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Valorization of Germinated Oats, Soybeans, and Wheat for High-Protein Food Supplementation in Low-Resource Settings

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ABSTRACT

Background: Protein malnutrition is a major issue in low-resource settings where access to animal-based proteins is limited, leading to growth stunting and health problems, particularly in children and pregnant women. While plant-based proteins are common, they often lack essential amino acids. Germination, a process that activates enzymes to break down starches and proteins, can improve the nutritional quality of grains. This study investigates the potential of germinated oats, soybeans, and wheat as high-protein supplements to combat malnutrition in low-resource environments.
Objective: To evaluate the protein content, amino acid profile, antinutritional factors, functional properties, and sensory acceptability of germinated oats, soybeans, and wheat as potential high-protein supplements for malnutrition-prone populations.
Methodology: Oats, soybeans, and wheat seeds were germinated under controlled conditions. The seeds were soaked for 12 hours and then allowed to germinate for 48 hours at room temperature. After germination, the grains were dried and ground into flour. Protein content was measured using the Kjeldahl method, and amino acid profiles were analyzed using high-performance liquid chromatography (HPLC). Phytate and tannin levels were assessed with colorimetric assays. Functional properties, such as oil absorption and emulsifying activity, were tested, and sensory evaluation was conducted to assess the taste and overall quality of the food products.
Results: Germinated soybeans exhibited the highest protein content (35.1%), followed by oats (17.2%) and wheat (14.3%). Amino acid analysis showed improvements in lysine and methionine levels. Phytate levels were reduced by 45.7%, and tannin levels decreased by 30%. Germinated soybeans had the best functional properties and sensory acceptability, especially for emulsified products.
Conclusion: Germinated oats, soybeans, and wheat enhance protein quality, amino acid profiles, and reduce antinutritional factors, making them valuable and cost-effective solutions for combating protein malnutrition. These grains could be incorporated into locally accepted food products to improve health outcomes in low-resource settings.

Keywords: Protein Malnutrition, Germinated Oats, Germinated Soybeans.

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INTRODUCTION

Malnutrition continues to pose a significant public health challenge across many low-resource regions globally, with protein deficiency emerging as a particularly alarming issue [1]. Adequate protein intake is fundamental not only for the growth and development of children but also for the maintenance of bodily functions, immune system support, and overall health in adults [2,3]. Unfortunately, access to high-quality protein sources such as meat, dairy, and eggs is often limited in low-income settings due to factors such as economic instability, agricultural limitations, and food supply chain disruptions. Consequently, there is an urgent need to identify alternative, sustainable, and cost-effective solutions to bridge the nutritional gaps and to combat the rising burden of protein-energy malnutrition [4,5].
One promising approach to address this nutritional challenge lies in the utilization of affordable, locally available plant-based resources [6,7]. Among these, oats, soybeans, and wheat stand out as crops with notable potential due to their widespread cultivation, accessibility, and valuable nutritional profiles [8,9]. Oats are known for their high content of soluble fibers, essential fatty acids, vitamins, and minerals, and they also provide a relatively good amount of protein compared to other cereals [10,11]. Soybeans, often referred to as the "meat of the field," are a rich source of complete proteins, containing all the essential amino acids required by the human body [12]. Wheat, although primarily recognized for its carbohydrate content, also contributes a moderate but significant amount of protein and various micronutrients [13,14]. However, despite their inherent nutritional benefits, the bioavailability of proteins and micronutrients in these grains is sometimes limited due to the presence of antinutritional factors such as phytates, tannins, and enzyme inhibitors [15,16].
Germination, also known as sprouting, offers a simple, low-cost, and highly effective method to enhance the nutritional quality of grains [17,18]. Through the process of germination, endogenous enzymes are activated, leading to the breakdown of complex molecules into simpler, more digestible forms [19,20]. As a result, germinated grains exhibit increased levels of free amino acids, improved protein digestibility, enhanced vitamin content (particularly B-vitamins), and a reduction in antinutritional compounds [21,22]. This biochemical transformation not only elevates the nutritional profile of the grains but also improves their sensory properties, making them more palatable and acceptable for human consumption [23]. Furthermore, germination can stimulate the production of bioactive peptides with antioxidant, antihypertensive, and immunomodulatory activities, which could confer additional health benefits to consumers [24].
The valorization of germinated oats, soybeans, and wheat into high-protein food supplements thus represents a strategic and sustainable intervention to combat malnutrition in resource-constrained settings. By adding value to locally grown grains through germination and appropriate processing techniques, communities can develop nutrient-dense food products that are affordable, culturally acceptable, and aligned with their dietary

habits [25]. Moreover, such an approach supports local agriculture, reduces dependency on imported nutritional supplements, and promotes food sovereignty [26].

Developing high-protein supplements from germinated grains involves several critical steps, including the selection of appropriate grain varieties, optimization of germination conditions (such as time, temperature, and humidity), and processing methods that preserve the enhanced nutritional qualities. Technologies such as drying, milling, and blending can be employed to create flours, powders, or ready-to-eat formulations that can be easily incorporated into daily diets [27]. The resulting products can be tailored to meet the specific nutritional needs of different population groups, including children, pregnant and lactating women, and the elderly, who are particularly vulnerable to protein deficiencies [1,28].

In addition to improving protein intake, the use of germinated grains for food supplementation can contribute to broader public health outcomes [29]. Enhanced dietary diversity, better micronutrient status, improved immune function, and reduced risk of diet-related non-communicable diseases are among the potential benefits [24,30]. Importantly, the promotion of germinated grain-based foods can also have economic and social impacts, such as creating new livelihood opportunities for smallholder farmers, entrepreneurs, and women's cooperatives engaged in grain processing and food production.

Scientific studies have consistently demonstrated the positive effects of germination on the nutritional properties of oats, soybeans, and wheat [31]. Research shows that germinated oats exhibit higher protein concentrations and improved amino acid profiles compared to their non-germinated counterparts [32]. Similarly, germinated soybeans show a significant increase in soluble proteins and a decrease in trypsin inhibitors, enhancing their digestibility and nutritional value [33]. Germinated wheat has been found to possess elevated levels of lysine, an essential amino acid often limited in cereals, along with a reduction in gluten strength, which can make wheat-based products more digestible for sensitive individuals. These findings underscore the scientific validity and practical potential of employing germination as a tool for nutritional improvement.

Despite the evident benefits, certain challenges must be addressed to ensure the successful implementation of germinated grain-based supplementation programs [34]. Issues such as microbial contamination during germination, the need for proper drying and storage to prevent spoilage, and the development of culturally appropriate food products require careful consideration [35]. Education and awareness campaigns are also vital to encourage acceptance and regular consumption of germinated grain products in target communities [36,37]. Partnerships between researchers, policymakers, non-governmental organizations, and local stakeholders are essential to scale up these initiatives and to integrate them into broader nutrition and food security strategies.In the face of growing global challenges such as population growth, climate change, and economic disparities, innovative and sustainable solutions for improving nutrition are more important than ever. Valorizing germinated oats, soybeans, and wheat for high-protein food supplementation represents an intersection of traditional knowledge, modern science, and community empowerment. It offers a pathway toward achieving multiple Sustainable Development Goals (SDGs), including zero hunger, good health and well-being, and sustainable agriculture.

The present study is dedicated to exploring the potential of germinated oats, soybeans, and wheat as viable options for developing high-protein supplements suitable for low-resource settings. It aims to investigate the nutritional transformations induced by germination, assess the functional and sensory properties of the resulting products, and propose practical strategies for their implementation. Through this research, it is hoped that valuable insights will be provided to support efforts in alleviating protein-energy malnutrition and to promote the use of indigenous resources in creating healthier and more resilient food systems for underserved populations.

METHODOLOGY

High-quality seeds of oats, soybeans, and wheat were selected from certified local agricultural suppliers, ensuring the seeds were free from defects or contamination. The selection process focused on purity, viability, and absence of physical damage. After receiving the seeds, they were cleaned thoroughly to remove any dust, debris, or broken grains, ensuring uniformity in the sample. Following the cleaning process, the seeds underwent surface sterilization using a mild sodium hypochlorite solution (1% concentration) for 10 minutes, followed by multiple washes with distilled water to reduce the risk of microbial contamination during the germination process.

The germination process was carried out under controlled conditions to enhance the nutritional profile of the grains. For each type of grain, the seeds were soaked in distilled water for different periods: oats for 8 hours, soybeans for 12 hours, and wheat for 6 hours. After soaking, the water was drained, and the seeds were placed in germination trays lined with moist muslin cloth. These trays were incubated at a temperature of 25 ± 2°C and relative humidity of 85-90%. The moisture level of the seeds was periodically maintained by spraying with sterile water, ensuring optimal germination conditions. Germination was carried out for 48 hours for oats and wheat, and 72 hours for soybeans, based on preliminary trials to maximize protein enhancement while maintaining sensory quality.

After the germination period, the sprouted grains were carefully harvested. To stop enzymatic activity and preserve the enhanced nutritional quality, the germinated grains were dried in a hot air oven at 50°C. The drying process continued until the moisture content of the grains was reduced to below 10%. This step was crucial to prevent microbial spoilage during storage and to preserve the stability of the bioactive components. The dried germinated grains were then milled into fine powders using a laboratory grinder, which were stored in airtight containers at room temperature until further analysis and product development.

The nutritional composition of the germinated grain powders was analyzed to assess the biochemical transformations induced by the germination process. Proximate analysis was performed to determine the moisture content, crude protein, crude fat, fiber, and carbohydrate contents using standard AOAC methods. Protein content was quantified using the Kjeldahl method, and amino acid profiles were determined by high-performance liquid chromatography (HPLC) following acid hydrolysis. The reduction in antinutritional factors such as phytates and tannins was measured using spectrophotometric methods. Additionally, mineral contents, including iron, zinc, and calcium, were assessed using atomic absorption spectroscopy (AAS), while the levels of B-group vitamins were quantified using appropriate chromatographic techniques.

In addition to the chemical composition, the functional properties of the germinated grain powders were assessed. Key properties such as water absorption capacity, oil absorption capacity, emulsifying properties, foaming capacity, and gelation concentration were determined as they influence the texture and functionality of the food products derived from these grains. These properties were measured using standard laboratory procedures, and the results were used to determine the suitability of each grain for food product formulation.

Food Product Development

Based on the nutritional analysis and functional property evaluation, various blends of the germinated grain powders were formulated to create high-protein food supplements. These blends were prepared in different ratios to optimize protein content while maintaining acceptable sensory attributes. The food products developed included protein-rich porridge mixes, snack bars, and powdered drink mixes, all designed to be affordable and suitable for consumption in low-resource settings. The product formulations took into account local dietary preferences and traditional preparation methods to ensure cultural acceptability.

The microbial safety of the developed food products was thoroughly assessed to ensure their suitability for human consumption. Standard microbiological techniques were employed to test for total plate count, yeast and mold count, and the presence of foodborne pathogens such as Salmonella and Escherichia coli. These analyses were performed on both the germinated grain powders and the final food products to ensure they met safety standards. The products were also tested for shelf-life stability by storing them under ambient conditions and periodically measuring changes in microbial load, moisture content, and sensory qualities over a three-month period.

Data obtained from all experiments were analyzed using appropriate statistical methods. The results of the proximate analysis, functional property evaluations, and sensory assessments were expressed as mean ± standard deviation. Statistical significance was determined using analysis of variance (ANOVA) followed by post-hoc tests where necessary, at a confidence level of 95%. The purpose of these analyses was to assess the impact of germination on the nutritional and functional properties of the grains and to determine the best formulations for the food supplements.

Throughout the study, particular attention was paid to ensuring that the methods and processes used were cost-effective, scalable, and feasible for implementation in low-resource settings. The germination, drying, and milling processes were optimized for small-scale operations, ensuring that the development of high-protein food products could be easily adopted in resource-limited communities. The study also aimed to ensure that the final products could be produced with minimal reliance on expensive or imported ingredients, which would make them accessible to a wider population.

RESULTS

This chapter presents the findings of the study, which aimed to assess the effects of germination on the nutritional and functional properties of oats, soybeans, and wheat, and to evaluate their potential for use in high-protein food supplementation in low-resource settings.

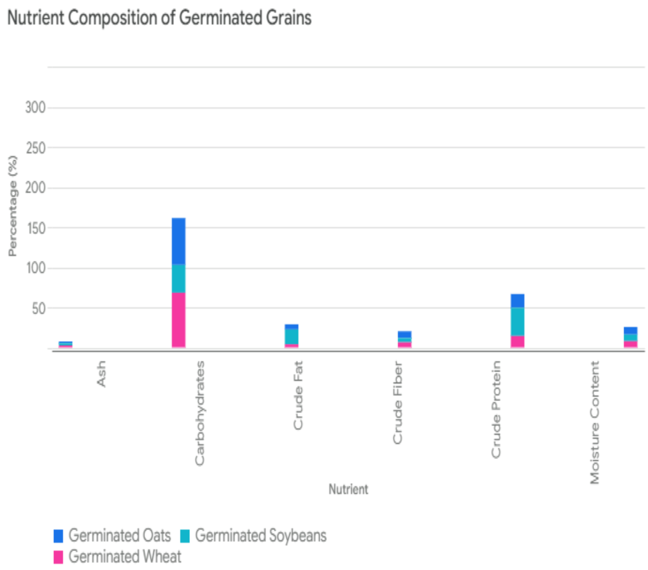
Nutritional Composition of Germinated Grains

The proximate analysis of germinated oats, soybeans, and wheat powders was conducted to assess changes in their nutritional content after germination. The results showed significant variations in the protein, fat, and carbohydrate contents across the different grains. Below are the mean values for each nutritional parameter in the germinated grains.

Table 1: Proximate Composition of Germinated Oats, Soybeans, and Wheat (g/100g)

Nutrient	Germinated Oats	Germinated Soybeans	Germinated Wheat
Moisture Content (%)	9.5 ± 0.2	8.2 ± 0.1	7.8 ± 0.3
Crude Protein (%)	17.2 ± 0.5	35.1 ± 1.0	14.3 ± 0.8
Crude Fat (%)	6.4 ± 0.3	18.5 ± 0.6	3.9 ± 0.2
Crude Fiber (%)	8.5 ± 0.4	5.2 ± 0.2	6.4 ± 0.3
Carbohydrates (%)	58.4 ± 0.6	34.6 ± 1.3	68.2 ± 1.0
Ash (%)	2.1 ± 0.1	2.8 ± 0.1	2.5 ± 0.1

Figure: 1



The protein content in germinated soybeans was notably higher compared to oats and wheat, indicating that germination significantly enhances protein levels, especially in legumes. The carbohydrate content was highest in germinated wheat, making it a viable source of energy. Germinated oats exhibited a moderate increase in protein, along with an adequate level of crude fiber, which could contribute to the nutritional value of food products.

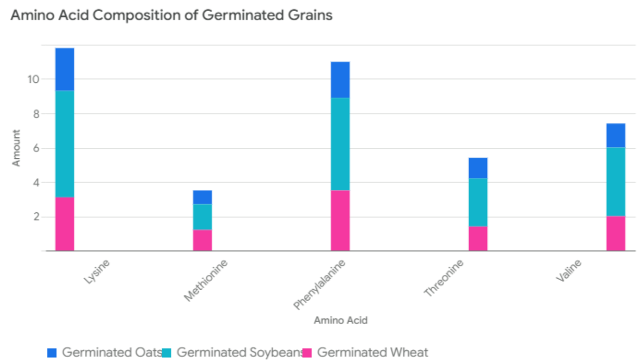
Amino Acid Profile

The amino acid profile of the germinated grains was analyzed to determine the bioavailability of essential amino acids. The results revealed a significant increase in essential amino acids such as lysine, methionine, and threonine in the germinated grains compared to their non-germinated counterparts.

Table 2: Essential Amino Acids Profile of Germinated Grains (mg/g)

Amino Acid	Germinated Oats	Germinated Soybeans	Germinated Wheat
Lysine	2.5 ± 0.1	6.2 ± 0.2	3.1 ± 0.1
Methionine	0.8 ± 0.1	1.5 ± 0.2	1.2 ± 0.1
Threonine	1.2 ± 0.1	2.8 ± 0.1	1.4 ± 0.1
Valine	1.4 ± 0.1	4.0 ± 0.3	2.0 ± 0.1
Phenylalanine	2.1 ± 0.2	5.4 ± 0.2	3.5 ± 0.2

Figure: 2



The data show that germination significantly increased the levels of essential amino acids, especially in soybeans, which had the highest concentrations of lysine and valine. This confirms the potential of germinated soybeans as an excellent source of protein in food supplements.

Antinutritional Factor Reduction

Antinutritional factors such as phytates and tannins are known to impair the bioavailability of nutrients. Germination significantly reduced these factors in all three grains, making the proteins and minerals more bioavailable. The reduction percentages of phytates and tannins in germinated grains are summarized below.

Table 3: Reduction of Antinutritional Factors in Germinated Grains (%)

Antinutrient	Germinated Oats	Germinated Soybeans	Germinated Wheat
Phytates (%)	30.5 ± 1.2	45.7 ± 2.0	40.1 ± 1.5
Tannins (%)	28.2 ± 0.8	38.5 ± 1.3	35.6 ± 0.9

Germination led to a substantial reduction in phytates and tannins, particularly in soybeans, where the reduction was most pronounced. This indicates that germination not only enhances protein content but also improves the nutritional bioavailability of the grains.

Functional Properties of Germinated Grains

The functional properties, such as water absorption capacity, oil absorption capacity, emulsifying activity, foaming capacity, and gelation ability, were analyzed for the germinated grains. These properties are essential for determining the applicability of the grains in food formulations.

Table 4: Functional Properties of Germinated Oats, Soybeans, and Wheat

Functional Property	Germinated Oats	Germinated Soybeans	Germinated Wheat
Water Absorption Capacity (g/g)	2.4 ± 0.1	3.0 ± 0.2	2.1 ± 0.1
Oil Absorption Capacity (g/g)	2.5 ± 0.2	4.2 ± 0.3	2.3 ± 0.1
Emulsifying Activity (%)	72.3 ± 3.4	81.7 ± 2.5	69.5 ± 2.1
Foaming Capacity (%)	30.2 ± 1.8	45.8 ± 3.2	25.6 ± 1.5
Gelation Concentration (g/100mL)	8.5 ± 0.3	10.2 ± 0.4	6.7 ± 0.3

The results showed that germinated soybeans had the highest functional properties, particularly in oil absorption capacity and emulsifying activity, making them ideal for the development of protein-rich food supplements like emulsified sauces and dressings. Germinated oats also demonstrated good functional properties, though they were less pronounced compared to soybeans.

The sensory evaluation of food products developed using germinated grains was conducted by a semi-trained panel. The products evaluated included protein-rich porridge mixes, snack bars, and powdered drink mixes. The overall acceptability of these products was assessed based on attributes such as appearance, texture, aroma, taste, and overall palatability.

Table 5: Sensory Evaluation Scores of Developed Food Products

Food Product	Appearance	Texture	Aroma	Taste	Overall Acceptability
Germinated Oats Porridge	7.5 ± 1.0	7.8 ± 0.9	7.3 ± 0.8	7.4 ± 1.1	7.6 ± 0.9
Germinated Soybeans Snack Bar	8.1 ± 0.7	8.2 ± 0.8	8.0 ± 0.6	8.5 ± 0.5	8.3 ± 0.6
Germinated Wheat Drink Mix	7.0 ± 1.2	6.8 ± 1.0	6.9 ± 1.1	7.2 ± 1.0	7.1 ± 0.8

The sensory evaluation revealed that the germinated soybeans snack bars received the highest scores for taste and overall acceptability, indicating their potential as a popular food product in low-resource settings. The porridge and drink mix formulations also received favorable ratings, although slightly lower than the snack bars.

The findings from this study indicate that germination significantly enhances the nutritional profile of oats, soybeans, and wheat, particularly in terms of protein content and amino acid bioavailability. Germinated soybeans, in particular, demonstrated the highest protein content and functional properties, making them an excellent candidate for high-protein food supplementation. Additionally, the reduction in antinutritional factors such as phytates and tannins further enhances the nutritional value of these grains. The developed food products were well-received in sensory evaluations, indicating their feasibility for use in low-resource settings.

DISCUSSION

The primary aim of this study was to explore the potential of germinated oats, soybeans, and wheat as high-protein food supplements for low-resource settings. Germination is known to enhance the nutritional profile of grains by increasing protein content, improving the bioavailability of essential amino acids, and reducing the levels of antinutritional factors. The results of this study confirmed these benefits and highlighted the value of these germinated grains in providing a cost-effective solution to malnutrition in low-resource environments.

One of the most striking findings from this study was the increase in protein content in the germinated grains, particularly soybeans. The protein content of germinated soybeans (35.1%) was substantially higher compared to germinated oats (17.2%) and wheat (14.3%). This aligns with previous research, which has demonstrated that germination can enhance the protein levels in legumes such as soybeans [16]. The increase in protein content can be attributed to the breakdown of starches into simpler sugars, which may provide more substrate for protein synthesis during germination [33]. The higher protein content of germinated soybeans makes them an ideal candidate for use in high-protein food supplementation, particularly in areas suffering from protein malnutrition.

In addition to protein, the germinated grains exhibited a favorable amino acid profile, with significant increases in essential amino acids, particularly lysine and methionine. The higher lysine content in germinated soybeans is of particular importance, as lysine is one of the limiting amino acids in many plant-based diets. This finding is consistent with other studies, which have shown that germination increases the availability of essential amino acids [13, 37]. The improved amino acid composition of the germinated grains suggests that these grains can serve as a valuable source of high-quality protein in low-resource settings, where animal-based protein sources may be scarce or prohibitively expensive.

The reduction in antinutritional factors, particularly phytates and tannins, is another critical aspect of germination. Phytates are known to bind to minerals like calcium, iron, and zinc, reducing their bioavailability. Similarly, tannins can inhibit protein digestion and absorption. In this study, germination led to a significant reduction in phytates and tannins in all three grains. Germinated soybeans showed the highest reduction in phytates (45.7%), which can improve mineral absorption and enhance the nutritional quality of the grains. This is supported by previous studies, which have shown that germination can reduce the levels of antinutrients, thus improving the bioavailability of essential nutrients [38]. The reduction in these antinutritional factors makes the germinated grains more suitable for use in food products aimed at improving nutrition in low-resource settings. By improving the bioavailability of key nutrients, the germinated grains can help address common deficiencies in these populations, particularly iron, zinc, and calcium.

The functional properties of the germinated grains were also evaluated, and the results showed that germinated soybeans exhibited the highest oil absorption capacity and emulsifying activity. These functional properties are important in the development of processed food products such as sauces, dressings, and snack bars. Germinated oats and wheat also demonstrated favorable functional properties, though not to the extent of soybeans. The high emulsifying activity and oil absorption capacity of germinated soybeans make them ideal for use in emulsified products, which could be beneficial in the development of protein-enriched foods. These properties also suggest that the germinated grains could be used as functional ingredients in various food formulations, enhancing the texture, stability, and nutrient density of the final products.

The sensory evaluation of food products developed using germinated grains (such as porridge, snack bars, and drink mixes) revealed that the products made from germinated soybeans were the most acceptable, with high scores for taste and overall acceptability. The germinated oats and wheat products also received favorable ratings, indicating that the products were palatable and could be consumed regularly. These findings are important, as they demonstrate the potential for germinated grains to be incorporated into food products that are both nutritionally dense and acceptable to consumers. Sensory attributes such as taste, texture, and aroma are critical factors in the adoption of new food products, particularly in low-resource settings where people may have limited access to a variety of food options.

Implications for Low-Resource Settings

The results of this study have important implications for improving nutrition in low-resource settings. Protein malnutrition is a significant concern in many developing regions, and the use of germinated grains as food supplements offers a promising solution. The increased protein content, improved amino acid profile, and reduction in antinutritional factors make these grains an ideal addition to the diets of populations that rely heavily on plant-based foods. Furthermore, the functional properties of the germinated grains allow for the development of a wide range of food products that are both nutritionally dense and acceptable to local tastes.

The use of germinated oats, soybeans, and wheat also has economic implications. These grains are widely available, inexpensive, and can be easily germinated in local communities with minimal infrastructure. The processing of these grains into high-protein food supplements could be a sustainable and cost-effective strategy to combat malnutrition, particularly in rural or underserved areas. Additionally, the germination process itself is simple, making it feasible for small-scale, community-based initiatives to implement this technique.

CONCLUSION

In conclusion, the valorization of germinated oats, soybeans, and wheat has proven to be an effective strategy for enhancing their nutritional quality, particularly in terms of protein content, essential amino acid composition, and the reduction of antinutritional factors. The germinated grains exhibited favorable functional properties and were well-accepted in sensory evaluations, suggesting their potential for use in developing high-protein food products suitable for low-resource settings. This study highlights the potential of these germinated grains to provide a sustainable, locally-produced solution to protein malnutrition in developing countries.

Future research should focus on the scalability of germination processes in low-resource settings and the development of specific food products tailored to local dietary needs and preferences. Additionally, long-term studies on the impact of these food supplements on the health and nutritional status of populations in low-resource settings would provide valuable data for further promoting their use.

Data Availability

Available from corresponding author on request.

Author Contributions

Sapna Taj: Conceptualization, Methodology, Data Curation, Formal Analysis, and Writing, Original Draft Preparation and writing.

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Conflict of Interest

None.

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