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Sprouted grain-based non-alcoholic beverages: a review

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ABSTRACT

The sprouting process, or germination, activates hydrolytic enzymes that enhance the nutritional profile of grains, making them ideal for health-conscious consumers. Sprouted grain-based soft drinks are a new product category in the food industry, and their popularity is increasing. This review article focuses on the processes and benefits of sprouted grain beverages, highlighting their nutritional enhancements and functional properties. The germination process, which includes soaking, sprouting, and drying, improves the availability of vitamins, minerals, and bioactive compounds while reducing anti-nutritional factors. Optimal conditions for germination, such as temperature and soaking duration, significantly influence the nutritional quality of the final product, with various grains like wheat, barley, and brown rice exhibiting enhanced protein, fiber, and antioxidant levels. Innovative production techniques, including enzyme-assisted extraction and fermentation using beneficial bacteria, further enhance the nutritional profiles of these beverages. However, challenges such as shelf life, flavor stability, and consumer acceptance remain. Sustainable agricultural practices and advancements in food processing technologies are essential for addressing these challenges and meeting the growing consumer demand for healthy, environmentally friendly products. The review emphasizes the potential of sprouted grain beverages as functional foods, offering a rich source of nutrients and health benefits while also addressing the importance of sustainable practices in their production.

Keywords: sprouted grains, beverages, germination, food processing, technology

INTRODUCTION

The composition and quality of nutrition play a crucial role in human health, resulting in a growing consumer demand for natural and balanced products. Today, it is essential that the food we consume not only boasts excellent sensory qualities but also includes beneficial nutrients. Sprouted grain is one of the promising components for food products that can enrich them with biologically active substances **[1]**. The consumption of sprouted grains is considered to be beneficial for human health. Positive consumer perception of sprouted cereal grains stimulates the development of new food products. Incorporating sprouted grains into food products has gained popularity globally, leading to research in various countries **[2]**, **[3]**.

A more promising approach is to incorporate sprouted grain into beverages, which allows for the enrichment of these products with biologically valuable components, as well as the expansion of the product range and an increase in consumer demand for the products. Sprouted cereal grains and their products are useful sources of nutritional fibers, vitamins, and macro- and microelements **[4]**. Moreover, products made from sprouted cereals are more effective in lowering the risk of cardiovascular and gastrointestinal diseases, as sprouted grains offer a range of biological benefits, including properties that are antidiabetic, antioxidant, and anticancer **[3]**, **[5]**. For instance, germinated quinoa seeds enhance nutrient content and bioavailability while reducing antinutritional factors, improving anti-anemic health benefits in treated rats **[6]**. It has been recommended that pea and lentil sprouts are the most commonly suggested and highly effective remedies for enhancing liver health in cases of fatty liver **[7]**. A recent study indicates that sprouting increases the quantity and variety of phenolic compounds that exhibit biological effects against colon cancer **[8]**. While earlier reviews have addressed sprouted grain-based food products, this is the first review focusing on non-alcoholic beverages derived from sprouted grains.

Objectives

The present review summarizes studies on various sprouted grain beverages. This overview will also highlight current trends in producing sprouted grain beverages and identify research gaps that could lead to future innovations in this growing sector.

Processing techniques for sprouted grain beverages and factors influencing the sprouting process

Sprouting process of grains and nutritional changes

The sprouting, also known as , "germination, " causes hydrolytic enzyme activation and de novo synthesis, making nutrients available for plant growth and development **[9]**. The sprouting process involves stages, including soaking, germination, and drying (Figure 1). The grains are initially soaked in water to initiate the sprouting process. This step helps to activate enzymes and begins the germination process. The soaking time can vary depending on the grain type. The duration of soaking and temperature impact the final product's nutritional quality and flavor. For instance, soaking glutinous sorghum grains at 70 °C for 6 hours optimally enhances enzymatic hydrolysis rate by 11.0%, increases amylose content by 53.1%, and improves final viscosity by 10.4% compared to non-soaked samples, while inhibiting bacterial growth **[10]**. Over-soaking can lead to mushy grains, while insufficient soaking may lead to incomplete sprouting. The findings suggest that a combination of 24-hour soaking and germination optimally enhances the nutritional profile of millet grains **[11]**. Moreover, the partial soaking treatment of brown rice resulted in γ-aminobutyric acid (GABA) content of up to 125 mg/100 g, higher total phenolic and flavonoid content, and superior antioxidant activity compared to other germination methods **[12]**.

After soaking, the grains are drained and kept in a controlled environment to promote germination. During this phase, the grains begin to sprout, which enhances their nutritional profile by increasing the availability of vitamins and minerals and reducing anti-nutritional factors **[13]**. It was observed that the germination of barley grains optimally enhanced nutritional and functional properties, resulting in a 1.4 to 2.5-fold increase in ascorbic acid, riboflavin, phenolic compounds, and GABA **[14]**. Sprouted grains are intriguing components for creating protein-rich food products **[15]**. Sprouted amaranth exhibited the highest oil yield at 5.71 ± 0.26%. In contrast, sprouted rye had the lowest omega-6/omega-3 ratio at 7 to 1, and germinated oat showed a significant fat content increase of 54.3% compared to the control **[16]**. In addition, incorporating 10 grams of germinated wheat into Korean *Sunsik* ready-to-drink enhanced its quality and appeal to health-conscious consumers **[17]**. General changes in chemical composition during germination are presented in Figure 2.

The germination period depends on the grain and environmental conditions. Optimal temperatures (usually between 20-30°C) encourage germination, while extreme temperatures can inhibit sprouting or damage the sprouts **[18]**. Optimizing germination conditions at 21 °C for 7 days yields wheat sprouts with a desirability score of 0.89, significantly enhancing their soluble phenolic composition and associated antioxidant and anti-inflammatory properties **[19]**. The ideal conditions for germinating foxtail millet sprouts to enhance total phenolic content and GABA levels involve soaking the seeds at 31 °C for 4.5 hours, followed by germination at 35 °C using a 4.5 g/L sucrose solution for 5 days **[20]**. Moreover, proper humidity levels and light are also essential during germination **[21]**. Research indicates that a light/dark photoperiod promotes earlier germination of wild oats by 2 to 6 days compared to continuous darkness **[22]**.

Once the desired sprout length is achieved, the grains are dried to halt germination and preserve their nutritional benefits. Drying can be done using various methods such as air drying or sun drying and it is crucial to maintain temperatures that do not damage the nutrients. Sorghum that had been soaked in water for 16 hours at 25 °C and 90% relative humidity, and then sprouted for 72 hours, underwent two different drying methods. The findings indicated that the drying process conducted at a lower temperature for a longer duration (40 °C for 12 hours) preserved the enzymatic activity that began during sprouting, in contrast to the drying method applied at a higher temperature for a shorter time (50 °C for 6 hours) **[23]**. The non-uniformity in microwave drying affected the assessment of GABA content in dried germinated brown rice, with an optimal average grain temperature of 64–67 °C helping to preserve higher GABA levels **[24]**. Jribi et al. (2022) concluded that while lyophilization best preserved the nutritional properties of durum wheat sprouts, microwave vacuum drying offered a favorable alternative with lower losses compared to oven drying, highlighting the importance of selecting appropriate drying methods based on desired outcomes **[25]**. In addition, another study successfully demonstrated that the thin-layer drying behavior of sprouted wheat is significantly influenced by drying temperature and duration **[26]**. A different study indicated that infrared drying is a promising technique for producing germinated naked barley rich in flavonoids and may offer potential health benefits **[27]**.

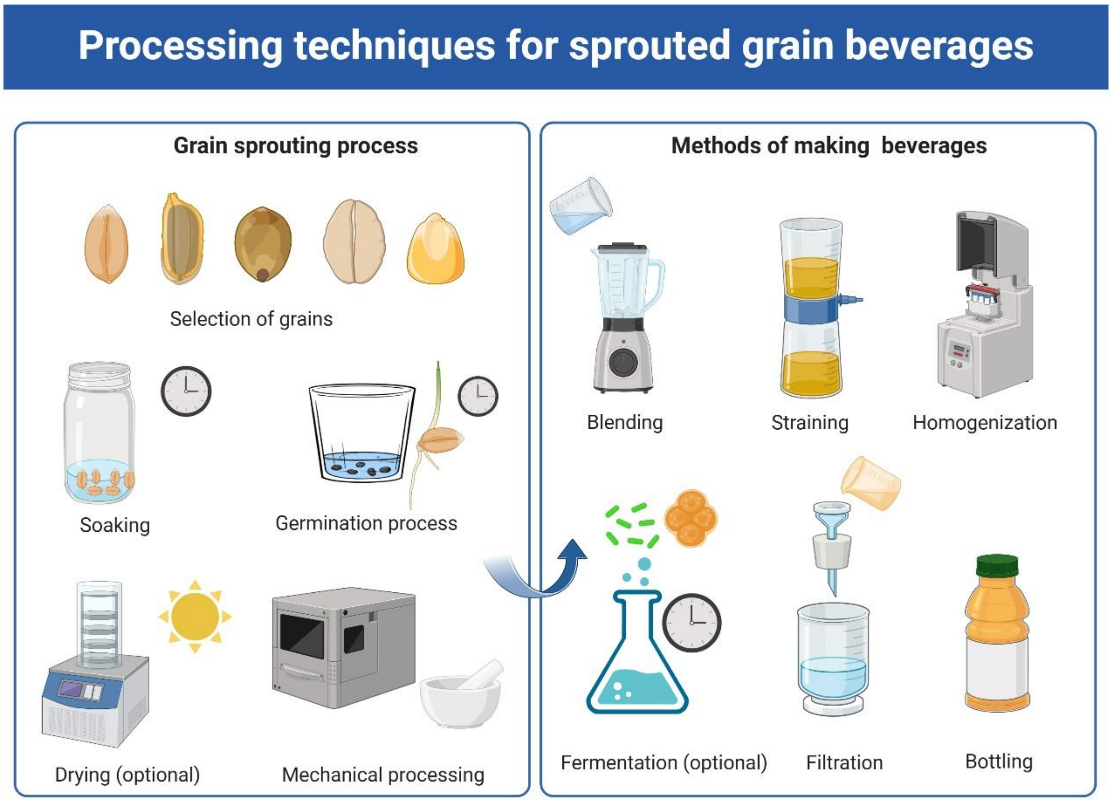

Figure 1 General steps in the production of sprouted grain-based beverages.

Beverage production methods

Various methods can be employed to produce beverages from sprouted grains. However, most soft drinks from grains are made by extracting the soluble substances of raw plant materials with water and separating the liquid. Soaked sprouted grains are blended with water and then strained to create a nutritious liquid. Unlike other methods, such as fermentation, blending preserves more raw nutrients and enzymes in the sprouted grains, resulting in a fresher and more vibrant flavor profile. Meanwhile, sprouted grains can be blended with other ingredients, such as fruits, vegetables, or spices, to create nutrient-rich smoothies or health drinks. This method allows for flavor customization and enhanced nutritional profiles **[28]**. The pulse electric field (PEF) method, microwave-existed extraction (MEE) method and enzyme-assisted method are all innovative techniques used to produce sprouted grain-based beverages. The PEF method utilizes short bursts of high-voltage electric pulses to permeabilize cell membranes, enhancing the extraction of bioactive compounds from sprouted grains while preserving their nutritional quality. The MEE method combines microwave energy with traditional extraction techniques to rapidly heat and break down plant cell structures, facilitating the efficient release of flavors and nutrients from sprouted grains into the beverage. The enzyme-assisted method employs specific enzymes to hydrolyze complex carbohydrates and proteins in sprouted grains, improving the extraction process and resulting in a smoother texture and enhanced nutritional profile in the final beverage **[5]**.

Fermentation uses yeast or bacteria to convert sugars in the sprouted grains into alcohol or lactic acid. Fermentation can enhance flavor complexity and probiotic content, resulting in beverages like sprouted grain beverages **[29]**. Most probiotic products currently available are milk-based, challenging the growing vegan market. In this context, fermented beverages from sprouted grains offer a valuable alternative **[30]**. Nowadays, fermented sprouted grain-based beverages commonly utilize several genera of bacteria, including *Lactobacillus*, *Leuconostoc*, *Bifidobacterium*, and *Streptococcus* **[31]**, **[32]**, **[33]**, **[34]**, **[35]**.

Homogenization is crucial for achieving a desirable texture and stability in sprouted grain beverages. Recent technological advancements have led to the development of more efficient homogenization techniques and equipment, allowing for better nutrient extraction and improved sensory attributes in sprouted grain beverages. Homogenization involves particle size's mechanical breakdown and emulsions' stabilization to ensure uniform consistency and prevent separation **[36]**. A colloid mill is designed to reduce the size of particles by applying shear and grinding forces. This method can be particularly effective for achieving a homogenous blend of sprouted grains and water, resulting in a smooth beverage. The high-pressure homogenization (HPH) method uses high pressure to force the liquid through a narrow space, breaking down the particles. It can significantly reduce the size of solid particles, leading to a smoother texture **[37]**. Ultrasonic homogenization (USH) involves using ultrasonic waves to create cavitation bubbles in the liquid, which collapse and create shear forces that break down particles **[38]**. This method can enhance the extraction of nutrients and flavors of beverages. Microfluidization is a process that involves the use of high pressure to force a liquid through a small orifice, resulting in the reduction of particle size and the creation of a more uniform dispersion. For instance, the study showed that whole oat milk produced from germinated oats via high-energy fluidic microfluidization significantly enhanced the nutritional quality of the final product **[39]**.

Stabilization techniques can be employed to maintain the quality and extend the shelf life of sprouted grain beverages. Heat treatment can help inactivate enzymes and microorganisms, improving stability, but it must be balanced to avoid nutrient loss. For instance, the beverage made from red, black, and white quinoa complied with sanitation standards following pasteurization and demonstrated satisfactory antioxidant capacity **[40]**.

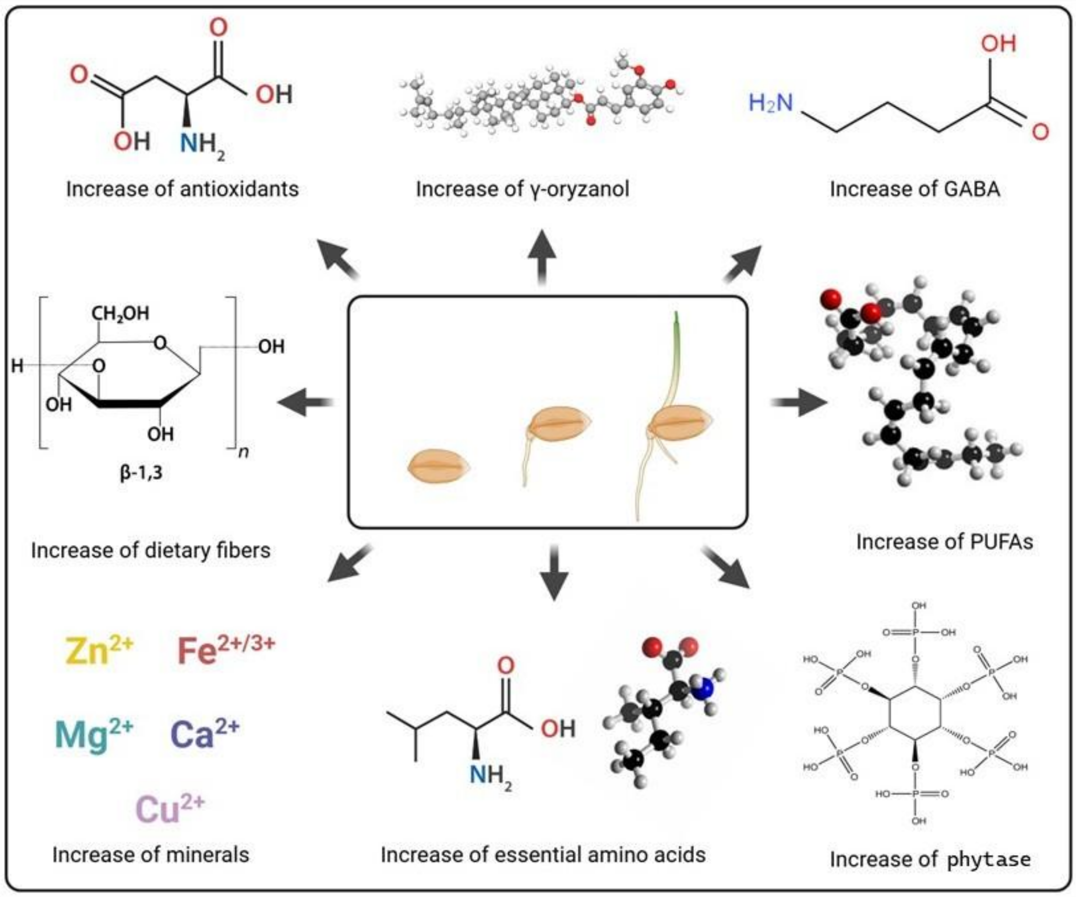

Figure 2 Overall changes in chemical composition during sprouting.

Types of sprouted grain beverages and nutritional benefits

Sprouted barley drinks

Sprouted barley drinks are rich in fiber, vitamins, and minerals **[41]**. The germination of highland barley for 40 hours significantly enhanced the total phenols and flavonoids in the fermented beverage, reaching 2.69 mg/mL and 1.71 mg/mL, respectively, which is an increase of 21.72% and 26.67% compared to the control. Additionally, the antioxidant activity improved markedly, with DPPH scavenging rates of 94.11% at 40 hours and ABTS scavenging rates of 64.64% at 48 hours, surpassing the control values **[31]**. The study by Castro et al. (2024) showed that germination of barley varieties significantly enhances their nutrient profile, including increased total sugars (269.52 mg/g), total phenols (18.17 mg GAE/g) and DPPH radical scavenging activity (327%) compared to ungerminated barley, indicating potential health benefits from barley-derived foods and extracts **[42]**. Another study demonstrated that beverages made from germinated barley, highland barley, and rice grains significantly enhanced the quality of non-dairy probiotic-fermented drinks, with those containing 6 g of the cereal mixture achieving the highest sensory acceptability scores and showcasing antioxidant capacities ranging from 1.08 to 1.26 mM compared to ungerminated **[43]**. In addition, the health mix-based functional drink, enriched with orange peel flour, malted barley, and fenugreek, demonstrates enhanced antioxidant properties and nutritional value but experiences a decline in sensory quality over time **[44]**. Yin et al. (2024) reported that germination significantly enhances GABA levels in highland barley beverages while minimally affecting taste and aroma, making it a key process for improving the functional quality of GABA-rich drinks **[45]**.

Sprouted wheat drinks

Sprouted wheat beverages are high in protein, essential amino acids, and dietary fiber.
For instance, the study found that after germination, the protein content in wheat flour increased from an unspecified level to 13.05 mg/100 g, and total phenolic compounds increased from 7.53 mg/g to 12.36 mg/g. In comparison, phytic acid decreased from 25.9 mg/g to 6.3 mg/100 g, and essential amino acids such as leucine and methionine emerged post-germination, highlighting significant nutritional enhancements **[46]**.

It has been explored that *Lactobacillus acidophilus* NCDC-14 can effectively be used to develop a probiotic beverage with optimized sprouted wheat flour, oat, wheat bran, and guar gum per, resulting in a beverage containing 10.43 log10 cfu mL$^{(-1)}$ probiotic count **[34]**. Furthermore, optimizing the roasting conditions of germinated wheat significantly enhanced total flavonoid content (0.74 mg CE/g), total phenolic content (1.95 mg GE/g), DPPH radical scavenging activity (5.10 µM TE/g), and Trolox equivalent antioxidant capacity (9.45 mM TE/g), while also achieving higher consumer preference scores for cold beverage **[47]**. A probiotic non-dairy drink based on sprouted cereals, including wheat, barley, millet, green gram, and oats, with the addition of soy milk, showed the best results in terms of sensory acceptability **[48]**. Table 1 shows beverages based on various sprouted grains.

Sprouted rice drinks

This beverage is made from sprouted brown rice and can be a popular gluten-free option. It provides complex carbohydrates, fiber, and a range of vitamins and minerals, especially in the form of antioxidants. It was shown that sprouted black rice and white rice are particularly promising for functional beverage production due to their high protein, fiber, and carbohydrate content, while sprouted pigmented rice showed potential as a natural antioxidant source and enhanced the nutritional and functional qualities of the beverages **[49]**. The study by Beaulieu et al. (2020) demonstrated that germination and enzyme processing of brown rice resulted in 96.7% germination, a 71.6% reduction in phytic acid, and significant macronutrient loss (27.0% protein, 30.9% oil, and 28.9% carbohydrate), leading to a viable method for producing a soluble matrix for value-added sprouted brown rice beverages **[50]**. Furthermore, it has been observed that initial germinated brown rice beverages' lipid profiles were higher than non-germinated brown and white rice beverages **[51]**. Jabeen et al. (2024) showed that the germinated brown rice beverage offers enhanced nutritional benefits with γ-oryzanol at 52.73%, total phenolic content at 26.68 mg GAE/100 g, niacin at 5.17%, GABA at 42.12 mg/100 g, and antioxidant activity at 74.23 µmol TE/100 g **[52]**. Pressurized germinated purple rice beverages, despite experiencing faster color changes and a decrease in certain phytochemicals during storage, maintained stable levels of GABA and γ-oryzanol while supporting the viability of encapsulated *Lactobacillus casei* 01 **[53]**.

Sprouted oat drinks

Sprouted oat beverages benefit individuals with gluten sensitivity, making them particularly important. Offers heart-healthy beta-glucans, fiber, and a range of vitamins and minerals **[54]**. Aparicio-García et al. (2021) reported that beverages based on fermented sprouted oat have some health effects on celiac people **[32]**. Meanwhile, another study observed good physicochemical properties, microbiological quality, and stability during 20 days of fermented oat drink storage with *L. plantarum* WCFS1 **[33]**. Furthermore, the sprouting and sprouting–acidic treatments yielded the highest oat milk yield (91.70%) and protein extraction yield (82.74%), highlighting the superior nutritional and functional benefits of two-stage treatments compared to singular therapies **[55]**. The study by Wei et al. (2024) demonstrated that whole oat milk produced from germinated oats via high-energy fluidic microfluidization at an optimal pressure of 120 MPa significantly enhanced nutritional quality, with total protein, γ-aminobutyric acid, total phenolics, and soluble protein **[39]**.

Sprouted pseudocereal drinks

Quinoa, buckwheat, and amaranth are pseudo-grains that can be sprouted and turned into beverages. Such beverages can be a complete protein source, rich in essential amino acids, and contain healthy fats and fiber. The research explored that the optimal quinoa beverage, composed of 81.67% sprouted black quinoa and 18.33% sprouted white quinoa, significantly enhanced antioxidant capacity and nutritional content compared to the control treatment while meeting sanitary standards for microbiological safety **[40]**. Interestingly, the study by Obaroakpo et al. (2019) observed that quinoa yogurt beverage fermented with *Lactobacillus casei* SY13 and *Lactobacillus casei* Zhang, optimized through germination-enhanced hydrolysis, exhibits a dual inhibitory effect on both α-glucosidase and angiotensin-converting enzyme (ACE) due to its bioactive peptides **[56]**.

The developed functional drink, optimized with a blend of buckwheat, amaranth, and oats, achieved significant nutritional benefits, including 2.93% dietary fiber, 0.89% β-glucan, 30.65% DPPH antioxidant activity, 19.63% ABTS antioxidant activity, 248.84 mg GAE/100 g total polyphenols, 1.23% fat, and 1452.6 mg/L calcium **[57]**.

The optimized gluten-free beverage fermented with *L. plantarum* and *B. bifidum* contained an average of 8.4 log (CFU ml-1) of live *lactobacilli* and 7.8 log (CFU ml-1) of viable *bifidobacterial* cells after 15 days of refrigerated storage. The final formulation included 51.96% sprouted buckwheat and 48.04% lentil flours, yielding a beverage with 0.25% acidity, 5.7 pH, and 41.02% DPPH antioxidant activity **[35]**.

Table 1 Beverages based on various sprouted grains

Sprouted grain type	**Method**	**Study outcomes**	**Source**
Barley	Fermented	Good antioxidant activity	**[31]**
Barley	Extraction	Germination significantly enhances their nutrient profile	**[42]**
Barley, highland barley, rice	Fermentation with *L. plantarum* ZJ5	Highest sensory acceptability scores and antioxidant capacities	**[43]**
Barley, orange peel, fenugreek.	Blending	Enhanced antioxidant properties and nutritional value but decreased sensory quality during storage	**[44]**
Highland barley	Extraction	Significantly enhanced GABA level	**[45]**
Oat	Fermentation with *L. plantarum*	Reduced cholesterol levels and anti-inflammatory effects	**[32]**
	Fermentation with *L. plantarum* WCFS1	Showed good physicochemical properties, microbiological quality, stability during storage	**[33]**
	Extraction	Yielded the highest oat milk and protein extraction yield	**[55]**
	Extraction	Enhanced nutritional quality and instability index, reduced particle size	**[39]**
Wheat	Fermentation with *L. acidophilus*	Increased probiotic count	**[34]**
	Extraction	Optimizing the roasting conditions of germinated wheat significantly enhanced nutritional and consumer acceptance scores	**[47]**
Wheat, barley, pearl millet, green gram, oat, soymilk	Fermentation with *L.acidophilus* NCDC14	Sensory acceptability was higher in those with soymilk	**[48]**
Brown rice	Blending	Enhanced the nutritional and functional qualities	**[49]**
	Extraction	Developed process yields a soluble matrix from sprouted brown rice with a high concentration of soluble solids	**[50]**
	Blending	Increased lipid profiles of germinated brown rice	**[51]**
	Blending	Enhanced γ-oryzanol, total phenolic content, niacin, GABA	**[52]**
Purple rice	Fermented with encapsulated *Lactobacillus case*i 01	Enhanced GABA and γ-oryzanol profile, but experienced quick change in color during storage	**[53]**
Quinoa	Blending	Significantly enhanced antioxidant capacity and nutritional content	**[40]**
	Fermentation with *L. casei* SY13 and *L. casei* Zhang	Inhibitory effect on both α-glucosidase and ACE	**[56]**
Buckwheat, amaranth, oats	Extraction	Achieved significant nutritional benefits	**[57]**
Buckwheat, honey buckwheat, inulin	fermentation with *L. plantarum*	Decrease of polyphenols and antioxidant activity in the gastric passage	**[58]**
Buckwheat, lentil	Fermentation with *L. plantarum*, *B. bifidum*	Increased viable cells after 15 days of refrigerated storage	**[35]**

Challenges and future directions

Producing sprouted grain beverages presents several challenges, including maintaining consistent quality, issues related to shelf life, and balancing flavor profiles to meet consumer preferences **[59]**. The shelf life of sprouted grain beverages is crucial because it affects their nutritional quality, flavor, and safety for consumption. The shelf life of sprouted grain-based beverages can vary significantly depending on several factors, including the ingredients used, the method of production, and storage conditions. Sprouted grain beverages can have a shorter shelf-life due to their high moisture content and presence of live cultures, which can lead to spoilage and potential food safety issues. Moreover, sprouted grains contain oils and fats that can oxidize, leading to rancidity. This not only affects flavor but also can produce harmful compounds. Effective preservation methods, such as pasteurization, high-pressure processing (HPP), or adding natural preservatives such as citric acid, are crucial to extending shelf-life while maintaining nutritional quality. Recent studies have demonstrated that employing a mathematical model to identify the ideal storage conditions for functional beverages made from sprouted grains could enhance their shelf life and reduce spoilage **[60]**. Products with a longer shelf life can reduce waste and increase profitability. Unsold items that spoil before consumption represent a loss for manufacturers and retailers, while extended shelf life can enhance marketability.

Maintaining flavor stability can be challenging due to the natural enzymatic activity present in sprouted grains. Off-flavors can develop over time, necessitating careful control of processing conditions and storage practices to ensure a consistent taste profile **[61]**. Therefore, it is essential to use high-quality sprouted grains and experiment with different sprouted grain varieties to find the most desirable flavor profiles. While the health benefits of sprouted grain beverages are widely recognized, consumer acceptance can vary. Factors such as taste, texture, and familiarity with the product play a significant role in market success.

Cultivating grains for beverages requires significant agricultural resources, including water, land, and energy. Sustainable practices can help minimize the environmental impact associated with these inputs. Conventional grain farming often involves synthetic fertilizers and pesticides, leading to soil degradation, water pollution, and biodiversity loss. Sustainable practices like organic farming and crop rotation can mitigate these effects. As consumers become increasingly aware of environmental issues, there is a growing demand for sustainably produced food and beverages. Focusing on local sourcing of grains, organic farming practices, and minimal processing could appeal to environmentally conscious consumers.

Innovations in food processing technology could improve the efficiency and scalability of producing sprouted grain beverages. Recently, a groundbreaking green processing technology was implemented to make a sprouted brown rice-based beverage, utilizing an innovative enzyme-driven approach that enhances sustainability while delivering a nutritious drink **[49]**. These innovations can enhance flavor retention, improve shelf life, and reduce the presence of anti-nutritional factors, making the final products more appealing to consumers.

Conclusion

Sprouting grains significantly enhances their nutritional profile, leading to beverages rich in vitamins, minerals, and bioactive compounds. Furthermore, innovative beverage production methods, including blending, fermentation, and advanced extraction techniques, enable the creation of nutrient-rich sprouted grain beverages that cater to health-conscious consumers while maintaining flavor and nutritional quality. Sprouted grain beverages, including those made from barley, wheat, rice, oats, and pseudocereals, exhibit enhanced nutritional profiles, antioxidant capacities, and potential health benefits due to germination. These beverages cater to specific dietary needs, such as gluten sensitivity, and demonstrate promise in promoting functional food innovations and probiotic applications. However, challenges like shelf life, flavor stability, and the need for sustainable agricultural practices must be addressed to meet market demands. The limited research on beverages made from sprouted grains indicates a clear need for further investigation. Continued research and innovation in processing technologies can further enhance the quality and acceptance of beverages based on sprouted grains.

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