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,
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 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 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 tetragonolobus*), 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.

Millet, 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.
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].

Millots’ 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

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

<table>
<thead>
<tr>
<th>Type of wheat</th>
<th>Protein</th>
<th>Carbohydrate</th>
<th>Lipid/Fat</th>
<th>Fiber</th>
<th>Ash</th>
<th>M.C.</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharbagi</td>
<td>12.18 ± 0.23</td>
<td>69.74 ± 0.44</td>
<td>2.39 ± 0.44</td>
<td>2.45 ± 0.26</td>
<td>1.61 ± 0.06</td>
<td>11.63 ± 0.38</td>
<td>[11]</td>
</tr>
<tr>
<td>Soft wheat (Triticum aestivum Giza 171)</td>
<td>-</td>
<td>84.16 ± 3.19</td>
<td>2.07 ± 0.04</td>
<td>0.71 ± 0.03</td>
<td>0.61 ± 0.02</td>
<td>12.58 ± 0.84</td>
<td>[12]</td>
</tr>
<tr>
<td>Triticum aestivum L.</td>
<td>10.02 ± 1.10</td>
<td>87.60 ± 6.83</td>
<td>1.92 ± 0.66</td>
<td>1.51 ± 0.56</td>
<td>1.01 ± 0.03</td>
<td>12.20 ± 1.26</td>
<td>[13]</td>
</tr>
<tr>
<td>Triticum aestivum</td>
<td>14.97</td>
<td>68.14</td>
<td>1.59</td>
<td>2.39</td>
<td>1.61</td>
<td>11.3</td>
<td>[14]</td>
</tr>
<tr>
<td>Gamma wheat</td>
<td>11.70 ± 0.25</td>
<td>75.28 ± 0.39</td>
<td>3.30 ± 0.06</td>
<td>7.83 ± 0.02</td>
<td>1.90 ± 0.09</td>
<td>7.16 ± 0.09</td>
<td>[15]</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Legumes</th>
<th>Protein</th>
<th>Carbohydrate</th>
<th>Fat</th>
<th>Ash</th>
<th>Fiber</th>
<th>Moisture</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chickpea</td>
<td>21.07 ± 0.12</td>
<td>62.60 ± 0.18</td>
<td>5.94 ± 0.03</td>
<td>2.70 ± 0.60</td>
<td>6.56 ± 0.69</td>
<td>7.69 ± 0.02</td>
<td>[16]</td>
</tr>
<tr>
<td>Lentil</td>
<td>24.6</td>
<td>49.6</td>
<td>1.10</td>
<td>2.4</td>
<td>19.4</td>
<td>-</td>
<td>[17]</td>
</tr>
<tr>
<td>Soy bean</td>
<td>29.09 ± 0.27</td>
<td>22.1 ± 0.26</td>
<td>24 ± 0.26</td>
<td>4.95 ± 0.11</td>
<td>14.4 ± 0.26</td>
<td>10 ± 0.30</td>
<td>[18]</td>
</tr>
<tr>
<td>Mung bean</td>
<td>26.07 ± 0.67</td>
<td>19.06 ± 0.60</td>
<td>2.17 ± 0.11</td>
<td>3.74 ± 0.09</td>
<td>6.62 ± 0.11</td>
<td>8.05 ± 0.30</td>
<td>[19]</td>
</tr>
<tr>
<td>Moth bean</td>
<td>23.60 ± 2.00</td>
<td>63.17 ± 0.23</td>
<td>0.38 ± 0.01</td>
<td>3.47 ± 0.03</td>
<td>6.00 ± 0.20</td>
<td>3.38 ± 0.13</td>
<td>[20]</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Millet type</th>
<th>Protein</th>
<th>Carbohydrate</th>
<th>Fat</th>
<th>Ash</th>
<th>Fiber</th>
<th>Moisture</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finger millet</td>
<td>7.61 ± 0.01</td>
<td>78.08 ± 052</td>
<td>3.84 ± 0.56</td>
<td>1.84 ± 0.59</td>
<td>5.54 ± 0.03</td>
<td>3.10 ± 0.53</td>
<td>[21]</td>
</tr>
<tr>
<td>Pearl millet</td>
<td>8.22</td>
<td>76.17</td>
<td>3.34</td>
<td>2.04</td>
<td>2.35</td>
<td>7.3</td>
<td>[22]</td>
</tr>
<tr>
<td>Proso millet</td>
<td>0.56</td>
<td>83.94</td>
<td>5.5</td>
<td>5.5</td>
<td>4.5</td>
<td>21.8</td>
<td>[23]</td>
</tr>
<tr>
<td>Barnyard millet</td>
<td>11.2</td>
<td>72.0</td>
<td>1.8</td>
<td>2.3</td>
<td>5.3</td>
<td>10.0</td>
<td>[24]</td>
</tr>
<tr>
<td>Foxtail millet</td>
<td>6.8</td>
<td>70.0</td>
<td>2.9</td>
<td>2.1</td>
<td>4.9</td>
<td>15.0</td>
<td>[25]</td>
</tr>
<tr>
<td>Kodo millet</td>
<td>6.70 ± 0.01</td>
<td>72.76 ± 1.87</td>
<td>3.60 ± 0.03</td>
<td>3.30 ± 0.01</td>
<td>4.20 ± 0.01</td>
<td>9.34 ± 0.02</td>
<td>[25]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of millet</th>
<th>Time of germination</th>
<th>Protein</th>
<th>Carbohydrate</th>
<th>Fat</th>
<th>Ash</th>
<th>Fiber</th>
<th>Moisture</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finger millet</td>
<td>72 h</td>
<td>7.81 ± 014</td>
<td>75.70 ± 0.44</td>
<td>2.73 ± 0.25</td>
<td>1.80 ± 0.27</td>
<td>8.81 ± 0.01</td>
<td>3.14 ± 0.56</td>
<td>[21]</td>
</tr>
<tr>
<td>Pearl millet</td>
<td>48 h</td>
<td>10.39</td>
<td>74.43</td>
<td>2.70</td>
<td>2.70</td>
<td>2.38</td>
<td>7.4</td>
<td>[22]</td>
</tr>
<tr>
<td>Proso millet</td>
<td>24 h</td>
<td>0.63</td>
<td>83.47</td>
<td>4.7</td>
<td>6.0</td>
<td>5.2</td>
<td>23.6</td>
<td>[23]</td>
</tr>
<tr>
<td>Proso millet</td>
<td>68 h</td>
<td>0.84</td>
<td>82.96</td>
<td>4.6</td>
<td>7.0</td>
<td>4.6</td>
<td>26.0</td>
<td>[23]</td>
</tr>
<tr>
<td>Proso millet</td>
<td>72 h</td>
<td>0.88</td>
<td>82.82</td>
<td>4.2</td>
<td>8.4</td>
<td>4.1</td>
<td>28.6</td>
<td>[23]</td>
</tr>
<tr>
<td>Barnyard millet</td>
<td>-</td>
<td>8.9</td>
<td>61.0</td>
<td>2.5</td>
<td>2.0</td>
<td>5.7</td>
<td>9.5</td>
<td>[24]</td>
</tr>
<tr>
<td>Foxtail millet</td>
<td>-</td>
<td>12.6</td>
<td>72.0</td>
<td>2.6</td>
<td>4.2</td>
<td>5.1</td>
<td>11.56</td>
<td>[24]</td>
</tr>
<tr>
<td>Kodo millet</td>
<td>35.82 h</td>
<td>7.90 ± 0.041</td>
<td>71.43 ± 1.34</td>
<td>2.8 ± 0.01</td>
<td>2.92 ± 0.02</td>
<td>5.12 ± 0.04</td>
<td>10.21 ± 0.04</td>
<td>[25]</td>
</tr>
</tbody>
</table>
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].

Modifications 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 lipoprotein 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-
erved increase in total protein and total lipids in germinated high-amyllose 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 Owuero 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 hydrolyases 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 decreased from 437.00 ± 1.04 to 29.00 ± 1.08, while the trough viscosity decreased after 72 h germination periods. This decrease in viscosity 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.

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

Figure 2 depicts the variations in the mineral content of calcium, phosphorus, and iron. Soaked mung beans and soybeans 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 soybeans 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].

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...
When germination time increased mineral content like sodium, iron, magnesium, zinc increased. Increased in magnesium content, in finger millet calcium content increased. Increase in polyphenolic content due to biosynthesis of polyphenolic compounds.

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

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

<table>
<thead>
<tr>
<th>Cereal/Legumes/Millet</th>
<th>Germination effects</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finger millet</td>
<td>Improved protein and sugar digestion increased tannins, phytates, starch.</td>
<td>[32]</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Increased ash and protein but with reduction in moisture. Increased amylpectin, water absorption index, but reduced amylose.</td>
<td>[57]</td>
</tr>
<tr>
<td>Pearl millet and finger millet</td>
<td>Increased in magnesium content, in finger millet calcium content increased.</td>
<td>[21]</td>
</tr>
<tr>
<td>Finger millet</td>
<td>Germination reduced the antinutritional components of finger millet flour, such as the phytate and tannin content, by around 50%.</td>
<td>[58]</td>
</tr>
<tr>
<td>Foxtail millet</td>
<td>Increase in polyphenolic content due to biosynthesis of polyphenolic compounds.</td>
<td>[59]</td>
</tr>
<tr>
<td>Proso millet</td>
<td>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.</td>
<td>[23]</td>
</tr>
<tr>
<td>Lentil</td>
<td>When germination time increased mineral content like sodium, iron, magnesium, zinc increased.</td>
<td>[52]</td>
</tr>
<tr>
<td>Chickpea</td>
<td>Increase in protein, increase in phenolic compounds. Chickpeas that were allowed to germinate for 48 h had much less carotenoid content. GABA content increased.</td>
<td>[48]</td>
</tr>
<tr>
<td>Wheat</td>
<td>Protein content, moisture content increased. Ash content decreased. Water absorption, water solubility index, oil absorption increased whereas falling number decreased.</td>
<td>[11]</td>
</tr>
</tbody>
</table>
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 Oghbæi 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 1.5×10^2 to 1.03×10^2 CFU/g, while optimized composite flour cookies had a count of 2.0×10^2 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.

Acknowledgment

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Conflict of Interest

None.

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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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