



Effect of Germination on the Physicochemical Properties and Mineral Composition of Pigeon Pea Flour and Its Protein Isolate

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ABSTRACT

The study investigated the effect of germination in the quality of pigeon pea flour and its protein isolate. Protein isolate was prepared from germinated pigeon pea grains. The protein isolate was used to substitute 5, 10, 15, and 20% wheat flour. The chemical composition, functional and pasting properties of pigeon pea flour and its protein isolate, and the wheat–germinated pigeon pea protein isolate blends were evaluated. Germination of the pigeon pea protein isolate increased the bulk density, swelling capacity, dispersibility, and least gelation concentration but decreased the water absorption capacity, fat absorption/foam capacity and stability, and emulsification capacity relative to the ungerminated isolate. Germination increased the peak, trough, breakdown, final, and setback viscosities of the isolate, while lowering peak time and pasting temperature. Proximate composition revealed that germination significantly ($p < 0.05$) increased the crude protein, fat, crude fibre, ash, moisture and carbohydrate content of the isolate. Mineral analysis showed that germination increased phosphorus, magnesium, sodium, potassium, and calcium levels of the pigeon pea protein isolate, with sodium showing the largest proportional increase (70.00–87.00 mg/100g). Increasing the level of germinated isolate inclusion (5% to 20%) in wheat flour blends increased the protein, ash, fibre, and mineral contents as well as the pasting viscosities compared with the 100% wheat flour (control). These results demonstrate that germination is an effective bioprocessing technique for enhancing the nutritional and functional quality of pigeon pea protein isolate and its wheat flour blends.

Keywords: Pigeon pea, protein isolate, germination, chemical composition, functional properties. .

INTRODUCTION

Pigeon Pea (*Cajanus cajan*) ranks fifth in importance among edible legumes in the world (Onimawo and Asuquo, 2004). From 2005-2010, world production of pigeon peas increased from 3.24 million Metric Tons (MTs) to 3.68 million MTs, an increase of 13 percent (Amarteifio *et al.*, 2000). Although, India remains the major producer of pigeon pea, the interest in pigeon pea in other parts of the world is ascribed to its nutritional, medicinal, economical and agronomic usefulness (Amarteifio *et al.*, 2000).

In Nigeria, different varieties of pigeon pea are grown where they are used for various preparations (Singh, 2014; Sharma and Kumar 2015). Pigeon peas contain 17.9-24.3% protein, 58.7% carbohydrate, 1.2-8.10% crude fiber and 0.6- 3.8% fat (Amarteifio *et al.*, 2000). Pigeon peas provide strong source of micronutrients, including vitamins C and B, calcium, phosphorus, magnesium, iron, sulphur, etc (Amarteifio *et al.*, 2000). In promoting health, clinical studies showed the potential of pigeon pea seed based meal in the dietary management of diabetes mellitus and cardiovascular diseases (Amarteifio *et al.*, 2000). Diets rich in phytochemicals such as carotenoids and phenolic compounds which are abundant in pigeon peas, have been associated with reduced risk of certain types of cancer, cataracts, inflammation, cardiovascular, muscular degeneration and neurodegenerative diseases (Popoola and Danbaki, 2024).

MATERIALS AND METHODS

Materials

Pigeon pea seeds were purchased from Wukari main market, while other ingredients such as wheat, sugar, salt, margarine, yeast, eggs, baking powder and packaging materials were purchased from Wukari new market. The reagents used for analysis were obtained from the Food Chemistry Laboratory of the Food Science and Technology Department, Federal University Wukari, Taraba State. The reagents used for the analysis were of analytical grade (Analar) and included hydrochloric acid, ethanol, sodium hydroxide, selenium crystals, methyl red, boric acid, bromocresol green, sulphuric acid among others. The experiment was carried out in Food Science and Technology Department Laboratories.

Methodology

Preparation of pigeon pea flour

The method described by Kushwaha and Said (2020) was used for the production of germinated pigeon pea seed flour. The flow chart for the production of germinated pigeon pea flour is given in Fig 3.1. The seeds were cleaned, washed in water and then, steeped in the distilled water (1:2 w/v, seed: water) at ambient temperature (32 °C) for 24 h. The soaked seeds were drained, rinsed with water and put into damped muslin cloth in a tray and germinated for 72 h. The germinating grains were sprayed at regular interval with distilled water. Thereafter, the sprouted grains were dried at 55 °C in a cabinet tray dryer to constant weight. The dried grains were dehulled using a dehuller, milled in attrition mill, sieved through a 300 µm sieve and then packaged in a high-density polyethylene bags prior to use.

Preparation of pigeon pea protein isolates

Pea protein isolate was prepared following the method of Morales-Olán *et al.* (2020). The pigeon pea flour was defatted in a Soxhlet apparatus using 96% ethanol. The defatted pigeon pea flour was dispersed into distilled water at a 1:15 ratio (flour: water). The pH of the dispersion was adjusted to pH 9.5 using NaOH and stirred for 1 h at ambient temperature. The mixture was centrifuged (Eppendorf Centrifuge 5810 R, Eppendorf SE, Germany) at 6000 rpm for 20 minutes. The resulting supernatant was adjusted to pH 4.5 with 3 M HCl to precipitate the proteins. The protein was recovered by centrifugation at 6000 rpm for 10 min and the protein-rich precipitate was redispersed in distilled water, being neutralized to pH 7.0 with CH₃COOH (methanol). The pigeon pea protein isolate was hot-air oven dried at 45° C to constant weight. The powdered protein isolates were stored in high density polyethylene bags in a refrigerator at 10 °C.

Blending of wheat flour and protein isolate

The blend formulation is shown in Table 1. The protein isolate was used to substitute 5, 10, 15 and 20% wheat flour in a food blender that was operated at full speed for 10 min. The blends were packaged in high density polyethylene (HDPE) bags and stored in a refrigerator (10° C) prior to use.

Table 1: Formulation of flour blends

Samples	Wheat flour (g)	Pigeon pea protein isolates (g)
A	100	0
B	95	5
C	90	10
D	85	15
E	80	20

Analytical methods

Determination of functional properties of wheat flour, protein isolates, and flour blends

Water absorption capacity

The water absorption capacity was determined using the method of Idowu *et al.* (2021) with minor modifications. Protein sample (1 g) was mixed in 10 mL distilled water in a 15 mL pre-weighed centrifuge tube. The dispersions was vortexed for 1 min, allowed to stand for 30 min and then centrifuged at 7000 rpm for 25 min at ambient temperature. The supernatant was decanted, and the excess water was drained while the sediment was weighed to determine the amount of water retained per gram of sample. Water absorption capacity was calculated as:

$$\text{Water absorption capacity} = \text{Amount of water absorbed} \times \text{density (water)} \quad (1)$$

Oil absorption capacity

The oil absorption capacity was determined using the method of Idowu *et al.* (2021) with minor modifications. Protein sample (1 g) was mixed in 10 mL pure canola oil in a 15 mL pre-weighed centrifuge tube. The dispersions was vortexed for 1 min, allowed to stand for 30 min and then centrifuged at 7000 rpm for 25 min at ambient temperature. The supernatant was decanted, and the excess oil was drained while the sediment was weighed to determine the amount of oil retained per gram of sample. Oil absorption capacity was calculated as:

$$\text{Oil absorption capacity} = \text{Amount of oil absorbed} \times \text{density (oil)} \quad (2)$$

Swelling capacity

The swelling capacity was determined as described by Adebawale and Maliki (2011). One gram of dried sample was weighed into 100 ml conical flask and 15 ml distilled water was added. The mixture was shaken for 15 min at low speed on a stirrer and transferred into a hot water bath (Stuart,model SWB3, Bibby Scientific Ltd., Staffordshire, U.K) and heated for 40 min at 85°C with constant stirring. The heated mixture was transferred to a pre-

weighed centrifuge tube and 7.5 ml distilled water added; centrifuged at 2200 rpm for 20 min. The supernatant was carefully decanted and cooled in a desiccator. The precipitate with the centrifuge tube was weighed. Swelling capacity was calculated as:

$$\% \text{Swelling capacity} = \frac{\text{Weight of precipitate/paste}}{\text{Weight of dry flour}} \times 100 \quad (3)$$

Bulk density

The bulk density of the flours was measured using method of Mudau *et al.* (2021). The sample (10 g) was weighed and put into 25 mL measuring cylinder and the volume was recorded as a loose volume. The bottom was tapped on a bench until a constant volume was observed. The packed volume was recorded. The loose bulk density (BD) and packed bulk density (BD) was calculated as:

$$\text{Bulk density (g/ ml)} = \frac{\text{Weight sample}}{\text{Volume of sample}} \quad (4)$$

Foaming capacity and foam stability

Foaming capacity and stability was determined according to the method reported by Adebawale and Maliki (2011). Two grams sample was whipped (homogenized) with 100 ml distilled water for 15 min in a Kenwood blender (Model KM400, Kenwood Ltd., Britain) at speed setting 'max' and then poured into a 250 ml graduated measuring cylinder. The total volume at time intervals of 0.0, 0.25, 0.50, 1.00, 1.50, 2.00, 3.00 and 4 h was noted. Percent volume increase was calculated according to:

$$\text{Foam capacity(\%)} = \frac{\text{Volume after whipping(ml)} \times \text{Volume before whipping(ml)}}{\text{Volume before whipping(ml)}} \times 100 \quad (5)$$

The volume of foam was recorded 1 hour after whipping to determine foam stability as per percentage of initial foam volume

$$\text{Foam capacity(\%)} = \frac{\text{Foam volume after time(t)}}{\text{Initial foam volume}} \times 100 \quad (6)$$

Least gelation concentration

Least gelation concentration was determined using the method of Idowu *et al.* (2021). Sample suspensions of 2,4,6,8,10,12,14 and 16 % (w/v) was prepared in 5ml distilled water and the dispersions was transferred into test tubes. The test tubes were heated in boiling water in a water bath and then cooled rapidly under tap water and further cooled at 4 °C for 14 h. The least gelation concentration was taken as the sample concentration at which the gel did not slip when the tube was inverted.

Dispersibility

The dispersibility of the flours was determined according to the method described by Chinma *et al.* (2022). A fixed sample weight of (10 g) was placed in 100 ml measuring cylinder and distilled water was added to reach a volume of 100 ml. The mixture was stirred vigorously and allowed to settle for 3h. The volume of settled particles was recorded and subtracted from 100. The difference was reported as percentage dispersibility.

Emulsifying capacity and emulsion stability

The emulsifying capacity and emulsion stability was determined following method of Ayoub and Abdul-Rahman (2023). The sample was dissolved in distilled water with a graduated pH of 2-10 to obtain a concentration of 1% (w/v). The 30 ml of the protein isolate solution was homogenized with 20 ml of sunflower oil using a laboratory homogenizer for one minute at room temperature. Then, the prepared emulsion was placed in a 100 ml graduated cylinder to estimate the total volume of the emulsion formed, and then left to settle for 60 minutes. The emulsifying capacity and emulsion stability was calculated as:

$$\text{Emulsifying capacity (\%)} = \frac{\text{total volume of emulsion after 60 minutes}}{\text{volume of total emulsion}} \times 100 \quad (7)$$

$$\text{Emulsion stability (\%)} = \frac{\text{total volume of emulsion after 180 minutes}}{\text{volume of total emulsion}} \times 100 \quad (8)$$

Protein solubility

Protein solubility was determined by the method of Liu *et al.* (2018) with minor modifications. The protein sample (50 mg) was dispersed in deionized water (25 mL) followed by stirring for 30 min at ambient temperature (25°C) The pH of suspensions was adjusted to the desired values (2–10) with 0.1 M HCl or NaOH. These suspensions were magnetically stirred for another 30 min then, centrifuged at 7000 rpm for 15 min. The total protein content was measured. The protein solubility was expressed as the percentage ratio of supernatant protein content to the total protein content.

Determination of pasting properties of flours

The pasting properties of the pigeon pea protein isolates, wheat flour, protein isolates and wheat flour blends was determined using a RapidVisco Analytical machine (RVA) of model RVA 4500, New-Port Scientific, Australia as described by Ide *et al.* (2019). The sample (3 g) was weighed into a previously dried canister and 25 ml of distilled water was dispensed into the canister containing the sample. The suspension was thoroughly mixed and the canister was fitted into the Rapid ViscoAnalyser as recommended. Each suspension was kept at 50 °C for 1min and then heated up to 95 °C with a holding time of 2 min followed by cooling to 50 °C with 2 min holding time. The rate of heating and cooling was at a constant rate of 11.85 °C per min.

Samples were assessed for pasting temperature, peak paste viscosity time to peak temperature at peak, hot and cold paste viscosity break down setback and final viscosity.

Determination of proximate composition

The proximate composition of ungerminated and germinated pigeon pea protein isolates, flours blends, wheat flour, and protein isolate breads including wheat flour bread was determined.

Moisture content

Moisture content was determined by hot air oven drying method described by AOAC (2020). Two grams of sample was weighed into a crucible of known weight and heated in the oven at 105°C for 4 h. The sample was removed from the oven and cooled in a desiccator before weighing. The crucible was put back into the oven and heated again until constant weight was recorded. The loss in weight from the original sample weight was calculated as the moisture content as:

$$\% \text{ Moisture content} = \frac{\text{Weight loss}}{\text{Weight of sample}} \times 100 \quad (9)$$

Crude protein content

The total nitrogen content was determined by using the semi-micro Kjeldahl method according to AOAC (2020). One gram of the sample was digested in Kjeldahl digestion system. After digestion the sample was allowed to cool and then distilled into a flask containing 5ml of 2% boric acid solution with a few drops of methyl red indicator. The distillate was diluted with distilled water, and approximately 5ml of 60% sodium hydroxide solution was added. The distilled sample was titrated against 0.1M HCl solution. A blank titration was performed. The percentage nitrogen content was calculated as:

$$\% \text{ Nitrogen} = \frac{V_s - V_b \times N_q \times 0.01401}{\text{Weight of sample}} \times 100 \quad (10)$$

Where

V_s = volume of acid

V_b = volume of base

N_q = normality of acid

The protein content was calculated as:

$$\% \text{ Crude protein} = \text{Total Nitrogen} \times 6.25$$

Ash content

The ash content was determined by the method described by AOAC (2020). The samples was ignited in a Muffle furnace at 550°C for 2 h, until a light gray ash was obtained, followed by cooling to ambient temperature in a desiccator and then weighing the sample. The ash content was calculated as:

$$\% \text{ Ash content} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100 \quad (11)$$

Fat content

Crude fat content was determined by the Soxhlet extraction method as described by AOAC (2020). A Soxhlet extractor fitted with a reflux condenser and a 500 ml round-bottom flask was set up. Two grams of sample were weighed into a thimble and sealed with cotton wool. The Soxhlet apparatus was refluxed for 6 hours, after which the petroleum ether was evaporated into a container for reuse and the sample was oven-dried at 105°C for 1 hour. It was then cooled in a dessicator and weighed. The percentage fat was calculated as:

$$\% \text{ Crude fat content} = \frac{\text{Weight of fat}}{\text{Weight of sample}} \times 100 \quad (12)$$

Crude fiber content

The crude fiber content was determined according to the method of AOAC (2020). Petroleum ether was used to defat 2g of sample. This was put in a beaker containing 200ml of 1.25% of H_2SO_4 , boiled for 30min, filtered through muslin cloth on a fluted funnel and was washed with boiling water until it was free of acid. The residue was returned into 200ml boiling NaOH and allowed to boil for 30min. It was further washed with 1.0% HCl and then with boiling water to free it from acid. The final residue was drained and transferred to silica ash crucible (porcelain crucible) and dried in the oven to constant weight and cooled. The crude fiber content was calculated as:

$$\% \text{ Crude fiber content} = \frac{W_1 - W_2}{W} \times 100 \quad (13)$$

Where;

W_1 = weight of content before ashing

W_2 = weight of crucible and ash

W = weight of dried material

Carbohydrate content

The carbohydrate content was estimated by difference as described by AOAC (2020).

$$\% \text{Carbohydrate} = 100\% - \% (\text{Moisture} + \text{Protein} + \text{Fat} + \text{Ash} + \text{Crude fibre}) \quad (14)$$

Determination of mineral composition

The mineral composition of ungerminated and germinated pigeon pea protein isolates, flours blends, wheat flour, and protein isolate breads including wheat flour bread was determined using the method described by Bala and Bashar (2017). Five gram (5g) of fine powdered sample was digested using a mixture of analytical grade acids HNO_3 : HCl (1:1). Calcium (Ca) and magnesium (Mg) levels was determined using atomic absorption spectrophotometer (210 vgp model). Sodium (Na) and potassium (K) levels was determined using flame photometric method while phosphorous (p) level will be determined colorimetrically using spectronic 20.

RESULTS AND DISCUSSION

Functional properties of wheat flour, pigeon pea flour, protein isolates and the blends

The functional properties of wheat flour, protein isolates, and flour blends is shown in Table 2:

Table 2: Functional properties of wheat flour, pigeon pea flour, protein isolates and the blends

Sam ple	WAC (g/g)	OAC (g/g)	BD (g/mL)	SC (mL/g)	FC (mL/g)	FS (mL/g)	EC (mL/g)	ES (mL/g)	Dispersibil ity	LG C
A	1.60 ^d ±0.01	1.40 ^b ±0.00	0.79 ^a ±0.00	9.18 ^a ±0.01	8.48 ^f ±0.01	6.84 ^c ±0.01	4.59 ^c ±0.00	6.25 ^c ±0.00	72.72 ^b ±0.04	10
B	1.74 ^c ±0.01	1.60 ^a ±0.06	0.71 ^b ±0.01	8.41 ^d ±0.01	15.48 ^a ±0.11	8.11 ^a ±0.49	5.67 ^a ±0.44	7.79 ^a ±0.49	78.05 ^a ±2.33	10
C	1.83 ^a ±0.00	1.61 ^a ±0.01	0.72 ^b ±0.00	8.41 ^d ±0.01	15.59 ^a ±0.01	8.45 ^a ±0.00	5.67 ^a ±0.01	7.48 ^a ±0.03	76.40 ^a ±0.03	10
D	1.73 ^c ±0.01	1.62 ^a ±0.01	0.74 ^a ±0.01	8.84 ^b ±0.08	12.41 ^c ±0.02	7.74 ^b ±0.00	5.36 ^b ±0.00	7.46 ^b ±0.01	79.72 ^a ±0.01	8
E	1.79 ^b ±0.01	1.61 ^a ±0.01	0.70 ^b ±0.01	8.70 ^c ±0.00	10.20 ^c ±0.01	7.80 ^b ±0.00	5.23 ^b ±0.00	7.35 ^b ±0.01	76.02 ^a ±0.01	10
F	1.80 ^b ±0.01	1.64 ^a ±0.01	0.69 ^b ±0.01	8.68 ^c ±0.01	11.16 ^d ±0.01	7.84 ^b ±0.00	5.51 ^a ±0.01	7.47 ^a ±0.00	78.31 ^a ±2.12	10
G	1.83 ^a ±0.00	1.64 ^a ±0.00	0.67 ^b ±0.04	8.64 ^c ±0.00	12.39 ^c ±0.00	8.59 ^a ±0.00	5.65 ^a ±0.00	7.54 ^a ±0.06	77.11 ^a ±0.00	10
H	1.86 ^a ±0.01	1.67 ^a ±0.03	0.65 ^c ±0.00	8.60 ^c ±0.00	12.58 ^b ±0.00	8.72 ^a ±0.00	5.72 ^a ±0.00	7.80 ^a ±0.00	77.22 ^a ±0.04	10

Values are means ± standard deviation of 2 replications. Means within a column with different superscripts differed significantly ($p < 0.05$). A = 100% Wheat flour, B = 100% Pigeon Pea Flour, C = 100% Ungerminated Pigeon Pea Protein Isolate, D = 100% Germinated Pigeon Pea Protein Isolate, E = blend containing 5% Germinated Pigeon Pea Protein Isolate, F = blend containing 10% Germinated Pigeon Pea Protein Isolate, G = blend containing 15% Germinated Pigeon Pea Protein Isolate, H = blend containing 20% Germinated Pigeon Pea Protein Isolate.

The Table 2, shows that substituting wheat flour with germinated pigeon pea protein isolate significantly ($p < 0.05$) influenced the functional properties.

The water absorption capacity increased from 1.60 g/g in sample A (100% wheat flour) to 1.86 g/g in the blend containing 20% germinated pigeon pea protein isolate. The increase suggested that the incorporation of pigeon pea protein isolate enhanced the water-binding ability of the flour blends. Germination activates hydrolytic enzymes that modify protein structure, exposing hydrophilic amino acid residues capable of binding water (Li *et al.*, 2023). Higher water absorption capacity is advantageous in bread production because it improves dough hydration, increases dough yield, enhances moisture retention, and delays crumb firming during storage (Goldstein *et al.*, 2010). Similar increase in water absorption capacity in wheat-cassava composite flour have been reported (Li *et al.*, 2023). Skibsted *et al.* (2015) also reported that plant protein ingredients generally increase water absorption in wheat-based bakery products because proteins contain numerous polar groups that readily interact with water molecules.

The oil absorption capacity followed similar trend, increasing from 1.40 g/g in wheat flour to 1.69 g/g in the ungerminated pigeon pea protein isolate. Oil absorption is the ability of proteins to bind and retain lipids through hydrophobic interactions (Ijemi *et al.*, 2025). The superior oil absorption observed in the flour blends showed that germination may have unfolded protein molecules, exposing more non-polar amino acid residues capable of interacting with lipids (Chinma *et al.*, 2021). Improved oil absorption contributes to flavour retention, mouthfeel and overall sensory quality of food products (Ayo and Gidado, 2018). Therefore, the incorporation of pigeon pea protein isolate may improve consumer acceptability through better flavour preservation and texture development (Ogabor *et al.*, 2026). Ijemi *et al.* (2025) reported increased in oil absorption capacity from 131.30-163.50 g/mL of wheat, acha and date fruit composite.

The bulk density decreased from 0.79 g/mL in wheat flour to 0.65 g/mL in sample containing 20% germinated protein isolates. Low bulk density represents lighter flour particles and greater porosity, characteristics that are desirable in bakery formulations because they facilitate mixing and improve packaging efficiency (Ijemi *et al.*, 2025). The reduction observed in the composite flours may be attributed to changes in particle arrangement following incorporation of protein isolate. Similar observations were reported by Ijemi *et al.* (2025), who noted that protein enrichment generally reduced flour bulk density through alterations in particle structure and composition.

The swelling capacity was highest in wheat flour (9.18 mL/g) but decreased significantly in pigeon pea flour, ungerminated pigeon pea protein isolate and in the flour blends, after protein isolate incorporation, particularly in pigeon pea flour (8.41 mL/g). The reduction in swelling capacity may be explained by dilution of wheat starch with protein isolate. Since starch granules are primarily responsible for swelling during heating, replacing part of the starch with protein decreases the amount of water available for starch gelatinisation. Swelling capacity is the ability of starch granules to absorb water and expand during heating (Ayo *et al.*, 2024). The findings of the present study are lower than those reported by Ijemi *et al.* (2025), who observed increased swelling capacities in wheat-acha and date fruit composite flours ranging from 16.08 - 22.14 g/ml. The variation in the result could be due to the size of the particles, types of variety and processing methods or unit operations (Ayo *et al.*, 2024). High swelling capacity is desirable in bread production because it contributes to dough expansion, gas retention, and final loaf volume. Therefore, the improved swelling characteristics observed in the samples indicate its suitability for bakery applications.

The foaming capacity increased from 8.48 mL/g in the control to 15.59 mL/g in the ungerminated protein isolate, while the germinated protein isolate had 12.41 mL/g. Foaming stability also increased from 6.84 mL/g to 8.72 mL/g in sample containing 20% germinated pigeon pea protein isolate. These results showed that germination substantially improved the surface-active properties of pigeon pea proteins. During germination, storage proteins undergo enzymatic hydrolysis, producing smaller peptides that rapidly migrate to the air-water interface and form stronger, more elastic films around air bubbles (Li *et al.*, 2023). Improved foaming properties are beneficial in bread making because they enhance gas retention during proofing, which bring about increased loaf volume and softer crumb texture (Ayo *et al.*, 2024). The findings of the present study are similar to those reported by Ijemi *et al.* (2025), who observed increased foaming capacities in wheat-acha and date fruit composite flours that ranged from 13.07-17.68 g/ml.

The emulsifying capacity and emulsion stability also improved significantly following protein isolate incorporation. The highest emulsifying capacity (5.72 mL/g) and emulsion stability (7.80 mL/g) were recorded in the 20% germinated pigeon pea protein isolate blend. These findings showed that germination enhanced the ability of pigeon pea proteins to stabilise oil-water emulsions. Work by Chinma *et al.* (2021) demonstrated that germinated legume protein exhibits a superior emulsifying properties, making them suitable functional ingredients for composite bread formulations. Proteins with balanced hydrophilic and hydrophobic regions readily adsorb at oil-water interfaces, reducing interfacial tension and preventing phase separation (Damak *et al.*, 2022). Enhanced emulsification contributes to improved dough consistency, uniform crumb structure and better texture of bread. Damak *et al.* (2022) reported higher emulsion capacity and stability of arrow root starch and wheat composite flour that ranged from 18.27-54.85% and 12.39-60.29% respectively. The higher emulsion capacity and stability in this study is due higher protein content from pigeon pea.

Dispersibility increased from 72.70% in wheat flour to 79.72% in the germinated protein isolate blend, whereas the ungerminated pigeon pea flour had 76.40%. High dispersibility indicates better ease of reconstitution in water and more uniform mixing during dough preparation (Adeyeye, 2016). Adeyeye (2016) reported lower value of dispersibility for wheat and sorghum composite flour, ranging from 23.52 - 53.41%. The higher dispersibility from this study may be attributed to enzymatic degradation of complex storage macromolecules into smaller, more soluble components during germination. Similar improvements in dispersibility following germination have been reported by Chinma *et al.* (2020), who concluded that germination enhanced the technological functionality of legume ingredients for bakery products.

The least gelation concentration (LGC) of wheat flour, pigeon pea flour, ungerminated and germinated pigeon pea protein isolates and flour blends shows important functional property that determines the ability of proteins and starches to form stable gel network capable of retaining water and contributing to the texture of food products (Damak *et al.*, 2022). The results showed that the flour blends differed in their gelation characteristics following substitution with germinated pigeon pea protein isolates. Wheat flour and the flour blends (5% - 20% germinated pigeon pea protein isolate), formed a stable gel at 10% concentration, whereas germinated pigeon pea protein isolate formed a stable gel at a lower concentration of 8%. The lower least gelation concentration observed in the germinated protein isolate blend showed higher gel-forming ability compared with both the control and the ungerminated protein isolate. The enhanced gelation capacity of the germinated pigeon pea protein isolate may be attributed to biochemical changes that occurred during germination. Germination activates endogenous enzymes that partially hydrolyse storage proteins, resulting in proteins with greater molecular flexibility (Chinma *et al.*, 2021).

Pasting properties of wheat flour, pigeon pea flour, protein isolates and the blends

Pasting properties of wheat flour, pigeon pea flour, ungerminated and germinated pigeon pea protein isolates and flour blends are presented in Table 3.

Pasting characteristics are important quality indices used to evaluate the behaviour of starch during heating and cooling in the presence of water (Jaramillo-De la Garza *et al.*, 2025). The results indicated significant ($p < 0.05$) differences among the flour blends with respect to peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, peak time, and pasting temperature, indicating that replacing wheat flour with germinated and ungerminated pigeon pea protein isolate altered the starch pasting behaviour of the flour blends.

Table 3: Pasting properties of wheat flour, pigeon pea flour, protein isolates and the blends

Sample	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown viscosity (RVU)	Final viscosity (RVU)	Setback viscosity (RVU)	Peak Time (min)	Pasting Temperature (°C)
A	236.35 ^a ±0.00	158.10 ^a ±0.00	78.25 ^a ±0.00	289.55 ^a ±0.00	131.45 ^a ±0.00	5.11 ^c ±0.00	82.15 ^c ±0.00
B	200.20 ^f ±0.07	142.32 ^b ±4.07	65.05 ^b ±3.11	261.80 ^b ±2.33	117.55 ^b ±0.42	5.35 ^a ±0.06	83.65 ^b ±0.71
C	198.25 ^g ±0.00	136.35 ^c ±0.00	61.85 ^c ±0.00	236.45 ^d ±0.00	112.05 ^b ±0.00	5.39 ^a ±0.00	84.15 ^b ±0.00
D	212.45 ^d ±0.00	145.20 ^b ±0.00	67.25 ^b ±0.00	263.65 ^b ±0.00	118.45 ^f ±0.00	5.31 ^b ±0.00	83.35 ^b ±0.00
E	224.15 ^b ±0.00	143.12 ^b ±0.00	66.15 ^b ±0.00	258.55 ^c ±0.00	128.15 ^b ±0.00	5.31 ^b ±0.00	83.05 ^c ±0.00
F	220.31 ^c ±0.00	140.19 ^b ±0.00	64.35 ^b ±0.00	257.25 ^c ±0.00	127.35 ^c ±0.00	5.33 ^b ±0.00	84.14 ^b ±0.00
G	200.52 ^e ±0.00	139.25 ^c ±0.00	63.15 ^b ±0.00	256.15 ^c ±0.00	126.05 ^d ±0.00	5.38 ^a ±0.00	85.25 ^a ±0.00
H	200.12 ^f ±0.00	138.42 ^c ±0.00	63.05 ^b ±0.00	255.45 ^c ±0.00	124.55 ^e ±0.00	5.42 ^a ±0.00	86.15 ^a ±0.00

Values are means ± standard deviation of 2 replications. Means within a column with different superscripts differed significantly ($p < 0.05$). A = 100% Wheat flour, B = 100% Pigeon Pea Flour, C = 100% Ungerminated Pigeon Pea Protein Isolate, D = 100% Germinated Pigeon Pea Protein Isolate, E = blend containing 5% Germinated Pigeon Pea Protein Isolate, F = blend containing 10% Germinated Pigeon Pea Protein Isolate, G = blend containing 15% Germinated Pigeon Pea Protein Isolate, H = blend containing 20% Germinated Pigeon Pea Protein Isolate.

Peak viscosity of the sample ranged from 198.25-236.35 RVU. Sample A (100% wheat flour) the highest peak viscosity (236.35 RVU), followed by sample D (germinated pigeon pea protein isolate) (212.45 RVU), while sample C (ungerminated protein isolate) had the lowest value (198.25 RVU). Peak viscosity represents the maximum swelling of starch granules during heating before structural breakdown occurs (Jaramillo-De la Garza *et al.*, 2025). The reduction in peak viscosity following protein isolate incorporation may be attributed to the dilution of wheat starch by pigeon pea proteins, thereby reducing the amount of starch available for gelatinization. Furthermore, germination activates amylolytic enzymes that partially hydrolyze starch molecules, reducing their ability to swell and produce high viscosity during heating (Chinma *et al.*, 2021). Similar reductions in peak viscosity of wheat-date fruit composite flours have been reported by Bolaji *et al.* (2022) where values ranged from 1090.50-1690.50 RVU asserted that relatively low peak viscosity in composite flour indicates that the flour may be suited for products requiring low gel strength and elasticity.

Trough viscosity followed the same trend, decreasing from 158.10 RVU in sample A (wheat flour) to 138.42 RVU in sample H (containing 20% germinated pigeon pea protein isolate) and 136.35 RVU in sample C (ungerminated pigeon pea protein isolate). Trough viscosity reflects the ability of swollen starch granules to withstand prolonged heating and mechanical shear (Jaramillo-De la Garza *et al.*, 2025). Lower trough viscosity suggested reduced paste stability during cooking. The observed decrease may be associated with the weakened starch matrix resulting from partial substitution with protein isolate. These findings agree with trough viscosity of 133.00-2670.00 cP for wheat composite flours enriched with avocado seed flour reported by Jaramillo-De la Garza *et al.* (2025).

Breakdown viscosity also decreased significantly from 78.25 RVU in wheat flour to 61.85 RVU in ungerminated pigeon pea protein isolate and decrease in the flour blends from 66.15 RVU in sample E (containing 5% germinated pigeon pea protein isolate) to 63.05 RVU in sample H (containing 20% germinated pigeon pea protein isolate). Breakdown viscosity measures the susceptibility of swollen starch granules to disintegration during continuous heating and stirring (Bolaji *et al.*, 2022). The lower breakdown viscosity observed in the germinated protein isolate and wheat flour blends showed improved paste stability during processing. Similar findings were reported by Chinma *et al.* (2022), who noted that incorporation of germinated Bambara nut flour improved the thermal stability of composite flour pastes by strengthening interactions between proteins and starch molecules. Higher breakdown viscosity of 172.00-801.00 RVU was reported for acha-guava composite flour (Ayo *et al.*, 2019). Although, lower breakdown values may indicate reduced swelling capacity, they also suggest greater resistance of the paste to mechanical shear and thermal degradation.

The wheat flour had the highest final viscosity (289.55 RVU), whereas the final viscosity decreased from 258.55 to 255.45 for sample containing 5% and 20% germinated pigeon pea protein isolate respectively. Final viscosity is the ability of gelatinised starch to reassociate during cooling and is an important indicator of the consistency and texture of food products after cooking. The reduction in final viscosity observed after protein isolate incorporation suggested that the presence of pigeon pea proteins limited starch retrogradation and paste thickening during cooling. Reduced retrogradation is desirable in bread production because it delays crumb firming and staling during storage. Jaramillo-De la Garza *et al.* (2025) reported similar final viscosity of 193-2670 cP. The incorporation of pigeon pea flour may interfere with amylose reassociation, thereby reducing gel strength. This characteristic is beneficial in bakery products because lower retrogradation rates are associated with delayed staling and improved shelf stability (Qi *et al.*, 2021).

Setback viscosity decreased from 131.45 RVU in the control to 112.05 RVU in the ungerminated pigeon pea protein isolates, 118.45 RVU in the germinated pigeon pea protein isolates and from 128.15 to 124.55 in the flour blends. Setback viscosity measures the tendency of starch molecules, particularly amylose, to reassociate after cooling. Lower setback values indicate reduced retrogradation and better storage stability of baked products. Therefore, the lower setback viscosity for the blend containing germinated protein isolate suggests that bread produced from this flour may retain softness for a longer period and exhibit delayed staling. Similar reductions in setback viscosity of wheat-date fruit composite flours have been reported by Bolaji *et al.* (2022) where values ranged from 343.00- 985.00 RVU. These findings support previous reports that incorporation of fibre-rich ingredients reduces starch retrogradation by disrupting amylose reassociation (Jaramillo-De la Garza *et al.*, 2025).

Peak time increased slightly from 5.11-5.39 minutes. Sample A (wheat flour) recorded the lowest peak time (5.11 min) while sample C (ungerminated pigeon pea protein isolate) recorded the highest peak time (5.39 min). The longer pasting time recorded for pigeon pea protein isolate may be attributed to gluten-starch interactions that delay water penetration and starch swelling. Similarly, the pasting temperature increased from 82.15°C in sample A to 84.15°C in sample D and from 83.05°C in sample E to 86.15°C in sample H. The increase in both parameters indicates that composite flour containing pigeon pea protein isolate required more time and higher temperatures to initiate starch gelatinization (Bolaji *et al.*, 2022). This may be attributed to competition between proteins and starch granules for available water, thereby delaying starch swelling. The shorter pasting time observed in acha flour indicates rapid hydration and gelatinization (Qi *et al.*, 2021). Pasting temperature is the minimum temperature required for starch gelatinization to commence (Usman *et al.*, 2024). Jaramillo-De la Garza *et al.* (2025) reported similar pasting temperatures of 81.97-86.37°C for wheat and avocado seed flour.

Proximate composition of wheat flour, pigeon pea flour, protein isolates and the blends

The proximate composition of wheat flour, protein isolates, and flour blends is shown in Table 4:

Table 4: Proximate composition of wheat flour, pigeon pea flour, protein isolates and the blends

Sample	Crude Protein	Fat	Crude Fibre	Ash	Moisture	Carbohydrate
A	12.03 ^a ±0.04	0.80 ^f ±0.00	1.19 ^b ±0.01	1.30 ^g ±0.00	10.50 ^a ±0.00	68.25 ^a ±0.06
B	18.00 ^b ±0.00	1.23 ^b ±0.01	2.10 ^c ±0.00	5.43 ^b ±0.00	10.95 ^d ±0.00	60.00 ^f ±0.01
C	1.25 ^b ±0.00	2.15 ^b ±0.00	5.46 ^b ±0.01	10.96 ^d ±0.01	60.04 ^e ±0.01	
D	1.30 ^a ±0.00	2.25 ^a ±0.00	5.73 ^a ±0.01	11.24 ^c ±0.00	60.12 ^e ±0.00	
E	0.88 ^e ±0.01	1.35 ^a ±0.00	2.41 ^f ±0.01	10.59 ^f ±0.00	62.15 ^b ±0.00	
F	0.93 ^d ±0.01	1.52 ^f ±0.00	3.80 ^e ±0.00	10.84 ^e ±0.00	61.22 ^c ±0.01	
G	0.95 ^c ±0.01	1.58 ^e ±0.00	4.20 ^d ±0.00	11.46 ^b ±0.01	60.46 ^d ±0.00	
H	0.98 ^c ±0.01	1.64 ^d ±0.00	5.42 ^c ±0.00	12.03 ^a ±0.01	60.10 ^e ±0.00	

Values are means ± standard deviation of 2 replication. Means within a column with different superscripts differed significantly ($p < 0.05$). A = 100% Wheat flour, B = 100% Pigeon Pea Flour, C = 100% Ungerminated Pigeon Pea Protein Isolate, D = 100% Germinated Pigeon Pea Protein Isolate, E = blends containing 5% Germinated Pigeon Pea Protein Isolate, F = blends containing 10% Germinated Pigeon Pea Protein Isolate, G = blends containing 15% Germinated Pigeon Pea Protein Isolate, H = blends containing 20% Germinated Pigeon Pea Protein Isolate.

Proximate composition of wheat flour, pigeon pea flour, ungerminated pigeon pea protein isolate, germinated pigeon pea protein isolate and the blends is presented in Table 3.

The crude protein contents ranged from 12.03% in 100% wheat flour to 19.23% in germinated pigeon pea protein isolate. The highest protein value observed in the germinated pigeon pea protein isolate showed the protein-rich nature of pigeon pea and the concentrating effect associated with protein isolation. The value for germinated pigeon pea protein isolate was also higher than that of the ungerminated isolate (18.01%), indicating a slight improvement following germination. The increase in protein contents of the blends from 13.54% at 5% incorporation to 16.54% at 20% incorporation showed that increasing the proportion of germinated pigeon pea protein isolate enhanced the protein contents of the wheat-based product. This is nutritionally important because pigeon pea is recognized as a good plant protein source, and incorporation of legume ingredients into cereal-based foods can improve the protein quality and nutritional value of the resulting products. Recent research has similarly reported increased protein content following Bambara nut germination, which has been attributed to biochemical changes occurring during germination (Chinma *et al.*, 2022). The improvement observed after germination may be related with the activation of hydrolytic enzymes and changes in seed constituents during sprouting.

The fat contents ranged from 0.80% in wheat flour to 1.30% in germinated pigeon pea protein isolate. A gradual increase was also observed in the blends as the level of germinated pigeon pea protein isolate increased, with values of 0.88, 0.93, 0.95 and 0.98% for samples E, F, G and H, respectively. The relatively low fat contents in all the samples indicate that the products were generally low-fat food materials. The increase in fat with increasing incorporation of germinated pigeon pea protein isolate may be associated with the contribution of pigeon pea fats to the blends. Similar result was reported

by Moktan and Ojha (2016) for fat content of germinated horse gram. Germination and other processing treatments have been reported to influence fat content, although the direction and magnitude of the change can depend on germination conditions, cultivar and processing method (Chinma *et al.*, 2022).

The crude fibre contents increased from 1.19% in wheat flour to 2.25% in germinated pigeon pea protein isolate. The incorporation of germinated pigeon pea protein isolates increased fibre contents from 1.35% at 5% incorporation to 1.64% at 20% incorporation. The higher fibre content of the pigeon pea-containing samples showed that incorporation of pigeon pea ingredients can improve the fibre of the product. Dietary fibre is important because it contributes to gastrointestinal health and can influence the digestion and absorption of nutrients. The increase observed with increasing pigeon pea protein isolate may, therefore, improve the nutritional functionality of the blends. The observation is consistent with research showing that germination can modify the dietary fibre profile of pigeon pea and improve some of its nutritional characteristics (Chinma *et al.*, 2022). Moktan and Ojha (2016) reported higher fibre contents of germinated horse gram that ranged from 5.23-5.83%. The variation in the results may be due to higher fibre content of the horse gram flour.

Ash contents ranged from 1.30% in wheat flour to 5.73% in germinated pigeon pea protein isolate. There was an increase in ash content as germinated pigeon pea protein isolate was incorporated into the blends, increasing from 2.41% at 5% incorporation to 5.42% at 20% incorporation. The higher ash content of the pigeon pea-based samples indicates a greater mineral contribution compared with wheat flour. Ash is commonly used as an approximate indicator of the total mineral content of food materials. Therefore, the increase in ash with increasing germinated pigeon pea protein isolate suggests that pigeon pea enrichment improved the mineral contents of the blends. This observation agrees with studies reporting that germination can improve the nutritional constituent of pigeon pea and increase or modify its mineral and ash composition (Chinma *et al.*, 2022).

Moisture contents ranged from 10.50% in wheat flour to 12.03% in the blend containing 20% germinated pigeon pea protein isolate. The moisture content generally increased with increasing incorporation of germinated pigeon pea protein isolate. The relatively moderate moisture values are important from a storage perspective because excessive moisture can promote microbial growth and accelerate deterioration of flour-based products. Nevertheless, the values obtained were relatively low. Moktan and Ojha (2016) reported higher moisture contents of germinated horse gram flour ranged to 12.26%. The slightly higher moisture values observed in the blends could be related to differences in the water-binding characteristics of the pigeon pea protein ingredient. Thus, although the incorporation improved several nutritional parameters, appropriate packaging and storage conditions would remain necessary to maintain product quality.

Carbohydrate was highest in wheat flour (68.25%) and lowest in pigeon pea flour (60.00%), while germinated pigeon pea protein isolate contained 60.12%. The carbohydrate contents of the blends decreased generally compared with wheat flour as germinated pigeon pea protein isolate was incorporated, with values of 62.15, 61.22, 60.46 and 60.10% for 5, 10, 15 and 20% incorporation, respectively. The reduction in carbohydrate content with increasing pigeon pea protein isolate is expected because the protein ingredient replaced part of the carbohydrate-rich wheat flour. Pigeon pea contains appreciable amounts of protein and other nutrients, thereby changing the overall nutrient distribution of the blends. Similar research has shown that incorporation of legumes flour into cereal products increases protein and ash while reducing the relative carbohydrate content of the cereal-based product (Chinma *et al.*, 2022).

Mineral composition of wheat flour, pigeon pea flour, protein isolates and the blends

The mineral composition of wheat flour, pigeon pea flour, ungerminated pigeon pea protein isolate, germinated pigeon pea protein isolate and the flour blends is presented in Table 5.

Table 5: Mineral composition of wheat flour, pigeon pea flour, protein isolates and the blends

Sample	P	Mg	Na	K	Ca
A	100.00 ^a ±0.00	87.60 ^f ±0.00	20.00 ^a ±0.28	105.00 ^g ±0.00	35.00 ^g ±0.00
B	300.00 ^b ±0.00	139.50 ^c ±0.71	69.50 ^c ±0.71	349.50 ^b ±0.71	229.50 ^b ±0.71
C	300.00 ^b ±0.00	140.30 ^c ±0.42	70.00 ^c ±0.00	350.50 ^a ±0.71	230.50 ^b ±0.71
D	304.00 ^a ±0.00	146.00 ^b ±0.00	87.00 ^d ±0.00	352.50 ^a ±0.71	235.50 ^a ±0.71
E	120.50 ^f ±0.71	102.00 ^e ±0.00	55.50 ^f ±0.71	122.50 ^f ±0.71	48.00 ^f ±1.41
F	135.00 ^e ±0.00	125.00 ^d ±0.00	105.00 ^c ±1.41	157.00 ^e ±0.00	58.50 ^e ±0.71
G	155.50 ^d ±0.71	145.00 ^b ±1.41	140.00 ^b ±1.41	180.50 ^d ±0.71	63.00 ^d ±0.00
H	170.00 ^c ±0.00	161.00 ^a ±0.00	185.00 ^a ±0.00	205.50 ^c ±0.71	82.00 ^c ±1.41

Values are means ± standard deviation of 2 replication. Means within a column with different superscripts differed significantly ($p < 0.05$). A = 100% Wheat flour, B = 100% Pigeon Pea Flour, C = 100% Ungerminated Pigeon Pea Protein Isolate, D = 100% Germinated Pigeon Pea Protein Isolate, E = blends containing 5% Germinated Pigeon Pea Protein Isolate, F = blends containing 10% Germinated Pigeon Pea Protein Isolate, G = blends containing 15% Germinated Pigeon Pea Protein Isolate, H = blends containing 20% Germinated Pigeon Pea Protein Isolate.

The phosphorus contents ranged from 100.00 mg/100 g in wheat flour to 304.00 mg/100 g in germinated pigeon pea protein isolate. Pigeon pea flour and ungerminated protein isolate had 300.00 mg/100 g each, while the germinated isolate had the highest value (304 mg/100g). In the blends, phosphorus increased from 120.50 mg/100 g at 5% incorporation to 170.00 mg/100 g at 20% incorporation. The increase in phosphorus contents with pigeon pea incorporation demonstrates the contribution of pigeon pea to the mineral quality of the blends. Phosphorus is an important mineral involved in bone and teeth formation, energy metabolism and cellular functions (Seraphins *et al.*, 2024). The higher value recorded for germinated pigeon pea protein isolate suggested that germination and protein concentration may have enhanced the measured phosphorus content.

The magnesium increased from 87.60 mg/100 g in wheat flour to 146.00 mg/100 g in germinated pigeon pea protein isolate. The blends showed increase from 102.00 mg/100 g at 5% incorporation to 161.00 mg/100 g at 20% incorporation, with the 20% blend recording the highest magnesium concentration among all samples. The increasing magnesium content is nutritionally desirable because magnesium participates in numerous enzymatic reactions and contributes to normal muscle and nerve function (Seraphins *et al.*, 2024). The result also demonstrates that increasing pigeon pea protein isolate incorporation can substantially improve the mineral density of wheat-based products. Germination has been reported to modify the mineral composition of pigeon pea, although changes may vary according to mineral type and processing conditions (Chinma *et al.*, 2022).

The sodium contents ranged from 20.00 mg/100 g in wheat flour to 185.00 mg/100 g in the 20% blend. Germinated pigeon pea protein isolate contained 87.00 mg/100 g, compared with 70.00 mg/100 g in the ungerminated isolate. Increasing the level of germinated pigeon pea protein isolate resulted in a marked increase in sodium from 55.50 mg/100 g in the 5% blend to 185.00 mg/100 g in the 20% blend. The increase suggests that pigeon pea protein isolate contributed appreciably to the sodium content of the blends. However, because sodium intake is generally required to be controlled in diets where excessive sodium is undesirable (Seraphins *et al.*, 2024), the increase should be considered when formulating the final product, particularly if salt or other sodium-containing ingredients are added during processing.

The potassium contents increased from 105.00 mg/100 g in wheat flour to 352.50 mg/100 g in germinated pigeon pea protein isolate. The blends demonstrated an increase from 122.50 mg/100 g at 5% incorporation to 205.50 mg/100 g at 20% incorporation. The higher potassium content of the pigeon pea-containing products indicates an improvement in the mineral profile of the wheat flour. Potassium is an essential electrolyte involved in fluid balance, nerve transmission and muscle function (Seraphins *et al.*, 2024). The result agrees with the general observation that legume incorporation can increase the mineral content of cereal-based foods.

The calcium contents ranged from 35.00 mg/100 g in wheat flour to 235.50 mg/100 g in germinated pigeon pea protein isolate. The blends showed an increase from 48.00 mg/100 g at 5% incorporation to 82.00 mg/100 g at 20% incorporation. The difference between wheat flour and pigeon pea-derived ingredients demonstrates the potential of germinated pigeon pea protein isolate as a calcium-enriching ingredient. Calcium is essential for skeletal development, bone maintenance, muscle contraction and other physiological processes (Seraphins *et al.*, 2024). The present finding is supported by research showing that germination can improve calcium and other mineral concentrations in pigeon pea. Chinma *et al.* (2022) reported increases in calcium and other micronutrients following germination.

Conclusion

Germination significantly altered the chemical composition, functional and pasting properties of pigeon pea protein isolate. It improved nutrient density, as reflected in higher crude protein, ash, fibre, and mineral (P, Mg, Na, K, Ca) contents, while also modifying the functional behaviour, notably increasing bulk density, swelling capacity, dispersibility, and pasting viscosities, and reducing water absorption, foam, and emulsification properties of the germinated protein isolate. Incorporating germinated pigeon pea protein isolate into wheat flour at increasing levels 5, 10, 15 and 20% enhanced the protein and mineral contents as well as viscosity profiles of the resulting blends relative to 100% wheat flour, indicating that germination not only improved the intrinsic quality of pigeon pea protein isolate but also enhanced its performance as a functional and nutritional fortificant in composite wheat flour products. Overall, germination is considered a viable, low-cost processing method for improving the nutritional and techno-functional properties of pigeon pea-based flour and protein isolate.

Recommendation

Based on the findings of this study, it is recommended that:

1. Germinated pigeon pea protein isolate be considered as a nutrient-dense, functional ingredient for fortifying wheat-based food products, particularly to improve protein and mineral contents.
2. A composite flour inclusion level of 10–20% germinated pigeon pea protein isolate should be explored in food product development as this range appeared to balance improved nutritional value with acceptable pasting and functional characteristics relative to the wheat flour control.

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