.

Peak viscosity values ranged from 216.7 to 248.7 RVU. Cassava F0 recorded the highest peak viscosity (248.7 RVU), indicating a greater swelling ability and water-binding capacity of starch granules during heating. However, peak viscosity generally decreased with increasing substitution levels in cassava blends, with significant reductions observed in F10 and F15 ($p < 0.05$). In contrast, yam-based blends showed lower peak viscosities overall, particularly Yam F0 (216.7 RVU), suggesting comparatively lower swelling characteristics. Maize blends exhibited progressive increases in peak viscosity with higher substitution levels, reaching 246.3 RVU in F15, which was significantly different from some yam blends (Table 5).

Breakdown viscosity, which reflects the stability of starch granules under heat and shear, varied between 111.7 and 131.7 RVU. Maize F0 showed the highest breakdown viscosity (131.7 RVU), indicating lower resistance to thermal and mechanical stress during heating. Cassava F15 also exhibited a relatively high breakdown value (130.0 RVU). Conversely, lower breakdown viscosities observed in Yam F5 and Maize F15 (111.7–115.0 RVU) suggest improved paste stability and stronger resistance to disintegration during cooking (Table 5).

Setback viscosity values ranged from 176.7 to 198.0 RVU. Cassava blends generally recorded higher setback viscosities, especially Cassava F10 (198.0 RVU), indicating a greater tendency toward retrogradation and gel formation upon cooling. Yam F10 showed the lowest setback viscosity (176.7 RVU), suggesting reduced retrogradation tendency and potentially better storage stability. Maize blends maintained relatively high setback values, particularly F5 and F10, indicating moderate reassociation of starch molecules after cooling (Table 5). The pasting temperature of all flour blends ranged narrowly from 80.67 to 84.60 °C, indicating similar cooking initiation temperatures among the samples. Yam F5 recorded the lowest pasting temperature (80.67 °C), suggesting faster gelatinization and lower energy requirement during cooking. Cassava F15 exhibited the highest pasting temperature (84.60 °C), indicating slightly greater thermal resistance before starch gelatinization commenced. Despite some significant differences ($p < 0.05$), the overall variations in pasting temperature were relatively small across blends.

Table 5: Table showing the Pasting Properties of the different flour blends

Flour Blend		Peak Viscosity	Breakdown Viscosity	Setback Viscosity	Pasting Temperature (°C)
Cassava	F0	248.7 ± 1.16	116.7 ± 5.77	197.0 ± 2.65	84.23 ± 0.21
	F5	245.0 ± 0.00	123.3 ± 7.64	195.3 ± 2.52	82.83 ± 0.21 ^a
	F10	228.3 ± 2.89 ^{ab}	123.3 ± 2.89	198.0 ± 0.00	84.23 ± 0.21 ^b
	F15	226.7 ± 7.64 ^{ab}	130.0 ± 5.00 ^a	195.0 ± 5.00	84.60 ± 0.36 ^b
Yam	F0	216.7 ± 11.56 ^α	116.7 ± 5.77	197.7 ± 2.52	83.93 ± 0.06
	F5	230.0 ± 17.32 ^α	111.7 ± 2.89 ^α	186.7 ± 2.89	80.67 ± 0.29 ^{a,α}
	F10	228.3 ± 2.89	127.3 ± 2.52 ^b	176.7 ± 15.28 ^{a,α}	83.93 ± 0.06 ^b
	F15	240.0 ± 8.66	115.0 ± 8.66 ^{c,α}	192.3 ± 3.05 ^c	83.87 ± 0.15 ^{b,α}
Maize	F0	233.3 ± 5.77 ^{αβ}	131.7 ± 2.89 ^{αβ}	194.3 ± 4.84	84.20 ± 0.17
	F5	238.0 ± 2.65	115.0 ± 5.00 ^a	197.7 ± 2.52 ^β	83.80 ± 0.26 ^{α,β}
	F10	245.0 ± 3.00 ^{αβ}	126.7 ± 7.64 ^{αβ}	196.7 ± 0.58 ^β	84.40 ± 0.35 ^{b,β}
	F15	246.3 ± 2.31 ^{a,α}	111.7 ± 2.89 ^{acα}	189.7 ± 0.58	83.90 ± 0.10 ^α

Values are means ± SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a, vs. F0, – b, vs. F5, – c, vs. F10, – α, vs. cassava, – β, vs. yam.

Figure 8 illustrates the resistant starch content (%) of cassava-, yam-, and maize-based flour blends formulated at different substitution levels with values ranged from approximately 3.6 to 4.6% (w/w).

Among the cassava-based blends, resistant starch content remained relatively stable across all formulations, with values ranging between approximately 3.9 and 4.2%. Cassava F5 recorded the highest resistant starch value within the cassava group (Figure 8).

For the yam-based blends, resistant starch values were comparatively lower at F0, F5, and F10, ranging from about 3.6 to 3.8%. Yam F15, however, exhibited a significant increased relative to F0, F5, and F10. However, the F0 and F5 Yam flour blends shows significant decrease in the resistant starch compared to their corresponding cassava blends (Figure 8).

Maize-based blends generally recorded the highest resistant starch contents among all flour bases. Maize F15 showed significant increase in the resistant starch compared to the Maize F5 and the Cassava F15 flour blend. The Maize flour showed significant increase in resistant starch compared to the yam flour. The Maize F10 flour blend showed significant increase in resistant starch compared to both cassava F10 and Yam F10 flour blends (Figure 8).

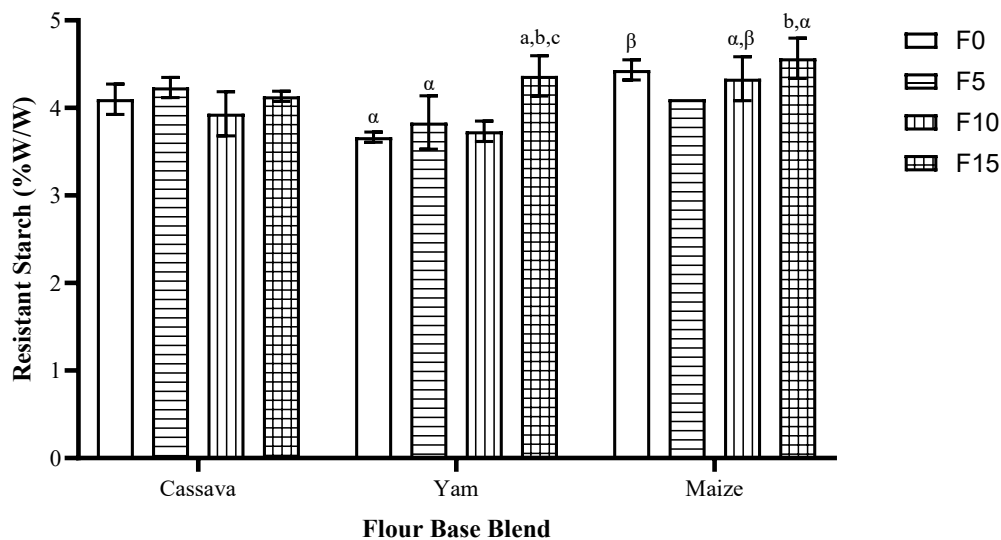


Figure 8: The percentage resistant starch of the flour base blend. Bars are means $\pm$ SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a, vs. F0, – b, vs. F5, – c, vs. F10, – α , vs. cassava, – β , vs. yam.

The amylose and amylopectin contents of cassava-, yam-, and maize-based flour blends formulated at varying substitution levels were shown figure 9 and 10.

Cassava-based blends exhibited very stable amylose and amylopectin contents across all formulations. No significant variation was observed among Cassava F0, F5, F10, and F15.

In yam- and Maize-based blends, amylose and amylopectin contents was also relatively consistent at F0, F5, and F10 however all significant lower to the Yam F15. Both F15 of Yam and Maize flour blends are significantly higher in amylose and amylopectin contents compared to the F15 cassava flour blend.

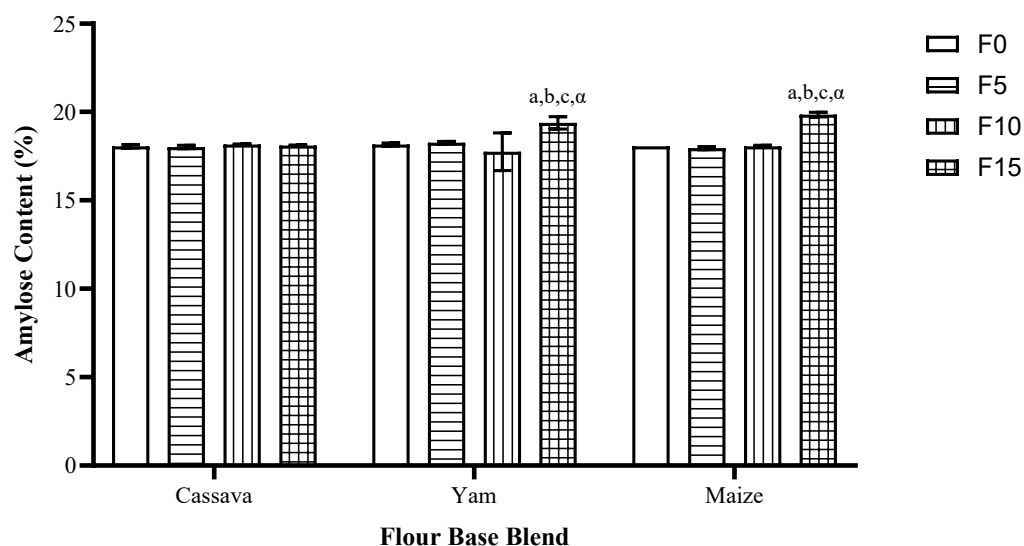


Figure 9: Amylose content of the flour base blend. Bars are means $\pm$ SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a, vs. F0, – b, vs. F5, – c, vs. F10, – α, vs. cassava.

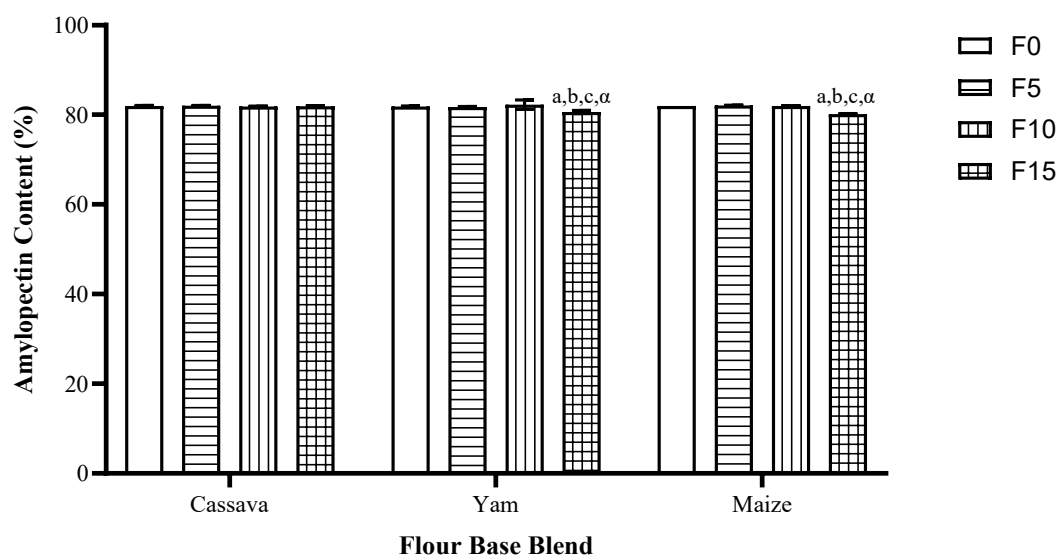


Figure 10: Amylopectin content of the flour base blend. Bars are means $\pm$ SD of three replicated measurements. Letters indicate significant differences by Tukey's test ($p < 0.05$): – a, vs. F0, – b, vs. F5, – c, vs. F10, – α, vs. cassava.

4.0 Discussion

The progressive increase in moisture content observed across cassava-, yam-, and maize-based flour blends with the increasing levels of potato peel powder substitution suggests that potato peel powder possesses a greater water absorption and water-holding capacity than the native flours. Potato peel is known to contain appreciable amounts of dietary fibre, pectin, and hydrophilic polysaccharides, which enhance moisture retention within flour systems (Joshi *et al.*, 2020; Sampaio *et al.*, 2020). Consequently, the incorporation of potato peel powder likely increased the availability of hydroxyl groups capable of binding water molecules, thereby elevating the overall moisture content of the composite flours. Although the relatively low moisture content recorded in the control samples (F0) indicates good shelf stability of the unfortified flours, since lower moisture levels are generally associated with reduced microbial growth and prolonged storage life (Cruz-Paredes *et al.*, 2021). The observed differences among flour types may be attributed to variations in starch composition, fibre characteristics, and particle structure of cassava, yam, and maize flours. At lower substitution levels (F5), cassava blends retained higher moisture contents than yam and maize blends, possibly due to the highly hydrophilic nature of cassava starch granules (Chamorro *et al.*, 2025). However, at higher substitution levels (F10 and F15), yam and maize blends exhibited comparatively higher moisture contents, suggesting stronger interactions between potato peel fibre and the protein-fibre matrix of yam and maize flour systems. This may also reflect differences in porosity and particle surface area, which influence water adsorption properties (Zhang *et al.*, 2024). The increase in moisture content with potato peel incorporation agrees with previous findings that dietary fibre enrichment generally elevates water retention in composite flour formulations (Çağlar *et al.*, 2025; Vescovo *et al.*, 2025).

The increase in crude protein content following incorporation of potato peel powder demonstrates the nutritional enhancement potential of potato peel in composite flour systems. Based on previous findings of Kibar *et al.*, (2025) and Ajaz *et al.*, (2026), potato peel contains moderate amounts of protein and amino acids, this may have contributed to the improved protein levels observed in the fortified blends. The significant increase in crude protein values of F5, F10, and F15 relative to the controls indicates that even low levels of substitution can improve the protein quality of traditionally carbohydrate-rich flours. The elevated protein values in yam F10 relative to cassava F10 suggest that yam flour may provide a more compatible matrix for protein enrichment or may possess synergistic interactions that improve nitrogen retention during analysis. Meanwhile, the comparatively lower crude protein content observed in maize blends was unexpected as maize is commonly recognized to contain

appreciable protein levels (Ifie *et al.*, 2026). This result may be associated with varietal differences, processing methods, dilution effects, or interactions between potato peel constituents and maize proteins. It is also possible that the protein quality of maize was affected during flour processing or that the maize flour used possessed relatively low intrinsic protein content. Nutritionally, the enhancement of crude protein is important because cassava- and yam-based products are generally deficient in protein. Therefore, fortification with potato peel powder could contribute to improved dietary protein intake, especially in populations where root and tuber products constitute staple foods. The improved protein levels may also support better growth, tissue repair, and metabolic functions (Tomé *et al.*, 2021).

The observed decreased in crude fat content among the composite flours may be attributed to differences in lipid composition of the flour bases and the dilution effect caused by potato peel incorporation. Nutritionally, moderate fat levels are desirable because lipids contribute to energy supply, fat-soluble vitamin absorption, and sensory properties (Malik *et al.*, 2023). However, lower fat content may enhance shelf stability by reducing susceptibility to oxidative rancidity (Gharby *et al.*, 2025). Therefore, the reduced fat levels observed in some fortified blends may improve storage quality while still maintaining acceptable nutritional value.

Ash content is an important indicator of total mineral composition in food materials (Ismail, 2024). Thus increase in ash content observed in cassava F5 and F15 suggests that potato peel powder contributed additional mineral elements to the blends. Potato peel is known to contain considerable quantities of potassium, calcium, magnesium, phosphorus, and trace elements (Joshi *et al.*, 2020), hence, its inclusion likely enhanced the mineral density of the cassava-based formulations. The nutritional implication of elevated ash content is significant because minerals are essential for bone formation, enzyme function, fluid balance, and metabolic regulation (Vescovo *et al.*, 2025). Therefore, incorporation of potato peel powder may improve micronutrient availability in the fortified flours, supporting better nutritional outcomes.

The reduction in carbohydrate content observed in cassava F15, yam F10, and maize F10/F15 blends can be attributed to the replacement of starch-rich flour fractions with potato peel powder, which contains comparatively higher levels of dietary fibre, ash, and non-carbohydrate constituents. Since cassava, yam, and maize flours are predominantly carbohydrate-based, substitution with potato peel naturally reduced the relative proportion of digestible carbohydrates. The decline in carbohydrate content may also reflect the inverse relationship between carbohydrate concentration and increases in protein, moisture, fibre, and ash content. Similar trends have been reported in fibre-enriched composite flour formulations where

incorporation of agricultural by-products decreases available carbohydrate fractions (Areti *et al.*, 2024; Abali *et al.*, 2025).

The observed decrease in total energy value with increasing substitution levels is consistent with the reductions in available carbohydrate and fat contents of the composite flours. Since carbohydrates and lipids are major contributors to caloric value (Vieira *et al.*, 2025), replacement with fibre-rich potato peel powder naturally reduced the overall caloric density.

The lower energy values observed in yam and maize blends at F10 and F15 relative to cassava blends may reflect greater reductions in digestible starch fractions within those formulations.

This finding is nutritionally important because lower-energy foods enriched with dietary fibre may support weight management and reduce risks associated with excessive caloric intake.

Additionally, the reduction in energy density coupled with improved protein, fibre, and resistant starch composition suggests that the fortified blends may be suitable for functional food development targeting individuals with obesity, diabetes, and other metabolic disorders.

Gelatinization temperature is an important indicator of starch behaviour during heating and reflects the energy required for starch granule swelling and disruption (Sethi *et al.*, 2022). The high gelatinization temperature observed in cassava F5 suggests stronger molecular interactions due to increased structural rigidity within the starch matrix at low levels of potato peel incorporation. The fibre components of potato peel may have restricted water mobility, thereby increasing the thermal energy required for gelatinization. Meanwhile, the relatively stable gelatinization temperatures observed across yam blends suggests that yam starch granules were less affected by substitution with potato peel powder. This stability may be associated with the inherent structural characteristics of yam starch, including granule size distribution and amylose-to-amylopectin ratio. However, the lower gelatinization temperatures observed in maize F10 and F15 relative to maize F0 suggest that higher potato peel inclusion facilitated earlier starch gelatinization, possibly due to disruption of starch granule organization or improved water penetration into the starch matrix (Sethi *et al.*, 2022).

Peak viscosity reflects the maximum swelling ability of starch granules during heating and is closely associated with water-binding capacity (Jia *et al.*, 2023). The high peak viscosity observed in cassava F0 confirms the superior swelling characteristics of cassava starch, which is typically associated with high starch purity and strong hydration capacity (Chamorro *et al.*, 2025). The reduction in peak viscosity with increasing substitution levels in cassava blends suggests that potato peel powder interfered with starch granule swelling. The fibre-rich nature of potato peel may have competed with starch for available water, thereby limiting granule expansion and reducing viscosity development (Lal *et al.*, 2024). Also, the lower peak

viscosities recorded in yam blends indicate comparatively weaker swelling properties, possibly due to differences in starch granule architecture and lower starch availability. Conversely, the increase in peak viscosity observed in maize blends at higher substitution levels suggests that interactions between maize starch and potato peel components may have enhanced water absorption and paste development. Functionally, the reduced peak viscosity may improve processing stability in products requiring controlled thickening, whereas higher viscosities may be advantageous for soups, porridges, and bakery fillings.

Breakdown viscosity reflects the ability of starch granules to withstand heat and mechanical shear during cooking (Pacheco *et al.*, 2024) with high breakdown values indicating weak paste stability and greater susceptibility to structural disintegration (Boonkor *et al.*, 2022). Hence, the high breakdown viscosity observed in maize F0 suggests poor resistance to thermal and shear stress, likely due to rapid swelling and collapse of starch granules. Similarly, cassava F15 exhibited relatively high breakdown values, suggesting that excessive potato peel incorporation may weaken paste integrity in cassava systems. Conversely, the lower breakdown viscosities recorded in yam F5 and maize F15 indicate improved thermal stability and stronger resistance to cooking stress. Thus suggests that potato peel fibre may reinforce starch matrices and reduce granule fragility in the yam and maize composite flour. However, improved paste stability is desirable in food products subjected to prolonged heating as it enhances product consistency and reduces viscosity loss during cooking.

The setback viscosity measures the tendency of starch molecules, particularly amylose, to re-associate during cooling, leading to retrogradation and gel formation (Li, 2024). Hence, the relatively high setback viscosities observed in cassava blends, especially Cassava F10, indicate a stronger tendency toward retrogradation. High retrogradation may contribute to firmer gel texture and increased resistant starch formation after cooling. However, excessive retrogradation may negatively affect sensory quality by promoting staling in processed foods (Ning *et al.*, 2025).

The resistant starch content of the composite flours increased modestly with potato peel incorporation, particularly in maize-based blends. Resistant starch represents the fraction of starch that escapes digestion in the small intestine and behaves physiologically like dietary fibre (Han *et al.*, 2023). The relatively stable resistant starch values observed in cassava blends suggest that potato peel incorporation had limited influence on resistant starch formation in cassava systems. However, the elevated values observed in maize F10 and F15 indicate enhanced formation of digestion-resistant starch structures, possibly due to stronger amylose-lipid and starch-fibre interactions (Krishnan *et al.*, 2021). The low resistant starch contents

observed in yam F0 and F5 relative to cassava blends may indicate greater starch digestibility in yam flour systems. However, the increase observed in Yam F15 suggests that potato flour higher substitution levels promoted resistant starch formation in the yam blends. The nutritional significance of resistant starch is substantial because it contributes to reduced glycaemic response, improved colonic health, enhanced satiety, and beneficial modulation of gut microbiota (Das *et al.*, 2024). Hence, the higher resistant starch levels observed in maize-based fortified blends suggest its potential application in functional foods designed for diabetic and health-conscious consumers.

Amylose and amylopectin are the principal polysaccharides responsible for starch functionality. The relatively stable amylose and amylopectin contents observed across cassava blends indicate that potato peel incorporation did not substantially alter starch composition in cassava systems. The reductions observed in yam and maize F15 formulations suggest that higher levels of potato peel substitution diluted native starch fractions or altered starch organization. According to Wang *et al.*, (2025), amylose contributes to gel firmness and resistant starch formation while amylopectin influences swelling and viscosity. Thus, these changes in both amylose and amylopectin of the composite blends may explain some of the functional differences observed in pasting behaviour. The comparatively higher amylose and amylopectin contents recorded in yam and maize F15 relative to cassava F15 may reflect inherent compositional differences among the flour bases. Higher amylose levels are generally associated with increased resistant starch formation, firmer gels, and slower digestibility (Wang *et al.*, 2025).

5.0 Conclusion

This study demonstrated that the incorporation of potato peel powder into cassava-, yam-, and maize-based composite flours significantly enhanced the nutritional and functional quality of the flour systems without adversely altering their inherent physicochemical characteristics. The enrichment process modified starch functionality and influenced important processing attributes while maintaining the overall structural integrity of the flour blends.

Potato peel powder proved to be an effective functional ingredient due to its appreciable content of dietary fibre, minerals, and bioactive compounds. Its inclusion improved the protein and ash contents of the composite flours while reducing available carbohydrate and total energy values, thereby producing nutritionally improved flour formulations with potential health benefits. The increase in resistant starch content, particularly in maize-based blends, further suggests possible applications in the formulation of low-glycaemic and health-promoting food products suitable individual with metabolic syndrome and other health-conscious consumers.

The study also revealed notable effects of potato peel enrichment on the functional and pasting characteristics of the flour blends. Cassava-based blends retained relatively high swelling capacity and setback viscosity, indicating stronger retrogradation tendencies and gel-forming ability. Yam-based blends exhibited comparatively stable thermal properties and lower setback viscosities, suggesting better storage stability and reduced retrogradation. Maize-based blends showed superior resistant starch enhancement and improved paste stability, indicating favourable processing and cooking characteristics. These variations demonstrate that the response of composite flours to potato peel enrichment is dependent on the intrinsic properties of the base flour.

Furthermore, the utilization of potato peel powder offers important environmental and economic advantages. Since potato peel is commonly treated as an agro-industrial waste, its conversion into a value-added functional ingredient supports sustainable food processing, waste minimization, and resource utilization. The findings therefore highlight the potential of potato peel powder as a low-cost fortifying material capable of improving both the nutritional and technological properties of composite flours.

Overall, the results of this study establish that potato peel powder can be successfully incorporated into cassava-, yam-, and maize-based composite flours to produce nutrient-enriched and functionally improved food materials with promising applications in functional food development and sustainable food systems.

6.0 Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. Potato peel powder should be considered as a functional ingredient for the development of nutritionally enhanced composite flours and other food products due to its beneficial effects on protein content, mineral composition, resistant starch formation, and functional properties.
2. Food industries and small-scale food processors should explore the incorporation of potato peel powder into staple flour products as a strategy for improving nutritional quality while reducing agro-industrial waste.
3. Further studies should be conducted to evaluate the sensory properties, consumer acceptability, and shelf-life stability of food products produced from potato peel-enriched composite flours.
4. Additional research should investigate the bioavailability of nutrients and the glycaemic response of products formulated from these composite flours in order to validate their potential health benefits for diabetic and health-conscious populations.

5. Advanced characterization studies involving starch microstructure, rheological behaviour, and molecular interactions should be carried out to better understand the mechanisms through which potato peel powder influences starch functionality and digestibility.
6. Optimization studies should be performed to determine the most suitable substitution levels of potato peel powder that provide the best balance between nutritional enhancement, functional performance, and sensory quality.

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