



Article

Influence of Germination on Physicochemical, Mineral, Textural, and Nutritional Properties of Sorghum and Its Application in Gluten-Free Health Bar Development

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Abstract: The present study aimed to evaluate the nutritional enhancement of sorghum through germination and its application in gluten-free health bar development. Sorghum grains were germinated for 48 h, dried at 60 °C for 7 h 35 min, and milled into germinated sorghum flour (GSF), while un-germinated sorghum flour (UGSF) was prepared similarly without sprouting. The different formulations of health bars were developed: control (no sorghum), 25% UGSF, and 25% GSF. Proximate analysis revealed that germination significantly increased the protein content of the flour from 6.83% in UGSF to 13.87% in GSF, while the crude fiber content increased from 2.32% to 10% in GSF. The textural analysis indicated that GSF bars had lower hardness (53.71 N) compared to UGSF bars (212.52 N), with reduced gumminess and chewiness, suggesting a softer, more palatable product. The study demonstrated that germination of sorghum effectively enhances nutritional and functional properties, and its incorporation into gluten-free health bars can provide a protein- and fiber-rich functional snack suitable for health-conscious and gluten-sensitive populations.

Keywords: germination; sorghum flour; health bar; sensory; texture

1. Introduction

T Sorghum (*Sorghum bicolor* L.), also known as great millet, ranks as the fifth most important cereal globally. It is a good source of B-complex vitamins and minerals such as potassium, phosphorus, iron, and zinc [1]. Its diverse phenolic profile—comprising phenolic acids, 3-deoxyanthocyanidins, and tannins—exhibits antioxidant, anti-inflammatory, and anti-diabetic activities [2]. Consumption of whole sorghum grains supports gut health and helps lower the risk of chronic diseases. Owing to its gluten-free nature and bioactive potential, sorghum is increasingly gaining recognition as a functional ingredient in health-oriented foods.

Although, the nutritional value of sorghum is very high, the presence of anti-nutritional factors obstructs the wide acceptance of this valuable crop as staple food. Phytic acid binds to the minerals and proteins, thereby making them unavailable for human digestion [3,4]. Food crops with high anti-nutrients are considered unfit for consumption due to their negative impact on digestibility and nutrient availability unless treated/processed thoroughly [5]. In order to get rid of antinutrients present in sorghum seeds, the seed germination is considered as an effective procedure which breaks down the stored proteins, carbohydrates, and fats into more easily digestible forms by triggering numerous enzymatic activities in a dormant seed [6–8]. In a previous study, the impact of sprouting and subsequent fermentation on the physicochemical characteristics of sorghum grains was studied and



a positive impact on human health, particularly in terms of lowering the risks of oxidative stress, microbiological safety, and chronic diseases including obesity, diabetes, and cytotoxicity was reported [5,9,10].

A healthy diet is necessary for an individual's body to function properly, but due to various reasons, people frequently skip eating essential nutrients and opt for unhealthy eatables or packaged food options [11]. Various food manufacturing units produce cereal bars, snack bars, and candy bars, which are popular among young generation due to the improved flavor, color, and texture and easy availability of these ultra-processed foods. However, such preparations do not fulfill the nutritional requirements of body and lack the degree of naturalness [12,13], rather they contribute to the increased risk of metabolic disorders, obesity, diabetes etc. In this context, sorghum-based functional cereal bars represent a promising alternative to conventional ultra-processed snack products, as they combine whole-grain nutrition with improved functional, mineral, and bioactive properties. In response to this problem, the current work was designed to manufacture an energy bar that is not only nutritional and healthy but also tasty. Germinated sorghum being nutritious and gluten-free alternative to common cereals like, wheat, rye, triticale and barley, was utilized for the composition of health bar and jaggery was used in place of white sugar due to its health benefits in the form of vitamins, minerals, and energy. As the sugar is linked to cause diabetes and dental cavities, so the jaggery can act as an alternative because it has long sucrose chains that are digested slowly and can deliver energy to body for a longer period of time [14]. Moreover, jaggery is a good source of vitamins and minerals due to which it can contribute to transform a standard snack into a functional food that aligns well with the current health-conscious and sustainable dietary trends [15,16]. According to reports, an energy bar (45–80 g) contains 20–40 g of carbohydrates, 3–9 g of fat, 7–15 g of protein, and 200–300 kcal (840–1300 kJ) of energy [17]. As per the research studies, energy bars may serve as effective source of dietary fiber, biologically active substances including phytochemicals with healthful nutrients [18,19]. As a result, it is an edible food product that may fall into classification of functional foods. Despite the recognized nutritional benefits of sorghum and the improvements induced by germination, limited studies have explored the incorporation of germinated sorghum in gluten-free cereal bars, particularly with comprehensive evaluation of physicochemical, mineral, and textural properties using texture profile analysis (TPA). Therefore, the present study aims to address this gap by developing and characterizing sorghum-based gluten-free health bars.

2. Materials and Method

2.1. Preparation of Germinated and Un-Germinated Sorghum Flour

All the basic ingredients viz., sorghum grains, oats, almonds, raisins, puffed rice, jaggery and butter were purchased from the local market of Faridabad, India. In order to avoid the cross contamination, all the ingredients were transferred in separate air-tight containers and the same were open during the preparation of snack bars only. In order to be assured about the gluten-free nature of oats, the same were purchased by carefully checking the nutritional chart, gluten-free claim and certified retailer information. Sorghum grains were soaked in water for 8 h at room temperature and after that grains were kept in a wet muslin cloth and observed on regular interval of 6–8 h for 2 days till the sprouting takes place. The high humidity (80–85%) environment was maintained by covering the seeds with another moist cloth in closed container. The room temperature i.e., 25–30 °C was maintained for the germination, while ensuring some airflow to avoid the fungal growth. The uniform sprout length among most of the seeds was recorded in the range of 1 cm and the healthy, firm and white sprouts were visible without any browning. Nearly, 80% of the seeds were germinated during the process. Further, germinated sorghum grains were dried using hot air oven at 60 °C for 7 h 35 min. Drying was done to reduce the moisture in grains so that the microbial activity could be decreased for flour sample prepared from germinated grains. After drying, germinated as well as un-germinated sorghum grains were ground separately, to fine flour using a laboratory-scale grinder. The sieving through 60-mesh sieve (British Sieve Standards) was done to maintain a uniform particle size of flour. Further, the flour samples were sealed in airtight containers for further analysis.

2.2. Formulation of Health Bars

The standard health bar was prepared by dry roasting oats and puffed rice together over low heat. Raisins and almonds were chopped into small pieces, while butter and jaggery were melted together on a low flame. All ingredients were then mixed thoroughly, moulded into bar shapes, and refrigerated for 1 h to set (Table 1). This formulation served as the control (Sample 1) and did not include sorghum flour.

Table 1. Composition of different bars prepared.

S. No.	Ingredients	Standard-1 (% by Weight)	Ungerminated Sorghum Flour Bar (g) Bar 2	Ungerminated Sorghum Flour (g) Bar 3	Germinated Sorghum Flour (g) Bar 4	Germinated Sorghum Flour (g) Bar 5
1.	Sorghum flour	-	25%	30	25	30
2.	Oats	25%	10%	5	10	5
3.	Puffed Rice	15%	5%	5	5	5
4.	Almonds	5%	5%	5	5	5
5.	Raisins	9%	9%	9	9	9
6.	Butter	10%	10%	10	10	10
7.	Jaggery	36%	36%	36	36	36

For sorghum-based bars, the same basic ingredients—oats, puffed rice, butter, jaggery, raisins, and almonds—were mixed with either un-germinated sorghum flour (UGSF) or germinated sorghum flour (GSF). Specifically, Sample 2 contained 25 g UGSF, Sample 3 contained 25 g GSF in addition to the other ingredients. Similarly, the mixtures were prepared following the same process as used in Sample 1 (control) preparation and moulded into bars and refrigerated for 1 h to set.

2.3. UGSF and GSF Flour and Formulated Bar Characteristics

2.3.1. Proximate Analysis

Moisture, ash, protein, fat, and crude fiber contents of UGSF and GSF samples and formulated bar samples were determined according to the standard methods of Association of Official Analytical Chemists (AOAC, 1990), namely moisture (Method 925.10), ash (Method 923.03), protein by Kjeldahl method (Method 960.52), fat by Soxhlet extraction (Method 920.39), and crude fiber (Method 962.09). Carbohydrate content (db) of the samples was calculated according to AOAC (1990) using the formula:

$$\text{Carbohydrate\%} = 100 - (\text{Moisture\%} + \text{Ash\%} + \text{Protein\%} + \text{Fat\%} + \text{Fiber\%}) \quad (1)$$

2.3.2. Energy Value

The calorie content of UGSF and GSF samples and the prepared product i.e., health bar was derived by multiplying the percentages of protein, fat, and carbohydrate following the given formula called as Atwater system or 4-9-4 rule:

$$\text{Energy} = (4 \times \text{Protein\%}) + (9 \times \text{Fat\%}) + (4 \times \text{Carbohydrate\%}) \quad (2)$$

2.3.3. Iron, Zinc and Phosphorus Content

The mineral content i.e., Iron and Zinc content in UGSF and GSF samples and prepared bar samples was determined by using Atomic Absorption Spectrophotometer (AAS). In brief, 1 g of sample was placed in a porcelain crucible and ashed in a muffle furnace at 600 °C to eliminate organic matter. The resulting ash was then dissolved in 2.5 mL of 1 N nitric acid. The solution was filtered and subsequently diluted with Milli-Q water. The diluted filtrate was analyzed for Fe, Zn and P content. The instrument was calibrated using 1000 ppm single-element standard solutions supplied by Agilent Technologies [20].

2.3.4. Textural Properties of Bar

Texture profile analysis (TPA) was performed on the formulated health bar within 5 min of bar preparation by using a TA-XT2 Texture analyzer (Stable Micro System, Godalming, UK) with a compression probe and EXPONENT software. A row of five filaments of bar samples with similar size (3 × 3 × 3 cm³) were laid perpendicular on a flat sheet of metal and compressed using TA setting with a rate of 1.0 mm/s at 70% from the initial length pressure platter probing. Also, the test speed of 5 mm/s, post-test speed of 5 mm/s, a distance of 10 mm, time of 1 s, and a trigger force of 5 g were other parameters adjusted for texture analysis of bar samples. TPA force-time curves have been employed to calculate hardness, cohesiveness, springiness, gumminess and chewiness [21].

2.3.5. Sensory Evaluation

Sensory analysis of prepared health bar from UGSF and GSF was done by following the method given by [22] with certain minor modifications. Briefly, fifty untrained panellists including students and staff members from

Department of Nutrition and Dietetics were invited for sensory evaluation. They evaluated randomly presented bar samples identified for appearance (visual properties including size, shape), texture, color, mouth feel (a sensation perceived by the nerves in the skin of the mouth cavity) and overall acceptability (means of the measured sensory attributes) on a nine-point hedonic scale (from 1 = extremely dislike to 9 = extremely like). Samples were served at room temperature (25 °C). Judges evaluated the samples in a testing area and were instructed to rinse their mouths with water between samples to minimize any residual effect. It is possible to define sensory quality and evaluation as a combination of the various senses of perception that are used in food selection and consumption, or as a scientific discipline that measures, analyses, and interprets the results of the properties of food and other products as they are perceived by the senses of smell, sight, touch, and taste. Finally, the product was evaluated for acceptance, flavour, texture through Hedonic scale methods by 10 semi trained panel members. This test explains liking or acceptance level of all developed products. Each sample was identified, and they were all grouped at random. The panel members were informed about the study's goals and the procedures to be used for the sensory evaluation of items. Samples were offered at 25 °C, or room temperature. In order to reduce any lingering effects, panellists were encouraged to rinse their mouths with water in between samples as they assessed the samples in a testing area. A scoring card was created to evaluate the items' sensory attributes, including colour, taste, texture, flavour, and general acceptability. The sensory qualities of each product were rated on a 9-point hedonic scale, with 9 representing an exceptionally positive experience and 1 representing an extremely negative one. Each panellist was asked to provide a score to represent their choice.

2.3.6. Statistical Analysis

All experiments were conducted in triplicate unless otherwise stated, and the results are expressed as mean \pm standard deviation. Two-way analysis of variance (ANOVA) was performed to evaluate the effects of independent variables, namely flour type (UGSF and GSF) and bar formulation level, as well as their interaction on the studied parameters. Statistical analysis was carried out using Minitab Release 14 (Minitab Inc., State College, PA, USA). Differences among means were considered statistically significant at a significance level of $\alpha = 0.05$ ($p < 0.05$). For parameters expressed in rank order, frequency distribution and percentages were calculated, while numerical parameters were further analyzed for mean, standard deviation, and standard error.

3. Results and Discussion

3.1. Proximate Analysis of UGSF and GSF

The moisture content of un-germinated sorghum flour (UGSF) and germinated sorghum flour (GSF) was recorded as 9.6% and 10%, respectively (Table 2), indicating an increase in moisture following germination. These findings are consistent with earlier reports in sprouted legumes and cereals [23,24]. Lower moisture levels are desirable for improved shelf stability. Variations in reported values across studies, such as 12.63% in soaked jowar flour [25], may be attributed to differences in sorghum variety and germination technique. Additionally, the ash content decreased from 2.57% in UGSF to 1.61% in GSF, likely due to the leaching of water-soluble minerals during steeping and washing in germination [26]. Similar reductions have been reported by [24], with variations attributed to sorghum variety and drying treatments. Moving ahead, the protein content increased markedly from 6.83% in UGSF to 9.88% in GSF. This enhancement is attributed to the breakdown of phytates, increased free amino acids, synthesis of enzymatic proteins, and loss of dry matter concentrating the protein fraction during germination [26–28]. Comparable increases have been reported in germinated sorghum and ragi flours [24,29,30].

Table 2. Proximate analysis of UGSF (ungerminated sorghum flour) and GSF (germinated sorghum flour).

S. No.	Parameters	UGSF	GSF
1.	Total Energy content (kcal)	352.04 \pm 2.26 ^b	351.2 \pm 1.92 ^a
2.	Protein (%)	6.8 \pm 0.59 ^a	9.88 \pm 0.52 ^b
3.	Carbohydrate (%)	76.71 \pm 1.11 ^b	72.07 \pm 0.96 ^a
4.	Fat (%)	2 \pm 0.01 ^a	2.6 \pm 0.05 ^b
5.	Crude Fiber (%)	2.32 \pm 0.08 ^a	3.84 \pm 0.09 ^b
6.	Iron (mg/100 gm)	4.2 \pm 0.44 ^a	7.3 \pm 0.56 ^b
7.	Zinc (mg/100 gm)	3.32 \pm 0.12 ^a	4.22 \pm 0.15 ^b
8.	Moisture Content	9.6 \pm 0.98 ^a	10 \pm 0.76 ^b
9.	Ash Content	2.57 \pm 0.12 ^b	1.61 \pm 0.14 ^a

^a and ^b indicate the values from lowest to highest according to statistical analysis using ANOVA.

Fat content showed a slight increase from 2% in UGSF to 2.6% in GSF. This change may result from lipase activity during germination, which hydrolyzes lipids into fatty acids and glycerol for energy or metabolic processes [31,32]. Furthermore, the crude fiber content rose significantly from 2.32% in UGSF to 3.84% in GSF. While some studies report a moderate increase in fiber after germination [26,33], others observed a decrease, indicating variability depending on the sample and germination conditions [1,29]. The total carbohydrate content decreased from 76.71% in UGSF to 72.07% in GSF. The reduction in the carbohydrate content of germinated sorghum might be due to the starch hydrolysis during the germination. The similar results were reported in germinated brown rice [34]. Overall, germination significantly altered the proximate composition of sorghum flour, improving its protein, fiber, and carbohydrate content while slightly increasing fat and moisture levels and reducing ash content, thereby enhancing its nutritional profile for functional food applications.

The energy provided by UGSF was 352.04 kcal and by GSF was 351.2 kcal/100 gm, which showed an insignificant variation in caloric value (Table 2). Marchini [24] earlier reported that energy of UGSF and GSF was 339 kcal and 385 kcal respectively. Kokani [30] reported that the energy content of unmalted ragi was 344.70 kcal and for malted ragi, it increased to 347.86 kcal. Generally, a seed's physiological energy increases after germination because stored reserves, like starch, proteins, and fats are broken down by enzymes into simpler molecules. These molecules fuel cellular respiration, producing ATP, which powers growth processes such as cell division, elongation, and synthesis of new biomolecules [35].

3.2. Iron and Zinc Content of UGSF and GSF

The zinc content of UGSF and GSF was recorded as 3.32 mg/100 g and 4.22 mg/100 gm, on dry weight basis, respectively (Table 2). A study reported an increase in zinc content during germination, with UGSF and GSF showed a zinc content of 3.32 mg/100 gm and 4.22 mg/100 gm, respectively [36]. The total content of iron present in the UGSF and GSF was examined as 4.2 mg/100 gm and 7.3 mg/100 gm, respectively. The results were in accordance with the study conducted by [26] in which the zinc content and iron content of different sorghum flour varieties was between 0.698 mg/100 gm and 6.484 mg/100 gm and 2.262 mg and 14.08 mg/100 g, respectively. Similar results of an increase in Zn and Fe content in the sorghum after 48 h of germination were reported by [26], which might be due to the loss of water-soluble constituents during steeping and washing. Germination activates phytase enzymes, breaking down phytate (which binds minerals) and improving Zn and Fe bioavailability despite partial leaching [2,37]. The result showed that these changes in mineral content with germination makes the GSF nutritionally superior, specifically for addressing the micronutrient deficiencies in staple diets [2,26].

3.3. Proximate Analysis of Formulated Health Bars

The proximate composition of health bars prepared using un-germinated sorghum flour (UGSF), germinated sorghum flour (GSF), and a control bar is presented in Table 3. The moisture content of the control bar was 8.47%, while bars prepared with UGSF and GSF showed 11.84% and 8.33%, respectively. The higher moisture in UGSF bars may be attributed to the water-binding capacity of un-germinated flour, whereas GSF bars retained lower moisture due to structural changes during germination. These results are comparable to previous reports of 13.04% in malted composite millet flour cake [5], and 7.08% in snack bars [38]. Additionally, the total ash content was 1.84% in the control bar, 1.97% in UGSF bar, and 1.77% in GSF bar, with the slight decrease in GSF bar possibly due to leaching of minerals during germination and prior drying of the flour. Similar trends were observed in malted ragi biscuits (2.04%) [39]. Protein content increased from 7.18% in the control to 13.87% in UGSF bar and 16.18% in GSF bar, likely due to reduction of anti-nutritional factors, release of free amino acids, and concentration of proteins during germination [27,36,40]. Previous studies reported similar values in oats-sorghum bars (8.09%) [41] and millet malt energy bars (7.4%) [42]. The enhanced protein content highlights the potential of GSF bars for supplementary nutrition and mid-day meal programs. Moving ahead, fat content was 2.42% in the control bar, 3.92% in UGSF bar, and 2.74% in GSF bar. The reduction in fat for GSF bars may result from the lower oil-holding capacity of germinated flour and increased lipolytic activity during sprouting [8,30]. Crude fiber content was slightly higher in GSF bars (1.92%) compared to the control (1.79%) and UGSF bar (1.59%), consistent with the increased fiber observed in germinated sorghum flour (10%) [8] and oats-sorghum bars (6%) [41]. Total carbohydrate content decreased from 78.3% in the control bar to 66.81% in UGSF bar but increased to 69.06% in GSF bar. The rise in carbohydrates for GSF bars compared to UGSF bars (3.92%) may be attributed to enzymatic breakdown of complex polysaccharides during germination, enhancing carbohydrate availability. Comparable carbohydrate contents have been reported in malted ragi bars (69%) [43], millet malt energy bars (64%) [42], and high-protein wheat flour bars (61%) [44].

Table 3. Proximate analysis of UGSF (ungerminated sorghum flour) bar and GSF (germinated sorghum flour) bar.

S.NO	Parameters	Control Bar (Amount per 100 g)	UGSF Bar (Amount per 100 g)	GSF Bar (Amount per 100 g)
1.	Total Energy content (kcal)	363.7 ± 3.11 ^b	358 ± 2.99 ^a	365.62 ± 2.56 ^c
2.	Protein (%)	7.18 ± 0.98 ^a	13.87 ± 1.01 ^b	16.18 ± 1.05 ^c
3.	Carbohydrate (%)	78.3 ± 1.59 ^c	66.81 ± 1.98 ^a	69.06 ± 1.85 ^b
4.	Fat (%)	2.42 ± 0.12 ^a	3.92 ± 0.15 ^c	2.74 ± 0.19 ^b
5.	Crude Fiber (%)	1.79 ± 0.11 ^b	1.59 ± 0.16 ^a	1.92 ± 0.13 ^c
6.	Iron (mg/100 gm)	125.47 ± 2.85 ^a	283.08 ± 2.42 ^b	284.2 ± 2.11 ^b
7.	Zinc (mg/100 gm)	29.3 ± 1.02 ^a	33.27 ± 1.05 ^c	30.2 ± 1.09 ^b
8.	Moisture Content	8.47%	11.84 %	8.33%
9.	Ash Content	1.84%	1.97%	1.77%

^{a, b, and c} indicates the values from the lowest to highest according to statistical analysis using ANOVA. (a-lowest, b-medium and c-highest values).

The energy provided by control bar, UGSF bar, GSF bar was reported as 363.7 kcal, 358 kcal and 365.62 kcal, respectively. Safvi [43] earlier reported energy of malted ragi bar as 371 kcal (Table 3). The result was in accordance with the previous study conducted by [41] who reported energy value of 367 kcal for oats-sorghum bar. Selokar [42] also reported energy value of 370.06 kcal for millet malt bar. Overall, incorporation of germinated sorghum flour improved the protein, fiber, and carbohydrate content of the health bars, while slightly reducing fat and ash content, thereby enhancing their nutritional quality and functional potential.

3.4. Iron and Zinc Content of Formulated Health Bars

Zinc in control bar, UGSF bar and GSF bar was 29.3 mg/100 gm, 33.27 mg/100 gm and 30.2 mg/100 gm, respectively (Table 3). Result showed that zinc was slightly high in the bar with ungerminated flour which could be due to the combination of other ingredients during bar preparation. The iron content in control bar, UGSF bar and GSF bar was reported to be 125.47 mg/100 gm, 283.08 mg/100 gm and 284.2 mg/100 gm, respectively. A similar trend of high Zn and Fe content in ready to eat snack bars was observed [45]. Zinc plays an important role in maintaining the structural integrity of proteins and in regulating gene expression. Also, iron plays a significant role in the making and functioning of hemoglobin. The iron deficiency results in anemia, which is the most common global health problem among the women during their reproductive age and the children under the age of 5 years [46]. Therefore, the formulation of such health bars using sorghum fortification may contribute in overcoming the problem of anemia among women and children, if added to their routine diet.

3.5. Texture Profile Analysis of the Formulated Bar

The texture profile analysis of the health bars demonstrated notable differences among the control, UGSF, and GSF formulations (Table 4). Hardness, which indicates the force required to compress the bar, was highest in the UGSF bar (212.52 N), more than double that of the control bar (97.87 N), reflecting a denser and firmer texture likely due to the structural properties of un-germinated sorghum flour. In contrast, the GSF bar exhibited the lowest hardness (53.71 N), indicating a softer and more tender structure, which can be attributed to the enzymatic breakdown of starch and protein during germination [47]. Germination generally activates amylase and protease enzymes, which degrade complex compounds into simpler, smaller molecules, leading to a less rigid and more porous structural network [48]. Cohesiveness, representing the internal bonding strength of the bars, was lowest in the UGSF bar (0.10), suggesting it may fracture or crumble more easily under stress, whereas the GSF bar showed slightly higher cohesiveness (0.12), though still lower than the control (0.20). Springiness, which reflects the ability of the bars to recover their shape after compression, was greatest in the UGSF bar (2.68 mm) and lowest in the GSF bar (1.59 mm), indicating that germination reduces elasticity and produces a softer texture. Gumminess, a product of hardness and cohesiveness, followed a similar trend: it was highest in the UGSF bar (20.29 N), slightly higher than the control (19.61 N), but markedly lower in the GSF bar (6.59 N), demonstrating that less energy is required to deform and chew the germinated flour bar. Chewiness, which combines gumminess and springiness and reflects the total energy needed to masticate the bar, was also highest in the UGSF bar (54.46 mJ) and lowest in the GSF bar (10.47 mJ), indicating that germination produces a bar that is easier to chew and more palatable [49]. Overall, these results highlight that incorporation of germinated sorghum flour significantly softens the bar, reduces chew resistance, and improves ease of mastication, whereas un-germinated sorghum flour produces a denser, firmer, and chewier texture. This suggests that germinated flour may be more suitable for creating functional bars with improved consumer acceptability and sensory quality.

Table 4. Textural analysis of bars.

Sample	Hardness 1	Cohesiveness	Springiness	Gumminess	Chewiness
Standard	97.87 N	0.20 ratio	2.49 mm	19.61 N	48.81 mJ
UGSF Bar	212.52 N	0.10 ratio	2.68 mm	20.29 N	54.46 mJ
GSF Bar	53.71 N	0.12 ratio	1.59 mm	6.59 N	10.47 mJ

Hardness 1, cohesiveness, springiness, gumminess, and chewiness ranged from 97.87 N to 53.71 N, 0.20 ratio to 0.12 ratio, 2.49 mm to 1.59 mm, 19.61 N to 6.59 N, and 48.81 mJ to 10.47 mJ, respectively.

3.6. Organoleptic Evaluation of Health Bar

The sensory evaluation of prepared UGSF and GSF bars was done and the results have been reported in Table 5(a–e). The 9-point hedonic rating scale revealed that the sample 2 (UGSF) containing 25 gm of ungerminated sorghum flour and sample 4 containing 25 gm germinated sorghum flour were the most acceptable among all the samples, excluding control (Sample 1). The mean of texture, appearance, color, taste and overall acceptability score of Sample 2 was 6.98, 7.5, 7.54, 7.64 and 7.78, respectively. Further, the mean of score given by 50 panelists for these organoleptic parameters was 7.3 (texture), 7.06 (appearance), 7.34 (color), 7.36 (taste) and 7.58 (overall acceptability), respectively. On the other hand, the overall acceptability score of Sample 3 and Sample 5 was 6.78 and 6.52, respectively, which was lesser than those of Sample 2 and Sample 4. This shows that both the samples made with the addition of 25 gm UGSF and GSF had the highest acceptance, hence indicating this amount of sorghum flour addition as the appropriate portion of bar composition. It was observed that increasing the concentration of sorghum flour gradually decreased the acceptability in all sensory parameters i.e., texture, appearance, color, taste of UGSF and GSF snack bars. Control (Sample 1), however, had the highest overall acceptance among all samples which might be due to the coarse texture of sorghum flour that tend to taste gritty when chewed. Nevertheless, the snack bars as a gluten-free formulation can be a great alternative to gluten products along with contributing to the daily energy requirement. Overall, the consumer acceptance was recorded for UGSF and GSF snack bars with 25 gm incorporation of sorghum flour.

Table 5. Organoleptic evaluation of health bar. The organoleptic evaluation of the developed product was performed by employing a 9-point hedonic scale.

(a) Sensory evaluation of control sample (Sample 1)					
S.No.	Texture	Appearance	Colour	Taste	Overall Acceptability
1	9	8	9	9	8
2	7	8	8	7	8
3	7	6	6	7	7
4	9	8	8	8	8
5	9	8	8	9	8
6	9	8	9	9	9
7	9	8	9	8	9
8	9	8	9	9	9
9	8	9	9	8	9
10	7	6	8	9	5
11	7	8	6	7	7
12	7	8	6	7	7
13	9	8	8	8	8
14	9	8	8	8	8
15	9	9	9	9	9
16	9	8	9	9	8
17	9	9	9	9	9
18	8	8	8	8	8
19	7	8	8	8	8
20	9	9	9	9	9
21	9	9	9	8	9
22	7	8	9	9	9
23	5	4	4	6	5
24	8	6	7	8	8
25	7	6	5	6	6
26	8	8	8	8	8
27	9	9	8	8	9
28	7	5	4	5	6

Table 5. Cont.

(a) Sensory evaluation of control sample (Sample 1)					
S.No.	Texture	Appearance	Colour	Taste	Overall Acceptability
29	7	8	8	8	8
30	7	8	9	7	8
31	7	7	8	8	8
32	9	9	8	8	8
33	9	9	8	8	9
34	9	8	9	9	9
35	9	9	8	8	9
36	8	8	9	9	8
37	9	9	8	8	9
38	9	8	9	9	9
39	9	9	8	8	9
40	9	9	9	8	9
41	9	9	8	8	9
42	8	8	7	8	8
43	8	8	9	9	9
44	8	8	7	8	8
45	8	7	6	7	7
46	8	8	9	9	9
47	9	9	8	9	9
48	9	9	9	8	9
49	8	8	9	9	9
50	9	9	8	8	9
MEAN	8.22	7.98	7.96	8.08	8.2
MEDIAN	9	8	8	8	8
MODE	9	8	9	8	9
SD	0.953832228	1.097120535	1.277114094	0.899886614	1.030157507
(b) Sensory evaluation sheet of sample 2. 25 gm un-germinated sorghum flour bar					
S.No.	Texture	Appearance	Colour	Taste	Overall Acceptability
1	8	7	6	8	8
2	7	6	6	7	7
3	7	6	6	6	6
4	8	7	6	7	8
5	7	6	7	6	7
6	8	9	8	7	7
7	7	8	9	9	9
8	8	7	7	8	8
9	8	7	8	8	8
10	7	8	9	7	8
11	9	8	9	8	8
12	9	8	9	8	8
13	4	5	8	8	6
14	8	7	6	7	7
15	8	8	7	8	8
16	8	7	6	8	8
17	9	9	8	7	8
18	9	9	8	9	8
19	7	7	7	7	7
20	9	7	8	9	8
21	9	9	9	8	9
22	7	7	7	8	8
23	4	4	4	5	5
24	7	8	8	8	7
25	8	9	8	9	8
26	7	6	8	7	7
27	8	8	7	8	8
28	8	9	8	9	9
29	8	8	9	9	9
30	8	8	9	7	9

Table 5. Cont.

(b) Sensory evaluation sheet of sample 2, 25 gm un-germinated sorghum flour bar						
S.No.	Texture	Appearance	Colour	Taste	Overall Acceptability	
31	7	8	7	7	7	
32	8	8	7	7	8	
33	8	8	7	7	8	
34	8	8	7	7	8	
35	8	7	8	7	8	
36	7	8	7	8	7	
37	8	7	8	7	8	
38	8	9	9	8	8	
39	8	9	9	9	9	
40	9	8	8	9	9	
41	9	8	9	8	9	
42	7	6	7	7	7	
43	7	7	8	8	8	
44	5	6	7	7	7	
45	7	7	6	7	7	
46	7	8	7	7	7	
47	8	8	7	7	8	
48	7	8	8	8	8	
49	9	8	8	9	9	
50	8	7	8	8	8	
MEAN	6.98	7.5	7.54	7.64	7.78	
MEDIAN	8	8	8	8	8	
MODE	8	8	8	7	8	
SD	1.102131516	1.092647039	1.091899674	0.898070494	0.86402003	
(c): Sensory evaluation sheet of sample 3, 30 gm un-germinated sorghum flour bar						
S.No.	Texture	Appearance	Colour	Taste	Overall Acceptability	
1	7	6	7	5	7	
2	7	6	5	6	6	
3	7	6	7	6	6	
4	7	6	7	7	7	
5	52	6	6	5	6	
6	8	8	9	8	7	
7	7	6	7	7	8	
8	7	7	6	7	7	
9	7	6	7	7	7	
10	9	7	9	8	9	
11	4	6	6	5	6	
12	4	6	6	5	6	
13	4	4	4	5	5	
14	7	6	6	6	6	
15	7	6	6	6	7	
16	7	6	7	5	7	
17	7	7	6	6	6	
18	7	8	7	7	7	
19	7	8	6	6	6	
20	8	8	7	8	7	
21	9	7	8	8	8	
22	7	8	7	7	7	
23	7	7	6	7	7	
24	5	5	7	6	6	
25	5	4	5	6	5	
26	8	7	7	8	8	
27	7	7	7	6	7	
28	5	7	6	5	5	
29	9	8	8	8	8	
30	8	8	9	6	7	
31	8	8	8	7	8	
32	7	7	7	6	7	

Table 5. Cont.

(c): Sensory evaluation sheet of sample 3, 30 gm un-germinated sorghum flour bar					
S.No.	Texture	Appearance	Colour	Taste	Overall Acceptability
33	7	7	6	6	7
34	7	7	7	6	7
35	7	6	5	6	6
36	7	6	7	8	7
37	7	7	6	7	7
38	7	9	8	8	7
39	8	8	7	8	8
40	8	7	8	7	8
41	9	8	9	8	9
42	6	6	5	6	5
43	7	7	6	6	7
44	7	6	5	5	6
45	7	6	6	6	6
46	7	6	6	7	6
47	7	6	5	6	6
48	8	7	7	7	7
49	8	8	7	6	7
50	7	7	8	7	7
MEAN	6.98	6.72	6.68	6.5	6.78
MEDIAN	7	7	7	6	7
MODE	7	6	7	6	7
SD	1.18648856	1.030949632	1.150687461	0.994884877	0.932190749
(d) Sensory evaluation of sample 4, 25 g germinated sorghum flour bar					
S.No.	Texture	Appearance	Colour	Taste	Overall Acceptability
1	7	5	5	6	7
2	7	7	6	6	7
3	8	7	7	7	7
4	7	8	8	7	7
5	5	6	7	7	7
6	8	7	6	5	6
7	8	9	7	9	9
8	8	7	8	7	8
9	7	6	8	7	8
10	9	8	9	9	8
11	9	8	9	8	8
12	9	8	9	8	8
13	5	4	5	7	6
14	8	7	8	7	7
15	7	7	6	7	7
16	7	5	5	6	7
17	6	6	9	9	8
18	7	8	7	7	8
19	7	7	7	6	7
20	7	7	8	8	7
21	9	7	7	9	8
22	7	7	7	7	7
23	5	5	5	5	5
24	8	7	7	7	8
25	8	9	8	9	8
26	8	7	8	8	8
27	8	8	7	7	8
28	7	8	8	8	8
29	9	9	9	9	9
30	8	8	8	6	9
31	8	8	8	7	8
32	7	8	7	8	8
33	7	8	8	7	8
34	8	7	7	8	8

Table 5. Cont.

(d) Sensory evaluation of sample 4, 25 g germinated sorghum flour bar					
S.No.	Texture	Appearance	Colour	Taste	Overall Acceptability
35	6	5	7	7	7
36	7	8	7	6	8
37	8	8	7	7	7
38	7	8	9	9	9
39	7	6	8	7	8
40	8	7	8	8	8
41	8	8	9	8	9
42	6	5	7	7	7
43	7	7	8	8	8
44	7	7	8	8	7
45	7	6	7	7	7
46	8	7	8	8	8
47	5	6	6	6	6
48	7	8	7	7	7
49	7	7	6	9	9
50	7	7	7	8	7
MEAN	7.3	7.06	7.34	7.36	7.58
MEDIAN	7	7	7	7	8
MODE	7	7	7	7	8
SD	1.015190743	1.132272413	1.099350458	1.045105209	0.859283042
(e) Sensory evaluation sheet of sample 5, 30 gm germinated sorghum flour bar					
S.No.	Texture	Appearance	Colour	Taste	Overall Acceptability
1	7	6	5	5	7
2	7	6	6	6	6
3	6	7	7	8	7
4	7	6	6	6	6
5	5	5	6	6	6
6	7	7	4	7	7
7	8	8	7	7	8
8	7	6	7	6	7
9	7	8	7	7	7
10	5	8	6	7	8
11	6	5	6	4	5
12	6	5	6	4	5
13	5	4	4	5	5
14	5	5	5	4	5
15	5	6	5	5	6
16	7	6	5	5	7
17	5	5	4	4	5
18	7	7	7	6	7
19	8	7	7	7	7
20	7	6	6	6	6
21	7	7	7	7	7
22	6	7	7	8	8
23	5	4	4	5	5
24	5	5	6	6	6
25	5	4	5	6	7
26	6	6	6	7	7
27	7	7	6	6	6
28	5	6	6	5	5
29	9	8	8	9	9
30	9	8	9	6	8
31	8	8	8	8	8
32	7	6	7	6	7
33	8	7	6	6	7
34	5	6	6	6	6
35	6	5	6	7	6
36	7	6	7	8	7

Table 5. Cont.

(e) Sensory evaluation sheet of sample 5, 30 gm germinated sorghum flour bar						
S.No.	Texture	Appearance	Colour	Taste	Overall Acceptability	
37	7	6	6	6	6	
38	7	6	7	7	7	
39	7	6	5	7	7	
40	7	7	6	7	7	
41	8	7	7	8	8	
42	7	6	5	5	6	
43	7	6	7	6	6	
44	5	6	6	6	6	
45	7	6	6	6	6	
46	7	6	6	5	6	
47	7	7	6	6	6	
48	5	6	6	7	6	
49	7	8	7	7	7	
50	7	7	6	7	6	
MEAN	6.54	6.26	6.12	6.22	6.52	
MEDIAN	7	6	6	6	6.5	
MODE	7	6	6	6	7	
SD	1.1104329	1.065411677	1.042759291	1.148024034	0.952761829	

4. Conclusions

The present study demonstrated that germination of sorghum significantly enhances its nutritional and functional properties, making it a valuable ingredient for gluten-free health bars. Incorporation of germinated sorghum flour (GSF) in health bars improved protein, fiber, and carbohydrate content, while slightly reducing fat and ash levels compared to bars prepared with un-germinated sorghum flour (UGSF) or control formulations. Texture profile analysis further indicated that GSF-based bars were softer and less chewy than UGSF bars, suggesting improved textural quality and potential consumer acceptability. Overall, the use of germinated sorghum flour improved both the nutritional composition and functional characteristics of the developed bars, highlighting its potential application in the formulation of value-added gluten-free snack products. These findings primarily support product development and value addition of sorghum, indicating that germinated sorghum-based bars may serve as nutritionally improved snack alternatives rather than implying direct clinical benefits for protein–energy–deficient populations.

Author Contributions

M.K.: Writing—original draft, Methodology, Investigation, Formal analysis, Data curation, Visualization, Conceptualization, Supervision, Resources. S.T.: Validation, Software, Formal analysis, Data curation. A.K. (Aparna Kumari): Writing—original draft & editing, Investigation. A.K. (Arun Kumar): Writing review and editing, Visualization, Formal analysis, Data curation. S.J.: Writing review and editing. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The datasets analysed during the current study are available from the corresponding author on reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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