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Review Article

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A Comprehensive Review on the Effect of Germination on the Physiochemical Properties of Wheat, Millet, and Legumes

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Abstract

Wheat, legumes, and millet play an important role in our diet and they can significantly increase our nutrient intake. These are excellent sources of protein, dietary fiber, vitamins, minerals, and phytochemicals, as well as providing energy. However, they also contain antinutritional and phytate contents that can reduce the absorption of minerals. The main hindrance to the release of nutrients is the interaction between the nutrients and antinutritional factors. The decrease in antinutritional factors and increase in nutritional value can be achieved through a traditional processing technique known as germination. Germination is the process by which a series of biochemical reactions (synthesis of enzymes, denaturation of protein, reduction in antinutrients, and increase in accumulation of antioxidants) take place which aid in the growth of a seedling. During germination, antinutrients decrease while antioxidants, phenolic acids, bioavailability, and vitamins increase, improving the food's nutritional properties. Germinated products have become increasingly popular nowadays due to improvements in protein, B-group vitamins, calcium, zinc, phosphorous, and iron which makes it an organic and healthy food. Understanding the physiochemical characteristics of germinated grains and legumes opens many ways for potential applications. This paper aims to explore the impact of germination on wheat, legumes, and millet, including its effects on physiochemical properties, antioxidants, processing, health benefits, and applications.

Keywords

Germination, Physiochemical properties, Antinutritional factors, Antioxidants, Enzyme activity, Bioavailability

Introduction

The food industry is now working to create healthier products that align with modern customer demands. Sprouted grains have recently become a popular new component in food culture. Sprouted grains' high nutritional value, technological properties, and sensory attributes make them a popular ingredient in food products [1]. The potential benefits of sprouted grains, such as increased nutrient value, lower levels of antinutrients, higher amounts of bioactive molecules, and a sweeter taste make them a promising new ingredient for the food market [2].

Germination is a simple, inexpensive, and environmentally friendly method of producing plant foods with functional properties. It enhances the nutritional and medicinal properties of plant foods by reducing antinutrients and increasing the accumulation of antioxidants, flavonoids, phenolic acids, and vitamins, thereby increasing the value of grains [3]. Germinated wheat is produced by soaking, steeping, and letting it to budding (germination). Cereal seeds undergo a significant biochemical and physical change during germination because of the production of hydrolytic enzymes, increased protein and carbohydrate digestibility,

and denaturing of amylase inhibitors and other antinutritional substances.

Triticum aestivium, commonly known as wheat, is one of the most important cereal crops in the world. The world produces roughly 785.1 million tons of wheat annually, which accounts for about 20% of the food required by the world's population [4]. According to estimates and data, by 2030, the total amount of wheat produced will need to increase by around (50%) given the world's growing population and the increased demand for and need for food [5]. Wheat is one of the major grains in the human diet. It is one of the 'three majors' cereal crops. Whole wheat is a rich source of protein, fiber, vitamins, minerals, and phytochemicals. It is the most popular energy crop to produce confectionery products because its protein (gluten) has unique properties, combining the strength and elasticity required to produce bread, cookies, and cakes [6].

The best sources of protein are legumes, followed by starch, vitamins, and minerals. They serve as meat substitutes or alternatives that give the vegetarian diet all the nutrients it needs due to their great nutritional value [7]. The family Leguminosae includes oilseeds like alfalfa, soybeans, peanuts, mesquite, clover, and pulses like dry grains of peas, beans, chickpeas, lupins, and lentils. Ancient societies in the middle east, Asia, North Africa, and South America produced and used legumes. Some of the varieties are mung beans (*Vigna radiata*), Lentils (*Lens culinaris*), winged beans (*Psophocarpus tetragonoloba*), soybeans (*Glycine max*), peas (*Pisum sativum*), cowpeas (*Vigna unguiculata*), black gram (*Vigna mungo*) and groundnuts (*Arachis hypogaea*) to name a few, are notable legume species.

Millets, cereal grains from the Poaceae grass family, were one of the first crops to be cultivated. The major two millets used for food and feed are generally recognized as finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*). While pearl millet is believed to have originated in sub-Saharan Africa, finger millet is supposed to have evolved in the sub-humid uplands of East Africa [8].

A lot of changes occur in wheat, legumes, and millets after germination, including nutritional properties, enzymatic reactions, physiochemical changes, and impact on antioxidant activities. Our review aims to investigate the process of germination in wheat, legumes, and millets. We will examine its complex mechanics, nutritional impact, and potential health benefits. Additionally, we will explore the physiochemical characteristics and potential uses of germinated wheat, millet, and legumes. We will also examine the wider health effects and useful applications of germinated grains and legumes, while also addressing current challenges and future research avenues.

Germination Process and Its Impact on Wheat, Millet, and Legumes

Germination: mechanism and stages

For a grain to germinate, the germ must be present and undamaged. As shown in figure 1 for germination to begin the wheat kernel must have a minimum moisture content range

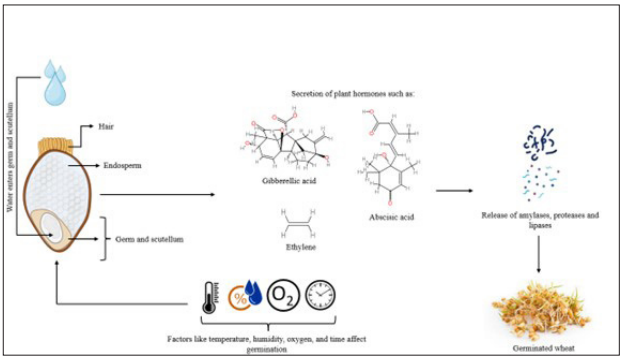

Figure 1: Mechanism of germination.

of 35% to 45% and be above a minimum temperature of 4 °C.Water enters the germ and scutellum of the wheat kernel through the micropyle to begin germination. Then, as it circulates within the kernel, it accumulates between the seed coat and pericarp. The seed begins the synthesis and/or release of plant hormones such as abscisic acid, gibberellic acid, and ethylene once the moisture content meets the minimal need. These plant hormones secrete amylase, proteases, and lipases, which are degrading enzymes, throughout the seed [9].

During the first phase (phase I), the dry seeds quickly take in water until all the matrix and cell contents are fully hydrated. A second phase (phase II), which has a low water, is connected to a substantial metabolic reactivation. Phase III is characterized by an increase in water intake that coincides with cell elongation and the end of germination [10].

Effects on nutritional composition

The nutritional composition of a seed plays a crucial role in the growth and development of a plant during germination. Germination is the process through which a seed turns into a seedling and involves various biochemical and physiological processes. Different species of seeds such as wheat, millet, and legumes have distinct dietary requirements and biochemical profiles, which can result in different responses to the nutritional content during germination. Table 1 shows the nutritional change in germinated wheat, table 2 shows the nutritional change in millets, and table 3 shows the nutritional change in legumes.

Changes in proteins

Proteins are important macronutrients in human and animal diets due to their nutritional value and health benefits. Plant-derived proteins may be more nutritionally adequate and less unsafe for the environment than animal-derived proteins. To make up for this deficiency, cereal protein which themselves are low in lysine but sufficiently high in methionine and cysteine are combined with legume proteins [26].

According to their solubility characteristics, wheat proteins have been categorized into four categories: albumin, globulin, gliadin, and glutenin. Gliadin, which contributes to dough viscosity, and glutenin, which contributes to the dough's strength and elasticity, must be balanced properly for the dough to have the desired qualities. The functional characteristics of dough are made up of the special fusion of these characteristics [27]. Germination of wheat flour increases

Table 1: Nutritional changes of wheat before and after germination.

Before germination							
Type of wheat	**Protein**	**Carbohydrate**	**Lipid/Fat**	**Fiber**	**Ash**	**M.C**	**Ref.**
Sharbati	12.18 ± 0.23	69.74 ± 0.44	2.39 ± 0.44	2.45 ± 0.26	1.61 ± 0.06	11.63 ± 0.38	[11]
Soft wheat (*Triticum aestivum* Giza 171)	-	84.16 ± 3.19	2.07 ± 0.04	0.71 ± 0.03	0.61 ± 0.02	12.58 ± 0.84	[12]
Triticum aestivum L.	10.02 ± 1.10	87.60 ± 6.83	1.92 ± 0.66	1.51 ± 0.56	1.01 ± 0.03	12.20 ± 1.26	[13]
Triticum aestivium	14.97	68.14	1.59	2.39	1.61	11.3	[14]
Gamaza wheat	11.70 ± 0.25	75.28 ± 0.39	3.30 ± 0.06	7.83 ± 0.02	1.90 ± 0.09	7.16 ± 0.09	[15]
After germination							
Sharbati	13.3 ± 0.19	69.17 ± 0.09	2.25 ± 0.29	2.03 ± 0.09	1.11 ± 0.20	12.15 ± 0.19	[11]
Triticum aestivum Giza 171	-	83.35 ± 3.18	1.84 ± 0.07	1.45 ± 0.04	1.25 ± 0.03	12.61 ± 1.04	[12]
Triticum aestivum L.	14.10 ± 1.83	80.32 ± 7.26	1.43 ± 0.26	1.62 ± 0.08	0.97 ± 0.09	13.56 ± 1.94	[13]
Triticum aestivium	11.23	71.08	1.91	1.42	1.26	13.1	[14]
Gamaza wheat	10.15 ± 0.31	79.48 ± 0.32	1.71 ± 0.01	6.77 ± 0.04	1.90 ± 0.02	8.97 ± 0.17	[15]

Table 2: Nutritional changes of legumes before and after germination.

Before germination							
Legumes	**Protein**	**Carbohydrate**	**Fat**	**Ash**	**Fiber**	**Moisture**	**Ref.**
Chickpea	21.07 + 0.12	62.60 + 0.18	5.94 + 0.03	2.70 + 0.60	6.56 + 0.69	7.69 + 0.02	[16]
Lentil	24.6	49.6	1.10	2.4	19.4	-	[17]
Soya bean	29.09 ± 0.27	22.1 ± 0.26	24 ± 0.26	4.95 ± 0.11	14.4 ± 0.26	10 ± 0.30	[18]
Mung bean	26.07 ± 0.67	19.06 ± 0.60	2.17 ± 0.11	3.74 ± 0.09	6.62 ± 0.11	8.05 ± 0.30	[19]
Moth bean	23.60 ± 2.00	63.17 ± 0.23	0.38 ± 0.01	3.47 ± 0.03	6.00 ± 0.20	3.38 ± 0.13	[20]
After germination							
Chickpea	20.92 + 0.07	63.48 + 0.22	5.85 + 0.10	2.45 + 0.14	4.23 + 0.38	7.30 + 0.08	[16]
Lentil	26.8	43.4	0.75	2.7	15.4	-	[17]
Soya bean	34.99 ± 0.22	17.9 ± 0.25	10 ± 0.28	11 ± 0.26	18.6 ± 0.27	11 ± 0.26	[18]
Mung bean	22.28 ± 0.92	19.06 ± 0.73	2.14 ± 0.09	3.69 ± 0.07	6.64 ± 0.08	7.33 ± 0.45	[19]
Moth bean	16.71 ± 1.15	69.93 ± 0.61	0.60 ± 0.06	3.27 ± 0.09	7.00 ± 0.12	2.50 ± 0.08	[20]

Table 3: Nutritional changes of millets before and after germination.

Before germination							
Millet type	**Protein**	**Carbohydrate**	**Fat**	**Ash**	**Fiber**	**Moisture**	**Ref.**
Finger millet	7.61 ± 0.01	78.08 ± 052	3.84 ± 0.55	1.84 ± 0.59	5.54 ± 0.03	3.10 ± 0.53	[21]
Pearl millet	8.82	76.17	3.34	2.04	2.33	7.3	[22]
Proso millet	0.56	83.94	5.5	5.5	4.5	21.8	[23]
Barnyard millet	11.2	72.0	1.8	2.3	5.3	10.0	[24]
Foxtail millet	6.8	70.0	2.9	2.1	4.9	15.0	
Kodo millet	6.70 ± 0.01	72.76 ± 1.87	3.60 ± 0.03	3.30 ± 0.01	4.20 ± 0.01	9.34 ± 0.02	[25]
After germination							
Type of millet	**Time of germination**	**Protein**	**Carbohydrate**	**Fat**	**Ash**	**Fiber**	**Moisture**	**Ref.**
Finger millet	72 h	7.81 ± 014	75.70 ± 0.44	2.73 ± 0.25	1.80 ± 0.27	8.81 ± 0.01	3.14 ± 0.56	[21]
Pearl millet	48 h	10.39	74.43	2.70	2.70	2.38	7.4	[22]
Proso millet	24 h	0.63	83.47	4.7	6.0	5.2	23.6	[23]
	48 h	0.84	82.96	4.6	7.0	4.6	26.0	
	72 h	0.88	82.82	4.2	8.4	4.1	28.6	
	96 h	1.00	81.1	3.1	10.0	4.8	37.2	
Barnyard millet	-	8.9	61.0	2.5	2.0	5.7	9.5	[24]
Foxtail millet	-	12.6	72.0	2.6	4.2	5.1	11.56	
Kodo millet	35.82 h	7.90 ± 0.041	71.43 ± 1.34	2.8 ± 0.01	2.92 ± 0.02	5.12 ± 0.04	10.21 ± 0.04	[25]

protein content and ash/nitrogen levels but decreases β-glucan content due to proteolytic enzymes and new amino acid creation. Sprouted wheat flour and whole wheat flour contain more protein than non-sprouted wheat flour, while refined flour has less protein after germination [14].

Millets' protein levels increased during germination, particularly the protein in pearl millet, which increased significantly. From the study conducted by Morah and Etukudo [23] the elevation in protein levels of proso millet can be attributed to various factors. The increase in protein content is caused by

the activation of proteolytic enzymes present in the seeds. This process is also associated with the breakdown of tannin-protein and enzyme-protein complexes, resulting in the release of more free amino acids and peptides. It has also been suggested that the rise in protein content can be attributed to an increase in enzyme activities, which leads to the net synthesis of enzymatic proteins [23]. During sprouting, the seed's protein is transformed into a soluble state, which accelerates the utilization of these amino acids and results in an overall increase in protein content. The production of enzymes or a general alteration brought on by the breakdown of other components could contribute to the increased protein content of the germinated millet [21].

Germination time also affects the protein content. According to the study of Kumar et al. [28] after 96 h of germination, the protein concentration dropped from 6.04% to 3.41%. The drop in protein concentration during germination is caused by proteolysis outpacing protein synthesis. As a result, the amount of free amino acids such as lysine, methionine, tryptophan, and cysteine increases. The movement of nitrogenous material from the seed to the developing embryo is another factor that lowers the protein concentration.

Legumes are an excellent source of high-quality protein because they contain 20-45% of it and typically have high levels of the important amino acid lysine [29]. Legume proteins are classified as albumins, globulins, glutelins, and prolamins based on how soluble they are. Albumins are soluble in water, prolamins in aqueous ethanol, glutelins in diluted alkali and acid solutions, globulins in diluted salt solutions, and globulins in diluted salt [26].

Alterations in carbohydrates

Carbohydrates are a significant component found in wheat, legumes and millets and it is also the body's primary source of energy. Starch is the main component of wheat and legumes, which is the main source of carbohydrates. Free sugars, glucofructans, and hemicelluloses (pentosans) are examples of additional carbohydrates. Millets are an excellent source of dietary fiber, slowly digesting starch, resistant starch, and energy, which results in a continuous release of glucose [30]. An essential element of whole grains is dietary fiber. Amylases catalyze the hydrolysis of starch, which is stored in grains as amylose and amylopectin, to simple sugars, mostly glucose and maltose, and, to a lesser extent, sucrose, increasing the grain's digestibility [10].

Amylase activity causes the starch content of wholegrain flour to decrease during germination; considerable changes are seen after 72 h, although no significant differences were identified in refined flours, presumably because starch degradation occurs differently in different parts of the kernel. Maltose and glucose levels climbed after sprouting, supporting earlier findings, while sucrose content dropped, especially in refined flours, probably because of higher enzyme activity during germination [31]. After germination, the amount of carbohydrates in wheat flour drops, probably because of an increase in the activity of enzymes such as alpha amylase [32]. Carbohydrates are broken down during germination, which causes a drop in starch and a rise in sugars [14].

According to the study by Nazni and Shobana [24] compared to boiling, pressure cooking and raw samples of the germinated barnyard millet flour has significantly less carbohydrate content than the other processed samples. Since the sprouts require carbohydrates for metabolism, there is a decrease in carbohydrates during the germination phase. According to Sharma et al. [25], the decrease in minor millets is explained to be due to an increase in alpha-amylase activity. Alpha-amylase converts complex carbohydrates into simpler and more absorbable sugars during the early stages of germination, which are utilized by the growing seedlings during the early stages of germination.

According to Xu et al. [33] during germination process legumes like lentils undergo changes which affect their nutritional composition. During germination, lentils undergo changes that reduce their starch, lipids, and amylose levels while increasing their ash content. Enzymes such as α-amylase, glucosidase, dextranase, and β-amylase are released during germination, which convert starch into monosaccharides or oligosaccharides. This decrease in starch content increases the availability of other nutrients, making lentils easier to digest. Chickpea and pea sprouting increased sucrose and decreased raffinose, the substance that causes flatulence. The rise in sucrose in sprouted goods is probably the result of compositional changes during sprouting, which might enhance the sensory qualities and leavening abilities of derived products [34].

Modification of lipids

The term "lipids" refers to a group of compounds that includes free fatty acids, mono-, di-, and tri-acylglycerols, phospholipids, glycolipids, sterol esters, and lipoproteins. Unsaturated fatty acids are abundant in all cereal grain lipids. Most cereals contain more linoleic than palmitic, which is a primary unsaturated fatty acid. In comparison to other grains, millets are higher in stearic acid [35]. Various fatty acids can be found in the lipids of legume seeds. Peanut, chickpea, soybean, garden peas, lentils, and broad beans are substantial sources of oleic and linoleic acids. Linoleic acid is the primary fatty acid present in lima, field, red, and horse gram beans.

When wheat seeds germinated for three days at 20 °C, there was no difference in the amount of fat found in the sprouted wheat compared to the seeds [36]. Sprouted wheat flour had less lipid-1.59% compared to 1.91% in non-sprouted wheat flour. Lipase activity increased three times after germination at 40 °C. Lipase is more sensitive to heat than lipoxygenase during drying [14].

The high-amylose wheat's germination-related alterations in free and bound lipids are depicted by Hung et al. [37]. While the number of bound lipids remained constant, the level of free lipids in wheat dramatically rose during germination. Extended germination periods led to an increase in the overall lipid content, which includes both free and bound lipids, in the germinated wheat. According to Hung et al. [37], when high amylose wheat undergoes germination, lipase is rapidly released and leads to the release of glycerol and free fatty acids. This results in a decrease in starch content, causing a reduction in grain weight and an increase in the proportion of total protein and lipid. This could be the reason for the ob-

served increase in total protein and total lipids in germinated high-amylose wheat.

It was learned that lipase activity in sprouted millet (3 days, 20–23 °C) caused the fat content to drop by 8–15% [36]. According to the study by Kumar et al. [28], after 48 h of germination, the crude fat level of finger millet reduced from 0.57% to 0.41%, and then it gradually rose to 0.85% in samples that had been germinated for 96 h. The oxidation of fat to fatty acids and water, as well as the use of fat as a carbon source, may be responsible for the drop in fat content during germination. There was also an increase in fat content during prolonged germination, which may be caused by the grains' reduction in carbohydrates and the replacement of sugars as an energy source. A study by Owheruo et al. [21] showed a decrease in the lipid content of finger millet and pearl millet after germination. The enzyme activity increased because of the significant decrease in fat content, and the fat may have also provided energy for germination.

In legumes germination process also influences the fat content of seeds. A study by Wu and Xu [38] concluded that the decrease in fat content during germination might be due to the increase in lipolytic activity, which hydrolyzes lipid compounds to ensure seed development. However, the reduction in fat content depends on the species undergoing the germination process. According to Medhe et al. [20] the lipid content of the sprouted moth bean sample was greater and increased with germination time. The increase in crude lipid content in sprouted seeds was due to the rise in lipase activity and important fatty acids. During sprouting, the breakdown of triacylglycerols into glycerol and its constituent fatty acids occurs due to lipolytic activity, leading to an increase in lipid content in sprouted moth beans. Also, a study conducted on chickpea flour also showed decrement in fat content during germination processing [16].

Impact on Antioxidant Compounds

A crucial protective feature that is significant for humans is antioxidant activity. The antioxidants perform a variety of biological functions through the mechanism of anti-oxidation in terms of their antimutagenic, anti-carcinogenic, and anti-aging capabilities. Therefore, by increasing the antioxidant activity of foods, it helps prevent the occurrence of several diseases [39].

The antioxidant activity of wheat flour increases with the length of germination. This positive correlation between germination time and antioxidant activity was observed in a study by Karwasra et al. [40]. According to Dhillon et al. [11] germination significantly enhances the antioxidant activity of wheat flour by as much as 169% compared to whole wheat flour. This increase in antioxidant activity may be brought on by the release of bound phenolic compounds as well as the destruction of cell walls and component parts during germination. Germination results in the production of greater quantities of antioxidant molecules like vitamin C and tocopherols. Germinated wheat contains a higher level of phenolic acids and gamma-aminobutyric acid (GABA), as well as higher concentrations of certain proteins like GBSS and GSTF, after 96 h of germination. These substances are recognized to possess antioxidant qualities that contribute to the overall antioxidant capacity of germinated wheat, as observed in a study by Kim et al. [41]. The study investigated the antioxidant activity of biscuits made with varying levels of wheat sprout substitution. Biscuits with higher sprout content showed increased radical-scavenging activity, likely due to elevated polyphenol content in sprouts [3].

A study done by Sharma et al. [39] showed that ungerminated kodo millet extracts increased to 50.24 mgAAE/g from 18.20 mgAAE/g in total antioxidant activity after germination, which may have been caused by glutamate decarboxylase activation and a rise in GABA levels brought on by hypoxia. Sharma et al. [25] studied that phytate level in foxtail millet reduced from 0.341 to 0.102 mol/kg, while tannin content reduced from 2.803 to 0.983 mg/100 g. These reductions in antinutritional components were linked to the enzyme phytase's increased hydrolytic activity during germination. The tannin content decreased significantly during germination because of soluble tannin molecules being leached out during soaking and the subsequent germination process. Kulla et al. [42] found that barnyard, foxtail, and small millet when germinated reduce the oxalate concentration by 15.9% to 33.9%. This occurs due to germination triggering oxalate oxidase, which releases calcium and breaks down oxalic acid. In addition, germination enhances the flavonoid content of tiny millet, foxtail, and barnyard.

It was found by Fouad and Rehab [43] that lentils significantly boosted their ability to scavenge free radicals, going to 62.19% from 40.76% in ungerminated samples after 6 days of sprouting. Depending on the kind of legume and germination temperature, the antioxidant activity of legume extracts varied, with soybean and kidney beans having the highest activity. This is explained by the differential activity of hydrolases and polyphenol oxidases during germination and by variations in seed matrices that regulate the release [44]. With the exception of black beans, increasing germination time significantly improved the antioxidant activities of legumes, including seed hulls cotyledons and radicles [45]. Flaxseeds that had been sprouted had significantly higher antioxidant activity than raw flaxseeds, which was brought about by metabolic changes during germination. In addition to phenolics, other chemicals like vitamin C, flavonoids, and quercetin may also be synthesized during sprouting, explaining why antioxidant activity increases during this process [46].

Enzyme Activity Changes During Germination

Wheat germination promotes the production of amylolytic enzymes, which causes starch to be broken down. Longer germination times cause these enzymes' activity to increase, which reduces falling number and causes starch chains to be hydrolyzed. Amylases, which are mostly present in the germ and pericarp, migrate to regions rich in starch, proteins, and lipids to start hydrolytic processes for energy generation in new plant growth. The distribution of enzymes in germinating grains impacts the composition of flour [47].

Amylase activity rises because of wheat kernel germination, which causes starch to break down. The dropping and stirring number, which reduces as the germination period grows, serves as confirmation of this. The decrease in viscosity during the heating and chilling processes suggests that the capacity of sprouted grains to swell, gelatinize, and gel is significantly reduced and is influenced by the duration of sprouting [31].

The increase in amylase activity during germination, which results in a starch breakdown process, may be responsible for the decrease in carbohydrate contents after germination. The activity of the lipase, which acts on triacylglycerols to convert them into free fatty acids required for energy production, may be the cause of the pH drop and acidity increase [48]. Legumes have phytase enzymes, which germination activates to break down phytate [32].

Physiochemical Properties of Germinated Wheat, Millet, and Legumes

Additionally, to the nutritional changes made to the wheat, legumes and millets grain by germination, alterations in the rheological characteristics also occur [28]. The research carried out by Afify et al. [15] found using germinated wheat flour as a substitute for wheat flour (82% extraction rate) in fermented dough resulted in higher raising capacity (measured in mm) after 120 min of fermentation. When 75% of wheat flour was substituted with germinated wheat flour, bread's rising capacity increased significantly to 212 ± 0.00 mm, attributed to higher levels of amylolytic and proteolytic activity. Cereals are ideal for beneficial bacteria due to high mineral and fiber content and low fermentable sugar levels.

Studies have shown that the sprouting of wheat can have a negative impact on its rheological characteristics. This is due to changes in gluten aggregation and the breakdown of gluten proteins, resulting in a decrease in flour quality and gluten strength [31]. Recent research by Sharma et al. [39] found that after germination, the breakdown value decreased from 35.00 ± 1.04 to 29.00 ± 1.08, while the trough viscosity decreased from 402.00 ± 12.05 to 182.00 ± 11.03, and the peak viscosity declined from 437 centipoises (cP) to 287.00 cP. These changes may be caused by enzymatic starch degradation and a decrease in molecular weight. However, the decrease in flour viscosity can be advantageous for the formulation of weaning foods made from kodo millet grain.

The ability of wheat flour samples to absorb water and their water solubility index both considerably increase during germination. This rise is due to a rise in lower molecular weight substances, such as soluble sugars, which have more hydrophilic side chains. The main chemical components of flour that increase their water absorption and solubility are proteins and carbohydrates due to the substances which have hydrophilic components like polar or charged side chains [40, 39]. Water absorption and solubility was studied by Nefale and Mashau [49]. It has been studied that the water absorption capacity of flour samples increases with longer germination periods of 48 and 72 h. This is likely due to the hydrophilic nature of the main chemical components in the flour, which are proteins and carbohydrates. However, when preparing soft porridge, a lower water absorption capacity is preferred. After 72 h germination period, millets showed the highest solubility index value of 8.32%. This increase in solubility can be attributed to the elevated levels of amylase activity during germination. The high solubility of germinated finger millet flour samples indicates that they are appropriate for newborns [49]. After germination, whole wheat flour's ability to absorb water significantly improved, probably because of an increase in protein content and the breakdown of starch, which can prolong the shelf-life of germinated flour [11].

Raw yellow pea and faba bean flours had similar water-holding capacities but soaking and germination slightly increased water-holding capacities by weakening the link between starch and protein/fiber, enabling better water binding. The duration of germination impacts the time required to mix germinated whole wheat flour. Longer germination times require less mixing time, possibly due to protein hydrolysis which reduces the molecular weight of gluten proteins, making them easier to hydrate [50]. According to research by Karwasra et al. [40] the swelling power of flour is considerably reduced with the length of germination. The swelling power has decreased because of changes in the branched-chain structure and increased enzyme activity during germination.

Bioavailability of Nutrients in Germinated Grains and Legumes

Germination is a process that can enhance the levels of bio-available minerals and nutrients in plant-based foods, making them more readily absorbed by the human body and ultimately improving their nutritional value [11]. The degradation of antinutrients like polyphenols and saponins, which prevent minerals from being bioavailable, is what causes the availability of minerals to increase during germination. Table 4 shows the mineral change before and after germination.

Legumes contain phytic acid, also known as phytate, which acts as a chelating agent by binding to minerals. However, during germination, the amount of phytate decreases due to the action of the enzyme phytase. Phytase breaks down phytate into inositol and free orthophosphate, releasing minerals in the process. This is why the amount of minerals in legumes increases after germination, resulting in improved digestive availability. Longer germination periods can further enhance the mineral content of legumes [53].

In the case of legumes, a study conducted by Desalegn [16] in chickpea found that both phytate and tannin were significantly reduced after soaking and germination. This decrease may be brought on by the release of soluble tannin compounds while soaking as well as an increase in the activity of the enzyme phytase, which breaks down phytate. After germination, the antinutrient reduction was considerably larger, indicating that this method may be more efficient than soaking alone. Soaking and germination can increase the bioavailability of crucial elements like iron, zinc, and calcium in chickpeas by lowering the amounts of antinutrients [16].

By lowering antinutrient levels, germination is also used to enhance the nutritional value and practical qualities of mil-

Table 4: Mineral changes of grains before and after germination.

Type of grain	Potassium	Sodium	Iron	Calcium	Magnesium	Zinc	Ref.
Before germination							
Barnyard millet flour	215	17	7.59	50	-	-	[24]
	-	22.07	37.68	21.66	38.19	-	[25]
Finger millet flour	469	509	90.8	821.4	1761.4	-	[21]
Wheat (*Triticum aestivium*)	-	-	6.59	3700	110	12.21	[14]
Mung bean	-	-	5.7	123.0	-	3.4	[51]
Chickpea	-	-	6.9	153.6	-	2.80	
Cowpea	-	-	4.36	78.8	-	3.0	
Lentil	-	26.08 ± 0.61	2.62 ± 0.18	-	122.35 ± 0.06	3.07 ± 0.20	[52]
Soybean	-	47.50 ± 1.06	5.31 ± 0.14	-	90.30 ± 0.10	1.91 ± 0.15	
Bean	--	38.15 ± 2.61	7.57 ± 0.75	-	141.65 ± 0.17	3.22 ± 0.20	
After germination							
Barnyard millet flour	298	18	9	60	-	-	[24]
	-	33.71	39.42	23.42	42.62	-	[25]
Finger millet flour	2292	149.8	73.9	4153.6	1614.7	-	[21]
Wheat (*Triticum aestivium*)	-	-	7.1	4100	1.40	13.05	[14]
Mung bean	-	--	5.7	106.5	-	3.4	[51]
Chickpea	-	-	6.5	139.9	-	2.82	
Cowpea	-	-	4.32	65.2	-	2.9	
Lentil	-	53.52 ± 1.57	2.75 ± 0.20	-	146.63 ± 0.12	3.12 ± 0.22	[52]
Soyabean		70.19 ± 2.03	5.38 ± 0.21	-	106.88 ± 0.08	1.94 ± 0.15	
Bean		64.42 ± 0.71	7.89 ± 0.80		152.15 ± 0.01	3.25 ± 0.20	

lets. It was discovered germination can significantly increase the bioavailability of minerals in millets also. Germination has been observed to improve the availability of minerals by breaking down substances that hinder nutrient absorption. Additionally, it enhances the availability of minerals such as zinc, calcium and iron in finger millet and pearl millet when assessed under laboratory conditions [54].

Figure 2 depicts the variations in the mineral content of calcium, phosphorous and iron. Soaked mung beans and soyabeans had lower zinc, iron, and calcium concentrations than raw beans, whereas germinated soybean and mung beans had higher zinc, iron, and calcium contents. Germination increases the bioavailability of zinc and iron in mung beans and soyabeans while decreasing the bioavailability of calcium [55]. Germination of chickpeas and green grams for 24 h increased the bioaccessible chromium by 19% and 30%, respectively. Although no significant effect was observed after 48 h of germination, bioaccessible copper increased. Germination also had a negative effect on bioaccessible manganese due to a reduction in phytic acid [56].

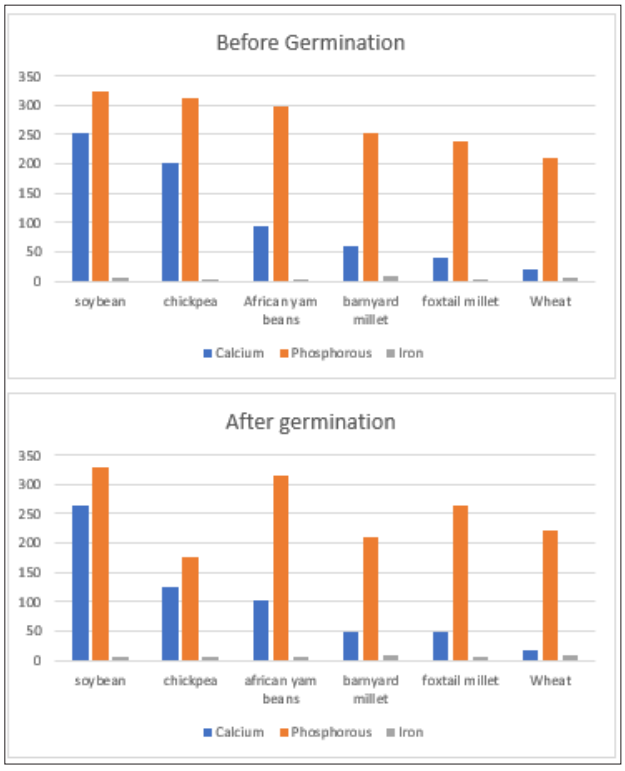

Figure 2: Calcium, phosphorus, and magnesium content before and after germination.

Health Benefits and Applications of Germinated Wheat, Millet, and Legumes

Nutritional advantages for human health

During germination, significant transformations occur in the composition of the grain, including alterations in carbohydrates, fibers, and proteins. These changes contribute to the overall improvement of the germinated grain. Some of the effects by germination are given in table 5. Increases in the antioxidant activity help in the prevention of oxidative stress, cancer, skin ageing, atherosclerosis, and ocular diseases (Figure 3).

Millet's germination can enhance its suitability for consumption, nutritional content, and encourage the buildup of useful substances like gamma-aminobutyric acid GABA. A few of its polyphenols have therapeutic adjuvant impact on cancer, diabetes, and heart related conditions [38]. GABA is a vital neurotransmitter in the brain. This is an amino acid that lacks

Table 5: Effect of germination in wheat, millets, and legumes.

Cereal/Legumes/Millet	Germination effects	Ref.
Finger millet	Improved protein and sugar digestion increased tannins, phytates, starch.	[32]
Sorghum	Increased ash and protein but with reduction in moisture. Increased amylopectin, water absorption index, but reduced amylose.	[57]
Pearl millet and finger millet	Increased in magnesium content, in finger millet calcium content increased.	[21]
Finger millet	Germination reduced the antinutritional components of finger millet flour, such as the phytate and tannin content, by around 50%.	[58]
Foxtail millet	Increase in polyphenolic content due to biosynthesis of polyphenolic compounds.	[59]
Proso millet	Increase in protein content, ash content increases. Sprouting increases the bioavailability of proteins and minerals by lowering levels of antinutritional substances such hydrogen cyanide, phytic acid, soluble oxalate, and total oxalate.	[23]
Lentil	When germination time increased mineral content like sodium, iron, magnesium, zinc increased.	[52]
Chickpea	Increase in protein, increase in phenolic compounds. Chickpeas that were allowed to germinate for 48 h had much less carotenoid content. GABA content increased.	[48]
Wheat	Protein content, moisture content increased. Ash content decreased. Water absorption, water solubility index, oil absorption increased whereas falling number decreased.	[11]

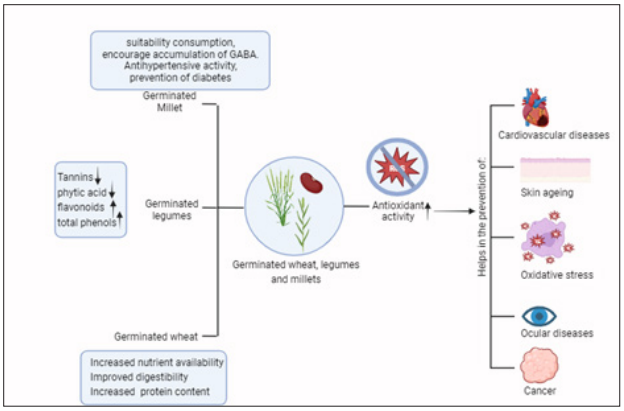

Figure 3: Impact of germination on antioxidant activity and disease prevention.

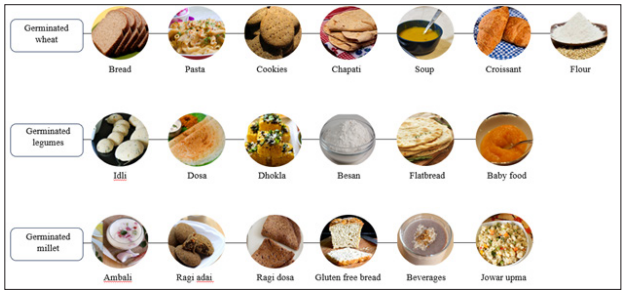

Figure 4: Culinary products from germinated wheat, legumes, and millet.

protein function but has notable biological effects. GABA has several pharmacological actions like lowering blood pressure, inducing relaxation, inhibiting sympathetic neurotransmitters, and prevention of diabetes. Wu and Xu [38] conducted a study on ungerminated millet flour and found that it had an initial GABA concentration of 11.4 mg/100 g. The study showed that following 48 h of germination using tap water treatment, the flour attained its maximum GABA content which was 73.10 mg/100 g. In the initial phases of sprouting, GABA content tended to increase, but as germination progressed, it gradually decreased. The activation of glutamic acid decarboxylase during germination catalyzes converting glutamate into GABA through decarboxylation. As a result of glutamic acid decarboxylase activation, millet seeds displayed an increased propensity for their GABA content during the early stages of germination.

Sprouts are packed with phytonutrients, proteins, vitamins, minerals, and other beneficial compounds, making them a functional food. Adding sprouts to food products can boost their nutritional value and reduce the risk of food-borne diseases [60]. In the past, consumers have displayed a favorable attitude towards the process germination and products made from germinated grains or their respective flours. Sprouts and flour made from germinated wheat can be used in breakfast foods soups, pasta, baked products, casseroles and salads [36]. Some of the culinary products are shown in figure 4. In food compositions, sprouted wheat flour can be employed as an ingredient because it has higher quantities of niacin, tocopherols, riboflavin, and free and bound phenolic chemicals. Food compositions that reduce antinutritional elements including phytate, tannin, and oxalate and increase functional qualities can include sprouted sorghum flour as a component [60].

Other products are wheat bread enhanced with phenolic compound-rich sprouted wheat flour which have good baking properties than control. Germinated moth bean flour is utilized as an ingredient in food formulation which compared to non-sprouted beans, exhibits increased gelation, heat stability, and viscosity preservation. Compared to non-sprouted beans, sprouted beans exhibit higher gelation, heat stability, and viscosity preservation. Noodles can be produced using germinated mung bean flour, providing the advantage of higher protein, as have functional qualities such water uptake, water solubility, ability to absorb oil, and water retention [60].

Challenges and Future Perspectives

Processing and storage considerations

There are several methods to treat germinated grains (Figure 5), including various cooking techniques, the application of high hydrostatic pressure, and ultrasound. To increase the

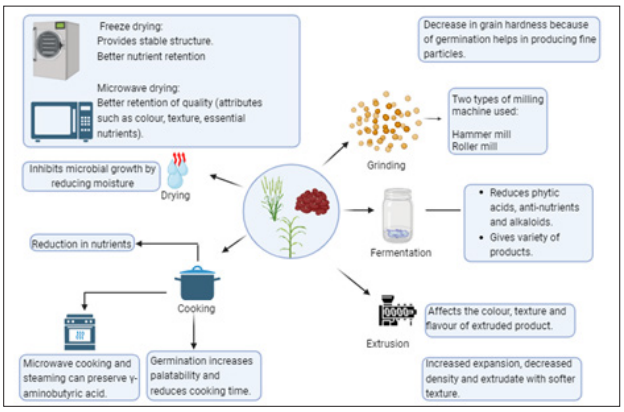

Figure 5: Processing techniques of germinated wheat, legumes, and millets.

nutritional value of germinated grains, phytochemicals with antinutrient effects can be reduced by using conventional processing techniques like heating and fermentation [61]. A study conducted by Oghbaei and Prakash [62] in 2017 investigated the preparation method of germinated and dehulled mung beans (*V. radiata*) using microwave heating and pressure-cooking techniques. Results showed that the nutritional content of the sprouted grains remained unaffected by the cooking techniques. However, the dietary fiber and phytate content was higher in microwave cooked samples as compared to the pressure-cooked ones. Despite this, cooking did not have any impact on the bioactive components of the grains.

Hassan et al. [63] investigated the impact of using microwave and ultrasonic technologies on the yield of oil from sorghum grains before and after germination. Results showed that while the fatty acid composition of the oil was not affected by the preparation techniques, germinated grains had a better composition of saturated fatty acids compared to ungerminated ones. The highest oil production was achieved when a combination of microwave power (700 W) and ultrasound was applied concurrently for 30 sec and 10 min, respectively.

More recent studies have focused on the extrusion method of processing germinated flour. Zhu et al. [64] investigated the impact of incorporating germinated wholemeal flour to wheat extrudates and tortillas. Results showed that compared to the control, items made from germinated wholemeal flour exhibited elevated levels of γ-aminobutyric acid and improved characteristics in tortillas.

Consumer acceptance and market trends

For many years, it has been common knowledge that seeds can grow into sprouts, particularly in Eastern cultures where consuming seedlings is a significant aspect of their cuisine. During the 1980s, there was a growing trend in Western nations towards the consumption of sprouted seed. Today, there is an increasing interest in sprouted grains and seeds, with emphasis on minimal processing and no additives. Sprouted grains and seeds contain more nutrients compared to regular grains and seeds, which is why they are preferred by many. As a result of the growing demand for sprouted grains and seeds, new products are introduced daily. Due to the health benefits and nutritional value, they offer, sprouted grains and seeds are becoming increasingly popular among health-conscious consumers. The global market for sprouted grains and seeds is projected to experience a CAGR of 10.2% during the forecast period. By 2022, the market is expected to be valued at USD 4.86 billion, with estimates suggesting that the market will exceed USD 12.86 billion by 2032 [65].

Sibian and Riar [66] studied that cookies with sprouted kidney bean, wheat and chickpea were found to have a greater moisture content, which grew during storage. Cookies made with composite flour contain nutrients that promote microbial growth, resulting in rising microbial count. Over a 90-day storage period, ungerminated wheat flour cookies had a microbial count within 1.5×10^1 to 1.03×10^2 cfu/g, while optimized composite flour cookies had a count of 2.0×10^1 at the beginning of storage and rose to 1.07×10^2 after 90 days. Balancing nutritional benefits and shelf life is crucial for consumer acceptance and market trends towards healthier options with extended freshness.

Opportunities for further research

In the field of future research, there are several important areas that show promise in advancing our understanding of how germination affects wheat, millet, and legumes. First and foremost, it is crucial to delve deeper into the nutritional changes that occur during germination. This entails conducting comprehensive analyses of amino acid profiles, fatty acid composition, and micronutrient content to gain a better understanding of how germination enhances the overall nutritional quality of these grains and legumes. Additionally, it is vital to investigate the bioavailability of nutrients in germinated grains and legumes. This research can shed light on how germination affects the absorption of key nutrients within the human digestive system, providing valuable insights into the potential health benefits associated with consuming germinated grains and legumes.

Enzyme characterization is another pivotal area for future exploration. A detailed understanding of the enzymes involved in the germination process, including their specific roles and regulatory mechanisms, can provide essential tools for optimizing germination conditions to achieve specific nutritional outcomes. Furthermore, it is essential to assess consumer preferences and acceptance of products that incorporate germinated grains and legumes. Sensory evaluations and consumer studies can help tailor these products to align with consumer expectations, ensuring their widespread appeal. Exploring the potential industrial applications of germinated grains and legumes, such as their use in baking, food processing, and functional foods, holds promise for diversifying their incorporation into everyday diets and expanding their reach. Sustainability considerations are paramount in the context of large-scale germination processes. Evaluating the environmental sustainability of these processes, including their impact on resource usage, waste reduction, and carbon footprint, can provide valuable insights into the ecological benefits of utilizing germinated grains and legumes.

Conclusion

The process of germinating grains results in significant

changes to their biochemical composition, transforming them into nutrient-rich food options. During germination, starch reserves are broken down, proteins become more easily digestible, fatty acids change, and antinutrients decrease while beneficial substances increase. These changes increase the antioxidant levels and improve nutrient availability, making sprouts a healthier option for humans. Further increases in phytochemical content can be achieved by adjusting germination parameters with biotic and abiotic elicitors. Research on improving germination, linking nutrients to health benefits, and scaling up production is crucial to fully harnessing the benefits of sprouted grains. Overcoming challenges such as creating uniform and regulated germination conditions, avoiding contamination, and customizing procedures for various grains will be key in maximizing benefits. Developing tailored germination procedures for each cereal and legume and exploring biotechnological methods to improve germination effectiveness and yield should be top priorities for research. In summary, sprouted grains offer great potential as functional foods that can enhance dietary intake and health. Ongoing research efforts will unlock the full potential of germination, resolve production issues, and provide more wholesome and secure food choices for consumers.

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Conflict of Interest

None.

References

1. Peñaranda JD, Bueno M, Álvarez F, Pérez PD, Perezábad L. 2021. Sprouted grains in product development. Case studies of sprouted wheat for baking flours and fermented beverages. *Int J Gastronomy Food Sci* 25: 100375. https://doi.org/10.1016/j.ijgfs.2021.100375
2. Ding J, Feng H. 2019. Controlled Germination for Enhancing the Nutritional Value of Sprouted Grains. In Feng H, Nemzer B, DeVries JW (eds) Sprouted Grains. Woodhead Publishing and AACC International Press, pp 91-112.
3. Đurović V, Radovanović M, Mandić L, Knežević D, Zornić V, et al. 2020. Chemical and microbial evaluation of biscuits made from wheat flour substituted with wheat sprouts. *Food Sci Technol Int* 27(2): 172-183. https://doi.org/10.1177/1082013220942441
4. Food and Agriculture Organization. [http://www.fao.org] [Accessed on November 01, 2023]
5. Gahlaut V, Jaiswal V, Tyagi BS, Singh G, Sareen S, et al. 2017. QTL mapping for nine drought-responsive agronomic traits in bread wheat under irrigated and rain-fed environments. *PLoS One* 12(8): e0182857. https://doi.org/10.1371/journal.pone.0182857
6. Adeoye BK, Alao AI, Famurewa JAV. 2017. Quality evaluation biscuits produced from wheat and pineapple peel flour. *Appl Trop Agric* 22(2): 210-217.
7. Chaturvedi S, Chakraborty S. 2020. Review on potential non-dairy synbiotic beverages: a preliminary approach using legumes. *Int J Food Sci Technol* 56(5): 2068-2077. https://doi.org/10.1111/ijfs.14779
8. Review of the African Millet Diversity.
9. Wen D, Xu H, Xie L, He M, Hou H, et al. 2017. A loose endosperm structure of wheat seed produced under low nitrogen level promotes early germination by accelerating water uptake. *Sci Rep* 7(1): 3116. https://doi.org/10.1038/s41598-017-03333-4
10. Benincasa P, Falcinelli B, Lutts S, Stagnari F, Galieni A. 2019. Sprouted grains: a comprehensive review. *Nutrients* 11(2): 421. https://doi.org/10.3390/nu11020421
11. Dhillon B, Choudhary G, Sodhi NS. 2020. A study on physicochemical, antioxidant and microbial properties of germinated wheat flour and its utilization in breads. *J Food Sci Technol* 57(8): 2800-2808. https://doi.org/10.1007/s13197-020-04311-x
12. Sakr AM. 2020. Evaluation of wheat germination for making gluten-free bread. *Curr Sci Int* 9(04): 677-689. https://doi.org/10.36632/csi/2020.9.4.61
13. Kavitha S, Parimalavalli R. 2014. Effect of processing methods on proximate composition of cereal and legume flours. *J Hum Nutr Food Sci* 2(4): 1051.
14. Al-Kharkhi SMH, Mousa AM. 2021. The effect of wheat germination processes on the nutritional parameters of wheat flour. *Plant Arch* 21: 789-797. https://doi.org/10.51470/PLANTARCHIVES.2021.V21.S1.119
15. Afify AEM, Abbas MS, El-Lattefi ABM, Ali AM. 2016. Chemical, rheological and physical properties of germinated wheat and naked barley. *Int J ChemTech Res* 9(9): 521-531.
16. Desalegn BB. 2015. Effect of soaking and germination on proximate composition, mineral bioavailability and functional properties of chickpea flour. *Food Public Health* 5(4): 108-113.
17. Oskaybaş-Emlek B, Özbey A, Kahraman K. 2021. Effects of germination on the physicochemical and nutritional characteristics of lentil and its utilization potential in cookie-making. *J Food Measure Charact* 15(5): 4245-4255. https://doi.org/10.1007/s11694-021-00958-y
18. Warle B, Riar C, Gaikwad S, Mane V. 2015. Effect of germination on nutritional quality of soybean (*Glycine max*). *IOSR J Environ Sci Toxicol Food Technol* 9(4): 12-15.
19. Vasantharuba S, Lanka S. 2013. Effect of malting on nutritional contents of finger millet and mung bean. *Am Eurasian J Agric Environ Sci* 13(12): 1642-1646.
20. Medhe S, Jain S, Anal AK. 2019. Effects of sprouting and cooking processes on physicochemical and functional properties of moth bean (*Vigna aconitifolia*) seed and flour. *J Food Sci Technol* 56(4): 2115-2125. https://doi.org/10.1007/s13197-019-03692-y
21. Owheruo JO, Ifesan BOT, Kolawole AO. 2019. Physicochemical properties of malted finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*). *Food Sci Nutr* 7(2): 476-482. https://doi.org/10.1002/fsn3.816
22. Inyang CU, Zakari UM. 2008. Effect of germination and fermentation of pearl millet on proximate chemical and sensory properties of instant "Fura" - a Nigerian cereal food. *Pak J Nutr* 7(1): 9-12. https://doi.org/10.3923/PJN.2008.9.12
23. Morah F, Etukudo UP. 2017. Effect of sprouting on nutritional value of *Panicium miliaceum* (proso millet). *Edorium J Nutr Diet* 4: 1-4. https://doi.org/10.5348/N09-2017-4-SR-1
24. Nazni P, Shobana DR. 2016. Effect of processing on the characteristics changes in barnyard and foxtail millet. *J Food Process Technol* 7(3): 1-9. https://doi.org/10.4172/2157-7110.1000566
25. Sharma S, Saxena D, Riar CS. 2016. Nutritional, sensory and *in-vitro* antioxidant characteristics of gluten free cookies prepared from flour blends of minor millets. *J Cereal Sci* 72: 153-161. https://doi.org/10.1016/j.jcs.2016.10.012
26. Ohanenye IC, Tsopmo A, Ejike CECCC, Udenigwe CC. 2020. Germination as a bioprocess for enhancing the quality and nutritional prospects of legume proteins. *Trends Food Sci Technol* 101: 213-222. https://doi.org/10.1016/j.tifs.2020.05.003

27. Uthayakumaran S, Wrigley C. 2017. Wheat: Grain-Quality Characteristics and Management of Quality Requirements. In Wrigley C, Batey I, Miskelly D (eds) Cereal Grains. Woodhead Publishing, pp 91-134.
28. Kumar A, Tripathi MK, Joshi D, Kumar V. 2021. Millets and Millet Technology. Springer, Singapore.
29. Maphosa Y, Jideani VA. 2017. The Role of Legumes in Human Nutrition. In Hueda MC (ed) Functional Food - Improve Health Through Adequate Food. IntechOpen.
30. Gowda NN, Siliveru K, Prasad PVV, Bhatt Y, Netravati BP, et al. 2022. Modern processing of Indian millets: a perspective on changes in nutritional properties. *Foods* 11(4): 499. https://doi.org/10.3390/foods11040499
31. Grassi S, Cardone G, Bigagnoli D, Marti A. 2018. Monitoring the sprouting process of wheat by non-conventional approaches. *J Cereal Sci* 83: 180-187. https://doi.org/10.1016/j.jcs.2018.08.007
32. Nkhata SG, Ayua E, Kamau EH, Shingiro JB. 2018. Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes. *Food Sci Nutr* 6(8): 2446-2458. https://doi.org/10.1002/fsn3.846
33. Xu M, Zhao J, Gu Z, Rao J, Chen B. 2020. Changes in odor characteristics of pulse protein isolates from germinated chickpea, lentil, and yellow pea: role of lipoxygenase and free radicals. *Food Chem* 314: 126184. https://doi.org/10.1016/j.foodchem.2020.126184
34. Erba D, Angelino D, Marti A, Manini F, Faoro F, et al. 2019. Effect of sprouting on nutritional quality of pulses. *Int J Food Sci Nutr* 70(1): 30-40. https://doi.org/10.1080/09637486.2018.1478393
35. Rosentrater KA, Evers AD. 2018. Introduction to Cereals and Pseudocereals and Their Production. In Rosentrater KA, Evers AD (eds) Kent's Technology of Cereals. Elsevier, pp 1-76.
36. Nemzer B, Al-Taher F. 2023. Analysis of fatty acid composition in sprouted grains. *Foods* 12(9): 1853. https://doi.org/10.3390/foods12091853
37. Hung PV, Maeda T, Morita N. 2015. Improvement of nutritional composition and antioxidant capacity of high-amylose wheat during germination. *J Food Sci Technol* 52(10): 6756-6762. https://doi.org/10.1007/s13197-015-1730-6
38. Wu F, Xu X. 2019. Sprouted Grains-Based Fermented Products. In Feng H, Nemzer B, DeVries JW (eds) Sprouted Grains. Woodhead Publishing and AACC International Press, pp 143-173.
39. Sharma S, Jan R, Riar CS, Bansal V. 2021. Analyzing the effect of germination on the pasting, rheological, morphological and *in-vitro* antioxidant characteristics of kodo millet flour and extracts. *Food Chem* 361: 130073. https://doi.org/10.1016/j.foodchem.2021.130073
40. Karwasra BL, Gill BS, Kaur M, Kaur H. 2018. Influence of germination period on physicochemical, pasting and antioxidant properties of Indian wheat cultivars. *J Food Measure Charact* 12(1): 68-77. https://doi.org/10.1007/s11694-017-9617-z
41. Kim MJ, Kwak HS, Kim SS. 2018. Effects of germination on protein, γ-aminobutyric acid, phenolic acids, and antioxidant capacity in wheat. *Molecules* 23(9): 2244. https://doi.org/10.3390/molecules23092244
42. Kulla S, Hymavathi TV, Kumari BA, Reddy RG, Rani CVD. 2021. Impact of germination on the nutritional, antioxidant and antinutrient characteristics of selected minor millet flours. *Ann Phytomed* 10(1): 178-184. https://doi.org/10.21276/ap.2021.10.1.18
43. Fouad AA, Rehab FMA. 2015. Effect of germination time on proximate analysis, bioactive compounds, and antioxidant activity of lentil (*Lens culinaris* Medik.) sprouts. *Acta Sci Pol Technol Aliment* 14(3): 233-246. https://doi.org/10.17306/J.AFS.2015.3.25
44. Mamilla RK, Mishra VK. 2017. Effect of germination on antioxidant and ACE inhibitory activities of legumes. *LWT* 75: 51-58. https://doi.org/10.1016/j.lwt.2016.08.036
45. Saleh HM, Hassan AA, Mansour EH, Fahmy HA, El-Bedawey AEFA. 2019. Melatonin, phenolics content and antioxidant activity of germinated selected legumes and their fractions. *J Saudi Soc Agric Sci* 18(3): 294-301. https://doi.org/10.1016/j.jssas.2017.09.001
46. Khare B, Sangwan V, Rani V. 2021. Influence of sprouting on proximate composition, dietary fiber, nutrient availability, antinutrient, and antioxidant activity of flaxseed varieties. *J Food Process Preserv* 45(4): e15344. https://doi.org/10.1111/jfpp.15344
47. Baranzelli J, Kringel DH, Colussi R, Paiva FF, Aranha BC, et al. 2018. Changes in enzymatic activity, technological quality and gamma-aminobutyric acid (GABA) content of wheat flour as affected by germination. *LWT* 90: 483-490. https://doi.org/10.1016/j.lwt.2017.12.070
48. Ferreira CD, Bubolz VK, da Silva J, Dittgen CL, Ziegler V, et al. 2019. Changes in the chemical composition and bioactive compounds of chickpea (*Cicer arietinum* L.) fortified by germination. *LWT* 111: 363-369. https://doi.org/10.1016/j.lwt.2019.05.049
49. Nefale FE, Mashau ME. 2018. Effect of germination period on the physicochemical, functional, and sensory properties of finger millet flour and porridge. *Asian J Appl Sci* 6(5): 360-367.
50. Poudel R, Finnie S, Rose DJ. 2019. Effects of wheat kernel germination time and drying temperature on compositional and end-use properties of the resulting whole wheat flour. *J Cereal Sci* 86: 33-40. https://doi.org/10.1016/j.jcs.2019.01.004
51. Bains K, Uppal V, Kaur H. 2014. Optimization of germination time and heat treatments for enhanced availability of minerals from leguminous sprouts. *J Food Sci Technol* 51(5): 1016-1020. https://doi.org/10.1007/s13197-011-0582-y
52. Atudorei D, Stroe SG, Codină GG. 2021. Impact of germination on the microstructural and physicochemical properties of different legume types. *Plants* 10(3): 592. https://doi.org/10.3390/plants10030592
53. Atudorei D, Codină GG. 2020. Perspectives on the use of germinated legumes in the bread making process, a review. *Appl Sci* 10(18): 6244. https://doi.org/10.3390/app10186244
54. Anagha KK. 2023. Millets: nutritional importance, health benefits, and bioavailability: a review. *Pharma Innov J* 12(8): 223-227.
55. Wang X, Yang R, Jin X, Chen Z, Zhou Y, et al. 2015. Effect of germination and incubation on Zn, Fe, and Ca bioavailability values of soybeans (*Glycine max* L.) and mung beans (*Vigna radiate* L.). *Food Sci Biotechnol* 24(5): 1829-1835. https://doi.org/10.1007/s10068-015-0239-0
56. Kumari M, Platel K. 2020. Impact of soaking, germination, fermentation, and thermal processing on the bio accessibility of trace minerals from food grains. *J Food Process Preserv* 44(10): e14752. https://doi.org/10.1111/jfpp.14752
57. Otutu OL, Ikuomola DS, Oloruntoba RO. 2014. Effect of sprouting days on the chemical and physicochemical properties of sorghum starch. *Am J Food Nutr* 4: 11-20.
58. Abioye VF, Ogunlakin GO, Taiwo G. 2018. Effect of germination on anti-oxidant activity, total phenols, flavonoids and anti-nutritional content of finger millet flour. *J Food Process Technol* 9(2): 1-5.
59. Sharma S, Saxena DC, Riar CS. 2018. Changes in the GABA and polyphenols contents of foxtail millet on germination and their relationship with *in vitro* antioxidant activity. *Food Chem* 245: 863-870. https://doi.org/10.1016/j.foodchem.2017.11.093
60. Miyahira RF, Lopes JO, Antunes AEC. 2021. The use of sprouts to improve the nutritional value of food products: a brief review. *Plant Foods Hum Nutr* 76(2): 143-152. https://doi.org/10.1007/s11130-021-00888-6
61. Pradeep PM, Sreerama YN. 2015. Impact of processing on the phenolic profiles of small millets: evaluation of their antioxidant and enzyme inhibitory properties associated with hyperglycemia. *Food Chem* 169: 455-463. https://doi.org/10.1016/j.foodchem.2014.08.010
62. Oghbaei M, Prakash J. 2017. Nutritional properties of green gram germinated in mineral fortified soak water: II. Effect of cooking on total and bioaccessible nutrients and bioactive components. *J Food Sci Technol* 54(4): 880-889. https://doi.org/10.1007/s13197-016-2382-x

63. Hassan S, Imran M, Ahmad N, Khan MK. 2017. Lipids characterization of ultrasound and microwave processed germinated sorghum. *Lipids Health Dis* 16(1): 125. https://doi.org/10.1186/s12944-017-0516-4

64. Zhu L, Adedeji AA, Alavi S. 2017. Effect of germination and extrusion on physicochemical properties and nutritional qualities of extrudates and tortilla from wheat. *J Food Sci* 82(8): 1867-1875. https://doi.org/10.1111/1750-3841.13797

65. Fact MR. [http://www.factmr.com] [Accessed on November 01, 2023]

66. Sibian MS, Riar SC. 2021. Optimization and evaluation of composite flour cookies prepared from germinated triticale, kidney bean, and chickpea. *J Food Process Preserv* 45(1): e14996. https://doi.org/10.1111/jfpp.14996