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A review of the effect of processing on the nutritional composition of barley

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Abstract
The fourth most widely grown cereal in the world is barley. Barley (*Hordeum vulgare* L.) is primarily produced for feed and for malting to make alcoholic beverages all over the world. In wealthy nations as well as, more so in poor nations, for animal feeding, barley straw is utilized for animal bedding. The majority of estimates state that in order to satisfy the rising demand, cereal production must rise by 50% or even more over the next 50 years; as a result, crop breeding and agronomy benefit from an understanding of the mechanisms governing the development, growth, and yield of cereals, including barley. The high nutritional value, high dietary fiber content (β-glucan), and excellent malt quality of naked barley, along with the lack of a dehulling procedure, provide it certain advantages in the food business. Barley is also rich in other beneficial dietary fiber elements, such as arabinoxylans, which have the health benefits of both soluble and insoluble fibers and support and affect the immune system. More total dietary fiber is present in high-glucan food barley cultivars than in other common cereal grains including wheat, rye, and oats. Barley also contains phytochemicals, ferulic acid is the most prevalent of them, followed by coumaric acid and sinapic acid in smaller quantities.

Keywords: Barley, nutritional composition, processing

Introduction

The fourth most produced cereal crop overall is barley (*Hordeum vulgare* L.), yet only a small portion of this grain is consumed by humans. Nevertheless, it is gaining popularity as a "functional grain" since it contains more bioactive substances, including β-glucan (4–11%), phytochemicals, soluble and insoluble dietary fibers, and other bioactive substances, including vitamins E and B-complex and minerals. Extensive research is still being conducted on the health advantages of barley β-glucan and other bioactive substances (Goudar *et al*., 2020) [21].

Barley comes in two main varieties: covered or hulled barley and naked barley. The high nutritional value, high dietary fiber content (β-glucan), and excellent malt quality of naked barley, along with the lack of a dehulling procedure, provide it certain advantages in the food business.

Consuming β-glucans has been associated with a number of physiological benefits, including lowering cholesterol, blood pressure, postprandial glucose response, and gut flora. Barley is also rich in other beneficial dietary fiber elements, such as arabinoxylans, which have the health benefits of both soluble and insoluble fibers and support and affect the immune system. More total dietary fiber is present in high-glucan food barley cultivars than in other common cereal grains including wheat, rye, and oats (Izydorczyk, 2019) [29].

Additionally, compared to other cereals and oilseeds, barley grain is a particularly rich source of vitamin E since it possesses comparatively high amounts of all eight tocochromanols (α-, β-, γ-, and δ-tocopherols and α-, β-, γ-, and δ tocotrienols) and a high ratio of tocotrienols to tocopherols. Research on vitamin E for many years largely focused on the antioxidant properties of -tocopherol, until the discovery of recent studies demonstrating that tocotrienols had powerful neuroprotective, antioxidant, and anti-cancer potential (Dueck *et al*., 2020) [15]. It has been demonstrated that tocotrienols lower cholesterol in humans and animals and inhibit the proliferation of a number of tumor cells, including those in the breast, colon, lung, and prostate (Izydorczyk, 2019) [29]. Examining the tocotrienol to tocopherol ratio (T3/T) can help you figure out the biopotential of grains and other foods that are thought to be sources of vitamin E (Dueck *et al*., 2020) [15].

Barley also contains phytochemicals, ferulic acid is the most prevalent of them, followed by coumaric acid and sinapic acid in smaller quantities. Other acids include p-hydroxybenzoic acid, vanillic acid, syringic acid, 2,4-dihydroxybenzoic acid, and p-hydroxybenzoic acid.

Nonpolar bioactives in barley include flavonoids, which include flavanols, anthocyanins, and proanthocyanidins as well as phytosterols such as sitosterol and campesterol. Barley also includes lignans (such as pinoresinol, medioresinol, syringaresinol, lariciresinol, cyclolariciresinol, and secoisolariciresinol).

Cereals undergo different types of processes in order to serve their different purposes and the nutrients contained in them could either be deteriorated or increased in quantity during the different food processing. Those processes include, pearling, milling, refining, soaking, germination, fermentation, roasting, puffing, extrusion etc… For instance, Six different barley varieties' kernels, flour, and extruded product were examined for dietary fiber and starch content. The starch content of kernels was found to be lower than that of flour and extruded goods. Arabinoxylan content was higher in sifted flour than in kernels despite extrusion reducing it. Extrusion increased the extractability of arabinoxylan while decreasing its molecular weight generally. Extrusion also decreased the mixed-linkage (1→3,1→4) β-D-glucan content, although it increased the extractability. Similarly, (de Paula *et al*., 2017) investigated the impact of extrusion, drying, and cooking on the physicochemical properties of barley blends and pasta as well as the molecular characterisation of β-glucan. The physicochemical characteristics of -glucan were altered, even though the amount of -glucan in the finished products was not significantly changed. Cooking significantly boosted the β-glucan's extractability and molecular weight, which in turn increased its viscosity and affected how effective it is physiologically. All pasta's β-glucan properties suffered with extrusion and drying.

This review will provide a close overview on all the broad techniques and their effects on barley's nutritional properties.

Barley structure

Barley cell walls encase starch granules embedded in a protein matrix. The large mealy grains' thin cell walls and loose endosperm packing allow for rapid water uptake and uniform distribution of water and enzymes synthesized during germination. On the other hand, small steely grains, slow mass transfer in the endosperm due to thick cell walls and densely packed endosperms (Abebaw, 2021) [1]. Large, plump kernels are preferred for malting. The fraction above the 2.5 mm sieve is typically used for malting, while the remainder is included in the feed fraction. A larger uniform grain size is preferred because it allows for more uniform water uptake and modification. The barley hull contains approximately 13% fiber, and dehulling is not practical for feed purposes because the hull is fused to the seed by a cementing substance produced by the caryopsis (Abebaw, 2021) [1].

Two classes of barley are based on the number of rows; the first is two rows, and the second is six rows

1. Two-row barley: It has one fertile floret per rachis node and two rows of seeds on each spike.
2. Six-row barley: This variety has six rows of seeds per spike and six fertile florets per rachis node (Inamdar & Meti, 2020) [28]. The main constituents of barley are:
   - Hull
   - Endosperm
   - Embryo
   - Caryopsis

A. Hull

The hull of the mature grains of barley, which is made primarily of cellulose, lignin, and silicon, develops from the lemma and palea at a late stage of grain development. In hulled barley, the hulls are firmly attached to the caryopsis; however, in naked barley, they are separated (Geng *et al*., 2022) [22]. At 9–29 days after pollination (DAP), during the late grain milk stage, a cementing layer is produced that binds the hull to the caryopsis. The cementing layer contains large amounts of octadecanol, tritriacontane, campesterol, and beta-sitosterol, and the composition and quantity of these substances are related to their adhesive properties (Brennan *et al*., n.d.). Furthermore, because of their impact on the synthesis of these chemicals, environmental factors during grain development affect the adhesive ability. The reduction in adhesive ability is brought on by warm preanthesis and cool post-anthesis conditions (Geng *et al*., 2022) [22]. According to CV type, hull accounts for 10–30% of the kernel. Dehulled barley is made by removing the hull from the grain using steam processing, which produces pearl barley. Similar to hulled barley, naked barley is grown without a hull until it is fully mature, at which point it becomes loose and is removed during harvest (Farag *et al*., 2022a) [17].

B. Endosperm

The barley grain's starchy endosperm, which makes up about 75% of its weight, is the largest morphological component. The starchy endosperm's job is to store nutrients for the developing embryo during germination. Dead cells without nuclei and starch granules embedded in a matrix of storage proteins make up this substance. Mixed-linkage (1→3, 1→4)-β-D-glucan (β-glucan) and arabinoxylan makeup 25% and 75%, respectively, of the surrounding cell walls. The subaleurone, the outermost layer of the starchy endosperm, has smaller, more regular cells with irregular borders, prismatic cells between the crease and the dorsal side of the grain, and irregular borders elsewhere (Holopainen-Mantila, 2015) [24]. The embryo, which resides in a unique sac, is encircled by the endosperm tissue's protective layer. For the developing embryo, the endosperm gathers fats, proteins, and starches (Farag *et al*., 2022a) [17]. Aleurone, sub-aleurone, and the starchy endosperm make up the majority of the grain's composition. Multilayered cells, typically three cell layers, make up barley aleurone. Aleurone contains a variety of micronutrients, including lipids, proteins, minerals, and B-type vitamins like niacin and folates (Geng *et al*., 2022) [22]. In aleurone cells, storage protein accumulates as aleurone granules. While more proteins are accumulated in the intermediate sub-aleurone between the outer aleurone and the inner starchy endosperm, starch granules are primarily accumulated in the inner starchy endosperm (Y. Zheng & Wang, 2014) [40].

C. Embryo

The embryo is made up of an acrospire, a nodal region between the root and the shoot, and a primary root covered in coleorhiza. The acrospire includes coleoptile, leaf primordia, and an apical meristem. Scutellum, a modified cotyledon, which is present during germination, serves to separate the embryo from the endosperm (Holopainen-Mantila, 2015) [24]. The scutellum's outermost layer, the scutellar epithelium, faces the grain's outermost layer of endosperm, which is a layer of crushed cells made of compressed cell wall material in this area of the grain (Holopainen-Mantila, 2015) [24]. The embryo, which attaches to one side of the rachis and is found on the dorsal side of the caryopsis, is the most crucial element of grains for flial generation (Geng *et al*., 2022) [22]. The embryo's main components, which provide nutrients for the growth and development of plants, are the embryonic axis, plumule, and radicle. The coleoptile and coleorhiza cover and well-protect the embryo (Geng *et al*., 2022) [22]. The scutellum is a protective tissue with an external recess and a fat shape that connects to the embryonic axis and endosperm on either side (Geng *et al*., 2022) [22].

D. Caryopsis

The majority of the mature cereal grain is made up of the caryopsis. The main components of the barley caryopsis are the embryo and endosperm, which are encircled by the nucellar layer, testa (seed coat), and pericarp (fruit coat) (Geng *et al*., 2022) [22]. The nucella layer-testa interval is the thinnest, whereas the testa-pericarp interval is the thickest (Brennan *et al*., n.d.).

Nutritional composition of barley

Barley grain nutrient composition varies depending on the cultivar, environment, and processing. Whole barley grain has a starch content of 65-68%, protein content of 10-17%, b-glucan content of 4-9%, free lipid content of 2-3%, and minerals content of 1.5-2.5%. Total dietary fiber ranges between 11 and 34%, while soluble dietary fiber ranges between 3 and 20%. Hulless or de-hulled barley grain has 11-20% total dietary fiber, 11-14% insoluble dietary fiber, and 3-10% soluble dietary fiber. Rediscovery of barley-based food preparations with a significant increase in use over the last two decades, which may be due to newly developed barley varieties with high nutrient content.

Carbohydrates

The majority of the dry matter in the barley grain is made up of carbohydrates. Starch, which makes up the majority of the carbohydrates in barley, is used as a source of energy during germination (Abebaw, 2021) [1]. The hulls contain more than 96% of the total cellulose in the grain (husks). Although present in smaller amounts, the concentration of mono- and disaccharides (sucrose, glucose, fructose, and maltose) in this cereal are twice that of other cereals (Abebaw, 2021) [21]. Due to the detrimental effects on digestion, the content of the non-starch polysaccharide fraction's arabinoxylan (total 6.7%, of which 0.4% is water-soluble; and β-glucan (4.6%) is relevant when barley is fed to young monogastric animals. Contrary to popular belief, it is noteworthy that low-digestible carbohydrates, in particular β-glucan and resistant starch, have a beneficial effect on human health by lowering postprandial blood glucose levels and lowering blood cholesterol levels (Abebaw, 2021) [1].

Starch

The barley kernel's main chemical constituent is starch, the amount of which varies inversely with protein percentage. Barley kernel starch is primarily amylopectin (74–78%), which contains straight chains of D-glucopyranose units linked by α-1,6 linkages, and amylose (22-26%), which contains straight chains of D-glucopyranose units linked by α-1,4 linkages (Newman & Mcguire, n.d.). There are two types of barley CVs based on the proportion of amylose and amylopectin: waxy starch and non-waxy starch. Amylose-free starch cv or that with a low percentage (up to 10%) is known as waxy or near-waxy cv, whereas non-waxy barely starch contains a higher percentage of amylose (17-24%) than the waxy cv (Farag *et al*., 2022b) [18]. Due to its low amylose content, waxy barley starch has a high viscosity, good cooking resistance, and ductility. As a result, waxy barley has been widely used in the food processing and brewing industries (Chen *et al*., 2020) [12]. Starch granules in barley are classified into two types: granule type A, which has a diameter of 10-20 µm and is lenticular, and granule type B, which has a diameter of less than 10 µm, is spherical in shape, represents 5-30% of total starch, has a lower amylose content, and is more associated with lipid and protein (Langenaeken *et al*., 2019) [31]. Amylose content influences the functional properties of barley starches: starch with a high amylose content is more sensitive to retrogradation, and its pastes are more elastic (Punia, 2020) [32]. Various methods, such as iodine-binding amperometry and spectrophotometry, gel-permeation chromatography (GPC), potentiometry, and others, have been used to determine the amylose content of whole/debranched starch but this goes beyond the scope of this review.

Non-starch polysaccharides (NSPs)

NSPs are structural compounds found throughout the entire caryopsis, aleurone layer, and endosperm cell wall in barley grains mainly β-Glucan.

β-Glucan

β-glucans are large linear polysaccharides of glucose monomers that are found in many cereal grains. The mixed linkage (1→3, 1→4)-β-D-glucans, in particular, are linear homopolymers of D-glucopyranosyl residues. Barley is thought to be the richest source of β-glucans, which account for approximately 75% of total cell wall polysaccharides in endosperm cell walls; the remainder is made up of arabinoxylans, cellulose, glucomannans, and proteins (Aldughpassi, n.d.). Internal aleurone and subaleurone cell walls are the most abundant source of β-glucans. EC 3.2.1.73, also known as licheninase or (1→3,1→4)-β-glucanase, regulates the content of β-glucan during endosperm development to facilitate endosperm cell-wall degradation during germination (el Khoury *et al*., 2012) [16]. There are three major types of barley in terms of fibre content: hulled barley (predominant, covered caryopsis with tough fibrous husk, mainly used in malting and brewing), hull-less barley (naked barley, uncovered caryopsis, hull easily removed during threshing and has high nutritional value), and pearled barley (more processed with less fibre content) (Farag *et al*., 2022a) [17].

Proteins

Protein levels in barley grains can reach 10-20% and are concentrated primarily in the endosperm. Gluten accounts for approximately 75% of barley protein (50% prolamins, primarily hordein, and 25% glutenins), making it unsuitable for celiac disease patients who are gluten intolerant (Farag *et al*., 2022a) [17]. Protein in barley contains both essential (28%, primarily; leucine, valine, threonine, phenylalanine, isoleucine, lysine, histidine, and methionine) and non-essential (72%, primarily; glutamic acid, aspartic acid, proline, tyrosine, glycine, and cytosine) amino acids, indicating that it is a good source of protein in food supplements (Huang, 2020) [25]. Lysine, a branched-chain amino acid found in muscle-building supplements, is one of the most important essential amino acids found in barley (Huang, 2020) [25]. Lysine is the most scarce amino acid in barley, as it is in other cereals. Increasing lysine content has thus been a key goal in the breeding of food barley. Different cereal cultivars with high lysine levels have been developed. In comparison to normal maize and sorghum, which have 2% lysine content, high lysine maize has 3.4% lysine content and high lysine sorghum has 3.33% lysine content (Geng *et al*., 2022) [22].

Lipids

All plant tissues contain a class of biomolecules known as lipids. They perform a variety of roles and duties, including those of cell membrane components, metabolic energy storage molecules, and stress-related signaling factors (Kuczyńska *et al*., 2019) [30]. Lipids make up a sizable portion of the reserves in the embryo and the aleurone layer of the grain, despite making up a small portion of the dry matter in most barley tissues. They are necessary for the cells' ability to function properly (Abebaw, 2021) [1]. Furthermore, the food industry relies heavily on plant lipids as a source of dietary phytochemicals. Lipids are typically stored in plants as triacylglycerol (TAG) droplets (Kuczyńska *et al*., 2019) [30]. The main nonpolar lipid is triacylglycerol, with minor amounts of steryl esters, diacylglycerol, monoacylglycerol, and free fatty acids. The relatively polar lipids in barley are represented by phospholipids. Fatty acids in barley kernel included linoleic acid (50–60%), palmitic (20–30%), oleic (10–15%), and linolenic acid (4–9%). Finally, the endosperm of the barley kernel is composed mostly of palmitic acid (46%) and linoleic acid (34%) (Farag *et al*., 2022a) [17]. Barley grains typically contain 3.0%–3.5% lipids, though some mutants had much higher lipid contents (Geng *et al*., 2022) [22]. For example, (Bravi *et al*., 2012) [9] investigated the influence of barley varieties (4 spring barley and 1 winter barley) coming from Italy and the malting process on the lipid content. The data showed that the total lipid content decreased significantly during the malting process as barley was converted into malt. Different barley varieties have varying Fatty Acid contents and Fatty Acid patterns. The relationship between barley lipid content and malt quality confirmed the negative influence of lipids.

Vitamins

Vitamins are typically divided into two groups: fat-soluble vitamins and water-soluble vitamins. Vitamins A, D, E, and K are water-soluble vitamins, while inositol, vitamins C, and B are fat-soluble vitamins. Cereals contain a lot of vitamin B overall (Idehen *et al*., 2017) [17]. Barley is one of the richest cereals in vitamin E (tocols) (primarily a-tocopherols) and a-tocotrienol (a-T3) which is thought to be good for human health because it reduces the risk of diseases (Farag *et al*., 2022a) [17]. Vitamin E levels in barley ranged from 8.5 to 31.5 µg/g dry weight, with levels influenced by storage and barley genotype. In general, hull-less (naked) or colored genotypes had lower vitamin E content (Farag *et al*., 2022a) [17].

Minerals

The mineral fraction of barley is primarily composed of magnesium, phosphorus, potassium, calcium, and sodium. The average mineral content varies significantly, which appears to be due to a combination of factors such as the variety in question, growing and soil conditions, and fertilizer application. Major constituents based on a global compilation. Phosphorus is bound to the phytate complex in large amounts in barley grain (51-66%), rendering much of it unavailable to monogastric animals (Abebaw, 2021) [1]. Mineral elements are distributed throughout the grain but are most concentrated in the outer layers. As a result, the mineral content of hulled barley is much higher than that of hulless barley. Minerals are classified into two groups based on their concentration in plant tissues: macro- and micro-elements. Ca, P, K, Mg, Na, Cl, and S are macroelements, while Co, Cu, Fe, I, Mn, Se, and Zn are microelements (Geng *et al*., 2022) [22]. The most abundant mineral elements in barley grains are K and P, which account for 0.37%-0.50% and 0.33%-0.60% of dry matter, respectively. The most abundant mineral elements in barley grains are K and P, which account for 0.37%-0.50% and 0.33%-0.60% of dry matter, respectively (Geng *et al*., 2022) [22]. Many enzymes require K to maintain their electrical potential, hydrostatic pressure, and biochemical activity. P is another essential macronutrient whose scarcity can impair plant growth and development. Phytic acid (PA) is the primary phosphorus storage form in barley and cereal grains, accounting for 65%-85% of total phosphorus in seeds. PA is a nutrient-limiting factor in animal feed, and excrements containing PA can contaminate water (Geng *et al*., 2022) [22].

Phytochemicals

Barley contains a variety of bioactive compounds, including phenolic acids, the most abundant of which is ferulic acid (68%), followed by coumaric acid, and small amounts of p-hydroxybenzoic acid, vanillic acid, syringic acid, 2,4-dihydroxybenzoic acid, and sinapic acid. Flavonoids, which include flavanols, anthocyanins, and proanthocyanidins, are another valuable constituent of barley (Baoguoosun & Editors, n.d.). Phytosterols, such as sitosterol (53-61%) and campesterol (14-20%), are nonpolar bioactives in barley. Furthermore, barley contains lignans (such as pinoresinol, medioresinol, syringaresinol, lariciresinol, cyclolariciresinol, and secoisolariciresinol). These compounds are primarily found in the husks, pericarp, testa, and aleurone of barley grain. The total phenolics content ranged from 130 to 481 mg gallic acid equivalents (GAE)/100 g dry weight. Ferulic acid (FA) and p-coumaric acid (p-CA) are the most abundant phenolic acids in barley, accounting for 1.13-4.04 g/g and 0.19-3.53 µg/g, respectively (Cai *et al*., 2016) [11]. The total flavonoid and total proanthocyanidins content ranged from 50 to 150 mg rutin equivalents (RE)/100 g and 29-65.26 mg/100 g dry weight, respectively (Shen *et al*., 2018) [33]. In the brewing industry, phenolic compounds have an impact on beer quality in terms of taste, flavor, haze stability, and appearance.

Effect of processing on barley

To improve convenience, nutritional quality, and palatability, cereal grains (oats, barley) are subjected to various processing treatments such as pearling, milling, refining, soaking, germination, fermentation, roasting, puffing, extrusion etc. either in combination or individually before consumption.

Pearling, milling and refining

The removal of hulls and manufacture of products such as grits, brokens, semolina, and flour for use in a wide range of products such as bread, biscuits, cakes, pasta, noodles, and morning cereals are the basic operations for pearling, milling, and refining cereal grains. The amount of pearling and refining affects the composition of bread, biscuits, cakes, pasta, noodles, and breakfast cereals, whereas milling parameters affect the size of starch granules, degree of starch damage, the proportion of cell wall constituents, minerals, vitamins, and other constituent levels (Felizardo & Freire, 2018) [19]. characterized barley grains after four commercial levels of pearling process and the results showed there was a 40 percent reduction in thickness, a 25% reduction in bulk porosity, a 30% reduction in permeability, and a 17% reduction in angle of repose. (B. Zhao *et al*., 2020) [37] combined pearling and modified milling of hull-less barley to increase the flour yield and quality and the results showed that β-glucan content of barley flour increased by 24.1% and 66.3%, respectively, and bran's total dietary fibre content increased by 82.7%. (Djurle *et al*., 2016) [14] studied the effect of milling and extrusion on dietary fibre and starch content and composition of six varieties of barley. It was demonstrated that Flour and extruded products contained more starch than kernels. Sifted flour had a larger concentration of arabinoxylan than kernels, but extrusion reduced it. Extrusion improved arabinoxylan extractability while lowering its molecular weight. Extrusion reduced the quantity of mixed-linkage (13),(14)-D-glucan in all cultivars while increasing its extractability. The milling and extrusion of the six barley cultivars had a similar effect on them. Pearling effectively removes as much husk as possible and milled grains absorb moisture more quickly and cook to a soft texture in less time.

Soaking

Whole grains can be made more nutritious by soaking and sprouting them, which helps release their nutrients and allows the body to absorb and use the variety of vitamins and minerals they contain (Bangar, Sandhu, Trif, Manjunatha, *et al*., 2022) [7]. Apart from cleaning and washing, soaking causes various physicochemical changes in barley grains. It softens grains, makes husk removal easier, separates anatomical components more efficiently, lowers anti-nutrient levels in outer layers, modifies endosperm slightly, and reduces energy consumption during milling. (Sorour *et al*., 2021) [34] studied the effect of soaking on free sugars, starch, and non-starch polysaccharides contents on some selected Egyptian barley cultivars. It was shown that after the soaking, the reducing, non-reducing, and total sugars after the treatment increased. Meanwhile these grains' starch, β-glucan, and pentosan contents were reduced by 2.9–5.3, 5.0–7.6, and 2.4-6.7%, respectively, after soaking for 12 hours (Sorour *et al*., 2021) [34].

Germination

Without understanding the biochemistry behind these occurrences, grain germination has been employed for generations to soften the kernel structure, enhance nutrient content and availability, decrease the number of antinutritive chemicals, and introduce novel flavours. The most well-known controlled germination method is barley malting, which produces malt for brewing and food applications (Sufiyan Farooqui, 2018) [35]. could observe protein and fibre content varied significantly between germinated and non-germinated barley flour, with 14.87%, 12.69%, and 3.28%, 1.74%, respectively. Calcium content was 130 and 110 mg/100g, phosphorus was 500 and 320 mg/100g, and magnesium was 180 and 160 mg/100g, respectively, in germinated and non-germinated barley flour. These results suggest that germinated flour has more nutritional properties than ungerminated flour.

(Bangar, Sandhu, Trif, Manjunatha, *et al*., 2022) [7] reported that there was a considerable increase in ash, protein and fibre content, and antioxidant properties (total flavonoid content, total phenolic content, antioxidant activity, metal chelating activity, and ABTS+ scavenging activity). (Sorour *et al*., 2021) [34] investigated how germination affected the contents of some chosen Egyptian barley cultivars' free sugars, starch, and non-starch polysaccharides. The reducing, non-reducing, and total sugars after the treatment were demonstrated. After 96 hours of germination, the starch, β-glucan, and pentosans contents of the barley grain samples decreased by 27.3-32.0, 41.0-42.7, and 33.6-36.0%, respectively (Sorour *et al*., 2021) [34].

Fermentation

Fermentation is a cost-effective and efficient food processing technology in which foods are exposed to the action of microorganisms to produce desired biochemical changes that result in a considerable modification of the food, resulting in increased nutritional content and acceptability of raw materials. Fermentation is one of the most cost-effective methods for eliminating anti-nutritional elements in a variety of foods.

(Xiao *et al*., 2020) [36] studied the effect of fermentation on structural characteristics and *in vitro* physiological activities of barley β-glucan. The results demonstrated that under acidic conditions, fermented β-glucan boosted inhibitory activities of α-amylase, α-glucosidase, and lipase, as well as cholesterol adsorption. The microstructure characteristics were transforming from a rod-like to sheet-like structure. (Abedeta Garbaba & Fikreyesus Forsido, 2020) [2] could observe a decrease in the anti-nutritional factors. The results showed that after fermentation of oats, barley flours and combination with amylase-rich flour phytate content was (18.63-175.07) and tannin content was (0.84-42.89) in (mg/100g).

(AL-Ansi *et al*., 2021) [3] investigated how natural fermentation affected the highlands barley starch's chemical makeup, morphology, physicochemical composition, and thermal properties. The results demonstrated that fermentation had no effect on the fine structure of starch but did reduce the molecular weight from 2.26 to 1.04 108 g/mol in native highlands barley and after 72 hours of fermentation (FHB72), respectively. Additionally, it reduced the B1 and B2 long chains of amylopectin while increasing the short chains. As fermentation progressed, it was discovered that the intensity ratio of the FT-IR bands 995/1022 and 1047/1022 increased, and the starch of FHB72 had the highest absorption-intensity at 3000-3600 cm1 and a higher swelling capacity. Pasting peak, final, and setback viscosities decreased during fermentation (AL-Ansi *et al*., 2021) [3].

Similarly, (Gutiérrez-Osnaya *et al*., 2020) [22] evaluated how the germination time affected the morphology, crystallinity, gelatinization, and viscosity characteristics of the Esmeralda and Perla barley varieties' starch. At 26 °C and 65% relative humidity, the two types of barley were allowed to germinate for 1 to 8 days. Pinholes and eroded surfaces were visible on micrographs. At 8 days after germination, Esmeralda's starch had completely been hydrolysed. From day 4, the crystalline area's molecular structuring was lost, reducing birefringence. Morphometric information: In both varieties, fractal dimension, area, perimeter, circularity, and roundness significantly decreased as germination time progressed. From 0.79 to 10.09 in Esmeralda and from 0.46 to 7.57 in Perla, the entropy increased noticeably. In the Perla, relative crystallinity dropped significantly from 24.7% to 23.6%. The pasting temperature was constant in Esmeralda but significantly decreased in Perla with germination from 95.43 to 95.19 °C. The gelatinization temperature increased significantly in Esmeralda but remained constant in Perla. Enthalpy significantly dropped in Esmeralda and Perla to 75.8% and 37%, respectively (Gutiérrez-Osnaya *et al*., 2020) [22].

Roasting

Roasting is thermal processing that is used to increase the shelf life of grains and also increases some nutritional properties of cereal flour. Roasting inactivation is often employed in cereal stabilization due to the demand for reduced processing investment. (Z. Zhao *et al*., 2022) [37] observed an increase in starch digestibility but a decrease in short fatty acids after sand roasting of Highland barley (HB) flour. The highest starch digestibility (94.0%) was found in sand-roasted HB flour with particle sizes of 150 m, although the lowest generation of total SCFAs (1.89–2.24 mM). (Bangar, Sandhu, Trif, & Lorenzo, 2022) [7] studies the effect of mild and strong toasting and roasting on the antioxidant properties of different barley cultivars. antioxidant properties studied were total phenolic content (TPC), total flavonoid content (TFC), antioxidant activity (AOA), metal chelating activity (MCA), and ABTS+ scavenging activity. The results showed that flour's scavenging activity for AOA, MCA, and ABTS+ rose following both treatments, while TFC declined. The TPC of flours increased after toasting but decreased after roasting. After toasting, peak viscosity (PV) and final viscosity (FV) increased, whereas after roasting, the opposite occurred.

Thermal Processing

Prior to being used in the production of food, cereals are thermally processed most frequently through the use of techniques like steaming, baking, extrusion, parboiling, heat-moisture treatment (HMT), and dry heat treatment (DHT), heat fluidization, and microwave cooking. Different thermal processing techniques have a significant impact on the quantity and makeup of different nutrients in foods.

Highland barley's thermal properties, color value, morphological characteristics, and crystallinity were studied in relation to the effects of parboiling processing (121 °C for 10, 15, and 20 min, 0.1 MPa)(Zhu *et al*., 2020) [36]. The color values Chroma B*, b* values increased, and L* values decreased during the 20-minute parboiling process. The crystallinity of the parboiled barley also showed A, B, and V-style polymorphs. The heat enthalpy (H) and onset, peak, and conclusion temperature of gelatinization, as well as the range of gelatinization (To, Tp, Tc, and Tc-To), were also decreased (Zhu *et al*., 2020) [36].

(B. Zheng *et al*., 2020) [39] examined *in vitro* and *in vivo* the nutritional effects of highland barley that had undergone heat-moisture treatment (HMT) and dry heat treatment (DHT). HMT and DHT may contribute to highland barley's decreased glycemic potency, according to *in vitro* research. In contrast, *in vivo*, findings demonstrated that supplementation with thermally-processed highland barley (THB) significantly reduced body weight and serum glucose, enhanced oxidation resistance, and changed the composition of gut microbiota. Bacteria that may be connected to the relatively higher content of dietary fiber in THB include *Bifidobacteria*, *Fusicatenibacter*, and *Desulfovibrio* (B. Zheng *et al*., 2020) [39].

(Bai *et al*., 2021) [5] applied three different thermal processes-heat fluidization, microwave cooking, and baking to highland barley (HB). Hardness, bulk density, thousand kernel weight, length/breadth ratio, and color difference all significantly decreased after thermal treatments, while puffing index rose. In the meantime, fissure formation was also noted in the appearance. The ability to extract β-glucan was improved and also there was an increase in reducing power and antioxidant activity. Heat fluidization was the factor that caused the greatest increase in bioactive compounds.

The effects of four thermal processing techniques (steaming, microwave, baking and extrusion processing) on highland barley that had been germinated (GHB) have been examined (Huang *et al*., 2021) [26]. Steaming, microwave cooking, baking, and extrusion processing significantly increased the contents of total dietary fiber (TDF) and total phenols while significantly reducing the contents of ash, starch, and resistant starch. With the exception of baking, the other three techniques enhanced the water's hydration qualities by raising the indexes for water absorption, water solubility, and swelling power. Due to damage to the whole grain powder particles during extrusion, thermally processed samples, especially those that were used to make a paste, showed improved thermal stability, pasting properties, and *in vitro* protein digestibility.

Effect on nutritional properties

Processing Techniques	Effect on nutritional properties	References
Pearling, milling and refining	- Increase of β-glucan content and dietary fibers	(B. Zhao *et al*., 2020) [37]
	- Increase of starch content	(Djurle *et al*., 2016) [14]
Soaking	- Increase of reducing, non-reducing sugars and total sugars	(Sorour *et al*., 2021) [34]
Germination	- Increase in protein, fiber calcium, magnesium content.	(Sufiyan Farooqui, 2018) [35]
	- Increase in Ash content and antioxidant properties	(Bangar, Sandhu, Trif, Manjunatha, *et al*., 2022) [37]
	- Decrease in the starch, β-glucan, and pentosans contents after 96 hours of germination	(Sorour *et al*., 2021) [34]
Fermentation	- Boost of cholesterol absorption - Increase in the inhibitory activities of of α-amylase, α-glucosidase, and lipase	
	- Decrease in anti-nutritional properties (phytate and tannin)	(Abedeta Garbaba & Fikreyesus Forsido, 2020)
Roasting	- Increase in starch digestibility	(Z. Zhao *et al*., 2022) [37]
	- Increase in the antioxidant activity	(Bangar, Sandhu, Trif, & Lorenzo, 2022) [7]
Thermal processing	- Decrease in glycemic potency - Increase in dietary fibers - Increase in protein digestibility	
	- Increase in reducing power and antioxidant activity	(B. Zheng *et al*., 2020) [39]

References

1. Abebaw G. Review on Structure, Functional and Nutritional Composition of Barley (*Hordeum vulgare*). Nutrition and Food Processing. 2021;4(2):01-08. https://doi.org/10.31579/2637-8914/046
2. Abedeta Garbaba C, Fikreyesus Forsido S. Reduction of post-harvest losses and value addition in east African food value chains proceedings of the reload sp5 wp2 and wp3 conference edited by reduction of post-harvest losse; c2020. https://www.researchgate.net/publication/343289795
3. AL-Ansi W, Sajid BM, Mahdi AA, Al-Maqtari QA, AL-Adeeb A, Ahmed A, *et al*. Molecular structure, morphological, and physicochemical properties of highlands barley starch as affected by natural fermentation. Food Chemistry. 2021;356:129665. https://doi.org/10.1016/J.FOODCHEM.2021.129665
4. Aldughpassi A. (n.d.). Physiological Effects of Barley: Examining the Effects of Cultivar, Processing and Food Form on Glycemia, Glycemic Index, Satiety and the Physico-Chemical Properties of β-glucan.
5. Bai YP, Zhou HM, Zhu KR, Li Q. Effect of thermal treatment on the physicochemical, ultra-structural and nutritional characteristics of whole grain highland barley. Food Chemistry. 2021;346:128657. https://doi.org/10.1016/J.FOODCHEM.2020.128657
6. Bangar SP, Sandhu KS, Trif M, Lorenzo JM. The Effect of Mild and Strong Heat Treatments on *In vitro* Antioxidant Properties of Barley (*Hordeum vulgare*) Cultivars. Food Analytical Methods; c2022. https://doi.org/10.1007/s12161-022-02288-1
7. Bangar SP, Sandhu KS, Trif M, Manjunatha V, Lorenzo JM. Germinated Barley Cultivars: Effect on Physicochemical and Bioactive Properties. Food Analytical Methods; c2022. https://doi.org/10.1007/s12161-022-02311-5
8. Baoguoosun J, Editors R. (n.d.). Bioactive Factors and Processing Technology for Cereal Foods.
9. Bravi E, Marconi O, Perretti G, Fantozzi P. Influence of barley variety and malting process on lipid content of malt. Food Chemistry. 2012;135(3):1112-1117. https://doi.org/10.1016/j.foodchem.2012.06.041
10. Brennan M, Shepherd T, Mitchell S, Topp CFE, Hoad SP. (n.d.). Husk to caryopsis adhesion in barley is influenced by pre-and post-anthesis temperatures through changes in a cuticular cementing layer on the caryopsis. https://doi.org/10.1186/s12870-017-1113-4
11. Cai S, Han Z, Huang Y, Hu H, Dai F, Zhang G. Identification of Quantitative Trait Loci for the Phenolic Acid Contents and Their Association with Agronomic Traits in Tibetan Wild Barley. Journal of Agricultural and Food Chemistry. 2016;64(4):980-987. https://doi.org/10.1021/acs.jafc.5b05441
12. Chen X, Shao S, Chen M, Hou C, Yu X, Xiong F. Morphology and Physicochemical Properties of Starch from Waxy and Non-Waxy Barley. Starch/Staerke. 2020;72(5–6). https://doi.org/10.1002/star.201900206
13. De Paula R, Abdel-Aal ESM, Messia MC, Rabalski I, Marconi E. Effect of processing on the beta-glucan physicochemical properties in barley and semolina pasta. Journal of Cereal Science. 2017;75:124-131. https://doi.org/10.1016/J.JCS.2017.03.030
14. Djurle S, Andersson AAM, Andersson R. Milling and extrusion of six barley varieties, effects on dietary fibre and starch content and composition. Journal of Cereal Science. 2016;72:146-152. https://doi.org/10.1016/j.jcs.2016.09.017
15. Dueck C, Cenkowski S, Izydorczyk MS. Effects of drying methods (hot air, microwave, and superheated steam) on physicochemical and nutritional properties of bulgur prepared from high-amylose and waxy hull-less barley. Cereal Chemistry. 2020;97(2):483-495. https://doi.org/10.1002/cche.10263
16. El Khoury D, Cuda C, Luhovyy BL, Anderson GH. Beta glucan: Health benefits in obesity and metabolic syndrome. In Journal of Nutrition and Metabolism; 2012. https://doi.org/10.1155/2012/851362
17. Farag MA, Xiao J, Abdallah HM. Nutritional value of barley cereal and better opportunities for its processing as a value-added food: a comprehensive review. In Critical Reviews in Food Science and Nutrition. 2022a;62(4):1092-1104. Taylor and Francis Ltd. https://doi.org/10.1080/10408398.2020.1835817
18. Farag MA, Xiao J, Abdallah HM. Nutritional value of barley cereal and better opportunities for its processing as a value-added food: a comprehensive review. In Critical

Reviews in Food Science and Nutrition. 2022b;62(4):1092-1104. Taylor and Francis Ltd. https://doi.org/10.1080/10408398.2020.1835817
19. Felizardo MP, Freire JT. Characterization of barley grains in different levels of pearling process. Journal of Food Engineering. 2018;232:29-35. https://doi.org/10.1016/j.jfoodeng.2018.03.017
20. Geng L, Li M, Zhang G, Ye L. Barley: a potential cereal for producing healthy and functional foods. In Food Quality and Safety. Oxford University Press. 2022, 6. https://doi.org/10.1093/fqsafe/fyac012
21. Goudar G, Sharma P, Janghu S, Longvah T. Effect of processing on barley β-glucan content, its molecular weight and extractability. International Journal of Biological Macromolecules. 2020;162:1204-1216. https://doi.org/10.1016/J.IJBIOMAC.2020.06.208
22. Gutiérrez-Osnaya LJ, Hernández-Uribe JP, Castro-Rosas J, Román-Gutiérrez AD, Camacho-Díaz BH, Palma-Rodríguez HM, *et al*. Influence of germination time on the morphological, morphometric, structural, and physicochemical characteristics of Esmeralda and Perla barley starch. International Journal of Biological Macromolecules. 2020;149:262-270. https://doi.org/10.1016/J.IJBIOMAC.2020.01.245
23. Han Z, Zhang J, Cai S, Chen X, Quan X, Zhang G. Association mapping for total polyphenol content, total flavonoid content and antioxidant activity in barley. BMC Genomics, 2018, 19(1). https://doi.org/10.1186/s12864-018-4483-6
24. Holopainen-Mantila U. Composition and structure of barley (*Hordeum vulgare* L.) grain in relation to end uses Academic dissertation at 12 o'clock noon. In Bio centre. 2015, 2. http://www.vtt.fi
25. Huang. Content analysis of vitamins, dietary fibers and amino acids in a wide collection of barley (*Hordeum vulgare* L.) from Tibet, China. Bioinformation. 2020;16(4):314. https://doi.org/10.6026/97320630016314
26. Huang L, Dong JL, Zhang KY, Zhu Y Ying, Shen RL, Qu LBO. Thermal processing influences the physicochemical properties, *in vitro* digestibility and prebiotics potential of germinated highland barley. LWT. 2021;140:110814. https://doi.org/10.1016/J.LWT.2020.110814
27. Idehen E, Tang Y, Sang S. Bioactive phytochemicals in barley. In Journal of Food and Drug Analysis. 2017;25(1):148-161. Elsevier Taiwan LLC. https://doi.org/10.1016/j.jfda.2016.08.002
28. Inamdar A, Meti R. Structure, health benefits and value added products of barley. ~ 532 ~ International Journal of Home Science. 2020;6(3):532-534. http://www.homesciencejournal.com
29. Izydorczyk MS. Chapter 9 Dietary Arabinoxylans in Grains and Grain Products. In Cereal Grain-based Functional Foods: Carbohydrate and Phytochemical Components; c2019. p. 167-203. The Royal Society of Chemistry. https://doi.org/10.1039/9781788012799-00167
30. Kuczyńska A, Cardenia V, Ogrodowicz P, Kempa M, Rodriguez-Estrada MT, Mikołajczak K. Effects of multiple abiotic stresses on lipids and sterols profile in barley leaves (*Hordeum vulgare* L.). Plant Physiology and Biochemistry. 2019;141:215-224. https://doi.org/10.1016/j.plaphy.2019.05.033
31. Langenaeken NA, De Schepper CF, De Schutter DP, Courtin CM. Different gelatinization characteristics of small and large barley starch granules impact their enzymatic hydrolysis and sugar production during mashing. Food Chemistry. 2019;295:138-146. https://doi.org/10.1016/J.FOODCHEM.2019.05.045
32. Newman CW, Mcguire CF. (n.d.). 4 Nutritional Quality of Barley. Punia S. Barley starch: Structure, properties and *in vitro* digestibility - A review. In International Journal of Biological Macromolecules. 2020;155:868-875. Elsevier B.V. https://doi.org/10.1016/j.ijbiomac.2019.11.219
33. Shen Y, Hu C, Zhang H, Jiang H. Characteristics of three typical Chinese highland barley varieties: Phenolic compounds and antioxidant activities. Journal of Food Biochemistry, 2018, 42(2). https://doi.org/10.1111/jfbc.12488
34. Sorour M, Ramadan B, Mehanni A, Kobacy W. Impact of Soaking and Germination Processes on Starch and Non-Starch Polysaccharides in some Egyptian Barley Cultivars. Journal of Food and Dairy Sciences. 2021;12(6):147-151. https://doi.org/10.21608/jfds.2021.78195.1021
35. Sufiyan Farooqui A. Influence of germination on chemical and nutritional properties of Barley flour. Journal of Pharmacognosy and Phytochemistry, 2018, 7(2).
36. Xiao X, Tan C, Sun X, Zhao Y, Zhang J, Zhu Y, *et al*. Effects of fermentation on structural characteristics and *in vitro* physiological activities of barley β-glucan. Carbohydrate Polymers, 2020, 231. https://doi.org/10.1016/j.carbpol.2019.115685
37. Zhao B, Wang L, Shang J, Liu L, Tong LT, Zhou X, *et al*. Application of pearling in modified roller milling of hull-less barley and effect on noodles quality. Journal of Food Processing and Preservation. 2020, 44(11). https://doi.org/10.1111/jfpp.14838
38. Zhao Z, Ming J, Zhao G, Lei L. Color, Starch Digestibility, and *In vitro* Fermentation of Roasted Highland Barley Flour with Different Fractions. Foods. 2022, 11(3). https://doi.org/10.3390/foods11030287
39. Zheng B, Zhong S, Tang Y, Chen L. Understanding the nutritional functions of thermally-processed whole grain highland barley *in vitro* and *in vivo*. Food Chemistry. 2020;310:125979. https://doi.org/10.1016/J.FOODCHEM.2019.125979
40. Zheng Y, Wang Z. Protein accumulation in aleurone cells, sub-aleurone cells and the center starch endosperm of cereals. In Plant Cell Reports. 2014;33(10):1607-1615). Springer Verlag. https://doi.org/10.1007/s00299-014-1651-2
41. Zhu Y Dan, Wang Z Yue, Wang Y, Li D, Wang L. jun. Effect on parboiling processing on structure and thermal properties of highland barley flours. Powder Technology. 2020;364:145-151. https://doi.org/10.1016/J.POWTEC.2020.01.049