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Research article

EFFECTS OF GERMINATION AND ROASTING ON THE NUTRITIONAL AND MINERAL PROFILES OF CEREAL AND LEGUME FLOURS

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ABSTRACT

The present study investigated the effects of germination and roasting on the proximate and mineral composition of maize, wheat, groundnut, and common bean seed flours. Samples were divided into three 200 g batches (raw, germinated, roasted). Germination was performed after pilot soaking tests (24, 48, 72 h); final conditions used were: soaking 24 h for wheat, maize and groundnut and 48 h for common bean, spreading on wet jute bags with moistening every 12 h, dehulling of sprouts, and oven-drying at 50°C for 24 h before milling. Roasting was performed on 200 g batches on a roasting pan over wood fire at approximately 300°C for 1 hour before milling. Proximate parameters, including moisture, protein, fat, ash, fiber, carbohydrates, and energy content, were analyzed using standard methods, while sodium, potassium, and calcium levels were determined through atomic absorption spectrophotometry. The results indicated that processing significantly influenced the proximate composition of the flours. Germination consistently increased moisture and protein content across all flours (observed maxima across processed samples up to ≈14.7 g/100 g for wheat, ≈10.8 g/100 g for maize, ≈30.2 g/100 g for common bean, and ≈33.6 g/100 g for groundnut), while fat, carbohydrate and energy values tended to decrease in germinated samples consistent with metabolic utilization during sprouting. Roasting produced variable effects depending on the crop. Mineral analysis showed cereals (wheat and maize) maintained relatively stable Na, K and Ca across processing, whereas germinated common bean and groundnut flours exhibited reduced potassium and calcium, likely due to leaching and metabolic changes during germination. These findings indicate that simple household-level processing (germination and roasting) can be used strategically to improve protein availability and overall nutritional quality of cereal–legume foods, supporting their role in nutrient-rich diet formulation.

1. Introduction

The primary objectives of this study is to quantify the effects of germination and roasting on the proximate composition (moisture, protein, fat, ash, fiber, carbohydrate and energy) of maize, wheat, common bean (Phaseolus vulgaris) and groundnut flours, to determine how these processes affect selected mineral contents (sodium, potassium and calcium) of these flours, and to evaluate the nutritional and practical implications of these processing-induced changes for food formulation and human diets, identifying which processing option may improve nutrient availability or be preferable for specific food applications.

Cereal and legume-based foods are vital because they contain carbohydrates (especially starch and fiber). They also contain vitamins, minerals, and other substances that are very important for our health. To reduce bulk and extend the storage time of legume and cereal-originated food compositions, roasting and germination are easy, flexible procedures (Maphosa and Jideani, 2017).

Germination and roasting are chosen because they are low-cost, widely practiced processes at household and small-industry scales, making the results directly relevant for producers, home cooks and food processors. During germination, enzymes mobilize stored reserves, breaking down complex carbohydrates and lipids to fuel sprouting, which increases measured protein content and moisture (via rehydration and biochemical synthesis) while reducing some carbohydrate and fat fractions. Germination has been shown to enhance the readily available vitamins and amount of free limiting amino acids with changing functional characteristics of seed components. Additionally, it improves protein digestibility, crude fiber content, and anti-nutritional factors (Ohanenye *et al.*, 2020). In this study, germination is expected to increase measured protein levels and moisture (through rehydration and biochemical changes) while decreasing some carbohydrate and fat fractions because these are consumed as metabolic substrates during sprouting. On the other hand, roasting boosts flavor, increases shelf life, improves color, and lessens the anti-nutrient characteristics of grains and legumes. During roasting, heat treatment may denature proteins, alter lipid structures, and cause Maillard reactions, which can improve protein availability in legumes such as peas and beans (Bachmann et al., 2020). For instance, a study revealed that roasting increased rumen-undegraded protein (RUP) in ensiled peas by approximately 28% (Effect of roasting grain silages from field peas (Bachmann *et al.*, 2020). In this study, roasting is anticipated to lower moisture and may concentrate some constituents while causing variable effects on protein and lipids depending on the matrix and roasting intensity.

Due to the strict essential quality of the proteins in wheat flour, most of the population uses wheat as a plentiful food source. Traditionally, maize was largely farmed for domestic usage as a staple grain, but recently, the necessity for it in commercial and feed applications has expanded significantly. According to (Añazco *et al.*, 2023) beans are a superior source of quality plant protein. In various parts of the world, groundnut is widely consumed. Groundnut (Arachis hypogaea), commonly called peanut, is botanically a member of the legume family (Fabaceae) and is an oil- and protein-rich seed (Singh *et al.*, 2021). The proximate composition is crucial for judging the quality of raw materials and very often serves as the beginning for judging their nutritional worth and widespread acceptability among consumers (Ganogpichayagrai and Suksaard, 2020). Minerals are necessary nutrients that must be consumed in trace levels to maintain good health. Although minerals don't contain calories or energy, they can support the body's other processes. The body cannot produce minerals. Minerals must be supplied through food to meet regular requirements. A high amount of minerals is also found in cereal and legumes. It is vital to assess their physicochemical properties to understand how components or food will behave physically during preparation and storage (Bachmann *et al.*, 2020). This research aimed to ascertain how roasting and germination affected the proximate and specific minerals constitution of maize, wheat, common bean seed (*Phaseolus vulgaris*), and groundnut.

2. Materials and methods

In this work, two conventional processing techniques, germination and roasting, are used to demonstrate the proximate constitution and amount of certain minerals (Na, K, and Ca) in flours made from legumes (groundnut and common bean seed) and cereals (maize and wheat).

2.1. Sample collection

Three samples of each legume (groundnut and common bean seed) and cereal (maize and wheat) were collected from 3 locations (sample size for each cereal and legume is 3, i.e. n=3) from February to August 2023 in the Chittagong area of Bangladesh, which is shown in table 1. All samples were collected directly into a cleaned polyethylene bag. Three distinct collections were formed from all samples. The first collection was used as an untreated raw sample and considered a control, the second collected samples were used for germination, and the third samples were used for roasting. All of these collections were stocked in a freezer at 15–17°C until analysis. All proximate and mineral analyses reported in this study were performed within 4-5 days of sample preparation (germination or roasting) to minimise post-processing compositional changes.

Table 1. Sampling locations and sample code of cereal and legume

Locations (Name of the local markets)	Sample code			
	Wheat	**Maize**	**Common bean seed**	**Groundnut**
Anwara, Chattogram	W1 (n=3)	M1 (n=3)	B1 (n=3)	G1 (n=3)
Patiya, Chattogram	W2 (n=3)	M2 (n=3)	B2 (n=3)	G2 (n=3)
Hathazari, Chattogram	W3 (n=3)	M3 (n=3)	B3 (n=3)	G3 (n=3)

2.2. Sample preparation

Locally grown cereal and legumes such as maize, groundnut, wheat, and bean seed were collected from selected locations in Chittagong, Bangladesh. The components were cleared of debris and stones, shade-dried, washed, and separated into three batches. Each sample's initial batch was unprocessed, and it served as the control. The raw samples (200g) were milled to a fine powder using the laboratory mill (Food processor, model: HR7761, China) and then stored in name-labelled polyethene bags at 4–6°C until used. The other two batch samples were roasted and germinated.

2.3. Germination

Germination of maize, wheat, groundnut, and bean seed was done as described in the literature (Atudorei *et al.*, 2021). The second batch of each sample (200g) was used for germination. A pilot study for germination was carried out by taking a small amount (10g) of each sample. Cleaned wheat, maize, common bean seed, and groundnut were soaked for 24, 48, and 72h to ascertain the appropriate soaking period for germination at room temperature. Soaking for 24h was found to be most appropriate for wheat, maize, and groundnut. For common bean seeds, the soaking time was 48h.

The seeds were soaked and spread separately on jute bags (wet) and covered with clean cloth made of cotton. Every 12 hours until the termination of the germination periods, the seeds were moistened using a sprayer. The seeds were carefully selected and washed, and the sprouts were dehulled and oven-dried at a temperature of 50°C for a day before being milled and kept in labelled polyethylene bags at 4-6°C until analysis. The summary of germination procedure is explained in table 2.

Table 2. Summary of germination procedure

Step	Condition / parameter	Duration	Notes
Sample size	200 g per batch	—	Cleaned and sorted seeds
Pre-soak	Room temperature water (clean)	24 h (wheat, maize, groundnut); 48 h (common bean)	Pilot tests indicated appropriate times — see main text
Germination setup	Spread on wet jute bags; covered with clean cotton cloth	24–72 h depending on seed	Seeds moistened every 12 h using a sprayer
Monitoring & selection	Manual removal of ungerminated/contaminated seeds	Every 12 h	Visual inspection
Post-germination washing & dehulling	Rinse to remove rootlets/impurities	—	To reduce off-flavors and remove debris
Drying	Oven-dry at 50°C	24 h	To constant weight prior to milling
Milling & storage	Laboratory mill; store at 4-6°C	Until analysis	Labelled polyethylene bags

2.4. Roasting

The roasting of wheat, maize, common bean seed, and groundnut was done according to the previously described method (Aung *et al.*, n.d.). For roasting, the third batch of each sample (200g) was put on a roasting pan and heated with wood to roughly 300°C, as is customary in the area. Roasting took place for 1 hour. The roasted seeds were then powdered and stored in name-labeled polyethylene bags at 4-6°C until analysis (Table 3).

Table 3. Summary of roasting procedure

Step	Condition / parameter	Duration	Notes
Sample size	200 g per batch	—	Cleaned and sorted seeds
Roasting method	Roasting pan heated with wood (traditional method)	~1 hour	Target surface temperature ~300°C (local practice)
Cooling	Air-cool to room temperature	Until cool	Avoid moisture uptake
Milling & storage	Mill to fine powder; store at 4-6°C	Until analysis	Labelled polyet

2.5. Proximate analysis

Proximate compositions of flour samples were examined using recognized standard procedures. The extrudates' moisture content was assessed using an AOAC method (AOAC, 2000). Fat, carbohydrate, and crude protein were multiplied by their respective water values of 9, 4, and 4 kcal/g to estimate the gross energy values. The sample's crude nitrogen content (N×6.25), as calculated by the Micro-Kjeldhal technique, was used to estimate the protein level. By using the Soxhlet method described in the literature (AOAC, 2000), the sample's dietary quantity of fat was determined. The difference approach was used to compute the amount of carbohydrates. The approach recommended by the AOAC was used to evaluate the crude fiber and ash levels of the samples (Kesre and Masatcioglu, 2022).

2.6. Mineral analysis

The samples' mineral (Na, K, and Ca) constituents were measured using AAS. The flour samples were prepared for AAS analysis by the wet digestion method using concentrated $HClO_4$ and HNO_3 (2:1, v/v). After adding 5 mL of 65% HNO_3 to the 0.5g sample, it was gently heated for 30 to 45 minutes. Once the liquid had cooled, 2.5 mL of 70% $HClO_4$ was added. The mixture was then slowly heated when dense white vapors started to form, the heat was removed. The mixture was then cooled, and 10 mL of water (deionized) was added; after that, more boiling was done until all of the fumes had been emitted (Palma *et al.*, 2015). The samples' Na, K, and Ca were measured in a lab using an AAS quality assurance program. (Model: AA-6800, Shimadzu, Japan).

2.7. Statistical analysis

Data are presented as mean ± standard deviation (n = 3). Statistical analyses were performed using IBM SPSS Statistics v18. Normality (Shapiro–Wilk) and variance homogeneity (Levene's test) were checked before comparisons. One-way ANOVA followed by Tukey's HSD was used for normally distributed data; otherwise, the Kruskal–Wallis test with Dunn's post-hoc (Bonferroni correction) was applied. All tests were two-tailed with $p < 0.05$ considered significant. Biological replicates (n = 3) were used, and technical replicates were averaged where applicable.

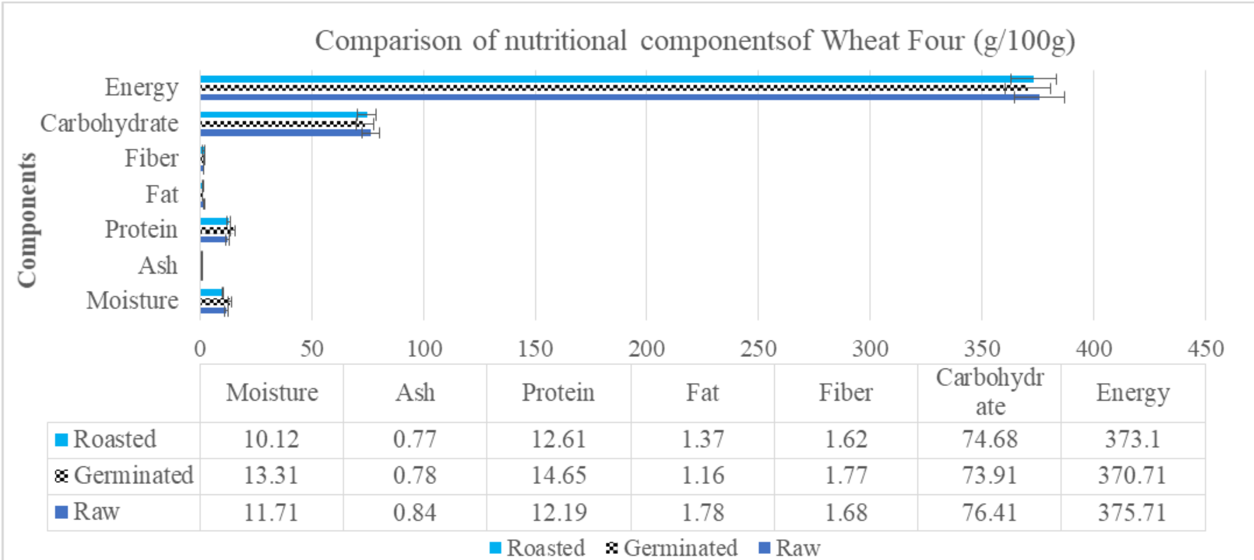
3. Results and discussions

3.1 Proximate compositions of cereal (wheat and maize)

The effects of processing conditions on the proximate composition of wheat and maize flour are given in Fig. 1. The water contents of wheat flour were found in the range from 9.94±0.85 to 13.92±1.35 g/100g. The highest moisture contents were found for germinated wheat flour. The results fall in the range that has been noted by other researchers (Al-Kharkhi and Mousa, 2021; Yang *et al.*, 2021). Research has demonstrated that decreased moisture level of food is advantageous because it reduces microbial growth (Organization, 2022). Food samples with less moisture could be stored for longer (Moore, 2020), whereas foods with high moisture content encouraged microbial development, which led to food degradation (Barbosa *et al.*, 2021).

Results are shown as mean ± SD, where the sample size is 3 (n=3). Average values of the components of the wheat and maize within the same superscript letter, meaning there are no significant differences; different superscripts are significantly different at $p<0.05$.

The highest value of ash contents was found for raw wheat flour then germinated and roasted wheat flour. A similar type of result is supported by (Malik *et al.*, 2021; Perveen *et al.*, 2024) who stated that the ash contents of raw wheat were 1.43±0.02%, and germinated wheat was 0.85±0.04%. The protein contents were between 11.58±0.83 to 14.74±1.63 g/100g. We have found that the protein contents of roasted and germinated wheat flour are higher than raw wheat flour. Previous studies found that roasting and germination enhanced the food product's nutritional value, especially in terms of its protein content (Nkhata *et al.*, 2018).



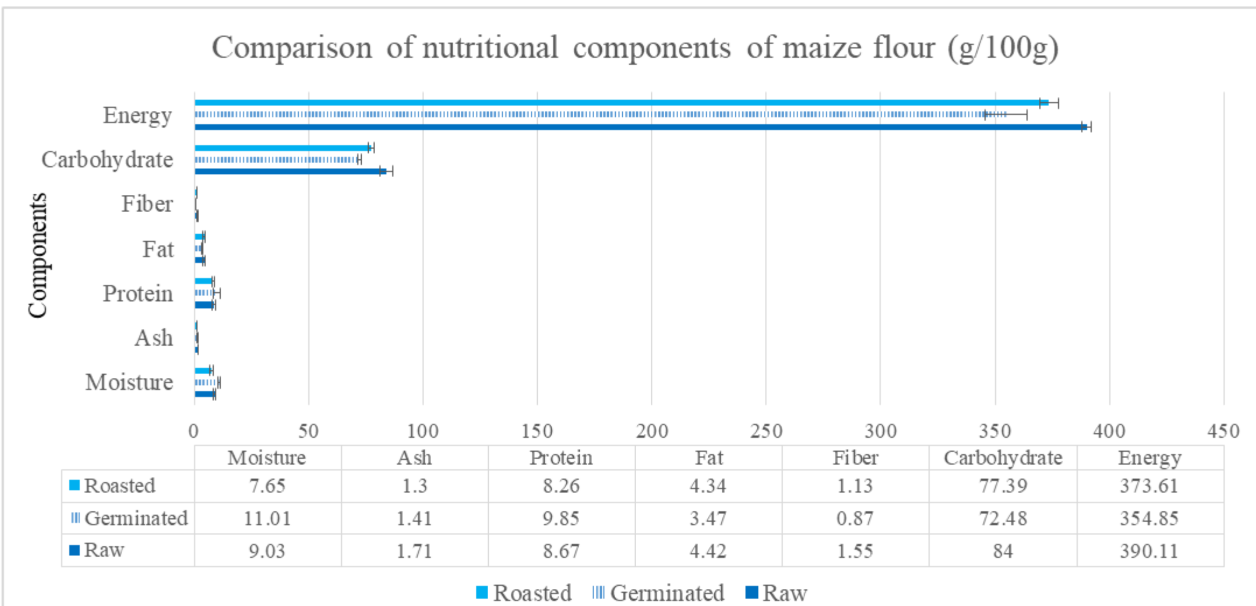


Figure 1. Proximate Composition of cereal (wheat and maize)

Increased water activity brought on by the stimulation of hydrolytic enzymes is what is responsible for the increase in protein levels observed in germinating flours (Li *et al.*, 2020), hormonal changes (Wang *et al.*, 2022) or a change in the composition due to the breakdown of other elements. Fat contents were found from 1.04±0.35 to 1.96±0.74 g/100g. Low-fat contents were obtained for germinated wheat flour. The decrease is probably caused by the lipid being used as a source of power during germination (Xu *et al.*, 2019). The amount of fat in raw wheat was 1.47±0.51%, whereas the amount in germinated wheat was 0.60±0.01%, according to research (Perveen *et al.*, 2024). The fiber content of germinated wheat flour, however, was higher than that of raw and roasted wheat flour. (Perveen *et al.*, 2024) found that raw wheat had a fiber content of 11.74 ± 0.02, and 72 hour sprouted wheat had a fiber level of 13.39 ± 0.02 g/100gm, lending credence to this conclusion. The energy and carbohydrate content of the wheat flour was 363.74±13.53 to 388.52±8.43 Kcal/100g and ranged from

71.43±4.74 to 81.03±6.48 g/100g, respectively. It was found that the results of the germinated sample were both lower than those of the samples of roasted and raw wheat flour. It occurred as a result of the seeds' germination process using fat and carbohydrates for biochemical processes (Atudorei *et al.*, 2021). A similar result was found by (Perveen *et al.*, 2024), who stated that energy and carbohydrate values of the germinated (72h) and raw wheat flour samples ranged from 357.7 ± 0.03 to 350.4 ± 0.20 Kcal/100g and 71.18 ± 0.2 to 68.64 ± 0.1 g/100g, respectively.

Maize flour's moisture content varied from 6.96±1.43 to 11.72±1.31 g/100g. Moisture contents of germinated maize flour were higher than raw and roasted maize flour. The ash content of raw maize flour was higher than germinated and roasted flour. It's possible that the leaching out of micro and macro components during processing is what caused the decrease in ash content (Matthew *et al.*, 2021). Protein contents were found from 7.78±0.42 to 10.83±1.54 g/100g. The protein contents of germinated maize flour were higher than raw and roasted maize flour. According to (Perveen *et al.*, 2024), the protein content of germinated maize flour increased compared to raw maize flour. The fat contents of germinated maize flour were lower than roasted and raw maize flour. Germinated maize flour had a lower amount of fiber than roasted and raw maize flour. A similar type of result was also found in the literature (Sharma *et al.*, 2015). Energy and carbohydrate values of the flour samples of maize ranged between 361.37±14.64 to 392.32±12.38 Kcal/100g and 71.73±9.54 to 86.82±7.48 g/100g, respectively. Compared to raw and roasted maize flour, the germinated sample's energy and carbohydrate levels were lower. Additionally, it was discovered that raw maize had a greater carbohydrate percentage content than roasted corn. In the literature, similar outcomes were also discovered (Gunathunga *et al.*, 2024).

Germination consistently increased moisture and protein levels in both wheat and maize, while reducing fat, carbohydrate and available energy (likely due to metabolic utilization during sprouting). Roasting produced more variable effects across proximate parameters (often lowering moisture and ash but occasionally increasing measured protein relative to raw samples). These processing-induced patterns were statistically supported by one-way ANOVA with post-hoc Tukey comparisons (significant differences reported at $p < 0.05$ where indicated by different superscript letters in the figures/tables). The observed trends are consistent across both cereals, although the magnitude of change varied between wheat and maize.

From a practical standpoint, these changes suggest that germination may be a useful processing technique to enhance protein content and modify energy density in cereal-based foods, while roasting may be leveraged to alter texture and moisture without drastically reducing nutrient value, both of which could inform dietary recommendations and industrial processing decisions.

3.2. Proximate compositions of legumes (common bean seed and groundnut)

The moisture, ash, protein, fat, fiber, and carbohydrate in common bean seed flour were 6.10±0.79 to 12.35±0.63, 2.21±0.07 to 3.12±0.07, 14.05±3.36 to 30.15±4.36, 1.64±0.54 to 2.54±0.27, 2.35±0.09 to 3.92±0.14, and 54.24±4.13 to 68.43±5.76 g/100g, respectively (Fig. 2). Moisture contents were found to be higher after germination. This finding is similar to that found by (Kassegn *et al.*, 2018) in germinated legumes. Legumes absorb water from their surroundings as germination progresses to get the process of metabolism to start. Dry legumes quickly absorb water due to their unique characteristics of the structure. The increased water intake over time is the result of the seed's growing number of wet cells (Vidak *et al.*, 2022). Ash contents were decreased in germinated and roasted bean seed flour than raw bean seed flour. Similar types of results are found in various literature (Kassegn *et al.*, 2018; Medhe *et al.*, 2019). To lessen the bitter smell throughout the germination stage, rootlets were washed in water, which resulted in a decrease of minerals (Saithalavi *et al.*, 2021).

Contents of protein were found to be increased in germinated seed flour of beans than raw and roasted bean seed flour. This result is similar with other studies found in the literatures (Kassegn *et al.*, 2018; Atudorei *et al.*, 2021; Bagarinao *et al.*, 2024). After the germination process, they discovered that protein amounts rose. The rise was thought to be caused by the production of proteins that encode enzymes or a structhoural change because of the disintegration of other ingredients (Wang *et al.*, 2024). Compared to raw bean seed flour, the fat level in roasted and germinated bean seed flour was lower. Similar results were found in the literature (Medhe *et al.*, 2019; Atudorei *et al.*, 2021), where the amount of fat decreases as germination time increases. This is because fat served as the main carbon source for seed growth (Cordero *et al.*, 2008; Balouchi *et al.*, 2023). These studies also revealed that the oxidation of fatty acid produces water and carbon dioxide to provide germination energy. In comparison to raw bean seed flour, the fiber content of germinated and roasted bean seed flour was lower.

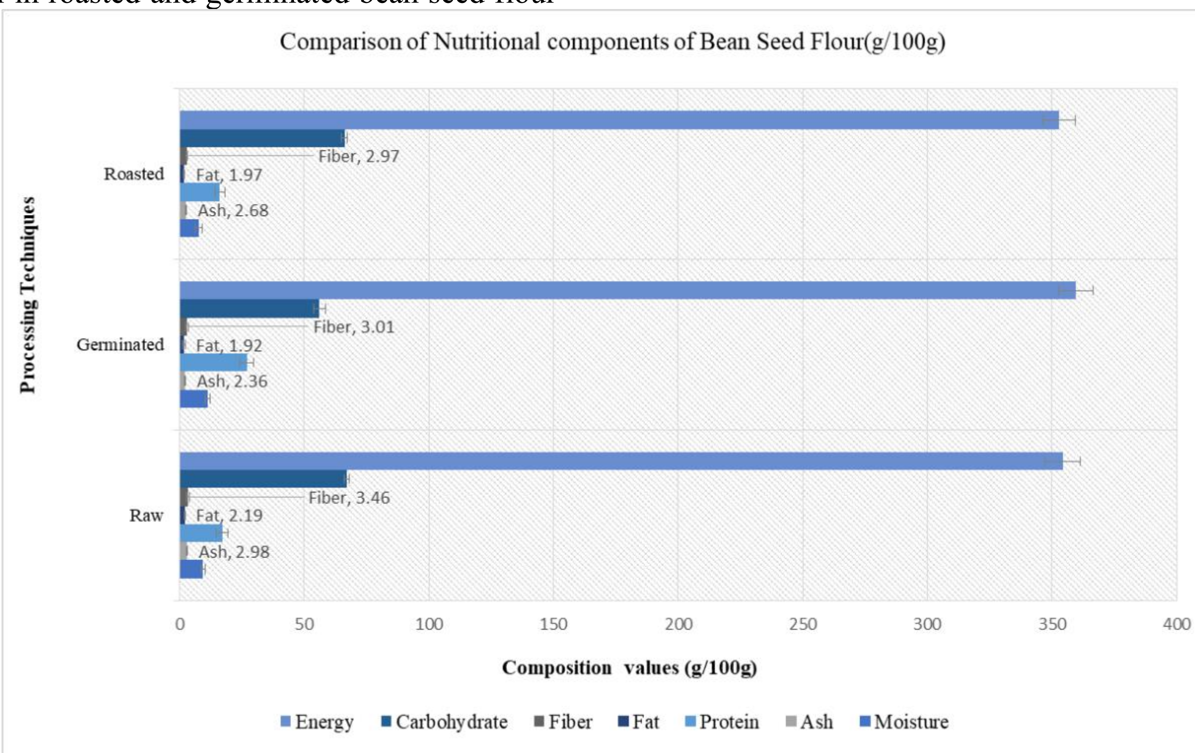


Figure 2. Proximate composition of common bean seed flour

According to (Liu *et al.*, 2024), the kind of legumes affected the germination's impact on fiber. In a previous study, it was found that (Megat *et al.*, 2016) soaked rice and soybeans have more fiber than soaked wheat, barley, peanuts, and mung beans. This suggests that the germination process affects the fiber content during the soaking phase before the actual germination phase. In comparison to raw and roasted bean seed flour, the carbohydrate content of germinated bean seed flour was lower. According to an explanation given by (Xie *et al.*, 2023), the usage of carbohydrates as a source of energy for embryonic growth during germination could account for changes in the carbohydrate content following germination. Additionally, the enzyme amylase increased the hydrolysis of starch into simple carbohydrates (Sofi *et al.*, 2023).

Results are shown as mean ± SD, where the sample size is 3 (n=3). Average values of the components of the wheat and maize within the same superscript letter, meaning there are no significant differences; different superscripts are significantly different at $p<0.05$.

The moisture, ash, protein, fat, fiber, and carbohydrate in groundnut flour were 1.74±0.35 to 3.58±0.32, 1.48±0.15 to 2.21±0.20, 28.57±1.38 to 33.63±2.24, 37.60±2.12 to 41.95±1.74, 1.52±0.26 to 2.38±0.32, and 21.37±4.49 to 26.48±4.48 g/100g, respectively as shown in Fig. 3. The moisture contents were increased in germinated groundnut flour than in raw and roasted groundnut flour. This is similar to the findings reported by (Ocheme *et al.*, 2018) in germinated groundnut. Ash contents were decreased in germinated groundnut flour than in raw and roasted bean groundnut flour. Similar types of results are found in the previously described pieces of literature (Ocheme *et al.*, 2018). They claimed that the reasons for the variations in ash level after drenching for a particular period were related to decreasing ash percentage. There were no discernible impacts of roasting on groundnuts, and germination decreased the amount of ash and fiber in groundnuts, according to (Quirino *et al.*, 2023; Zhang *et al.*, 2024). Protein contents were increased in germinated groundnut flour than in raw and roasted groundnut flour. It was observed that (Chinma *et al.*, 2021) the protein content of germinated groundnut is increased. (Chinma *et al.*, 2025) also stated that the protein content in germinated groundnuts was higher than in raw seeds.

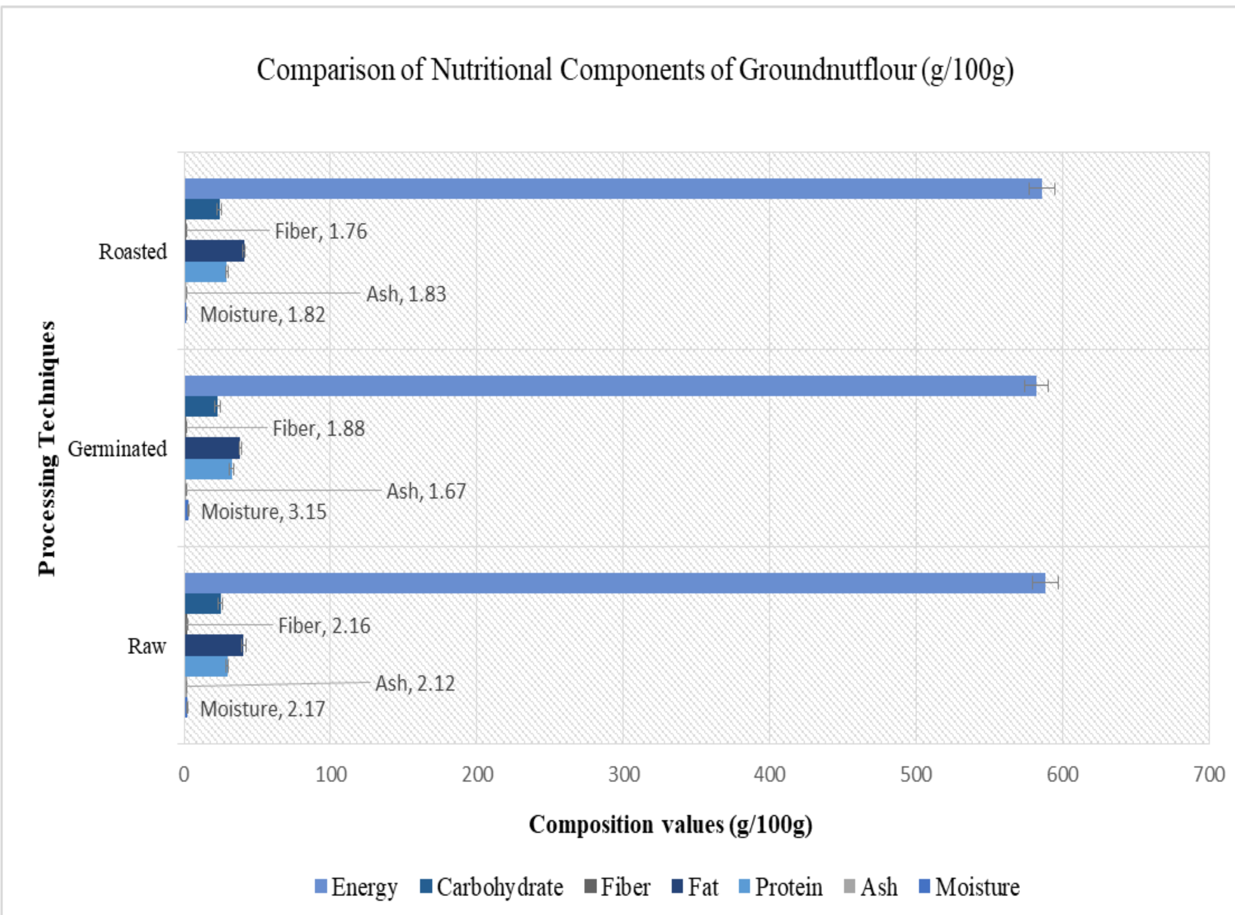


Figure 3. Proximate composition of groundnut flour

According to literature (Chinma *et al.*, 2025), the rise was brought on by the production of protein enzymes or by a compositional shift brought on by the breakdown of other components. (Lu *et al.*, 2024) provided a different hypothesis, noting that the synthesis of protein took place at the time of soaking and that changes in hormones are crucial to successful germination. (Okpala and Kanu, 2023) found that germinated groundnut flour has less fat than raw and roasted groundnut flour. According to studies, the glyoxylate cycle converts fatty acids into carbohydrates, which results in a drop in the quantity of lipids during germination (Penfield *et al.*, 2005). Fiber contents were decreased in germinated and roasted groundnut flour than in raw groundnut flour. Carbohydrate contents were decreased in germinated groundnut flour than in raw and roasted groundnut flour. Energy values were decreased in groundnut flour after germination and roasting than in raw groundnut flour. The literature states that the process of soaking and steeping dry seeds in water results in chemical changes caused by the hydrolysis of complex macromolecules like protein and starch into lower-molecular-weight and more easily digestible molecules (Bagarinao *et al.*, 2024; Lu *et al.*, 2024). Furthermore, the increased metabolic processes in the germination seeds are powered by the starch oxidation and breakdown seen during respiration. That could account for the groundnut's lower energy content when roasted and germinated than when raw (Zhang *et al.*, 2024).

3.3. Mineral contents of cereal (wheat and maize)

The amount of sodium was found in the range of 4.58 ± 0.13 to 6.15 ± 0.24 mg/100g. It was found in Fig. 4 that similar values of sodium contents in all wheat flour. The level of potassium was found to be between 364.69 ± 4.45 to 390.63 ± 5.49 mg/100g, as shown in Fig. 5. The concentration of calcium in wheat flour was found to be in the range of 34.27 ± 2.14 to 40.83 ± 2.65 mg/100g. From the experiment, it was found that the processing condition doesn't have any significant effect on sodium, potassium, and calcium in wheat flour. According to (Ijarotimi *et al.*, 2022), processing had no impact on the sodium: potassium ratio in whole-wheat flour but a sizable one in white flour. The ratio of calcium to phosphorus in the kernel and whole-wheat flour was not statistically different, although it was significantly higher in white flour. The removal of the phosphorus-rich bran and germ during the milling process of wheat into white flour enhanced the calcium: phosphorus ratio (Heshe *et al.*, 2016). Additionally, it was demonstrated that adding minerals and bleaching the experimental white flours did not affect their mineral concentration. The contents of potassium, sodium, phosphorus, and calcium in the bleached not enhanced, untreated, and bleached enriched flours did not differ significantly from one another (Kaim and Goluch, 2023).

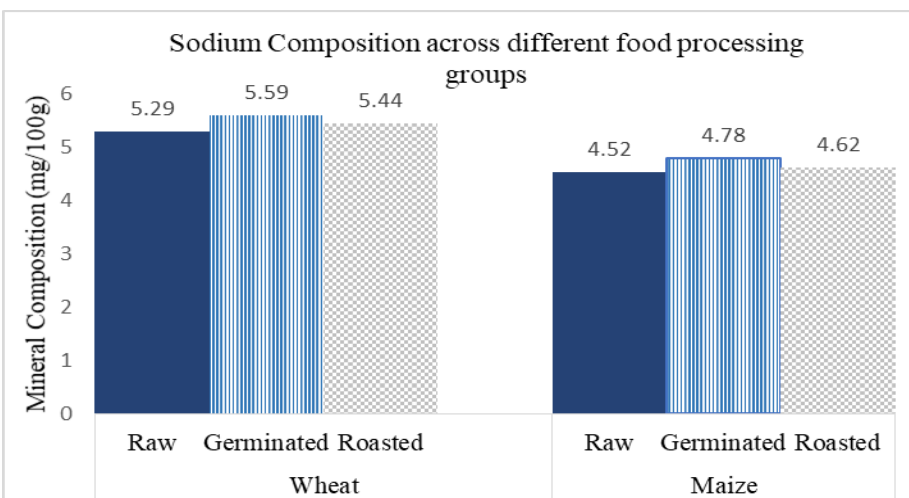


Figure 4. Sodium content of cereal (wheat flour and maize) (mg/100g)

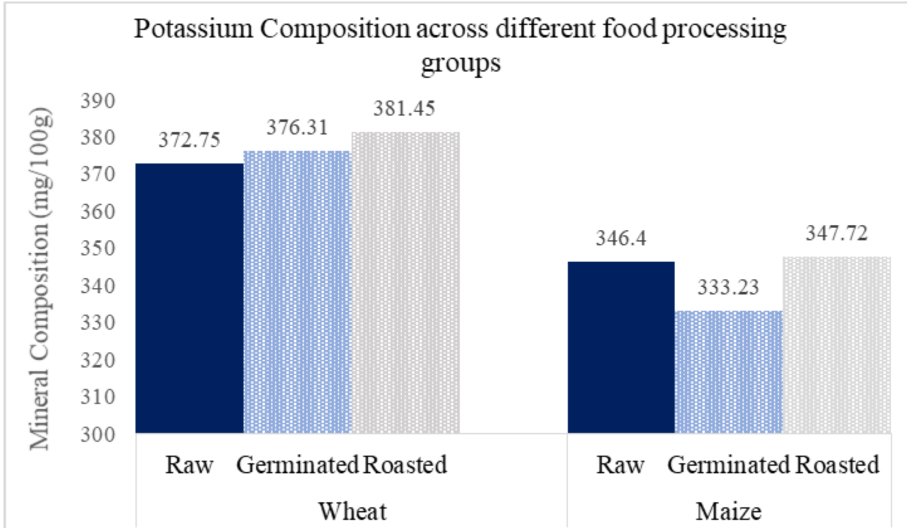


Figure 5. Potassium content of cereal (wheat flour and maize) (mg/100g)

Results are shown as mean ± SD, where the sample size is 3 (n=3). Average values of the minerals of the wheat and maize within the same superscript letter, meaning there are no significant differences; different superscripts are significantly different at $p<0.05$.

The levels of sodium in maize flour were found between 3.96 ± 0.28 to 5.53 ± 0.32 mg/100g. The potassium contents were found in the range from 307.71 ± 6.39 to 368.86 ± 9.14 mg/100g. Calcium contents were found to be from 5.03 ± 0.14 to 6.74 ± 0.26 mg/100g (Fig. 6). From the result, it was found that random values were found for all maize flour. There are no significant effects of processing on selected mineral contents of maize flour found in the current study. It was discovered that the variations in mineral content in these goods may be caused by genetic variables as well as environmental variables such as soil composition, fertilizer usage, and irrigation frequency (Haydar *et al.*, n.d.; Langyan *et al.*, 2022). According to (Suri and Tanumihardjo, 2016), the various processing techniques alter the nutritional profile of maize products, which can have a significant impact on the communities that rely heavily on this crop for a significant amount of their caloric demands' micronutrient intake. Additionally, they noted that research on the impact of various processing techniques on the nutritional value of maize from field to plate shows that, in general, the fresher and less prepared the corn is, the more nutritional value it keeps (Haydar *et al.*, n.d.).

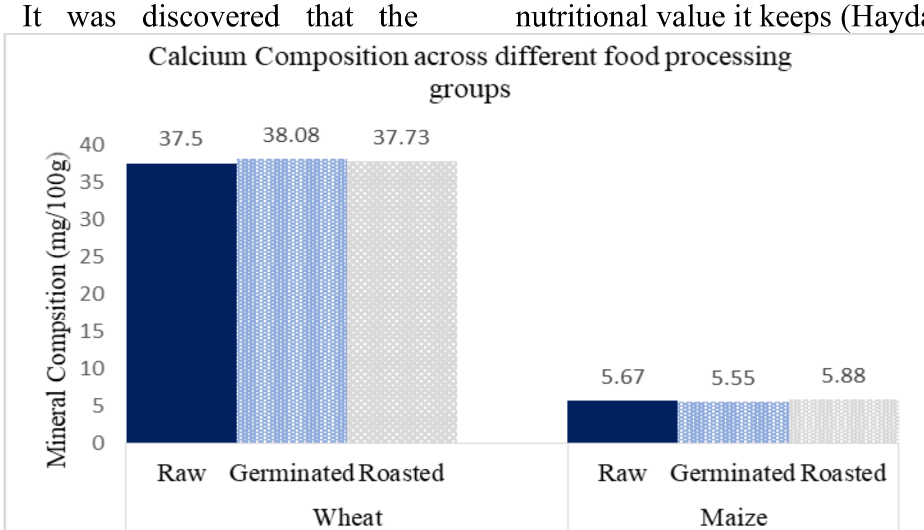


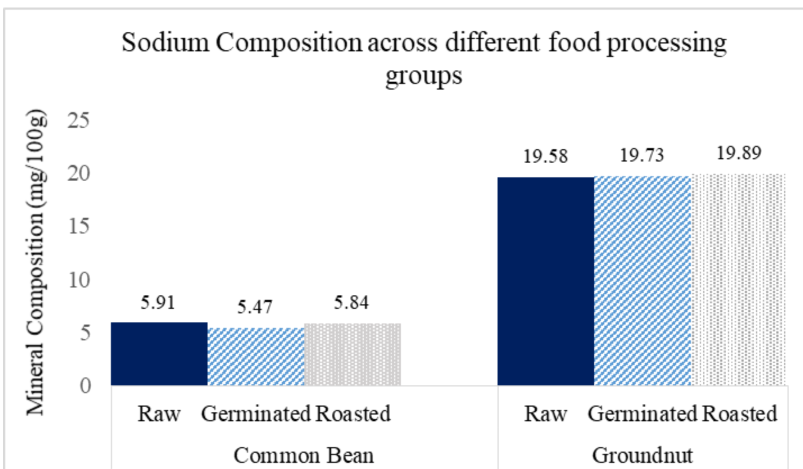
Figure 6. Calcium content of cereal (wheat flour and maize) (mg/100g)

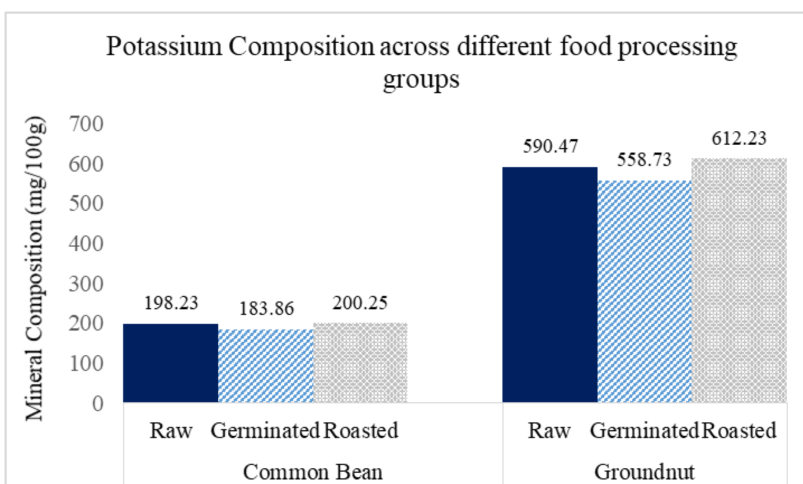
The lack of large, statistically significant changes in total Na, K and Ca concentrations with roasting or germination is biologically plausible because minerals are inorganic elements (they are not destroyed by heat). Roasting (a dry-heat process) typically does not chemically decompose mineral elements; by contrast, wet processes (soaking, blanching, dehulling) can cause soluble mineral losses via leaching. During germination there can be a redistribution of minerals between seed compartments or temporary metabolic use of certain ions, but the total elemental content often remains similar unless leaching or removal of seed fractions occurs. In addition, natural variability introduced by genotype, soil composition and sampling location can mask small processing-related shifts; this, combined with the analytical precision of triplicate AAS measurements, explains why ANOVA returned non-significant differences for many mineral comparisons ($p > 0.05$).

From a practical perspective, this indicates that roasting or germination of wheat and maize can be adopted without significant concern for mineral depletion, making these processes viable for preserving mineral content in both home and industrial food preparation.

3.4. Mineral contents of legumes (common bean seed and groundnut)

The sodium, potassium, and calcium contents of common bean seed flour and groundnut flour are presented in Fig. 7. The sodium contents were found in the range from 5.18 ± 0.28 to 6.22 ± 0.34 mg/100g. The potassium level in common bean seed flour was between 172.36 ± 4.14 and 221.49 ± 5.65 mg/100g.





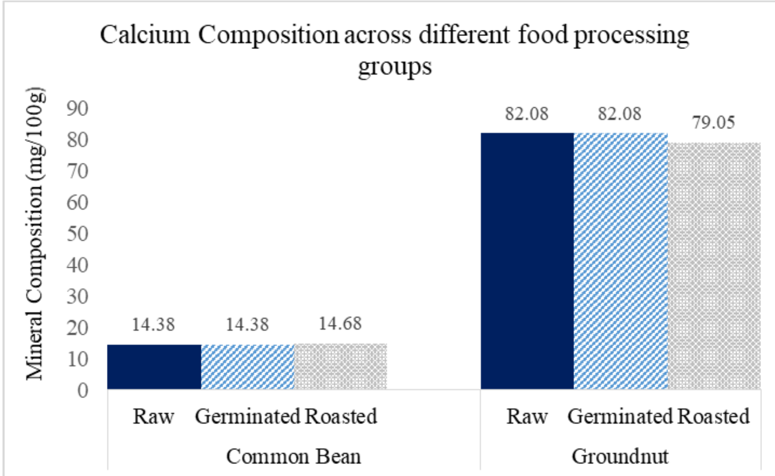


Figure 7. Mineral contents of legumes (common bean seed and groundnut)

Calcium contents were found to be from 11.73 ± 1.15 to 16.58 ± 1.85 mg/100g. All the elements, viz. sodium, potassium, and calcium, were found to have decreased levels for germinated common bean seed flour compared to raw and roasted common bean seed flour. Leaching, dehulling, or seedlings using it for metabolism may be to blame for the reduced values for all the treated samples (Liu *et al.*, 2023). There is still a lack of knowledge regarding how thermal processing affects the quantities of vital elements in beans. Heat treatment raised the concentrations of Mg, K, Ca, Zn & P in black species and jalo while having no adverse effects on the concentrations of Zn, Cu, Fe, and S. Both the Fe and Ca concentrations fell in the rajado and fardinho species, as well as in the jalo and rajado species (Tovar *et al.*, 2022). (Zhou *et al.*, 2022) reported that cooking did not change the overall amounts of these vital substances, but research on chemical species and bioavailability is necessary before drawing any conclusions regarding the impact of heat on chemical species. These studies are crucial for breeding strategies that aim to increase the mineral content of cultivated bean species. According to a study, ground beans that were allowed to sprout for 48 hours had a higher mineral content than beans that were allowed to germinate for 72 or 96 hours (Kassegn *et al.*, 2018). This supports the findings of the (Kassegn *et al.*, 2018) research but contradicts the findings of (Ikram *et al.*, 2021) in the areas of green gram, cowpea, and chickpea.

Results are shown as mean ± SD, where the sample size is 3 (n=3). Average values of the wheat and maize minerals within the same superscript letter, meaning there are no significant differences; different superscripts are significantly different at $p<0.05$.

The amounts of sodium in groundnut flour were found between 18.64 ± 2.53 to 21.07 ± 3.16 mg/100g. The potassium levels were found in the range from 495.79 ± 14.43 to 632.71 ± 19.27 mg/100g. Calcium contents were found to be from 71.53 ± 5.21 to 87.36 ± 5.32 mg/100g. The potassium and calcium contents in germinated groundnut flour were found to be lower than raw and roasted groundnut flour. However, the sodium contents were found mostly unchanged in all groundnut flour samples in this current study. (Eltom *et al.*, 2023) reported that the roasting process did not affect the sodium, potassium, calcium, and phosphorus content of the peanuts studied. No significant differences were seen between the raw and roasted peanuts for any of the minerals. These results agreed with data published by (Kumar *et al.*, 2013). (Eltom *et al.*, 2023) also reported that blanching caused significant losses of potassium and calcium but not of sodium and phosphorus from the peanuts studied. Possibly, some of the loss of calcium after blanching was due to the removal of the peanut skins. It was unclear why potassium and calcium were lost during blanching and phosphorus and sodium were not. These results were in agreement with those published by (Razzak *et al.*, 2023) with peas. (Yahaya *et al.*, 2022) reported that boiling significantly reduced the percentage levels of copper, calcium, and manganese and improved the percentage levels of magnesium, sodium, and zinc in bambara groundnut. They also reported that roasting improved the percentage levels of potassium, calcium, phosphorus, magnesium, and sodium. Similar types of results were also recorded by (Eltom *et al.*, 2023).

Overall, germination tended to reduce potassium and calcium concentrations in the examined legumes — likely a result of a combination of leaching during washing/dehulling and the metabolic use or redistribution of ions during sprouting, whereas sodium concentrations were largely preserved. Roasting showed more variable effects but generally had a smaller impact on total mineral levels than germination. These trends were assessed statistically (ANOVA/Kruskal–Wallis as appropriate) and where indicated differences were significant at $p < 0.05$. From an application standpoint, if mineral retention is a priority, minimizing prolonged water exposure (or adopting shorter germination/soaking times) may help preserve K and Ca levels.

4. Conclusions

Cereal and legume flours are great sources of nutrients for human health. Different processing techniques, such as germination & roasting, affect the nutritional profile of wheat, maize, common bean seed, and groundnut flours. Germination and roasting affect the ash, moisture, fiber, protein, carbohydrate, energy, and fat content of all cereal and legume flours. Germination increased the protein and moisture contents of all flours. The results of this experiment will be helpful to fulfil the nutritional needs of human health and to guide in the formulation of numerous foods.

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Sha Md. Shahan Shahriar and Mahnoor: Conceptualization, methodology, writing - original draft, writing - review & editing. Shireen Akther, Ujala Tahir and Md. Sarwar Hossain: Conceptualization, investigation, data curation, and formal analysis, Sumaiya Dipti and Hossain Mohammad Zakir: data curation, investigation, methodology, and software. Md. Shabudden Ahamed, Talha Riaz and Sayed M A

Salam: Conceptualization, resources, supervision, validation.

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Data availability

Data will be made available on request

Declarations

Ethics approval and consent to participate

The authors declare that they have no human and/ or animal studies in this manuscript.

Competing interests

The authors declare that they have no known competing fnancial interests or personal relationships that could have appeared to infuence the work reported in this paper.