



Proximate Composition and Tannin Content of Whole-Grain Sorghum Flour and Formulated Sorghum Rusks

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Abstract

Sorghum (*Sorghum bicolor* (L.) Moench) is a climate-resilient, gluten-free cereal with considerable potential for food diversification, value addition and improved food and nutrition security. This study evaluated the proximate composition, tannin content of whole-grain sorghum flour and sorghum-based rusks to assess changes associated with processing and product formulation. Whole sorghum grains obtained from local farmers in Lesotho were cleaned, washed, dried and milled to produce whole-grain sorghum flour. The flour was subsequently used to formulate rusks with additional ingredients, including pumpkin, eggs, milk, margarine, raisins, sugar, salt and bicarbonate of soda. Proximate composition was determined using standard analytical methods, while tannin content was assessed. Significant differences ($P \leq 0.05$) were observed between sorghum flour and rusks for the measured proximate components. Sorghum flour contained higher moisture (10.90 g/100 g), carbohydrate (71.29 g/100 g), crude fibre (5.10 g/100 g) and tannin (3.90 g/100 g), whereas the rusks contained higher ash (2.14 g/100 g), fat (14.71 g/100 g), protein (16.65 g/100 g) and energy (435.51 kcal/100 g). The moisture content decreased to 6.50 g/100 g in the rusks, reflecting the drying effect of the baking process. Tannin content decreased from 3.90 to 3.30 g/100 g in the formulated rusks. The higher protein, fat and ash contents of the rusks are attributable primarily to the incorporation of additional ingredients, while moisture reduction is consistent with baking and drying effects. Overall, the findings demonstrate the potential of rusk production as a value-addition approach for improving the utilization of sorghum and developing convenient, lower-moisture and nutritionally enhanced cereal products. Sorghum-based value-added products may contribute to dietary diversification, food security and agro-processing development in sorghum-producing regions such as Lesotho.

Keywords: Sorghum; *Sorghum bicolor*; Value Addition; Proximate Composition; Tannin; Particle Size Distribution; Rusks; Agro-Processing

The rusks contain several additional ingredients, so increased protein, fat and ash are primarily associated with formulation, while moisture reduction is consistent with baking/drying.

Introduction

Sorghum (*Sorghum bicolor* (L.) Moench), locally known in Sesotho as mabele, is the fifth most important cereal crop globally after wheat, maize, rice, and barley [1]. Indigenous to Africa, sorghum is widely cultivated due to its adaptability to harsh climatic conditions, including drought and poor soils [2]. The crop is classified into four main types based on end use: grain sorghum, sweet sorghum, forage sorghum, and broomcorn [3]. Additionally, five major races, bicolor, guinea, caudatum, kafir, and durra have been identified, each with distinct agronomic and quality characteristics [4].

Sorghum grains exhibit a wide range of colours, from tan to deep purple, largely due to the presence of polyphenolic compounds in the pericarp and testa [5]. These compounds, particularly tannins, influence the sensory and functional properties of sorghum-based foods by contributing to bitterness, astringency, and darker product colour [6]. While tannins possess antioxidant properties, they are also considered anti-nutritional factors as they can bind proteins, digestive enzymes, and minerals, thereby reduce nutrient bioavailability and inhibit fermentation processes [6]. Furthermore, the hard vitreous endosperm structure of sorghum often results in coarse flour with gritty textural characteristics, which can affect the quality of baked products such as biscuits and rusks [7]. Structurally, the sorghum grain comprises the seed coat (7.3-9.3%), embryo (7.8-12.1%), and endosperm (81.1-84.6%) [8]. The endosperm, which constitutes the largest proportion, is rich in starch and proteins and therefore serves as the primary nutritional component for human

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consumption and animal feed. Overall, sorghum grain is composed of approximately 65-75% carbohydrates, 7-12% protein, 2-6% lipids, and 12-14% moisture. It is also a valuable source of dietary fibre, B-vitamins (including thiamine, riboflavin, and pyridoxine), fat-soluble vitamins, and essential minerals such as potassium, phosphorus, magnesium, and zinc [9].

Globally, sorghum is utilized for diverse purposes, including animal feed, bio-ethanol production, and traditional fermented foods [10, 11]. Importantly, sorghum is naturally gluten-free, making it a suitable alternative for individuals with celiac disease and other gluten-related disorders [7]. Celiac disease is a chronic immune-mediated condition triggered by gluten ingestion, affecting approximately 1% of the global population. Individuals diagnosed with this condition must adhere to a strict gluten-free diet, which is often nutritionally imbalanced and limited in variety. In this context, sorghum-based products present a promising opportunity to develop nutritious and functional gluten-free foods [7].

Despite its nutritional and functional potential, sorghum remains underutilized in many parts of Lesotho. Its consumption has declined partly because of labour-intensive traditional processing methods, lengthy preparation times and changing consumer perceptions of traditional sorghum foods [1]. Limited application of modern processing and product-development technologies has further constrained opportunities for commercial utilization and value addition [12].

The development of convenient, shelf-stable and nutritionally valuable products provides an opportunity to increase the utilization of locally produced sorghum. Rusks are particularly suitable for value addition because their low moisture content and extended baking process can produce a relatively shelf-stable product while allowing the incorporation of other locally available and nutrient-rich ingredients. However, processing and formulation can alter the nutritional composition and physical characteristics of sorghum-based products [13]. Understanding these changes is therefore important for the development and commercialization of acceptable and nutritionally valuable sorghum products.

Although sorghum has been investigated extensively for its nutritional composition and application in baked products, there is limited information on the nutritional changes associated with processing whole-grain sorghum flour into formulated rusks in the Lesotho context. This study therefore evaluated the nutritional composition and tannin content of whole-grain sorghum flour and sorghum-based rusks. The study further considered the implications of processing and formulation for sorghum value addition and product development in Lesotho.

Materials and Methods

Sample collection

Whole sorghum grains were purchased from local farmers in Lesotho. Other ingredients were purchased from the local supermarkets in Maseru, Lesotho.

Preparation of whole-grain sorghum flour

Sorghum grains were manually sorted to remove dirt, damaged kernels, and other foreign materials, followed by washing under running water and thorough drying. The cleaned and dried grains were then milled using a small-scale hammer mill located in Roma Valley, Lesotho, to produce fine sorghum flour.

Milling techniques are known to influence flour characteristics and functionality. For instance, stone milling produces whole grain flour by grinding the entire kernel without separating the endosperm, bran, and germ [14]. In contrast, roller milling separates the bran and germ from the endosperm, allowing the flour to pass through a series of sieves to achieve varying degrees of fineness [6]. The milling process may also cause mechanical damage to starch granules, altering their physicochemical properties, including increased water absorption capacity and susceptibility to enzymatic hydrolysis [15]. Additionally, failure to remove the germ during milling can lead to reduced shelf life due to the high oil content, which promotes rancidity and negatively affects product palatability [7]. Overall, milling has a significant impact on the sensory and functional properties of cereal-based products and subsequent cooking processes. In this study, whole grain sorghum flour was produced by retaining all anatomical components of the grain, namely the bran, germ, and endosperm, in proportions similar to those found in the intact caryopsis. The sorghum flour was then packaged and stored until needed for use.

Formulation and preparation of sorghum rusks

Sorghum Rusks were prepared using plain sorghum flour, pumpkin, margarine, bicarbonate of soda, eggs, salt, sugar, milk and raisins. All ingredients (Table 1) were mixed together in a bowl. After mixing, the dough was hand kneaded for 5 minutes. A stiff dough is prepared from the ingredients then round balls of dough are closely packed in pans and baked at 180°C, after which long chunks are cut or broken off and slowly re-baked at 80°C to dry consistency. The dried rusks were cooled and packed into polythene bags and stored under refrigeration (4°C) until needed for analysis.

Bakers' percentage

The quantities of ingredients were calculated and adjusted to produce the required yield. The Baker's percentage was used because it is considered the most precise and easy to follow step-by-step procedure for standardising baked formulas. Baker's percentages were calculated by expressing the weight of each ingredient as a percentage of the total flour weight, with sorghum flour designated as 100% as follows: The following formula was used to calculate the weight of all other ingredients:

$$\text{Ingredient (\%)} = (\text{Weight of ingredient} / \text{Weight of flour}) \times 100$$

Proximate analysis of Sorghum products

The procedures for proximate analysis of products are stated below:

Moisture: The moisture content of the flours was determined by oven drying method American Association of Cereal Chemists; 2000.

Table 1: Formulation of sorghum rusks expressed as baker's percentages.

Ingredients	Baker's Percentage
Sorghum flour	100
Margarine	34.6
Pumpkin	31.4
Eggs	37.7
Salt	1.6
Sugar	37.1
Milk	39.3
Raisins	22.0
Bicarbonate of soda	1.5

Table 2: Proximate composition per 100g weight of sample analysed.

Samples	Ash	Moisture	Crude Fibre	Carbohydrate	Fat	Protein	Total Energy kcal/100g
Sorghum Flour	1.22±0.01 ^a	10.9±0.04 ^a	5.10±0.43 ^a	71.29±0.01 ^a	2.60±0.13 ^a	8.89±0.82 ^a	344.12 ±0.03 ^a
Sorghum Rusks	2.14±0.03 ^b	6.5±0.01 ^b	3.74±0.03 ^b	56.26±0.02 ^b	14.71±0.43 ^b	16.65±0.4 ^b	424.03 ±0.04 ^b

*Values are means ± S.D of triplicate determinations. ($P \leq 0.05$)

Different letters in the same column indicate significant differences ($p \leq 0.05$)

Method 44-15A. Moisture content was determined by weighing 2.0 g of the sample and drying in an oven at 105°C for 3 hours. The dried samples were cooled and weighed. Moisture content was determined using the equation below:

$$\text{Moisture (\%)} = \frac{[(\text{Weight of wet sample} - \text{Weight of dry sample}) / \text{Weight of sample}] \times 100}{}$$

Ash: Ash was determined using a muffle oven according to American Association of Cereal Chemists; 2000, Method 08-01. Fresh 2.0g sample was weighed into a porcelain crucible and placed in a furnace preheated to 600°C and it was held at this temperature for 2 hours, then it transferred directly to a desiccator to cool and weighed immediately.

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

Crude fibre: Fresh 2.0g sample was refluxed with 100mL 0.023 M H_2SO_4 for 30 minutes and filtered, the residue was washed with 40 mL warm water to remove the acid. The residue was refluxed 100mL of 0.312M of NaOH for 30 minutes and filtered, oven dried for 10 min at 80°C and weighed. It was then ashed using low flame burner.

$$\text{Crude fibre (\%)} = \frac{[(\text{Weight of residue} - \text{Weight of ash}) / \text{Weight of sample}] \times 100}{}$$

Protein

Protein content determination: Determination of protein content in samples was performed by Kjeldahl flask method as recommended by the AOAC International [16]. The conversion factor of nitrogen to protein was 6.25. About 1g of the sample was digested with 98% sulfuric acid, 10g K_2SO_4 and 0.1g of CuSO_4 used as a catalyst. The mixture was heated for 4 hours for a colorless solution to emerge and cooled for 30 minutes. The digest was then diluted with 250 mL of distilled water 100mL of 50% NaOH was added and distilled with NH_3 which was collected into 4% boric acid, the ammonia collected was then titrated using with 0.1N sulphuric acid.

Fat content: Crude fat was determined by a Soxhlet extraction method (American Association of Cereal Chemists, 2000). Method 30-25. The sample was pre-dried and about 2.0g was weighed into a pre-dried extraction thimble, with porosity permitting a rapid flow of n-hexane. The sample in the thimble was covered with glass wool. 3 pre-dried boiling flasks were also weighed. N-hexane was then placed in boiling flask. The boiling flask, Soxhlet flask and a condenser were then assembled. Extraction was done at rate of 5 or 6 drops per second by condensation for about 4 hours. Boiling flasks with extracted fat were oven dried at 100°C for 30 minutes, cooled in a desiccator and weighed.

$$\text{Fat (\%)} = \frac{[(\text{Weight of flask} + \text{extracted fat} - \text{Weight of empty flask}) / \text{Weight of sample}] \times 100}{}$$

Carbohydrate content: The carbohydrate content was determined by the difference by summing up the determined values of moisture, ash, protein, crude fat and deducting from the total weight of the food [17].

Calculation of carbohydrate content:

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

Energy content determination: The energy content (E) of the bread samples was calculated using method as described by (Adegunwa et al., 2017).

$$(\text{Protein} = 4 \text{ kcal/g, Fat} = 9 \text{ kcal/g, Carbohydrate} = 4 \text{ kcal/g})$$

$$E = (4 \times \text{Protein}) + (9 \times \text{Fat}) + (4 \times \text{Carbohydrate})$$

Tannin content determination: Tannin content was determined using the vanillin-hydrochloric acid (vanillin-HCl) colorimetric method. Briefly, 0.2 g of each sample was weighed into a conical flask and extracted with 10 mL of 1% concentrated hydrochloric acid in methanol. The flask was tightly closed and continuously shaken for 20 minutes. The extract was then centrifuged at 2500 rpm for 5 minutes. Following centrifugation, 1.0 mL of the supernatant was transferred into a test tube containing 5 mL of vanillin-HCl reagent. The mixture was incubated at 30°C for 20 minutes, after which absorbance was measured at 450 nm using a UV-visible spectrophotometer. A blank was prepared for each analytical run. Tannin concentration was determined from the measured absorbance and expressed as catechin equivalents, using the established vanillin-HCl colorimetric procedure. All determinations were conducted in triplicate, and results were expressed as mean ± standard deviation.

Experimental design and statistical analysis

The results were subjected to a one-way Analysis of Variance (ANOVA) and Duncan's multiple range tests were used to establish if there were significant differences between mean values at ($P < 0.05$) using the Statistical Package for the Social Sciences (SPSS), version 23.0.

Results and Discussion

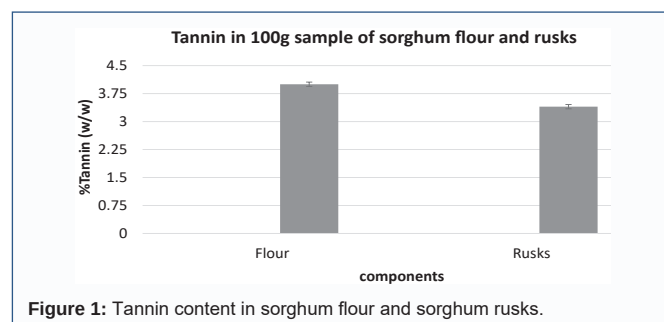
Proximate composition

The ash content of sorghum rusks (2.14 g/100 g) was noticeably higher than that of sorghum flour (1.22 g/100 g), as presented in Table 2. Ash content represents the total mineral composition of a food product and is an important indicator of its nutritional value [18]. The observed increase in ash content in the sorghum rusks can be attributed to the incorporation of additional ingredients such as pumpkin, milk and eggs during product formulation. These ingredients are known to contribute significant amounts of essential minerals, thereby enhancing the overall mineral content of the final product. However, individual mineral concentrations and their bioavailability were not determined in this study. It is important to note that the high temperature may cause the volatilization of certain elements (particularly K, Na, Cl, and P) and may also cause the mineral matter to melt and fuse. The results suggest that processing and formulation play a critical role in improving the nutritional profile of sorghum-based products. The enrichment of sorghum rusks with mineral-rich ingredients not only enhances their ash content but

Table 3: Absorbance and measured tannin content of whole-grain sorghum flour and formulated sorghum rusk-(Tannin g catechin equivalents/100 g sample).

Sample	Absorbance	Tannin (g/100g)
Sample flour	0.032±0.0015 ^a	3.9 ^a
Sample rusks	0.025±0.0026 ^b	3.3 ^b

Values are means ± standard deviation of three determinations. Different superscript letters indicate significant differences ($p \leq 0.05$)



may also improve their dietary value, making them a more nutritious alternative to unprocessed sorghum flour.

The moisture content of sorghum rusks was significantly lower than that of sorghum flour, with values of 6.5 g/100 g and 10.9 g/100 g, respectively (Table 2). This indicates that the moisture content of sorghum flour was nearly twice that of the processed product. The lower moisture content of the rusks is primarily associated with the baking and subsequent drying steps, which remove water from the product. These results are in agreement with Serrem *et al.*, [19] who obtained 11.8g moisture in sorghum flour. In contrast, sorghum rusks possess a more compact and rigid structure, limiting their ability to retain water. A major contributing factor to the reduced moisture content in sorghum rusks is the processing method, particularly the double baking process, which facilitates extensive moisture removal [20]. Similar reductions in moisture content during processing have been reported by Ahmed *et al.*, [18] who observed a significant decrease ($P \leq 0.05$) in moisture levels following thermal treatment of sorghum-based products. From a storage and safety perspective, moisture content is a critical quality parameter. High moisture levels promote microbial growth and enzymatic activity, leading to rapid deterioration during storage. Therefore, the lower moisture content observed in sorghum rusks is advantageous, as it may contribute to enhanced shelf stability and reduced susceptibility to microbial spoilage.

The carbohydrate content was lower in the formulated rusks (56.26g/100 g) than in the whole-grain flour (71.29g/100 g) (Table 2). The carbohydrate was calculated by difference, this lower value of carbohydrates in rusks reflects the relative contribution of the other proximate components, particularly the higher protein and fat contents of the formulated product. This difference can also be attributed to the thermal processing conditions during rusk preparation. The high temperatures applied during baking promote chemical changes such as caramelization and Maillard reactions, which can reduce measurable carbohydrate content. Additionally, the loss of moisture during baking concentrates some components while altering the overall composition of the final product [21]. Furthermore, the incorporation of additional ingredients during rusk production contributes to an increase in other nutrients, particularly protein and fat, thereby proportionally reducing the carbohydrate content. The results of this study are in line with the record that cooking did

not reduce the carbohydrate content significantly ($P > 0.05$), whereas samples fermented and added with curd had significantly reduced carbohydrate ($p \leq 0.05$) [22]. Carbohydrates are the primary source of energy for the human body, providing approximately 4 kcal per gram. They are recommended to constitute the largest proportion of daily caloric intake, with a reference intake of about 300 g per day for an average adult. It is documented that beyond the slower gastric emptying rate, slowed starch digestion and beneficial effects on satiety have also been observed for sorghum. For example, a study that fed men muffins made with whole sorghum flour compared to whole wheat flour found that the sorghum muffins produced a reduced insulin and glucose responses; the mean incremental Area Under Curve (iAUC) for plasma glucose was reduced an average of 35% with sorghum, and the insulin responses reduced by 55% [23].

The results in Table 2. revealed that the fat content of the sorghum rusks samples showed a significant variation ($p \leq 0.05$). Sorghum rusks had the highest fat content (14.71g/100 g), while the flour sample had the lowest fat content (2.60g/100 g). Higher fat content can accelerate oxidative rancidity in baked goods, potentially affecting the shelf life of the samples. This increase is primarily attributed to the addition of ingredients such as milk and margarine during the preparation of the rusks, both of which contribute significant amounts of fat. Higher fat content enhances the energy density of the product, as fats provide approximately 9 kcal per gram, compared to 4 kcal per gram from carbohydrates and proteins. Consequently, sorghum rusks have a higher energy value than sorghum flour. Although lower levels of fat content were record in sorghum flour it is important to note that the major fatty acids in sorghum oil are linoleic, oleic and palmitic acids, respectively, comprising over 90% of the total fatty acids. The oils contained a high concentration of the unsaturated fatty acids (>70%) consisting of mainly linoleic acid followed by oleic acid. Linolenic acid was less than 2%. Arachidonic acid was present in negligible amount [24].

The protein content was higher in the formulated rusks (16.65 g/100 g) than in the whole-grain sorghum flour (8.89 g/100 g). This difference is primarily associated with the incorporation of protein-containing ingredients, particularly eggs and milk, into the rusk formulation.

The protein content was higher in sorghum rusks (16.65 g/100 g) than in the whole-grain sorghum flour (8.89 g/100 g). This difference is primarily associated with the incorporation of protein-containing ingredients, particularly eggs and milk, into the rusk formulation. The protein value obtained as shown in Table 2. for sorghum flour in the present study is lower than that reported by Serrem *et al.*, [19] who found a crude protein content of 12.21%. This discrepancy may be attributed to differences in sorghum variety, agronomic conditions, or post-harvest handling and milling processes, all of which are known to influence grain composition. The marked increase in protein content in sorghum rusks can be primarily linked to the incorporation of protein-rich ingredients such as eggs and milk during formulation. This suggests that product development strategies involving ingredient fortification can effectively enhance the nutritional profile of sorghum-based foods. However, while the quantity of protein is improved, the overall protein quality should also be considered, as it depends on the amino acid composition and digestibility Sorghum proteins are generally limited in essential amino acids such as lysine; therefore, the inclusion of animal-based ingredients likely improves the amino acid balance of the final product. From a nutritional perspective, the higher protein content of

sorghum rusks enhances their potential as a functional food product, particularly in addressing protein-energy malnutrition in vulnerable populations [17, 25]. Increased protein intake supports body growth, tissue repair, and the maintenance of essential physiological functions. Nevertheless, it is important to note that processing conditions, such as high-temperature baking, may also affect protein digestibility and availability, which warrants further investigation. Overall, the findings highlight the importance of value addition and formulation in improving the nutritional quality of sorghum-based products, making them more competitive with conventional wheat-based alternatives.

The fibre content was higher in sorghum flour (5.10 g/100 g) than in sorghum rusks (3.74 g/100 g), as presented in Table 2. This difference can be attributed to the use of 100% whole sorghum flour in the analysis, which retains all components of the grain, particularly the bran layer where most dietary fibre is concentrated in the outer layers of the sorghum grain [26]. In contrast, the fibre content in sorghum rusks is comparatively lower, likely due to dilution effects arising from the incorporation of other ingredients during processing, as well as possible fibre degradation during baking. Additionally, findings by Montonen *et al.*, [27] reported that sorghum contains approximately 9.42% Total Dietary Fibre (TDF), comprising 8.33% insoluble and 1.09% soluble fibre. The lower fibre content of the formulated rusks is more can probable be explained by dilution of the sorghum flour with the other ingredients used in formulation. Dietary fibre plays a crucial role in maintaining digestive health, particularly by promoting proper bowel function and preventing constipation. Furthermore, it has been associated with a reduced risk of several chronic conditions, including diabetes [28], elevated blood cholesterol [29], coronary heart disease [30], and obesity [31].

The total energy content of sorghum rusks (435.51 kcal/100 g) was higher than that of sorghum flour (415.48 kcal/100 g). This increase is primarily due to the higher fat and protein content in rusks, both of which contribute significantly to caloric value. The higher energy density of sorghum rusks makes them a suitable option for populations requiring energy-dense foods, particularly in contexts where food security and nutrient adequacy are of concern.

Tannin content

The tannin content of the sorghum flour was 3.90 g/100 g, compared with 3.30 g/100 g in the formulated sorghum rusks (Table 3; Figure 1). Thus, the rusks had a lower tannin content than the sorghum flour. This reduction was accompanied by a decrease in mean absorbance from 0.032 ± 0.0015 for the sorghum flour to 0.025 ± 0.0026 for the rusks. The difference in tannin content between the two samples was statistically significant ($p \leq 0.05$).

The reduction in tannin content may be associated with the processing conditions used in rusk preparation, particularly baking and subsequent drying. Thermal processing can modify phenolic compounds and may reduce the amount of tannin detected by colorimetric assays. The difference may also reflect the incorporation of the additional ingredients used in the rusk formulation. Therefore, the observed difference represents a change in tannin content between the whole-grain sorghum flour and the formulated, processed product and should not be attributed exclusively to thermal processing.

The observed reduction is consistent with findings reported by Xiong *et al.*, [32], who observed significant reductions ($p \leq 0.05$) in tannin content during a 24-hour fermentation period in three sorghum

varieties, namely Hamra, Shahla and Baidha, with reductions of 31%, 15% and 35%, respectively. Although the processing conditions differed from those used in the present study, these findings support the observation that processing can alter tannin levels in sorghum-based products.

Tannins are recognized as anti-nutritional factors because of their ability to interact with proteins and minerals and potentially influence their utilization [24]. The lower tannin content observed in the formulated rusks may therefore have nutritional relevance. However, mineral bioavailability, nutrient absorption and protein digestibility were not directly measured in the present study. Consequently, the reduction in tannin content should not be interpreted as direct evidence of increased mineral absorption or improved nutrient bioavailability. Rather, the finding demonstrates that formulation and processing of the sorghum flour were associated with a reduction in the measured tannin content [33, 34].

Conclusion

This study demonstrated clear differences in proximate composition and measured tannin content between whole-grain sorghum flour and formulated sorghum rusks. The rusks had higher protein, fat, ash and energy contents, primarily reflecting the incorporation of eggs, milk, margarine and other formulation ingredients. In contrast, the whole-grain sorghum flour had higher moisture, carbohydrate and crude fibre contents. The measured tannin content was lower in the formulated rusks (3.30 g/100 g) than in the sorghum flour (3.90 g/100 g). The lower moisture content may contribute to improved storage stability; however, shelf life and microbial stability were not directly evaluated. Similarly, the reduction in measured tannin content may have nutritional relevance, but mineral bioavailability, nutrient absorption and protein digestibility were not determined. Overall, the findings demonstrate the potential of rusk formulation as a value-addition approach for increasing the utilization of sorghum and developing convenient sorghum-based products in Lesotho. Further research should evaluate sensory acceptability, storage stability, mineral bioavailability and protein digestibility.

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Conflict of Interest

The author declares no conflict of interest.

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