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Effect of Germination on the Proximate, Physical, Functional, Antinutritional and Sensory Properties of Wheat–Flaxseed Composite Biscuits

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Abstract: This study investigated the influence of germinated flaxseed flour on the nutritional, physical, functional, antinutritional, and sensory characteristics of wheat-based biscuits. Four formulations were prepared: 100% wheat flour (control) and wheat flour substituted with 5%, 10%, and 15% germinated flaxseed flour. The incorporation of germinated flaxseed significantly enhanced the nutritional quality of the biscuits by increasing protein, fat, fibre, and ash contents, while reducing carbohydrate levels. Protein increased from 9.50% to 12.74%, fibre from 2.72% to 6.12%, and fat from 4.95% to 8.84%, demonstrating the nutritional contribution of germinated flaxseed. Functional properties such as water and oil absorption capacities, emulsion capacity and stability, and foaming capacity also improved with increasing substitution, indicating enhanced functionality for bakery applications. Although higher flaxseed levels influenced biscuit dimensions, the 5% substitution level produced biscuits with the most desirable physical characteristics, including weight, height, and spread ratio. Germination effectively reduced antinutritional compounds, with marked decreases in phytate, tannin, oxalate, saponin, and trypsin inhibitor activity, reflecting the beneficial effect of enzymatic degradation during germination. Sensory evaluation showed that biscuits containing 5% germinated flaxseed flour were as acceptable as the control in terms of taste, aroma, texture, and overall acceptability, whereas higher substitution levels slightly reduced consumer preference. Overall, the findings demonstrate that incorporating 5% germinated flaxseed flour into wheat biscuits is an effective strategy for producing nutrient-enriched functional biscuits with improved functional properties, lower antinutritional factors, and high consumer acceptability, making them a promising option for health-conscious consumers.

Keywords: *Antinutritional, Bakery, Bioprocessing, Fibre, Functional, Germination, Nutritional.*

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I. INTRODUCTION

The growing global interest in functional foods has been driven by increased awareness of the relationship between diet and health. Among these foods, flaxseed (*Linum usitatissimum*) has gained significant attention because of its rich nutritional and therapeutic properties. Flaxseed contains important bioactive compounds such as omega-3 fatty acids, particularly alpha-linolenic acid (ALA), dietary fibre, protein, lignans, antioxidants, and other phytochemicals that contribute to human health (Nowak and Jeziorek, 2023). Flaxseed have shown that these components help reduce the risk of cardiovascular diseases, improve digestive health, provide anti-inflammatory effects, and may also contribute to cancer prevention (Al-Madhagy, *et al.*, 2023). Due to these health-promoting properties, flaxseed is increasingly incorporated into functional food products, especially baked goods such as biscuits, to improve their nutritional quality. Functional foods are foods that provide health benefits beyond basic nutrition (Fekete, *et al.*, 2025). Sharma *et al.*, (2025) noted that functional foods contain bioactive substances that positively influence body functions and help reduce chronic diseases. The World Health Organization also emphasized the importance of developing healthier food products to combat malnutrition and noncommunicable diseases globally (WHO, 2024). In food processing, flaxseed

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is valued for its emulsifying, stabilizing, and thickening properties, making it suitable for incorporation into bakery products such as biscuits according to (Zhang, *et al.,* 2023). Studies have shown that adding flaxseed to baked foods can improve both their nutritional and functional qualities (Khan, *et al.,* (2024).

Biscuits are widely consumed snack products, and the incorporation of flaxseed flour into biscuit formulations can improve their protein, fibre, and antinutritional content while enhancing moisture retention and reducing staling according to (Perea-Escobar, *et al.,* 2025). With increasing concerns about malnutrition and diet-related diseases, there is growing interest in developing healthier functional foods that support the World Health Organization dietary recommendations. Despite its nutritional benefits, flaxseed contains antinutritional compounds such as phytic acid, tannins, oxalates, and cyanogenic glycosides, which may reduce nutrient absorption and limit its direct use in food formulations reported by (Talwar, *et al.,* 2025). However, bioprocessing techniques like germination, fermentation, and enzymatic treatment can significantly reduce these compounds while improving nutrient bioavailability, digestibility, and functional properties according to (Talwar, *et al.,* 2026). These processes also enhance water absorption, oil retention, and emulsification properties, which are important in biscuit production. Malnutrition and diet-related non-communicable diseases remain global health concerns. According to Ahmed, *et al.,* (2024), unhealthy dietary patterns characterized by low intake of nutrient-dense foods and high consumption of refined products contribute significantly to rising cases of obesity, diabetes, and cardiovascular diseases worldwide. In line with the United Nations Sustainable Development Goals (SDG 2: Zero Hunger and SDG 3: Good Health and Well-being), there is an increasing emphasis on developing functional and nutrient-rich foods that can improve public health and nutrition outcomes. However, there is limited research on how germination affects the proximate, functional, and antinutritional properties of flaxseed-based biscuits. Therefore, this study investigates the effect of germination on the proximate composition, physical and functional properties, antinutritional factors, and sensory attributes of flaxseed flour-based biscuits, with the aim of developing a nutritious and acceptable functional bakery product.

II. MATERIALS AND METHODS

➢ *Materials*

Flaxseed (*Linum usitatissimum*) used for this study was obtained from a local market in Jos, Plateau State, Nigeria, while wheat flour and other ingredients for biscuit production were purchased from Muda Lawal Market, Bauchi State, Nigeria. Chemicals and laboratory reagents used for analysis were sourced from the Department of Food Science and Technology, Federal Polytechnic Bauchi. Equipment employed during the study included an oven (ET-9100A), analytical balance (FA2204B), milling machine (HGBTWTS3), spectrophotometer (GENESYS 1XX), t and viscometer (Prolabo NO. 63072).

➢ *Germination of Flaxseed*

The flaxseed samples were germinated using the method described by (Chima *et al.,* 2022). Flaxseeds were cleaned, soaked in distilled water for 12 hours at room temperature, drained, and then spread on moist jute bags. The seeds were allowed to germinate for 48 hours at 25 ± 2 °C with regular watering at 12-hour intervals. After germination, the seeds were dried in a hot air oven at 50 °C for 12 hours and milled into fine flour using a laboratory milling machine.

➢ *Biscuit Preparation*

Four biscuit samples were produced following the method described by Singh *et al.,* (2023), with modifications. A control sample containing 100% wheat flour (WFCBW) and three composite samples containing 5%, 10%, and 15% germinated flaxseed flour substitution levels (WFGFBX, WFGFBY, and WFGFBZ, respectively) were prepared. The biscuit dough was prepared by creaming fat and sugar, adding eggs and milk, followed by gradual incorporation of flour and baking powder. The dough was rolled, cut into circular shapes, and baked at 180 °C for 20 minutes. The biscuits were cooled for 30 minutes and stored in polyethylene bags prior to analysis.

➢ *Proximate Analysis*

Proximate composition of the four biscuit samples was evaluated following the methods described by the Association of Official Analytical Chemists (AOAC, 2012). Moisture, fat, crude protein, crude fibre, and ash contents were determined. Carbohydrate content was calculated by difference.

➢ *Physical Properties*

Physical properties of the biscuits including height, diameter (width), weight, and spread ratio were determined following the procedure of Nasiri *et al.,* (2024). Height and diameter were measured using a vernier caliper, while weight was measured using an analytical balance. Spread ratio was calculated as the ratio of biscuit diameter to height.

➢ *Functional Properties*

Functional properties were assessed according to the method described by (Sarabandi, *et al.,* 2023).

- *Water Absorption Capacity (WAC)*

Water absorption capacity (WAC) was determined according to the method described by (Sosulski *et al.,* 1976). Water absorption capacity (WAC) was determined by weighing 1.0 g of sample was weighed into a pre-weighed centrifuge tube, and 10 mL of distilled water was added. The mixture was thoroughly mixed and allowed to stand at room temperature for 30 min with intermittent stirring. The suspension was centrifuged at about 3,000 × g for 15–20 min. The supernatant was carefully decanted, and the tube containing the sediment was weighed. Water absorption capacity was expressed as grams of water absorbed per gram of sample (g/g).

WAC was calculated as:

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$$WAC(\%) = \frac{\text{Weight of water absorbed}}{\text{Weight of dry sample}} \times 100$$

- *Oil Absorption Capacity (OAC)*

Oil absorption capacity (OAC) were determined according to the method described by (Sosulski *et al.*, 1976). Oil absorption capacity (OAC)was determined similarly using refined vegetable oil instead of water. One gram of sample was mixed with 10 mL of refined vegetable oil in a centrifuge tube. The mixture was stirred thoroughly, allowed to stand for 30 min at room temperature, and centrifuged at approximately 3,000 × g for 15–20 min. The unabsorbed oil was decanted, and the retained oil was determined gravimetrically. Oil absorption capacity was expressed as grams of oil retained per gram of sample (g/g).

- *Swelling Capacity*

Swelling capacity was determined according to the method of described by (Adebowale *et al.*, 2005: Leach *et al.*, 1959), where 2 g of sample was mixed with 20 mL distilled water in graduated centrifuge tubes, heated at 90 °C for 15 minutes, and the volume change recorded. Foaming capacity and stability were assessed by whipping flour suspensions and measuring foam volume. Emulsion capacity and stability were determined by mixing flour with oil and water and measuring the emulsified layer.

➢ *Antinutritional Analysis*

- *Phytate Content*

Phytate content was determined based on the (AOAC 2005: Haug, and Lantzsch, 1983) colorimetric method. To 1 g of flour, 20 mL HCl was added and the mixture agitated at 25 °C for 2 hours, followed by centrifugation for 15 minutes. A 3 mL aliquot of filtrate was diluted to 18 mL with distilled water and passed through a 200–400 mesh AG1-X8 chloride anion exchange resin. Phytic acid was determined based on the pink colour of Wade reagent. Absorbance was measured at 640 nm using a UV-spectrophotometer (Genesys G10S, Thermo Fisher Scientific). Phytate values were expressed as mg/100 g on dry weight basis.

- *Tannin Content*

Tannin concentration was determined with the vanillin method described by (AOAC, 2005: Price, *et al.*, 1978). A 2 g sample was extracted with 50 mL of 99.9% methanol for 20 minutes at room temperature with constant agitation. After centrifugation at 653 × g for 10 minutes, 5 mL of vanillin-HCl (2% vanillin and 1% HCl) reagent was added to 1 mL of aliquots. The colour developed after 20 minutes at room temperature was read at 500 nm. Tannin content was expressed in mg/100 g (dry basis) using catechin as standard.

- *Trypsin Inhibitor Activity*

Trypsin inhibitor activity (TIA) was assayed following the procedure outlined by Chinma *et al.* (2022), as reported by Liu and Markakis (1989), using 0.04 g/L of BAPA (Nα-benzoyl-L-arginine 4-nitroanilide hydrochloride) as trypsin substrate. To 1 g of sample, 10 mL of 0.15 mol/L phosphate buffer (pH 8.1 at 4 °C) was added and kept overnight. Extracts were incubated with trypsin solution and diluted with phosphate buffer. BAPA solution was added and warmed to 37 °C for 10 minutes. Trypsin inhibitor was calculated from absorbance read at 410 nm against a reagent blank, and results reported as TIA unit per g (dry weight basis).

- *Saponin Content*

Saponin content was determined using a modified colorimetric method involving ethanol extraction and quantification with a diosgenin standard, as described by (Hiai *et al.* 1976; Obadoni and Ochuko, 2001). A 1 g sample was extracted with 20 mL of 20% ethanol, heated for 4 hours at 55 °C, and filtered. The extract was evaporated to dryness and the residue re-dissolved in 5 mL ethanol. Absorbance was measured at 560 nm. A standard curve using diosgenin was used for calculation.

- *Oxalate Content*

Oxalate content was determined using the permanganate titrimetric method described by Oke (1966), following the principles of quantitative analysis outlined by Day and Underwood (1986). Results were expressed as mg/100 g d

➢ *Sensory Evaluation*

Sensory analysis of the biscuits was evaluated using a 9-point hedonic scale scored 1–9 (1 = extremely dislike, 9 = extremely like) as described by (Jagadiswaran *et al.*, 2021). Twenty (20) semi-trained panelists judged the taste, aroma, appearance, texture, and overall acceptability of the products. Panelists were provided with biscuit samples in randomized order, with distilled water for mouth rinse after each sample evaluation.

➢ *Statistical Analysis*

All analyses were performed in triplicate. The resulting data were subjected to one-way analysis of variance (ANOVA) using SPSS version 23 (IBM Corp., Armonk, NY, USA). Differences between means were determined using Tukey's test at a 5% significance level ($p < 0.05$).

III. RESULTS

➢ *Proximate Composition*

The proximate composition of biscuits produced from wheat flour partially substituted with different levels of germinated flaxseed flour is presented in Table 1. Clear variations were observed in moisture, fat, fibre, protein, ash, and carbohydrate contents across the samples, indicating that flaxseed incorporation significantly influenced the nutritional properties of the biscuits.

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Table 1 Proximate Composition of Biscuit

Samples	WFCBW	WFGFBX	WFGFBY	WFGFBZ
Moisture %	12.25±0.28[c]	9.70±0.14[b]	15.68±0.32[d]	11.13±0.25[b]
Fat %	4.95±0.03[a]	7.17±0.25[b]	8.50±0.21[b]	8.84±0.30[b]
Fibre %	2.72±0.25[a]	6.12±0.11[d]	3.45±0.21[b]	5.13±011[c]
Protein %	9.50±0.04[a]	10.19±0.17[b]	11.48±0.07[c]	12.74±0.05[d]
Ash %	10.40±0.17[a]	12.34±0.23[b]	14.12±0.39[c]	16.20±0.43[d]
Carbohydrate	60.18±0.02[a]	54.48±0.12[b]	46.77±0.34[c]	45.96±0.91[c]

Means in the same row with different superscripts differ significantly at $p < 0.05$. WFCBW (Wheat flour control biscuit W served as control contained 100% wheat flour), WFGFBX (Wheat flour germinated flaxseed biscuit X 95% wheat flour and 5% germinated Flaxseed flour), WFGFBY (Wheat flour germinated flaxseed biscuit Y 90% wheat flour and 10% germinated Flaxseed flour) and WFGFBZ (Wheat flour germinated biscuit Z 85% wheat flour and 15% germinated Flaxseed flour)

The result of proximate composition is presented Table 1 for biscuits produced from wheat flour partially substituted with 5% (WFGFBX), 10% (WFGFBY), and 15% (WFGFBZ) flaxseed flour, revealing notable improvements in nutritional quality. Moisture content ranged from 9.70% to 15.68% WFGFBZ sample containing the highest, increasing with higher flaxseed inclusion, likely due to its high water-binding capacity from soluble fiber and mucilage reported by (Lorenc *et al.,* 2022). Fat content rose steadily from 4.95% in the control to 8.84% at 15% WFGFBZ sample containing the highest substitution, reflecting the oil-rich nature of flaxseed, particularly its omega-3 fatty acids describe by (Al-Madhagy *et al.,* 2023).

Dietary fibre content was higher in all fortified samples compared to the control, despite slight variations, confirming flaxseed as a good source of both soluble and insoluble fibre according to (Zhang *et al.,* 2023). Protein content also increased significantly from 9.50% to 12.74% WFGFBZ sample containing the highest, consistent with the high protein content of flaxseed described by (Sá *et al.*, 2025). Similarly, ash content increased from 10.40% to 16.20% WFGFBZ sample containing the highest, indicating enhanced mineral composition, as flaxseed is rich in essential minerals such as calcium, magnesium, and potassium reported by (Khare *et al.,* 2021). Conversely, carbohydrate content decreased from 60.18% in the control to 45.96% at 15% substitution due to the replacement of starch-rich wheat flour with nutrient-dense flaxseed (Krupa-Kozak *et al.,* 2022). Overall, these findings demonstrate that flaxseed incorporation significantly enhances the nutritional profile of biscuits, supporting its use in developing functional, nutrient-dense bakery products.

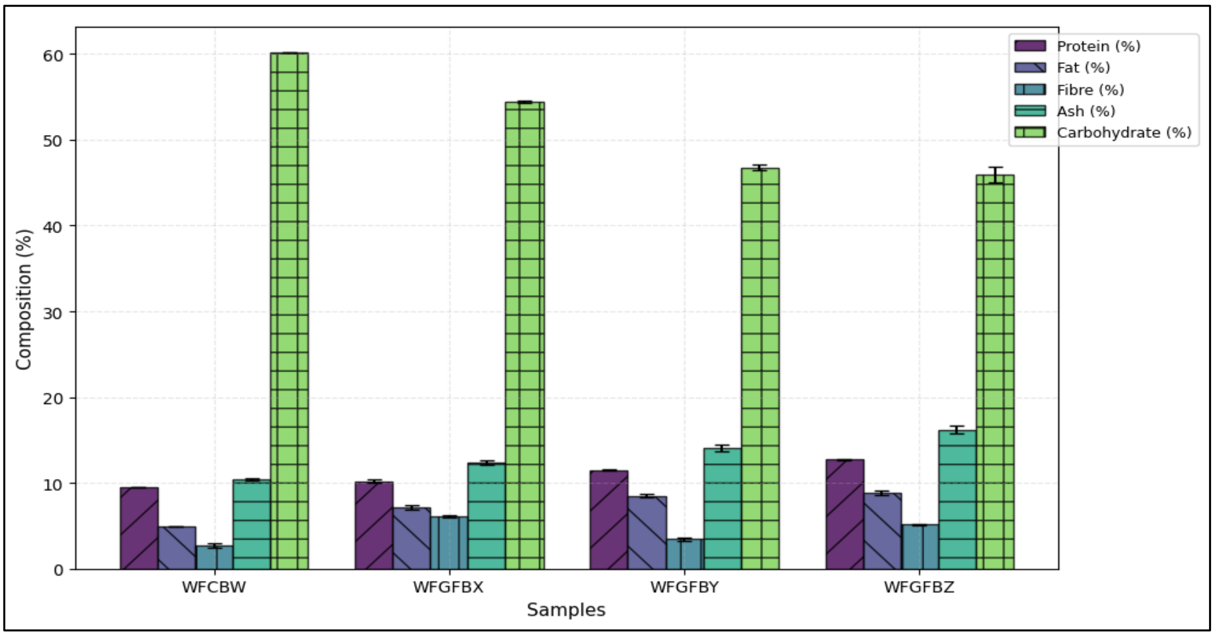

Fig 1 Proximate Composition of Wheat-Flaxseed Composite Biscuits Across Different Substitution Levels.

- *Key:*

✓ WFCBW (Biscuit produced from wheat flour 100% (control)
✓ WFGFBX (Biscuit produced from 95% wheat flour and 5% germinated Flaxseed flour,
✓ WFGFBY (Biscuit produced from 90% wheat flour and 10% germinated Flaxseed flour)
✓ WFGFBZ (Biscuit produced from 85% wheat flour and 15% germinated Flaxseed flour).

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➢ *Physical Properties of Biscuit*

Table 2 Physical Properties of Biscuit

Sample	Height (cm)	Width (cm)	Weight (g)	Spread Ratio
WFCBW	1.00 ± 0.00^b	4.50 ± 0.00^b	15.0 ± 0.00^d	4.50 ± 0.00^c
WFGFBX	0.75 ± 0.35^b	4.75 ± 0.35^b	14.5 ± 0.71^c	4.75 ± 0.00^d
WFGFBY	1.00 ± 0.00^b	3.50 ± 0.71^a	10.5 ± 0.71^a	3.50 ± 0.00^a
WFGFBZ	0.30 ± 0.28^a	4.25 ± 0.35^a	11.0 ± 1.41^b	4.25 ± 0.00^b

Means in the same row with different superscripts differ significantly at $p < 0.05$. Key: WFCBW (Biscuit produced from wheat flour 100% (control)), WFGFBX (Biscuit produced from 95% wheat flour and 5% germinated Flaxseed flour, WFGFBY (Biscuit produced from 90% wheat flour and 10% germinated Flaxseed flour) and WFGFBZ (Biscuit produced from 85% wheat flour and 15% germinated Flaxseed flour). The physical properties of biscuits produced from wheat flour and germinated flaxseed flour blends showed significant differences ($p < 0.05$) among the formulations (Table 2).

Biscuit height ranged from 0.30 ± 0.28 to 1.00 ± 0.00 cm. The highest height was recorded in WFCBW (100% wheat flour) and WFGFBY (10% germinated flaxseed flour) at 1.00 cm, while WFGFBZ (15% germinated flaxseed flour) had the lowest value of 0.30 cm. The reduction in height at higher substitution levels may be attributed to the dilution of gluten-forming proteins and the increased fibre content of germinated flaxseed flour, which can weaken the dough structure and reduce gas retention during baking described by (Dossa, *et al.*, 2026). Biscuit width varied from 3.50 ± 0.71 to 4.75 ± 0.35 cm, with WFGFBX (5% germinated flaxseed flour) recording the highest value and WFGFBY the lowest. The increased width observed in WFGFBX may be due to the oil-rich nature of flaxseed, which promotes dough spread during baking.

Weight ranged between 10.5 ± 0.71 and 15.0 ± 0.00 g, with WFCBW having the highest weight and WFGFBY the lowest. The decrease in weight with flaxseed incorporation may result from moisture loss and structural modifications associated with germination, which enhances enzymatic activity and alters starch and protein composition.

The spread ratio ranged from 3.50 ± 0.00 to 4.75 ± 0.00, with WFGFBX exhibiting the highest value and WFGFBY the lowest. Higher spread ratios are generally associated with desirable biscuit quality, reflecting better dough flow during baking. Overall, moderate incorporation of germinated flaxseed flour (5%) improved biscuit spread characteristics, while higher substitution levels reduced height and weight due to gluten dilution and increased fibre content resulting from germination. These findings suggest that germinated flaxseed flour can be successfully incorporated into biscuits without adversely affecting key physical properties at lower inclusion levels.

➢ *Functional Properties*

The functional properties of the composite biscuit flours showed significant differences ($p < 0.05$) among the formulations (Table 3). Bioprocessing significantly affected the functional properties, with emulsion, foaming, and absorption capacities improving markedly with increasing flaxseed inclusion, while dispersibility decreased and gelation temperature reduced significantly.

Table 3 Functional Properties

Property	WFCBW	WFGFBX	WFGFBY	WFGFBZ
Dispersibility (%)	85.86 ± 0.54^d	83.72 ± 0.58^c	82.04 ± 0.59^b	78.92 ± 0.40^a
Emulsion Capacity (mL/g)	9.90 ± 0.27^a	10.93 ± 0.28^b	12.06 ± 0.36^c	13.02 ± 0.30^d
Emulsion Stability (%)	81.71 ± 0.62^a	88.81 ± 1.35^b	92.41 ± 1.62^c	96.97 ± 0.38^b
Foaming Capacity (%)	66.60 ± 0.01^a	77.55 ± 2.02^b	86.79 ± 1.62^c	96.00 ± 0.38^d
Foaming Stability (%)	72.26 ± 0.30^a	75.84 ± 1.42^b	75.60 ± 1.17^b	79.13 ± 0.84c
Gelation Temperature (°C)	77.69 ± 0.29^d	75.43 ± 0.50^c	73.48 ± 0.68^b	71.82 ± 0.12^a
WAC (g/g)	1.75 ± 0.07^a	1.98 ± 0.35^a	2.17 ± 0.27^a	2.37 ± 0.05^a
OAC (g/g)	1.21 ± 0.01^a	1.43 ± 0.03^a	1.59 ± 0.02^c	1.76 ± 0.02^d

Means in the same row with different superscripts differ significantly at $p < 0.05$. WFCBW (Wheat flour control biscuit W served as control contained 100% wheat flour), WFGFBX (Wheat flour germinated flaxseed biscuit X 95% wheat flour and 5% germinated Flaxseed flour), WFGFBY (Wheat flour germinated flaxseed biscuit Y 90% wheat flour and 10% germinated Flaxseed flour) and WFGFBZ (Wheat flour germinated biscuit Z 85% wheat flour and 15% germinated Flaxseed flour) Table 3.

WAC = Water Absorption Capacity; OAC = Oil Absorption Capacity. Dispersibility decreased progressively from 85.86% in the control to 78.92% at 15% flaxseed substitution (WFGFBZ). Both emulsion capacity and emulsion stability increased significantly with higher flaxseed inclusion reported by (Gao, *et al.*, 2025). Emulsion capacity rose from 9.90 mL/g (control) to 13.02 mL/g (15% flaxseed), while emulsion stability increased from 81.71% to 96.97%. Foaming capacity increased sharply from 66.60% (control) to 96.00% (WFGFBZ), while foaming stability increased moderately from 72.26% to 79.13% across samples described by (Rai, 2022). Gelation temperature decreased significantly from 77.69 °C in the control to 71.82 °C at 15% flaxseed inclusion. Water absorption capacity increased from

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1.75 g/g (control) to 2.37 g/g (WFGFBZ) as reported by (Zhang, *et al.*, 2023). Oil absorption capacity increased from 1.21 g/g in the control to 1.76 g/g at 15% substitution also reported by (Rai, 2022).

➢ *Antinutritional Properties*

Table 4 Antinutritional Properties

Nutrient	WFCBW	WFGFBX	WFGFBY	WFGFBZ
Phytate (mg/100g)	126.00 ± 1.27[d]	117.60 ± 1.13[c]	104.50 ± 0.98[b]	96.35 ± 1.63[a]
Tannin (mg/100g)	10.00 ± 0.43[d]	9.00 ± 0.14[c]	7.70 ± 0.14[b]	7.00 ± 0.28[a]
Oxalate (mg/100g)	4.35 ± 0.07[b]	3.85 ± 0.07[b]	3.35 ± 0.07[a]	2.90 ± 0.14[a]
Saponin (mg/100g)	13.85 ± 0.21[c]	12.45 ± 0.21[b]	11.05 ± 0.21[a]	10.00 ± 0.28[d]
Trypsin inhibitor (TIU/g)	1.49 ± 0.01[b]	1.37 ± 0.01[a]	1.22 ± 0.01[a]	1.13 ± 0.01[a]

Means in the same row with different superscripts differ significantly at $p < 0.05$. Key: WFCBW (Biscuit produced from wheat flour 100% (control)), WFGFBX (Biscuit produced from 95% wheat flour and 5% germinated Flaxseed flour, WFGFBY (Biscuit produced from 90% wheat flour and 10% germinated Flaxseed flour) and WFGFBZ (Biscuit produced from 85% wheat flour and 15% germinated Flaxseed flour).

The antinutritional properties of the biscuit samples differed significantly ($p < 0.05$) among the formulations, with a consistent decline in all measured antinutrients as the level of flaxseed flour increased. Phytate content ranged from 96.35 ± 1.63 to 126.00 ± 1.27 mg/100 g, with the control sample (WFCBW) recording the highest value and the 15% flaxseed flour biscuit (WFGFBZ) the lowest. This reduction may be attributed to processing operations such as germination processed which promote phytate degradation and improve mineral bioavailability described by (Sarkhel, and Roy, 2022). Tannin content also decreased from 10.00 ± 0.43 mg/100 g in WFCBW to 7.00 ± 0.28 mg/100 g in WFGFBZ, likely due to heat-induced degradation and dilution effects. Lower tannin levels are beneficial because tannins can interfere with protein digestibility by forming complexes with proteins and digestive enzymes.

Similarly, oxalate content declined from 4.35 ± 0.07 to 2.90 ± 0.14 mg/100 g, while saponin content decreased from 13.85 ± 0.21 to 10.00 ± 0.28 mg/100 g. These reductions may be linked to germination and thermal processing during biscuit production, which can reduce the stability of these compounds described by (Ahmad, *et al.*, 2025). Lower oxalate levels enhance calcium availability and reduce the risk of kidney stone formation, while reduced saponin levels improve nutrient utilization and palatability. Trypsin inhibitor activity also decreased from 1.49 ± 0.01 TIU/g in WFCBW to 1.13 ± 0.01 TIU/g in WFGFBZ, likely due to protein denaturation during baking, thereby enhancing protein digestibility. Overall, the progressive reduction in antinutrients from WFCBW to WFGFBZ demonstrates that flaxseed flour incorporation, combined with processing treatments, improved the nutritional quality of the biscuits by enhancing mineral and protein bioavailability.

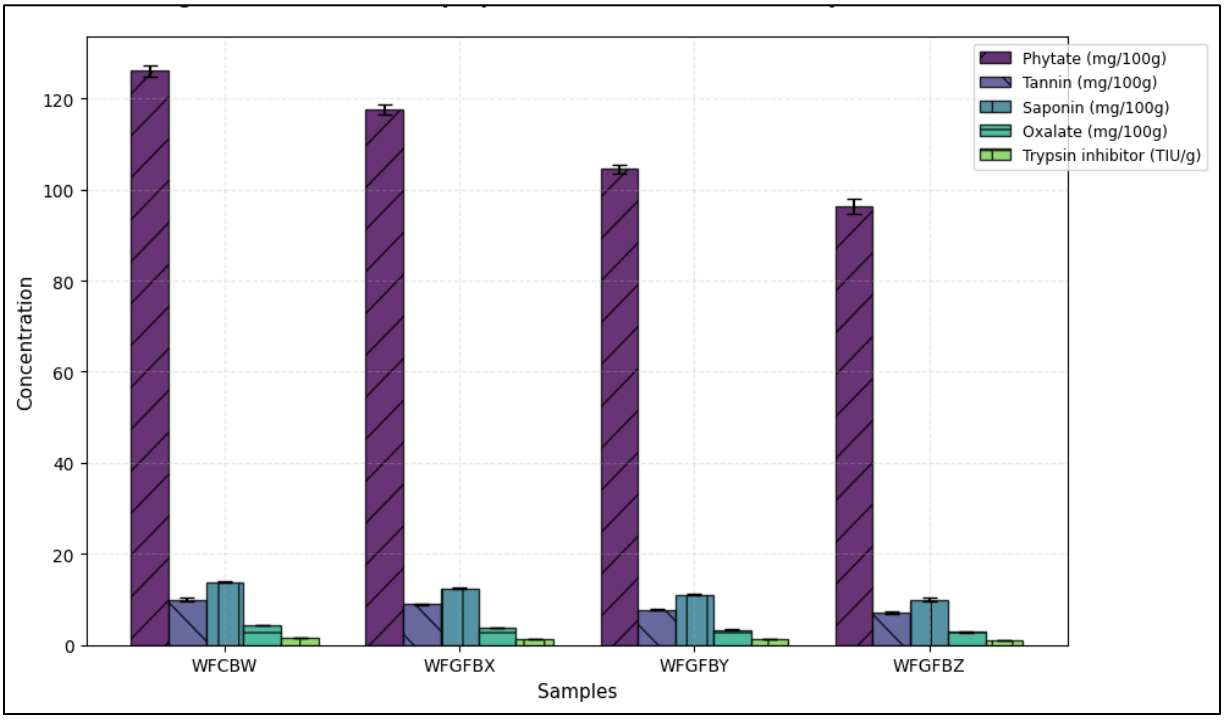

Fig 2 Antinutritional Properties of Wheat-Flaxseed Composite Biscuits Across Different Substitution Levels.

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- *Key:*

✓ WFCBW (Biscuit produced from wheat flour 100% (control)
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✓ WFGFBZ (Biscuit produced from 85% wheat flour and 15% germinated Flaxseed flour).

➢ *Sensory Evaluation*

The result of sensory evaluation is presented in Table 5 for biscuits produced with different levels of flaxseed flour substitution. The results showed that increasing flaxseed flour levels gradually affected the sensory qualities of the biscuits.

Table 5 Sensory Evaluation of Biscuit

Attribute	**WFCBW**	**WFGFBX**	**WFGFBY**	**WFGFBZ**
Taste	7.40 ± 0.94^{b}	7.20 ± 1.24^{b}	6.95 ± 1.19^{b}	5.85 ± 1.46^{a}
Aroma	6.70 ± 1.38^{c}	6.65 ± 1.09^{c}	6.30 ± 1.63^{b}	6.00 ± 1.65^{a}
Appearance	7.75 ± 1.21^{c}	7.25 ± 1.16^{b}	6.55 ± 1.23^{b}	6.45 ± 1.19^{a}
Texture	7.20 ± 1.11^{b}	6.95 ± 0.89^{b}	6.80 ± 1.06^{b}	6.30 ± 1.56^{a}
General Acceptability	7.65 ± 0.99^{b}	6.75 ± 1.41^{a}	6.50 ± 1.28^{a}	6.75 ± 1.52^{a}

(Mean ± SD, n = 20 panelists). Means in the same row with different superscripts differ significantly at $p < 0.05$. WFW (Wheat flour biscuit W served as control contained 100% wheat flour), WFGFBX (Wheat flour germinated flaxseed biscuit X 95% wheat flour and 5% germinated Flaxseed flour), WFGFBY (Wheat flour germinated flaxseed biscuit Y 90% wheat flour and 10% germinated Flaxseed flour) and WFGFBZ (Wheat flour germinated biscuit Z 85% wheat flour and 15% germinated Flaxseed flour)

Sensory evaluation results showed that flaxseed flour substitution significantly influenced biscuit acceptability. Taste scores ranged from 5.85–7.40, with the control sample (WFCBW) recording the highest score, while the 5% flaxseed biscuit (WFGFBX) remained closely comparable, indicating that low flaxseed incorporation did not adversely affect flavor. According to Man *et al.*, (2021), moderate flaxseed inclusion in baked products enhances nutritional quality without greatly affecting palatability. However, higher substitution levels of 10% (WFGFBY) and 15% (WFGFBZ) reduced taste and aroma scores because of the stronger nutty and slightly bitter flavor associated with flaxseed. Appearance scores also declined with increased substitution due to darker coloration and altered surface texture. Texture evaluation revealed that WFCBW, WFGFBX, and WFGFBY maintained acceptable mouthfeel, whereas WFGFBZ was less preferred because the higher fiber content produced a denser texture. General acceptability followed a similar trend, confirming that flaxseed flour can be successfully incorporated up to 5% substitution without negatively affecting sensory quality described by (Rodsamran *et al.*, 2021).

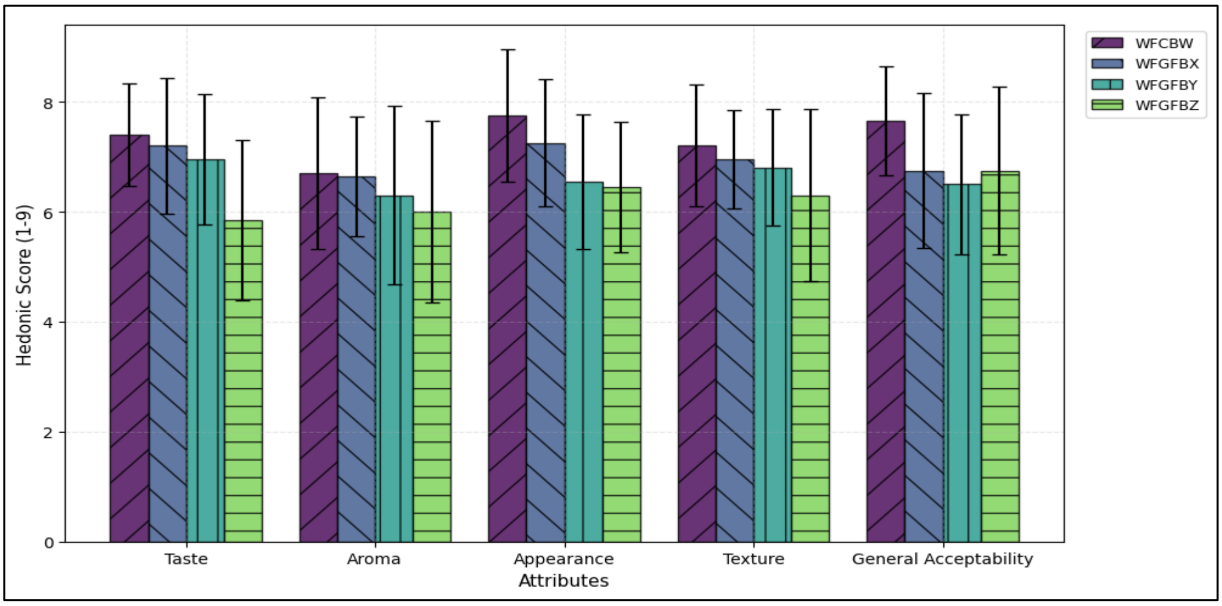

Fig 3 Sensory Evaluation of Wheat-Flaxseed Composite Biscuits Across Different Substitution Levels.

- *Key:*

✓ WFCBW (Biscuit produced from wheat flour 100% (control)
✓ WFGFBX (Biscuit produced from 95% wheat flour and 5% germinated Flaxseed flour,
✓ WFGFBY (Biscuit produced from 90% wheat flour and 10% germinated Flaxseed flour)

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- ✓ WFGFBZ (Biscuit produced from 85% wheat flour and 15% germinated Flaxseed flour).

IV. CONCLUSION

This study demonstrated that the incorporation of germinated flaxseed flour into wheat-based biscuits significantly influenced the proximate, physical, functional, antinutritional, and sensory characteristics of the final products. Increasing levels of germinated flaxseed flour substitution (5–15%) significantly improved the nutritional profile of the biscuits, with protein content increasing from 9.50% to 12.74%, fat from 4.95% to 8.84%, ash from 10.40% to 16.20%, and fibre from 2.72% to 6.12%, while carbohydrate content decreased from 60.18% to 45.96%. Low to moderate levels of germinated flaxseed substitution (5%) improved certain physical properties, particularly biscuit diameter and spread ratio, with WFGFBX exhibiting the most desirable baking characteristics. Functional properties including emulsion capacity, emulsion stability, foaming capacity, water absorption capacity, and oil absorption capacity all improved with increasing flaxseed inclusion, while gelation temperature decreased, indicating enhanced protein–starch interactions. The germination process was effective in reducing antinutritional factors. Phytate, tannin, oxalate, saponin, and trypsin inhibitor levels decreased progressively with increasing germinated flaxseed substitution, with WFGFBZ recording the lowest values and WFCBW the highest. The relatively low antinutrient levels obtained suggest improved mineral bioavailability, protein digestibility, and overall nutritional quality. Sensory evaluation indicated that biscuits containing 5% germinated flaxseed flour achieved scores closely comparable to the control in taste, aroma, texture, and overall acceptability, while higher substitution levels (10–15%) caused minor sensory declines. Therefore, incorporating 5% germinated flaxseed flour is recommended as the optimal substitution level, supporting the development of functional bakery products that balance improved nutritional benefits with acceptable physical quality and consumer acceptability. Wheat–flaxseed composite biscuits have significant potential as nutritious and acceptable functional snack products for health-conscious consumers.

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