Chapter

Benefits of Barley Grain in Animal and Human Diets

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Abstract

Barley (*Hordeum vulgare* L) is one of the major cereal grains grown in temperate countries and ranked globally as the fourth largest grain crop. Currently, it is produced in more than 100 countries around the world with a global production of approximatively 159 million tonnes and 51 million hectares in 2019. The production and value-added barley products impact breweries, food processors, feed mills, and livestock operations. Barley grain is used primarily as an energy and protein source in beef cattle diets and as a malt source for alcoholic beverages, especially in the beer industry. Also, barley is used in bread, soups, stews, and health products since the barley grain is rich in several health-boosting components. As such, barley is high in protein, fibre, vitamins and natural bioactive antioxidants such as phenolics and lipids. However the studies of bioactive and nutritional properties of barley and the utilization of the crop as a functional food in animal and human diet is still limited. The work herein provides a review covering world production, end-use and processing, nutritional attributes, and will advocate its potential as a functional food for animal and human health and its role in preventing some chronic diseases.

Keywords: barley, feed, functional ingredients, food, health benefits, malt

1. Introduction

Barley (*Hordeum vulgare* L) was domesticated in approximately 10,000 BC and is considered one of the oldest cultivated grains [1]. While the Fertile Crescent is widely accepted as the center of origin through the years, there were numerous debates, for example, regarding the number of times and locations [2–5] that barley was domesticated, the number of wild barley populations descended from [6, 7] and so on. Relatively recent, comparative genomic analysis of 6,000-year-old barley grains, found in a cave in the Judean Desert, and modern Israeli landraces showed close affinity and supported the previously proposed location, Jordan Valley, as the origin of the domesticated barley [8]. Moreover, the availability of additional barley reference genomes such as those recently reported by [9] may also help elucidate some of these controversies [10].

Currently, barley ranks fourth in both quantities produced and in the area cultivated for cereal crops globally. It was presumably first used as human food but evolved primarily into a feed, malting and brewing grain, in part due to the rise in prominence of wheat and rice [11]. Due to its ability to be cultivated in a wide range of climates, the crop is essential in places in the world where food security is an issue [12]. Moreover, barley has also been used as a principal food source in places where other cereals are more challenging to grow [13].

Barley is classified as spring or winter type, two-row or six-row, hulled or hulless, and malting or feed by end-use (**Figure 1**). Based on grain composition, barley is further classified as normal, waxy or high amylose starch types, high lysine, high beta-glucan, and proanthocyanidin-free types [14]. It has been shown that both genetics and environment could affect the overall metabolite composition of the barley and subsequent malt [15]. For example, [16] demonstrated a direct association between barley genotype and beer flavour, independent of the malt quality traits.

One of the most genetically diverse cereal grains, barley, is also considered a model plant in research allowing advances in plant genetics, plant physiology, plant pathology, plant biochemistry, and plant biotechnology [17]. Genetic diversity provides an ample opportunity to identify and breed barley varieties for specific end-uses for processors.

Barley is used as feed in ruminant, swine, poultry, and aquaculture production. As reported by [18] compared to feed grain corn, besides offering greater protein, barley grain is also richer in methionine, lysine, cysteine, and tryptophan. Moreover, compared to corn, due to its more rapid starch fermentation rate, barley provides a more simultaneous release of energy and nitrogen, consequently improving the microbial nutrient assimilation. The benefits of using fermented barley grain in the diets of broilers were also demonstrated. Fermented barley is

Figure 1.
Examples of different types of barley: two-row (upper left), six-row (upper right), hulled (bottom left) and hulless (bottom right). Source: authors' personal photo collection.

considered a valuable functional ingredient that can improve performance, breast meat quality, and intestinal health of birds [19].

Nowadays, human health and well-being are foremost. Therefore balanced nutrition and diet are receiving more and more attention. In this context, functional foods are much sought. Beyond meeting basic nutrients, these foods also provide additional health benefits by promoting and combating chronic diseases [20]. Thus, barley grain is gaining renewed attention worldwide due to the richness in functional ingredients. In particular, the nutritional composition meets the needs of a diet high in protein, fibre and vitamins, and low in fat and sugar [21]. The increase in the use of barley and malt in processed foods is mainly due to its natural antioxidants and the unique soluble fibre beta-glucan [22]. Barley is rich in groups of bioactive compounds, including phenolics and lipids, that have potential health benefits [23]. The epidemiological studies have shown that long-term consumption of diets rich in barley flour can offer protection against the development of hyperlipidemia, diabetes, and atherosclerosis [24]. The phenolic compounds found in barley, such as cinnamic acid derivatives and benzoic, proanthocyanidins, flavonols, flavanones, and flavones, could have beneficial effects, antioxidative and antitumor, decreasing blood lipids and hypoglycemic, on human health [22, 25]. In addition, the consumption of barley is an important source of macro- and micro-nutrients that is needed in the typical human diet and has beneficial effects against the development of illnesses such as cardiovascular disease, diabetes, and cancer [26].

2. Barley production

Barley is very versatile and has adapted well throughout its evolution. Its high prevalence is likely due to its high adaptability to a variety of climates, including cold and drought, and its adaptability to poor soil conditions compared to wheat. Much of the world's barley is produced in the regions where cereals such as maize and rice cannot grow well [27].

To date, barley is produced by more than 100 countries around the world [28]. In 2019, the global barley production was approximatively equal to 159 million tonnes (M t), after rice (755 M t), wheat (765 M t), and corn (1,148 M t). From 1961 to 2019, the average global production was 142 M t, with the highest production of 178 M t recorded in 1990 (**Figure 2**). In 2019, Europe accounted for more than 60% of the global barley produced, followed by Asia (16%) and North and Central America (9%) (**Figure 3**). Among the European barley producers, the Russian Federation, France, and Germany have exceeded, on average, 10% each for the past ten years. Australia and Canada follow them at 8.9% and 8.4%, respectively (**Table 1**).

United Kingdom of Great Britain and Northern Ireland; Source: prepared based on data from [28].

In 2019, the total area harvested for barley was 51 million hectares (M ha) and ranked fourth after rice (162 M ha), corn (197 M ha) and wheat (216 M ha). Over the past six decades, barley maintained its position in the global top five most cultivated cereal crops, and its harvested area ranged from 50 to 80 M ha, with the highest reached in 1979 at nearly 84 M ha (**Figure 4**).

In 2019, barley yield was 3.1 tonnes per hectares (t/ha) and ranked fourth after wheat (3.5 t/ha), rice (4.7 t/ha), and corn (5.8 t/ha). The average yield of the top cereal crops has been continuously increasing since 1961. During this period, barley yield averaged 1.8 t/ha in the '60s and '70s, 2.2 t/ha in the '80s and '90s, and 2.7 t/ha since the 2000s. In 2016, it broke the 3 t/ha barrier, with the highest yield reached in 2019 at 3.1 t/ha (**Figure 5**).

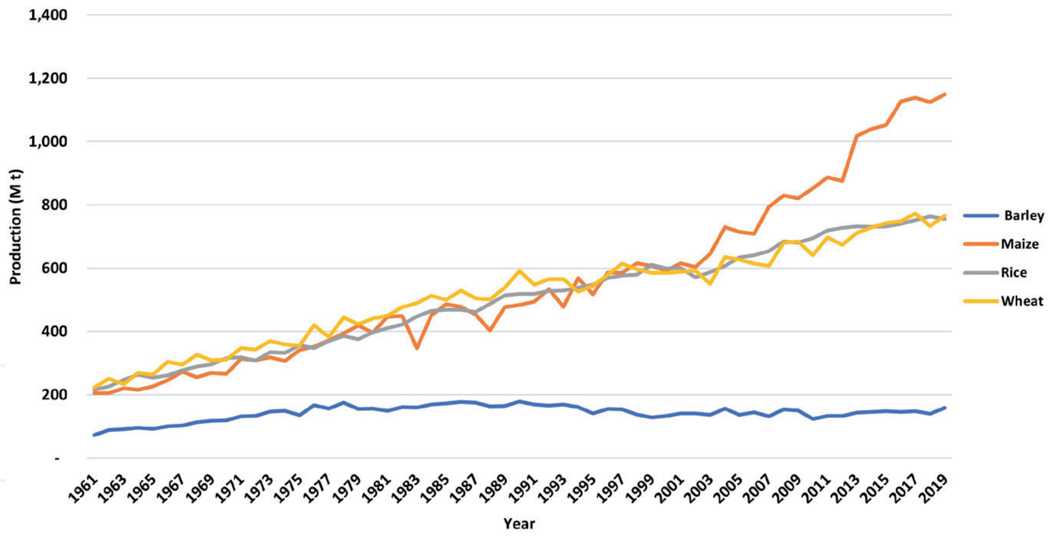

Figure 2.
Global top cereal crops production (M t), 1961–2019. Source: prepared based on data from [28].

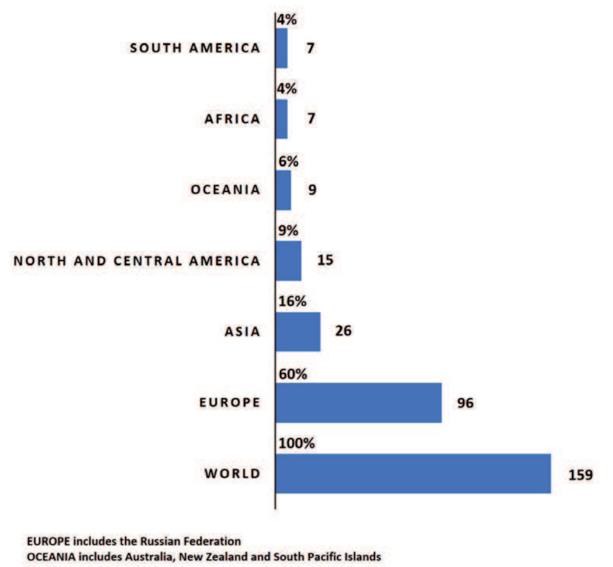

Figure 3.
Global barley production (M t) by region, 2019. Source: prepared based on data from [28].

3. End-use and processing of barley grain

Different barley classes often differ in physical and compositional characteristics and accordingly have different processing properties and end-use quality. Overall, worldwide barley has three primary uses: malting, feed, and food (**Figure 6**). In most countries, the majority portion of the barley is used as animal feed, particularly for cattle and pigs, and the use of barley as human food is more limited [13]. Although feed is the main use of barley, in many instances, more value comes from the crop if it is used for malting and production of beverages such as beer and whiskey [12]. However, barley is still considered a major staple food in several regions such as some areas of North Africa and the Near East, in highlands of Central Asia, the Horn of Africa, the Andean countries and the Baltic States, which are characterized by harsh living conditions. In 2016, per capita consumption was reported to be the highest in North Africa, with Morocco at 41 kg/person, Ethiopia and Syria at 15 kg each [30]. By contrast, very little barley is used as human food in developed countries. Overall, in 2016, the global per capita food use of barley was estimated at 1 kg/person compared to 17 kg of maize, 54 kg of rice and 67 kg of wheat. However,

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Country	Year										Average
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	
Russian Federation	8.3	16.9	13.9	15.3	20.4	17.5	17.9	20.6	16.9	20.4	**16.8**
France	10.1	8.7	11.3	10.3	11.7	13.0	10.4	12.0	11.0	13.5	**11.2**
Germany	10.3	8.7	10.3	10.3	11.5	11.6	10.7	10.8	9.5	11.5	**10.5**
Australia	7.8	7.9	8.2	7.4	9.1	8.6	8.9	13.5	9.2	8.8	**8.9**
Canada	7.6	7.8	8.0	10.2	7.1	8.2	8.8	7.8	8.3	10.3	**8.4**
Ukraine	8.4	9.0	6.9	7.5	9.0	8.2	9.4	8.2	7.3	8.9	**8.3**
Spain	8.1	8.2	5.9	10.0	6.9	6.7	9.1	5.7	9.5	7.7	**7.8**
Turkey	7.2	7.6	7.1	7.9	6.3	8.0	6.7	7.1	7.0	7.6	**7.3**
United Kingdom	5.2	5.4	5.5	7.0	6.9	7.3	6.6	7.1	6.5	8.0	**6.6**
Argentina	2.9	4.0	5.1	4.7	2.9	2.9	4.9	3.7	5.0	5.1	**4.1**

Table 1.
Global top barley producers (M t), 2010–2019.

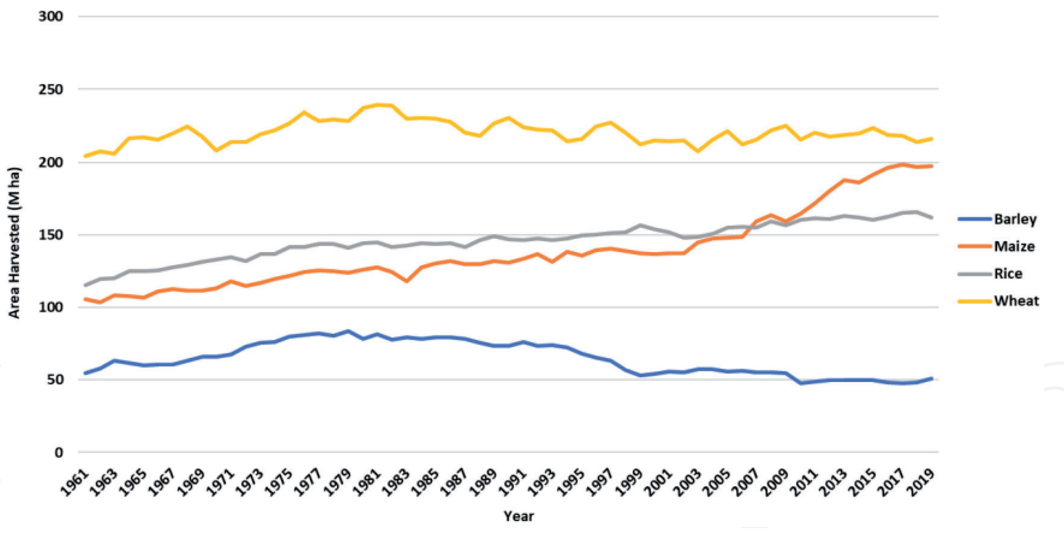

Figure 4.
Global top cereal crops area harvested (M ha), 1961–2019. Source: prepared based on data from [28].

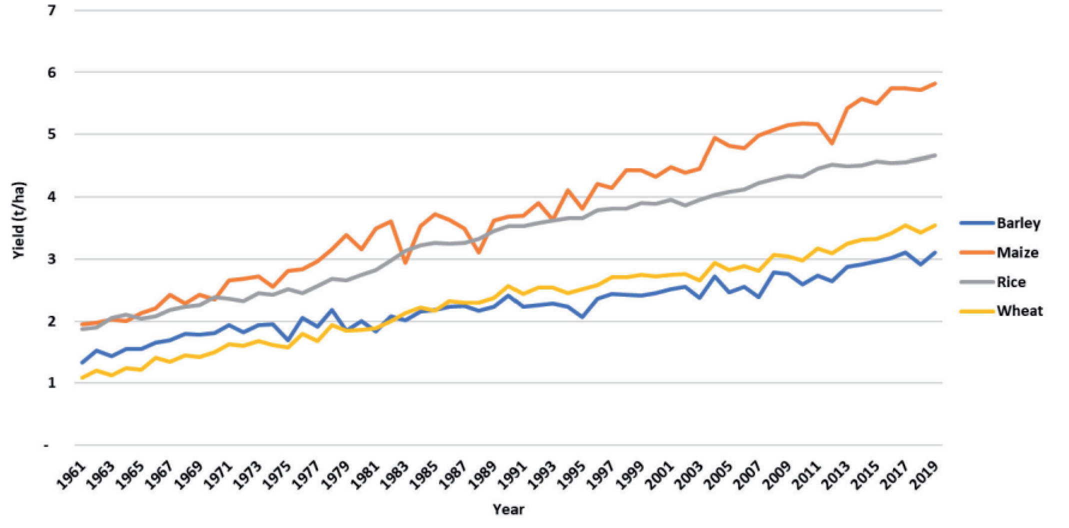

Figure 5.
Global top cereal crops grain yield (t/ha), 1961–2019. Source: prepared based on data from [28].

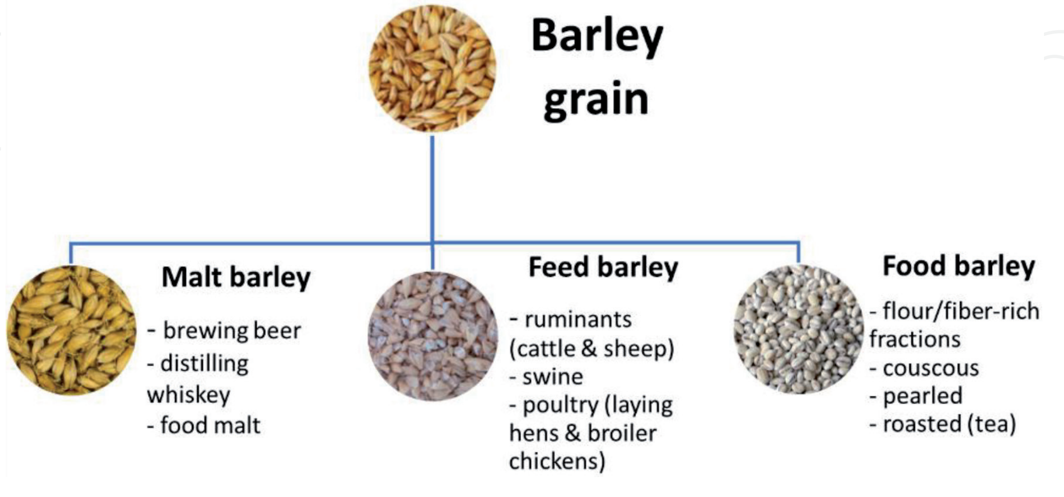

Figure 6.
Main end-uses of barley grain, worldwide. Source: elaborated from [29].

there is renewed interest throughout the world in barley food because of its nutritional value [14]. During the past decade, of the total global barley consumption, about 65% is used as feed, followed by industrial at about 20%, which includes

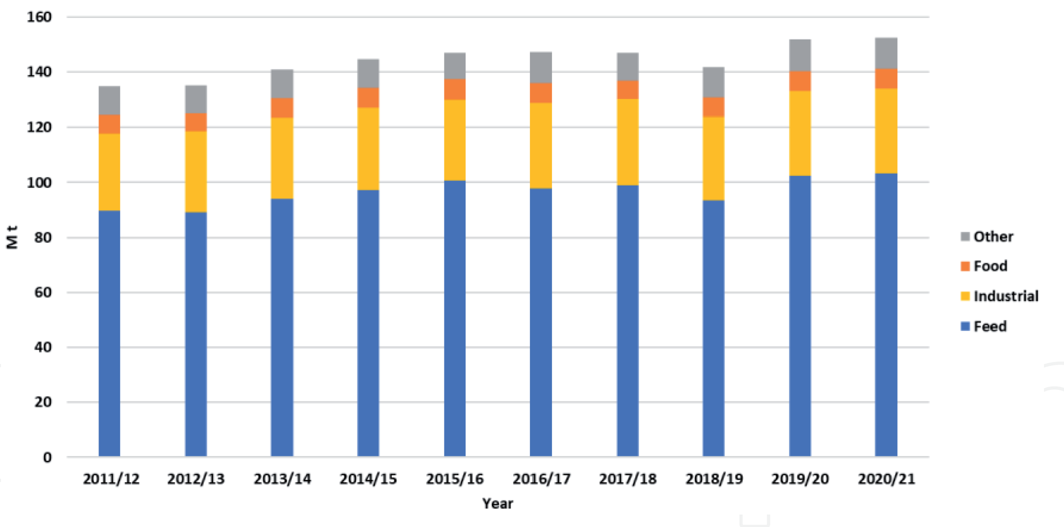

Figure 7.
Global consumption of barley grain by end-uses (M t), 2011–2020. Source: prepared based on data from [31].

malting. A smaller percentage is used for food (5%) as well as some for other uses (7%) (**Figure 7**).

The processing (e.g. rolling, grinding, flaking) improves the digestibility of barley grain. For example, whole barley grain is 15 to 30% less digestible than the same barley grain when dry rolled [32]. Studies showed that the barley starch is readily degradable for ruminants without gelatinization, unlike corn that requires steam-flaking to make starch available by breaking down the protein that surrounds starch granules within the endosperm [33].

After the inedible outer shell has been removed during processing, the barley grain is considered a healthy whole grain. The more commonly available pearled barley is not a whole grain because the fibre-containing bran has been removed [34]. Despite that, pearled barley still has a high beta-glucan content (**Figure 8**). When assessing the content and distribution of beta-glucan of low and high beta-glucan barley genotypes, [36] found that the highest content was in the subaleurone

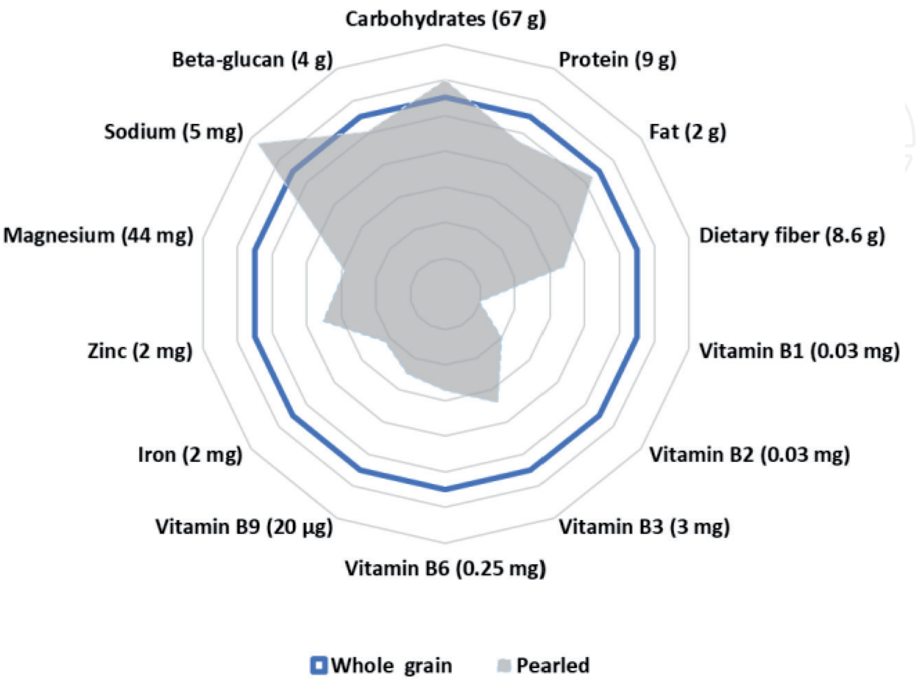

Figure 8.
Nutritional profiles of pearled barley vs. whole grain. Source: prepared based on data from [35].

region, in the case of low beta-glucan barleys, while in the high beta-glucan ones, it was distributed more evenly throughout the endosperm.

A significant high-value use of barley is in producing malt as a raw material for the brewing and distilling industries. In short, the malted barley is barley grains that have been made to germinate and then stopped from further germination by drying. The process comprises five stages: barley grading and cleaning, steeping, germination, kilning and malt cleaning and grading. To obtain 100 kg of malt approximately 120 to 130 kg of screened barley are necessary, depending on grain quality and purity. The average ratio used is 1.267 [37]. The contribution of barley to beer flavour is primarily developed through the malting process, as well as its macro-chemical contribution to brewing [38]. Barley malt provides saccharides, proteins, free amino nitrogen, and enzymes that facilitate fermentation reactions in brewing, and the malt quality traits can influence the flavour of the beer [39].

4. Nutritional attributes of barley grain

The nutrient composition of barley grain varies with the cultivar, environment, and processing [34]. In the last two decades, we have seen a rediscovery of food preparations with barley with a significant increase of use and may be due to recently developed barley varieties that are rich in nutrient composition [39]. The composition and nutritional attributes of barley as food and feed are described below.

4.1 Carbohydrates and fiber

Barley starch content is nearly 20% lower than that of wheat or corn grain [14]. It has been reported that hulled or hulless regular varieties have higher starch contents than hulled or hulless waxy barley grain cultivars. For example, the waxy or regular barley is determined by the composition of amylose to amylopectin levels. Thus, regular barley typically has a ratio of amylose to amylopectin of 1:3, whereas waxy barley contains higher amylopectin levels (up to 100%) [34].

Beta-glucan is one of the non-starch water-soluble fiber in barley grain. The beta-glucan content varies in different barley varieties from 2 and 11% in dry grain [40]. For example, 1.2 to 6.7% in hulled varieties and 4.6 to 7.3% for regular versus waxy barley, and hulless varieties ranging from 2.8 to 7.3% DM (non-waxy) and 4.8 to 16.9% DM (waxy) [34]. The water-insoluble fibre in barley is comprised of lignin and other non-starch polysaccharides, such as cellulose and hemicellulose, that are concentrated in the hull of the grain. The total fibre contents are different between hulled (13.2 to 27.0 vs. 19.6 to 22.6% DM; regular vs. waxy) and hulless (9.4 to 20.2 vs. 12.6 to 33.4% DM, regular vs. waxy) barley varieties concentrated in the endosperm cell walls. It is considered that due to the hull, barley grain provides greater dietary fibre than wheat or corn, and a larger portion of the fibre is in an insoluble form [41].

4.2 Proteins and amino acids

Barley grain protein content is an important quality factor determining grain end-use value [42]. Prolamins are a class of storage proteins that account for up to 70% of the total protein in barley, however, the amino acid composition of prolamins is characterized by high levels of glutamine, proline and low amounts of essential amino acids such as lysine, threonine and tryptophan [43]. A recent study on the comparative proteomics analysis between the six-row and two-row barley cultivars indicated that 20 proteins were differentially abundant between the two cultivars [44]. Variation in the abundances of hordoindoline proteins was one of the key differences between them, and the authors suggested that the type of hordoindoline proteins may contribute to the differences between the seed hardness of these two cultivars.

In a 2018 survey, conducted in Western Canada, where barley plays a prominent role as a source of feed for both ruminants and monogastric farm animals, it was found that the average crude protein content is higher than the average found in corn, rye, and oats [45]. Earlier, [34] also reported that barley has 4% higher protein content than corn grain. Also, [46] investigated the grain protein concentration and harvestable protein under future climate conditions on a large collection of barley accessions and reported that despite the increase in grain protein concentration (5% at elevated temperature and 29% at elevated CO_2), the decrease in grain yield under the predicted future climate conditions resulted in 23% less harvestable protein. However, variation in the reponse of the barley accessions tested was observed and could be exploited.

4.3 Vitamins

Vitamins in barley include B1, B2, B3, E and gamma-aminobutyric acid, which may vary based on the cultivars. For example, it was shown that vitamins B1 and B2 were the most variable within a barley collection from Tibet, China [47]. Vitamin B1 was present as the highest proportion, followed by B2 and E, while B3 was present as the lowest proportion in the collection. The content in gamma-aminobutyric acid was also highly variable. Moreover, it was found that the content of vitamins B1, B2 and C, and proteins increased notably after germination [48].

4.4 Phenolic compounds

Barley is a good source of phenolic compounds, which can be found free as well as bound to fibre [49]. Phenolic compounds in barley include monophenol, phenolic acids, flavonoids and other polyphenols [22]. The flavanols, such as catechin, procyanidins and prodelphinidins, are the main compounds in the free phenolic fraction of barley grain, while phenolic acids, such as ferulic, coumaric and vanillic acids, are major constituents of the bound phenolic fraction [49–51]. However, ferulic acid is the most abundant hydroxycinnamic acid found in barley and accounts for up to 90% of total polyphenols [52]. Flavanols, anthocyanins, and proanthocyanidins (polymers of flavonoids) are the major types of flavonoids found in barley grains (**Table 2**). Flavanols are located in the pericarp of barley grains, while anthocyanins are water-soluble vacuolar pigments mainly present in the pericarp or the aleurone layers of barley grain, causing purple or blue hues of kernel colour [61]. Anthocyanins in barley include cyanidin, cyanidin 3-glucoside, delphinidin, pelargonidin, pelargonidin glycosides, and petunidin 3-glucoside [60]. It was reported that the bran-rich fraction of barley grain contained the most flavonoid content, whereas the hull fraction did not contain any significant flavonoid content [62]. Out of major proanthocyanidins in barley, prodelphinidin B3 (90–197 μg/g) accounted for the majority of proanthocyanidins, whereas procyanidin C2 (5–19 μg/g) was reported to be present only in minor quantities [63]. In the malting process, the green malt had the highest antioxidant activity (79.80%) and total phenolic content (122.43 mg/100 g) than those of barley and malt [64]. For example, carotenoid (1.71 μg/g), (+)-catechin (69.06 mg/100 g), 1,2-dihydroxybenzene (37.21 mg/100 g), quercetin (30.78 mg/100 g) and isorhamnetin (22.44 mg/100 g) contents were higher in green malt.

Phenolic acids	Free form (μg/g)	Conjugated form (μg/g)	Bound form (μg/g)	Health benefit	Reference
p-Hydrobenzoic acid	Not determined	5.8–26.7	0.5–5.4	Anticarcinogenic effects	[53]
2,4-Dihydroxybenzoic acid	0.04–2.62	6.8–61.8	11.1–74.4		
Vanillic acid	1.45–4.71	8.9–30.2	0.5–7.5	Anti-inflammatory effect and neuroprotection	[54, 55]
Syringic acid	0.45–3.74	2.2–10.0	0.0–3.0	Antioxidant, antimicrobial, anti-inflammatory, antiendotoxic, neuro and hepatoprotective activities	[56]
Sinapic acid	Not determined	12.4–24.4	8.9–17.8	Exhibit antioxidant, anti-inflammatory, anticancer, antimutagenic, antiglycemic, neuroprotective, and antibacterial activities	[57]
Ferulic acid	1.32–5.87	21.7–42.5	104.3–365.4	Anti-inflammatory, antidiabetic, anticancer, antiapoptotic, antiaging, hepatoprotective, neuroprotective, radioprotective, pulmonary protective, hypotensive effect, and antiatherogenic effect	[58]
p-Coumaric acid	0.57–7.01	1.7–13.1	2.7–109.7	Protective role against heart diseases	[59]
o-Coumaric acid	0.27–1.31	1.2–3.2	2.7–4.7		

Source: elaborated from [60].

Table 2.
Composition of the total, free, conjugated, and bound phenolic acids in barley, and their health benefits.

4.5 Lipids

Barley lipids include fatty acids, phytosterols and tocols (**Table 3**). A recent study comparing Irish barley varieties showed that linoleic acid is one of the most abundant unsaturated fatty acid, while phytosterols vary, beta-sitosterol being the most abundant sterol, and alpha-tocotrienol is the most abundant tocol homologue [72].

Compound	Mean	Health benefit	Reference
Tocols (μg/g) Beta-Tocopherol Delta-Tocotrienol	61.49 0.22 1.01	Protection against toxins, neurological diseases like Alzheimer's disease, diabetes, and modulating degenerative diseases such as cancer and cardiovascular diseases	[60, 65]
Unsaturated fatty acids (mg/100 g)	1505.32	Reduce the cardiovascular risk by decreasing the low density lipoprotein-cholesterol level	[66, 67]
Sterols (mg/100 g)	71.24	Cholesterol lowering effect	[68]
Flavones (μg/g) Apigenin-6-C-arabinoside-8-C-glucoside Apigenin-7-O-glucoside	11.81 1.53 0.38	Decrease endothelial dysfunction, lower blood pressure and cholesterol, and modulate energy metabolism	[69]
Anthocyanin (μg/g) Pelargonodin- rutinoside Malvidin-rutinoside-hexoside-pentoside Delphinidin glucoside Pelargonodin-malonylglucoseide Cyanidin-malonylglucoside Peonidin-malonylglucoside derivative Petunidin malonylglucoside Peonidin- rutinoside Peonidin- hexoside-pentoside Delphinidin- rutinoside Cyanidin-dimalonylglucoside Delphinidin-dimalonylglucoside Unknown (peonidin glucuronide derivative)	4.82 0.41 0.11 0.16 0.09 0.45 0.10 0.07 0.23 0.23 0.05 0.68 0.06 1.44	Antioxidant, lower risk of myocardial infarction, and cardiovascular disease related mortality	[70, 71]

Source: elaborated from [49, 72].

Table 3.
Mean values of lipids (tocols, unsaturated fatty acids and sterols), flavones, and anthocyanin compounds present in barley.

Tocopherols and tocotrienols (Vitamin E), also called tocols, are known to have several chemical and physiological properties in barley [49]. Besides, [73] showed that the total lipid content and fatty acid composition varies with the barley variety and decreases during the malting process. However, a study showed that barley lipids contained 18.53% palmitic, 19.94% oleic and 51.74% linoleic acids while malt oil contained 17.33% palmitic, 15.62% oleic and 56.56% linoleic acids, and linoleic acid content increased during the malting process while oleic and palmitic acid content decreased [64].

5. Potential of barley as a functional food for animal and human health

The human lifestyle, including diet composition and the pattern of physical activities, have undergone a major shift since the last millennium. In recent years, it has been well documented that healthy eating practices, maintaining a normal body weight, controlled blood pressure, and regular physical activity could prevent up to 80% of coronary heart disease, 90% of type-2 diabetes and one-third of all cancers [74]. Consumers are becoming more aware of the relationship between diet and disease, and there is an ongoing shift from animal-derived to plant-based meals. Thus, globally, more effort in developing novel, healthier, more nutritious and fortified functional foods is invested nowadays. Likewise, continuous efforts are made to ensure the health and well-being of animals raised for food since this is a critical component of providing safe food products. For example, use of bioactive compounds are encouraged since they have similar proprieties as withdrawn antibiotic growth promoters [75]. Additionally, [76] demonstrated the transfer efficiency of tocotrienols from barley into egg yolk when offered as a dietary supplement and signalled the possibility of developing hen's eggs that are nutritionally-enriched in specific health-promoting tocotrienols.

Barley, which recently is seeing renewed interest, is a versatile crop used both for human nutrition and as an animal feed for energy and nutrients [11, 17] due to its high content of biologically active constituents such as dietary fibre, especially beta-glucan, tocols, including tocopherols and tocotrienols, and phenolic compounds.

5.1 Benefits of barley as an animal feed

The nutritional quality of barley grain fed to animals is traditionally defined by energy content [77]. Accurate and rapid evaluation of the energy content of barley is key to ensure the optimum nutrient content of the barley as an animal feed. Usually, barley is fed to beef cows when they graze poor-quality pastures to increase the energy content of their diet [34]. Beef cattle could be fed barley either as whole or processed, with the last one providing greater animal performance. Barley is also considered suitable for inclusion in the diet of all types and ages of poultry, with older birds being more able to utilize barley than younger chicks. Inclusion of whole barley grain in broiler diets has been reported and may be cost-effective due to limited processing required [78]. Barley has been suggested to be included in the diets of horses, rabbits, and fish to provide energy and nutrients. However, the level of inclusion may need to take into consideration the digestive physiology of the animal and its ability to digest fibre [34].

High levels of insoluble dietary fibre can increase fecal bulk due to its high water holding capacity [79]. In animal nutrition, high-amylose barley is associated with enzymatic resistance to digestion in swine and poultry, contributing to slower glucose release and prolonged satiety. In addition, increased amylopectin is associated with faster digestion of starch to glucose, which may result in higher feed intake due to rapid rises in insulin [34].

While it was demonstrated earlier that the use of fermented barley is a valuable functional ingredient for broilers diets [19], recently it was shown that feeding fermented barley can also be a possible nutritional strategy for managing nursery pigs without in-feed antimicrobial growth promoters [80]. It has been suggested that feeding high-barley diets to finisher pigs may improve pork quality attributes compared with feeding corn since barley has lower fat and linoleic acid content than corn, resulting in firmer and whiter pork fat, increasing its contrast with myoglobin and thus enhancing the visual appeal of loin marbling [81].

5.2 Health benefits of barley for humans

Barley can be breakfast, lunch, or dinner. However, it surpasses the meals since it has unique advantages. The renewed interest in barley grain is mainly due to its unique soluble fibre beta-glucan and antioxidant phytochemicals (**Figure 9**).

The effectiveness of barley beta-glucan in barley food products in lowering blood cholesterol [83–87] and glycemic index [88–91] has been reported in numerous studies. Therefore, foods containing substantial levels of barley beta-glucan are considered functional foods, and in several countries, they are permitted to carry health claims. So far, barley health claims have been approved by the US Food

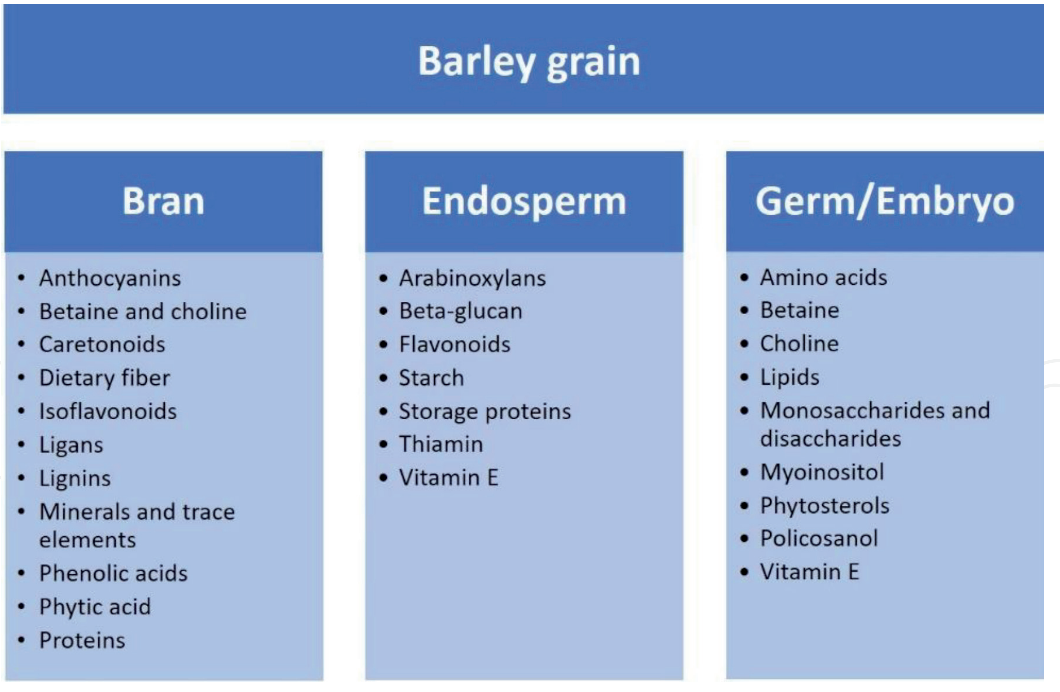

Figure 9.
Barley grain anatomy and the distribution of the key biologically-active phytochemicals within the barley grain. Source: elaborated from [82].

and Drug Administration (FDA) (2006), European Food Safety Authority (EFSA) (2011), Health Canada (2012), and more recently by Food Standards Australia and New Zealand (FSANZ) (2017) [92–95].

Besides health-benefiting beta-glucan, barley contains phytochemicals in varying concentrations, usually determined by genotypic or environmental factors or the interaction of both factors [60]. These phytochemicals in barley may exist in free, conjugated, or bound forms, categorized into several major classes, including phenolic acids, flavonoids, lignans, tocols, phytosterols, and folates [96]. Tocols are components.

of plant oils that provide benefits such as protection against toxins, neurological diseases like Alzheimer's disease, and diabetes [60]. For example, barley is a rich source of tocols, including tocopherols and tocotrienols. When assessing the grains of 16 feed/food barley genotypes, it was found that on average, the total tocols were 69.8 μg/g, with tocotrienols being the most abundant averaging 53.10 μg/g, while tocopherols were averaging only 16.69 μg/g (**Figure 10**). The genotype was found to significantly affect the content of all individual tocols, combined tocopherols, combined tocotrienols, and total tocols for those barley genotypes [97]. In addition to their antioxidant properties known to reduce serum low-density lipoprotein cholesterol [98, 99], the tocol content of cereals such as barley can confer health benefits, including modulating degenerative diseases such as cancer and cardiovascular diseases [65]. Also, [67] suggested that alpha-tocotrienol and polyunsaturated fatty acids are hypocholesterolemic components in barley oil. Furthermore, studies indicate that a high intake of alpha-tocopherol decreases lipid peroxidation and platelet aggregation, functioning as a potent anti-inflammatory agent [49, 100]. Recent studies showed a significant correlation between phenolic components and antioxidation especially suggesting that coloured barley grains are rich in phenolic compounds with antioxidant capacity [22, 49]. It was also reported by [101] that the free and bound phenolic extracts in the blue hulless barley grains have an equivalent proportion in the total phenol and co-exist in two forms. The bound forms of barley grain phenols contribute to the antioxidative and antiproliferative

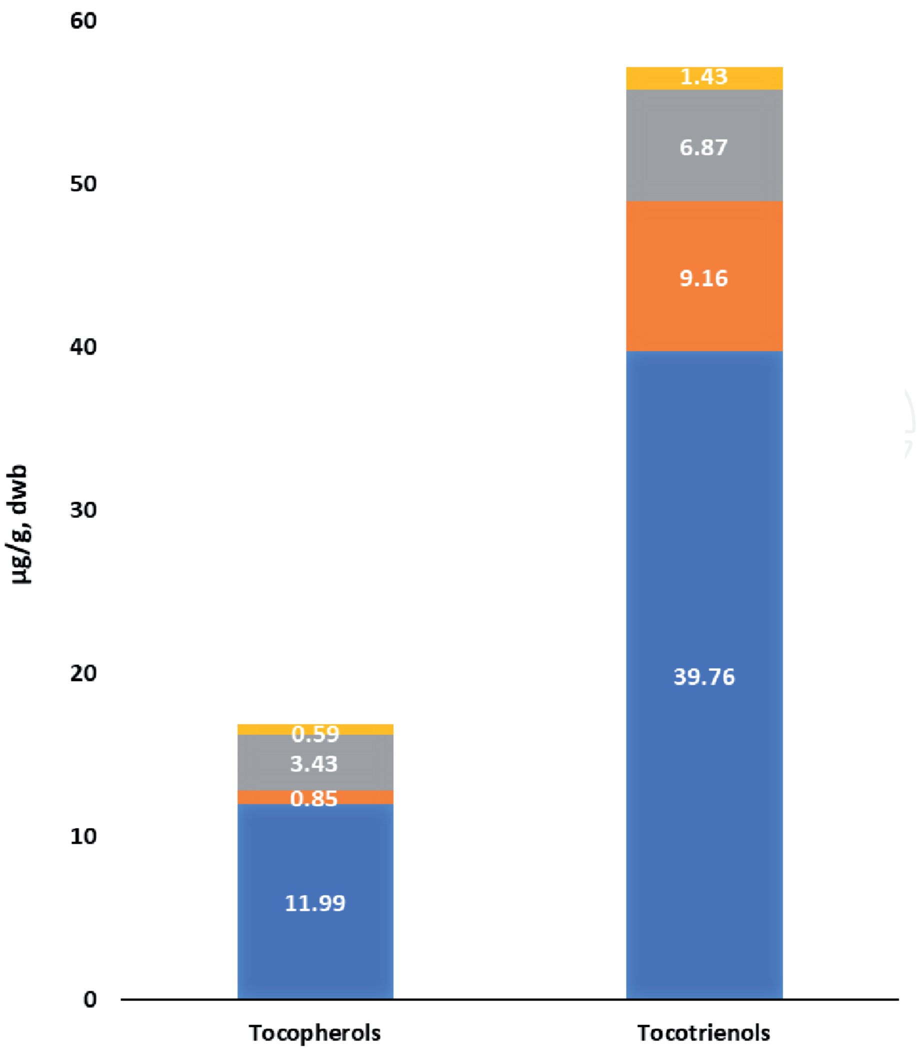

Figure 10.
Average of individual and total tocopherols and tocotrienols in the barley whole grain. Source: prepared based on data from [97].

activity against cancer cells in the human liver. Their high concentration in barley may be responsible for its usefulness in controlling certain diseases [21, 60]. For instance, a phenolic acid named ferulic acid in barley has a wide range of health benefits, including anti-inflammatory, therapeutic usage, antidiabetic, anticancer, antiapoptotic, antiageing, hepatoprotective, neuroprotective, radioprotective, pulmonary protective, hypotensive effect, and antiatherogenic [58, 102]. Coumaric acid has anti-inflammatory, anticancer, antimicrobial and antioxidant effects, and by decreasing low-density lipoprotein peroxidation, coumaric acid has a protective role against heart diseases [59, 103]. Vanillic acid is considered a bioactive molecule for treating inflammatory diseases [54, 55]. In addition, sinapic acid can attenuate various chemically induced toxicities [57], whereas syringic acid shows a wide range of therapeutic applications in preventing diabetes, cardiovascular diseases, cancer and cerebral ischemia [56].

Studies have consistently shown that regular consumption of barley whole grain reduces the risk of developing chronic heart diseases, cancer, and gallstones [60, 104–106]. Based on an recent pre-clinical study, it was demonstrated that life-long barley intake could positively contribute to healthy ageing [107]. It was found that barley intake prolonged the lifespan, delayed locomotor atrophy, reduced loss of balancing ability and spatial recognition and significantly increased the particle sizes of high-density lipoprotein cholesterol, which is associated with a reduced risk of total stroke.

6. Conclusion

Barley is one of the first cultivated crops, globally grown in diverse soil conditions and in areas where other crops cannot be easily cultivated. Although the crop is primarily grown as an animal feed and as a source of malt for alcoholic beverages, more and more it is included as a component of various foods due to the health benefits attributed mostly to dietary fibre, lipids, vitamins and antioxidant phytochemicals. These components are broadly distributed in barley and play an important role as substrates in the biosynthesis of various metabolic compounds and influence the flavour, taste, and colour of foods. Nutritional attributes of barley contribute to the prevention of numerous metabolite disorders providing antioxidant, anti-carcinogenic, anti-inflammatory, and cardio- and neuro-protective effects. Overall, having barley in animal and human diets showed beneficial effects against the development of chronic illnesses.

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Conflict of interest

The authors declare no conflict of interest.

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