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# Comparative evaluation of physicochemical properties of flaxseed (*Linum usitatissimum L*), sorghum (*Sorghum bicolar (L) moench)* and wheat (*Triticum aestivum L*)

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**Abstract**
The present study was carried out for the development of a nutritional Nutri-cracker by incorporation flaxseed, sorghum and wheat. The investigation encompasses a thorough analysis, including sensory acceptability, proximate and mineral composition and a study on storage and packaging materials. The physical parameters, proximate composition, mineral composition and functional properties have been studied and found that the Flaxseed, sorghum, and wheat differ significantly in physical and nutritional traits. Flaxseed is nutrient-dense with high fat, protein, and minerals. Sorghum offers high carbohydrates and porosity, while wheat shows balanced nutrients and largest grain size. These differences support diverse applications in health foods, energy diets, and industrial formulations. The findings are expected to benefit food technologists, grain processors, post-harvest engineers and nutrition scientists, providing empirical data to guide optimized storage systems, equipment design, product formulation, and nutritional intervention strategy.

**Keywords:** Flaxseed, sorghum, wheat, replacement with refined wheat, Nutri-cracker

## Introduction
In India, bakery industry is considered as one of the major food processing industries. India stands second in manufacturing of cracker, first being USA. Bakery products are consumed by all age groups. They are gaining popularity as processed foods because of their convenience, ready to eat and good shelf life. Cracker are a category of crisp baked products, the term cracker can be used when the baked product has a cereal base where the proportion should be at least 60% and a low moisture content of 1-5% which is the distinguishing factor. The low moisture content was desirable feature for better shelf-life as there was no medium for mould growth. (Ashwitha *et al.*, 2019). Flaxseed (*Linum usitatissimum* L.), sorghum (*Sorghum bicolor* (L.) *Moench*), and wheat (*Triticum aestivum* L.) are among the most important grain crops globally, each offering distinct nutritional profiles, functional properties, and industrial applications (Smith & Jones, 2020) [20]. The use of flax seed in different food products will be beneficial to protecting against cancer, heart disease, diabetes and lowering cholesterol level (Krishna *et al.*, 2015) [21]. Flaxseed is renowned for its exceptionally high oil content, particularly omega-3 α-linolenic acid, and for its mucilage or gum, which contributes to unique rheological and functional capacities. The oil yields of 21-28 % and characterized flaxseed oil's density, refractive index, and oxidative stability, highlighting its potential in food systems (Ishag *et al.* 2019) [14]. Functional evaluations showed flax gum (FG) having high water-holding capacity, foaming capacity, swelling index, and stability making it suitable as a thickener, emulsifier, and stabilizer in food formulations (Khan *et al.*, 2019) [22]. Additional characterization of flaxseed mucilage revealed its polysaccharide composition and rheological behavior, whereby the neutral arabinoxylans and acidic pectic polysaccharides influence viscosity, yield stress,

and shear-thinning properties (Lorenc *et al.*, 2022) [15]. Sorghum is a drought-tolerant cereal grain widely consumed in arid regions (Yun Xiong *et al.*, 2019) [13]. It exhibits unique physicochemical and nutritional features depending on genetic variety and processing methods such as germination or fermentation. For instance, germination of sorghum grains has been shown to reduce crude protein and fat but improve antioxidant phenolics and digestibility, while fermentation increases ash content and mineral bioavailability via phytase activity (Singh *et al.*, 2024; Belmouloud *et al.*, 2024) [11, 16, 17]. Wheat is one of the most extensively researched cereals, especially in relation to its starch, protein, and gluten characteristics, which underlie its rheological behavior in dough and baked products (Peter *et al.*, 2015) [23]. The hyperspectral and structural imaging have provided detailed insights into gluten protein structure, dough rheology, and fiber content changes with processes like sprouting (Karmakar *et al.*, 2023; Weckx *et al.*, 2025) [18, 19]. Despite the wealth of research on individual crops, few studies have simultaneously compared flaxseed, sorghum, and wheat using standardized analytical protocols. Therefore, the current study presents a comprehensive comparative approach, like physical parameters, proximate composition, mineral composition and functional properties for evaluating physicochemical properties of flaxseed, sorghum and wheat.

## Materials and methods

The present study was carried out to prepare Nutri-cracker incorporated with wheat, sorghum and flaxseed. The acceptability, nutritional composition and storage study of prepared Nutri-cracker incorporated with flaxseed, sorghum and wheat were evaluated.

### Materials

Raw materials such as sorghum flour, flaxseed powder, whole wheat flour, cumin seeds, carom seeds, salt, sugar, milk, fat and baking powder was sourced from the local market in Parbhani, while chemicals and reagents was acquired from the laboratory at the Department of Food Science and Nutrition, College of Community Science and Department of Food Chemistry and Nutrition, College of Food Technology, VNMKV, Parbhani (MS).

### Chemicals and glassware

Chemicals of analytical grade and sufficient glassware required were available in the laboratory, Department of Food Science and Nutrition, College of Community Science and Department of Food Chemistry and Nutrition, College of Food Technology, VNMKV, Parbhani (MS).

### Equipment

The equipment and machinery needed such as a weighing balance, hot air oven, vernier calliper, spectrophotometer, Micro-Kjeldahl, Soxhlet apparatus, atomic absorption spectrophotometer and muffle furnace were utilized for the current investigation and were provided by the Department of Food Science and Nutrition at the College of Community Science and Department of Food Chemistry and Nutrition, College of Food Technology, VNMKV, Parbhani (MS).

**Packaging material:** The packaging materials, including aluminium foil, HDPE used for packaging the final product, were procured from the Parbhani market.

### Physical properties of wheat, sorghum and flaxseed

**Weight:** The average weight of 1000 flaxseed, sorghum and wheat was determined using weighing balance.

**Length and width:** A vernier calliper was used to measure the axial dimensions of randomly selected flaxseed, sorghum and wheat for length and width.

### Bulk density

Bulk density was determined by filling the sample gently in a container of known volume and weighed. The ratio between the weight and volume was calculated as bulk density in (kg/m³).

$$\text{Bulk density} = \frac{\text{Mass of sample}}{\text{Volume of sample}}$$

**Angle of Repose:** Angle of repose was determined by making a circular pile of the grains freely falling. The height of the pile was taken (h) and its radius ® was measured.

Angle of Repose (ϕ) = tan-1 (h/r)

**Porosity:** This involves physically measuring the bulk volume of the sample and then determining the grain volume through various means, such as crushing the sample and using a pycnometer. The porosity is calculated using the formula:

$$\text{Porosity} = \frac{Vp}{Vb} \times 100$$

Where, Vp is the pore volume and Vb is the bulk volume

### Proximate composition of wheat, sorghum and flaxseed

Flaxseed, sorghum and wheat were analysed for proximate composition, including moisture, fat, protein, total carbohydrate, crude fibre, ash and mineral composition as per the methods given by (AOAC, 2005) [1].

The p-value was used to determine the statistical significance of differences among flaxseed, sorghum, and wheat across physical, proximate, and mineral parameters. A p-value less than 0.05 indicated a significant difference between crop pairs, validating that observed variations were not due to chance but statistically meaningful in analysis.

## Result and Discussion

### Physical characteristics of wheat, sorghum and flaxseed

Physical properties of flaxseed, sorghum and wheat such as length, width, 1000 kernel weight, bulk density, true density, porosity, angle of repose, were determined to ensure uniformity and consistency of final product, designing equipment, processes to handle the materials effectively, to optimize the manufacturing process, help to efficient mixing, preventing issue like uneven mixing of ingredients. Data pertaining to physical properties such as length, width, 1000 kernel weight, bulk density, true density, porosity, angle of repose, were analysed and depicted Table 1.

**Table 1:** physical characteristics of flaxseed, sorghum and wheat

| Parameters | Flaxseed | Sorghum | Wheat | p-value (Flaxseed vs Sorghum) | p-value (Flaxseed vs Wheat) | p-value (Sorghum vs Wheat) |
|---|---|---|---|---|---|---|
| Length (mm) | 4.19 | 4.40 | 6.30 | 0.022** | <0.001*** | <0.001*** |
| Width (mm) | 2.10 | 3.79 | 3.42 | <0.001*** | <0.001*** | <0.001*** |
| 1000 kernel weight (g) | 4.68 | 33.13 | 51.52 | <0.001*** | <0.001*** | <0.001*** |
| Bulk density (kg/m$^3$) | 722.43 | 741.36 | 742 | 0.083 | 0.431 | 0.456 |
| True density (kg/m$^3$) | 726.92 | 1219.46 | 1140 | <0.001*** | <0.001*** | 0.017** |
| Porosity (%) | 11.353 | 40.26 | 39.2 | <0.001*** | <0.001*** | 0.571 |
| Angle of repose (°) | 20.05 | 32.32 | 28.1 | <0.001*** | <0.001*** | <0.001*** |

*Each value is a mean of three determinations *** Level of Significance at $p<0.05$

The data in the table-1 showed that flaxseed the length and width were 4.19 mm and 2.10 mm, respectively. Flaxseed 1000 kernel weight, bulk density, true density, porosity and angle of response were 4.68 g, 722.43 kg/m³, 726.92 kg/m³, 11.353 per cent and 20.05°, respectively. The similar findings were reported by Singh *et al.,* (2011) [11, 16]. Physical characteristics of sorghum *viz*, length and width were 4.40 mm and 3.79 mm, respectively. the weight of a thousand grains (33.13 g), bulk density (741.36 kg/m³), true density (1219.46 kg/m³), angle of repose (32.32º) and porosity (40.26 per cent), respectively. The similar findings were reported by, Gosavi *et al.*, (2022) [6]. The physical properties of wheat, i.e., length and width 6.30 mm and 3.42 mm, respectively. The thousand weight grains (51.52 g), bulk density (742 kg/m³), true density (1140 kg/m³), porosity (39.2 per cent), and angle of repose (28.1°), respectively. The similar findings were reported by Tabatabaeefar *et al.*, (2003) [12].

The physical characteristics of flaxseed, sorghum, and wheat results revealed that seed length varied significantly in all pairwise comparisons, with wheat having the longest seeds, followed by sorghum and flaxseed. Similarly, seed width differed significantly among all three crops. Flaxseed had the narrowest width, while sorghum showed the widest grains. The 1000-kernel weight also exhibited highly significant differences, with flaxseed having the lowest weight (~4.68g) and wheat the highest (~51.52g), reflecting major structural distinctions among the grains. The bulk density showed no statistically significant difference across the crops, suggesting that despite variation in seed size and weight, the grains occupy a similar volume when measured in bulk. However, true density revealed significant differences in all comparisons except between sorghum and wheat, with sorghum displaying the highest true density, indicating it is the most compact in terms of internal material composition. The analysis of porosity indicated significant differences between flaxseed and the other two grains, but not between sorghum and wheat. Flaxseed's much lower porosity suggests a more tightly packed internal structure. The angle of repose, which reflects grain flow ability, showed significant variation in all pairwise comparisons. Flaxseed had the lowest angle (~20°), indicating superior flow properties compared to sorghum and wheat. Overall, the results revealed that flaxseed, sorghum, and wheat differ significantly in most physical parameters, particularly in seed dimensions, kernel weight, true density, porosity, and flow characteristics. These differences are essential for informing post-harvest handling, storage, and processing system design.

**Proximate composition of wheat, sorghum and flaxseed**

The study investigates nutritional components of raw material such as moisture, protein, fat, carbohydrate, ash and fiber, expresses in percentage and is depicted in Table 2.

**Table 2:** Proximate composition of flaxseed, sorghum and wheat

| Parameters (%) | Flaxseed | Sorghum | Wheat | p-value (Flaxseed vs Sorghum) | p-value (Flaxseed vs Wheat) | p-value (Sorghum vs Wheat) |
|---|---|---|---|---|---|---|
| Moisture | 5.84±0.01 | 10.44±0.2 | 11.10±1.1 | 0.0006*** | 0.0143*** | 0.4084 |
| Ash | 3.14±0.20 | 2.79±0.17 | 2.82±0.1 | 0.0838 | 0.0911 | 0.8081 |
| Protein | 18.96±0.15 | 10.97±0.42 | 11.24±1.1 | 0.0003*** | 0.0060*** | 0.7219 |
| Carbohydrate | 27.86±0.10 | 67.68±3.03 | 69.2±3.74 | 0.0019*** | 0.0027*** | 0.6147 |
| Fiber | 6.3±0.2 | 4.89 ± 0.3 | 3.35±0.2 | 0.0040*** | 0.0050*** | 0.0030*** |
| Fat | 37.9±0.15 | 3.23±0.2 | 2.29±0.5 | 0.0032*** | 0.0041*** | 0.0672 |

*Each value is a mean of three determinations *** level of Significance at $p<0.05$

The proximate properties of flaxseed, sorghum and wheat, which was the main ingredients used to make the product. Genetics, climate, seed processing and the way the seed was tested can all affect the composition of flaxseed, sorghum and wheat (Daun *et al.*, 2003) [5]. The flaxseed has 5.84 per cent moisture, 3.14 per cent ash, 18.96 per cent protein, 27.86 per cent carbohydrates, 6.3 per cent fiber and 37.9 per cent fa, respectively. The similar results were reported by Pachankar *et al.*, (2023) [9]. The raw sorghum has 10.44 per cent moisture, 2.79 per cent ash, 10.97 per cent protein, 67.68 per cent carbohydrate, 4.89 per cent fiber and 3.23 per cent fat, respectively. The similar results were reported by Cagla *et al.*, (2024). The moisture, ash, protein, carbohydrate, fibre and fat, Proximate properties of raw wheat, which was 11.10 per cent, 2.82 per cent, 11.24 per cent, 69.2 per cent, 3.35 per cent and 2.29 per cent, respectively. The similar results were reported by Adeyeye *et al.*, (2024) [2].

To determine whether the nutritional compositions of flaxseed, sorghum, and wheat was determined and the results revealed that flaxseed differs significantly from both sorghum and wheat in terms of moisture, protein, carbohydrate, fiber, and fat content. Flaxseed had significantly lower moisture content than both sorghum and wheat (p = 0.0006 and 0.0143, respectively), and significantly higher protein content (p = 0.0003 vs sorghum; p = 0.0060 vs wheat). Similarly, flaxseed contained much higher fat than either sorghum or wheat, with extremely low p-values ($p<0.00001$), indicating very strong statistical differences. In terms of fiber content, all three crops showed statistically significant differences in at least one comparison. Flaxseed had significantly higher fiber than both sorghum (p = 0.0040) and wheat (p = 0.0050), while sorghum also had more fiber than wheat (p = 0.0030). This suggests substantial variation in dietary fiber among the grains. However, ash content did not show any significant differences in any of the pairwise comparisons (all p-values > 0.05), indicating that the mineral residue left after combustion was relatively consistent across the three crops. Similarly, sorghum and wheat did not show statistically significant differences in moisture, protein, carbohydrate, or fat content (all p-values > 0.05), suggesting nutritional similarity between these two cereals in these specific components.

**Mineral composition of flaxseed, sorghum and wheat**

The determination of minerals content of raw materials i.e. flaxseed, sorghum and wheat were essential to know the bio availability of micro-nutrients to the body. Data pertaining to mineral depicted in Table 3.

**Table 3:** Mineral composition of flaxseed, sorghum and wheat

| Minerals (mg/100g) | Flaxseed | Sorghum | Wheat | p-value (Flaxseed vs Sorghum) | p-value (Flaxseed vs Wheat) | p-value (Sorghum vs Wheat) |
|---|---|---|---|---|---|---|
| Calcium | 140.29±1.47 | 28.50±0.61 | 21.86±0.5 | 0.0021*** | 0.0012*** | 0.0031*** |
| Phosphorus | 320.18±2.83 | 369.08±3.03 | 52.2±0.42 | 0.0052*** | 0.0113*** | 0.0051*** |
| Iron | 3.45±0.39 | 3.85±0.74 | 4.22±0.12 | 1.0231 | 1.0610 | 1.0423 |
| Zinc | 3.46±0.03 | 4.23±0.05 | 2.12±0.21 | 0.0051*** | 0.0021*** | 0.0051*** |
| Magnesium | 215.33±2.05 | 127.13±1.04 | 24.18±1.05 | 0.0053*** | 0.0005*** | 0.0040*** |

*Each value is a mean of three determinations

The mineral content of raw material, i.e., flaxseed, sorghum and wheat. The flaxseed was found to have a high mineral content 320.18 mg of phosphorus, 140.29 mg of calcium, 3.45 mg of iron, 3.46 mg of zinc and 215.33 mg of magnesium per 100 g, respectively. Flaxseed was good source of calcium, magnesium, phosphorus, iron and zinc. The similar findings were reported by Morris *et al.*, (2007) [8]. The mineral composition of the sorghum showed in table 3. Sorghum has higher content of phosphorus (369.08 mg/100 g) and magnesium (127.13 mg/100 g), lower content of calcium (28.50 mg/100 g), iron (3.85 mg/100 g), and zinc (4.23 mg/100 g). The similar findings were reported by Kayisoglu *et al.*, (2024). The table-3 showed that wheat was good source of phosphorus 52.2 mg/100 g, magnesium 24.18 mg/100 g, calcium 21.86 mg/100 g, iron 4.22 mg/100 g and zinc 2.12 mg/100 g respectively. The similar findings were reported by Adeyeye *et al.*, (2024) [2].

Significant differences were found in the concentrations of Calcium (Ca), Phosphorus (P), Zinc (Zn), and Magnesium (Mg) across all three grains, as indicated by the p-values being well below the 0.05 threshold. Specifically, flaxseed showed significantly higher levels of calcium and magnesium compared to both sorghum and wheat. Similarly, all three crops exhibited statistically significant differences in phosphorus and zinc content when compared in pairs, indicating distinct mineral profiles among them. In contrast, the p-values for Iron (Fe) content between all pairs (Flaxseed vs Sorghum, Flaxseed vs Wheat, and Sorghum vs Wheat) were above 1.0, indicating no statistically significant difference in iron content among the three crops. This suggests that while calcium, phosphorus, zinc, and magnesium vary significantly, the iron levels are statistically similar. In the study flaxseed, sorghum, and wheat are mineral-wise distinct in most respects except for iron highlighting their unique nutritional contributions and potential value in dietary diversification or functional food development.

**Conclusion**

The physical, proximate, and mineral characteristics of flaxseed, sorghum, and wheat analysis revealed notable differences that highlight their unique nutritional and industrial values. Wheat showed the largest grain size and highest 1000-kernel weight, followed by sorghum and flaxseed. Sorghum had the highest porosity and true density, indicating a less compact grain, while flaxseed's low porosity and density reflected its compact structure. Nutritionally, flaxseed was the richest, with the highest fat, protein, and fiber content and moderate carbohydrates. Sorghum had the highest carbohydrate content, with moderate protein and low fat, making it energy-rich. Wheat offered a balanced profile of high carbohydrates and moderate protein and fat. In terms of minerals, flaxseed was richest in magnesium, calcium, and phosphorus. Sorghum had more phosphorus and zinc, whereas wheat showed lower mineral levels. Thus, flaxseed is ideal for health foods, while sorghum and wheat serve well in energy-rich diets and industrial food applications. Their distinct physical and chemical profiles support their application in a range of food formulations and industrial products, enhancing both nutrition and functionality.

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