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Status of Barley as a Dietary Component for Human

Madhusweta Das* and Sumeet Kaur

Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur-721 302, India

Review Article

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***For Correspondence**

Madhusweta Das, Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur-721 302, India

E-mail: madhu@agfe.iitkgp.ernet.in

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ABSTRACT

Production wise, barley is the fourth among the major cereal crops in the world. The grain is mainly exploited as feed or as raw material for malt production, with only a small fraction, about three percent of the total produce currently being used for human food purpose. Widespread use of maize, wheat, and rice as main food grains has presently relegated barley to the underutilized status. Poor baking quality and grey/dark color development on cooking, probably, have discouraged the use of barley in human food. However, composition wise, barley contains starch as the main carbohydrate, low fat, protein of moderate quality, minerals, vitamins, especially vitamin E (tocopherols and tocotrienols) and other antioxidants, mainly polyphenolics, and insoluble and soluble dietary fiber, i.e., β-glucans, chemically (1-3,1-4)-β-D-glucans.

Recent researches have claimed, because of β-glucans, consumption of barley in food offers several health benefits to alleviate the problems of life style disorder. These include control of blood cholesterol and glucose level, and induction of satiety effect required to control body weight. Barley's potential as a prebiotic has increased significantly as β-glucans promote the growth of beneficial intestinal microorganisms. Besides these, tocotrienols as antioxidants have been the focus of growing research interest for their hypocholesterolemic action. Additionally, tocotrienols may affect the growth and/or proliferation of several types of human cancer cells. To utilize the impressive health benefits, incorporation of barley in food may be advocated through improved technology to overcome the so called undesirable effects. However, in line with the increasing health consciousness, several whole grain products are now getting popularized with sacrifice of desirable colors. It is appreciated that through sustained research and development, barley, currently underutilized, will be considered as a prized food for good nutrition and health in near future.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is among the most ancient of cereal crops, evolving over eons. It was first domesticated dating from about 10,000 years ago in the Fertile Crescent of the Middle East [1]. Presently, production wise, barley occupies fourth position among the cereal crops in the world. Although barley was used extensively as a food in the past, has now been relegated to animal feed (about 60%), malt (about 30%), or seed (about 7%), with only a small amount (about 3%) for human food in most countries [2]. Predominance of maize, wheat, and rice as main food grains has presently demoted barley to the status of "poor man's bread" [1,2].

Besides the usual nutritional benefits of cereal grain, most importantly, barley cell wall has good amount of soluble dietary fiber, β-glucans, chemically (1-3,1-4)-β-D-glucans distributed throughout the entire kernel **(vide Plates 1 and 2)**, in which 30% are

1-3 glycosidic linkage and the remainder being 1-4 [3-7]. Cell walls of the starchy endosperm consist of 75% of β-glucans, 20% of arabinoxylan, 2% of cellulose and 2% of glucomannan. The walls of aleurone cells consist of 71% of arabinoxylan and 26% of β-glucans, with 3% of cellulose and glucomannan [8]. Due to β-glucans, barley as food increases viscosity in the intestinal contents [9], and thereby reduces absorption of glucose and trap bile acids, and function as hypoglycemic and hypocholesterolemic agent [10]. In addition, bran in whole barley offers a source of insoluble fiber, the ingredient necessary for bowel clearance and hence to maintain colon health [11]. Thus, use of barley as a food/food ingredient could be a preventive or controlling measure to check the alarming frequency of diabetic mellitus and other associated lifestyle disorder. The aim of this article is to comprehensively present the classification, production, and composition of barley highlighting β-glucans and its importance in relation to human health benefits.

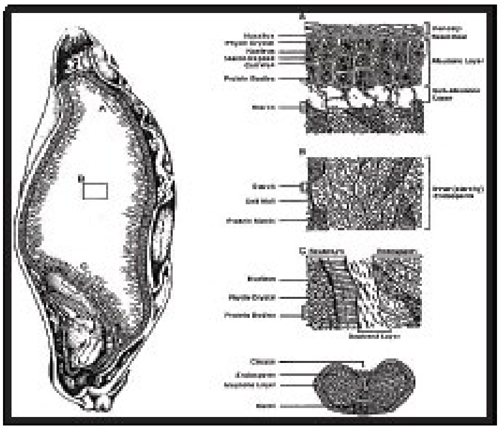

Plate 1. Barley grain with enlarged cross sections [4].

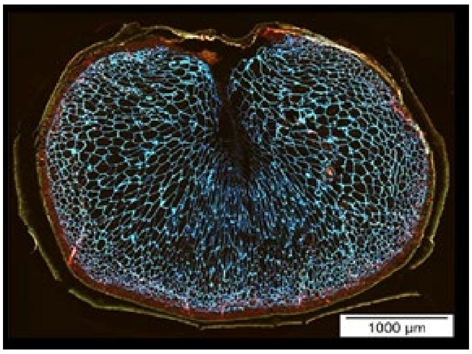

Plate 2. Whole barley grain cross section showing distribution of β-glucans in cell walls (blue) stained by Calcofluor [6].

CLASSIFICATION OF BARLEY

Barley is classified as: i) spring or winter types (depending on whether they need a cold exposure, ranging from two to several weeks before making the transition to the reproductive phase of growth); ii) two-row or six-row, based upon the fertility of the florets on the spike (in six-rowed barleys, all of the florets are fertile, leading to six vertical rows of seeds on the spike; whereas in two-rowed types only the central floret of the three at each node is fertile, and thus just two rows of seeds develop on opposite sides of the rachis); iii) hulled (hulled barley is covered with palea and lemma, require dehulling to remove the tough inedible outer hull) or hull-less (barley has an outer hull that's so loosely attached to the kernel that it generally falls off during harvesting); and iv) malting (high starch content) or feed (high protein) by end-use type. Based on grain composition, barley is further classified as normal, waxy or high amylose, high lysine, high β-glucans, and proanthocyanidin-free [2]. The number of rows on spike has no bearing on how the grain is used, that is decided mainly by regional preference. The main difference between two row and six row barley is that the latter contain more protein and therefore more nutritious [12]. Hulled barley is preferred to hulless barley for malting and brewing because of the contribution of the hull to flavor development in beer and as a filtering aid during brewing [2].

PRODUCTION OF BARLEY

Barley is one of the seven internationally grown cereal grains, currently ranking fourth in world production behind maize, wheat, and rice, and ahead of sorghum, oats, and rye [1]. The area harvested for barley and its production are mentioned in **Table 1** [13]. In the table, world production in 2011 was approximately 134.28×10^9 kg on 48.60×10^{10} m^2 area, where Europe had the largest contribution, producing 81.30×10^9 kg, i.e., 60.54% share from 24.40×10^{10} m^2.

COMPOSITION OF BARLEY

Chemical components and their nutritional implications of barley were thoroughly reviewed by Newman and Newman [1], Baik and Ullrich [2] and Ullrich [14]. Compositional data quoted in this section come from these references unless otherwise mentioned.

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Table 1. Barley production: Area harvested (×10^{-10} m^2) and production (×10^{-9} kg).

Year	Parameter	Africa	America	Asia	Europe	Oceania*	World
2004	Area harvested	5.47	6.63	11.90	28.90	4.70	57.60
	Production	6.29	21.60	21.4	96.50	8.04	153.90
2005	Area harvested	4.99	6.06	11.90	28.00	4.46	55.40
	Production	4.65	18.80	22.30	83.10	9.79	138.68
2006	Area harvested	4.91	5.59	11.90	29.70	4.23	56.40
	Production	6.24	16.70	23.20	88.90	4.53	139.51
2007	Area harvested	4.89	6.65	12.00	27.30	4.95	55.80
	Production	4.41	18.60	20.80	82.80	7.52	134.12
2008	Area harvested	4.28	6.41	10.60	29.20	5.08	55.50
	Production	3.92	20.50	16.50	105.38	8.41	154.72
2009	Area harvested	5.43	5.41	10.70	27.70	4.52	53.80
	Production	8.99	17.40	21.20	95.60	8.34	151.54
2010	Area harvested	4.73	4.81	11.00	22.90	4.14	47.60
	Production	6.69	16.00	20.10	73.40	76.00	123.84
2011	Area harvested	4.90	5.02	10.60	24.40	3.75	48.60
	Production	6.82	16.60	21.20	81.30	8.36	134.28

*Oceania includes Australia, New Zealand, Melanesia, Micronesia, and Polynesia [13]

Whole barley grain consists of about 65-68% starch, 10-17% protein, 2-3% free lipids, 4-9% β-glucans and 1.5-2.5% minerals. Total dietary fiber ranges from 11-34% containing soluble dietary fiber within 3-20%. The non-starch polysachharides in barley are β-glucans, arabinoxylans, and cellulose, the major one being β-glucans; these modify the energy value of barley. Significant differences in β-glucans content have been reported among barley types with various starch amylose contents, the average amount being 7.5% in high amylose, 6.9% in waxy, 6.3% in zero amylose waxy and 4.4% in normal starch types. The β-glucans content of barley grains is mainly determined by genetic factors and less by environmental factors. Hulless or de-hulled barley grain contains 11–20% total dietary fiber comprising 11–14% insoluble dietary fiber and 3–10% soluble dietary fiber. Waxy hulless cultivars generally exhibited much greater grain β-glucans content than normal covered cultivars, while there was no difference between two-row and six-row cultivars. Barley endosperm protein has moderate nutritional quality with protein efficiency ratio averaging 2.04. Amino acid composition of barley protein is similar to other cereal grains, however, lysine and threonine are the limiting amino acids followed by methionine and tryptophan. Moreover, high glutamine and proline and considerable cysteine content are its characteristics [15]. Lipid levels in barley are considerably low. The major fatty acids in barley triacylglycerol are palmitic acid, oleic acid, linoleic acid, and linolenic acid. Fatty acids in barley are similar to those in wheat except that barley tends to have more linolenic acid. Barley is rich in fat-soluble vitamin E (tocotrienols) and contains varying amounts of vitamin B complex except vitamin B_{12}. The major elements in barley grain are phosphorus, potassium, calcium, magnesium, sulphur, selenium, and sodium, the first two being the most abundant. Restriction of dietary oxalate intake is preferred to check kidney stone, and it is worth mentioning that barley is categorized as medium oxalate grain.

In terms of phytochemicals in barley, in addition to tocotrienols, the important ones are the sterols, flavanols, and phenolic acids. Barley grains contain much greater amounts of phenolic compounds (0.2–0.4%) than other cereal grains. The main flavanols found are the catechins, procyanidin B_3, and prodelphinidin B_3. According to Holtekjølen [3], from analysis of sixteen varities, the total amount of flavanols ranged from 325 to 527 μg/g of fresh weight of barley flour, with no associations between proanthocyanidin levels and different barley types. Holtekjølen [3] also opined that the total amount of phenolic acids ranged from 604 to 1346 μg/g of fresh weight of barley flour, with ferulic acid as the dominating one. The amount of phenolic acids varied according to occurrence or lack of hull, with significantly higher levels in the hulled varieties.

HEALTH BENEFITS AND UTILIZATION IN FOOD

Both animal studies and human clinical trials have shown a link between barley and health benefits focusing a decrease in the risk of chronic heart disease by lowering blood cholesterol, and an increased insulin response thus lowering the risk of type-2 diabetes [4]. Behall [16] observed that blood lipids significantly reduce by diets containing barley in moderately hypercholesterolemic men, as shown in **Figure 1.** According to Food and Drug Administration (FDA), 3 g of barley β-glucans per day is a sufficient dietary intake to achieve a decrease in serum total and low-density lipoprotein cholesterol [4]. These beneficial effects may be attributed to the presence of β-glucans that increase intestinal viscosity leading to slow absorption of food *vis a vis* controlling blood glucose level and binding bile acids [4]. When the bile acids are trapped in soluble fiber and subsequently excreted, stored cholesterol gets depleted to produce new bile acids [1]. In an in vitro experiment, Aastrup [7] reported a direct logarithmic relationship between the viscosity and the β-glucans content of the acid flour extracts **(Figure 2)** from 18 barley genotypes. Similar effect due to increased viscosity is also caused by arabinoxylans in barley [1]. The control of blood glucose by barley is exemplified in **Figure 3** where the glucose responses of subjects fed with plain durum wheat pasta (plain pasta) and pasta containing 40% β-glucans-enriched barley flour (barley pasta) is displayed. Also, the increased viscosity in intestine extends gastric transition time, prolongs satiety and reduces the hunger pangs, thus preventing the obesity [1,17]. Moreover, barley's potential as a prebiotic has increased significantly as β-glucans and resistant starch promote the growth of selective beneficial microorganisms in intestine [1,4], resulting in the formation of short chain fatty acids, especially butyrate and propionate; benefits of these fatty acids in the large intestine are healthy colonic mucosa and provision of an energy source for epithelial cells [1]. Besides these, tocotrienols as antioxidants have been the focus of growing research interest for their hypocholesterolemic action. Additionally, tocotrienols may affect the growth and/ or proliferation of several types of human cancer cells [18].

Extracted β-glucans have been successfully incorporated into a wide variety of innovative food products including nutrition bars, chews, breakfast cereals, beverages, baked products, yogurt, ice cream, pasta, and dietary supplements [19]. Apart from extracting the β-glucans, incorporation of processed whole cereal may be more attractive on the basis of cost benefit ratio. Czuchajowska [20] strongly favored barley for incorporation in the human diet. When consumed as grain, hulless barley is generally preferred- because the absence of the hull makes the post-harvest processing easier, and the product is more palatable. Covered barley can also be dehulled, milled, and polished to remove the bran layers for production of rice-like product. Barley can also be pearled, which removes the outer layers of the seed as well as the embryo, followed by processing to produce small rounded pieces of the endosperm. Several researchers have suggested that barley can be incorporated in the forms of pearled/grits/flakes in porridges and soups as rice substitutes, or flour as thickener and extender into several food products like yogurt, beverages, soups, porridges, cookies, noodles, muffins, flour snacks, and extruded cereal products [11,21,22]. However, barley flour (either alone or in mixtures with wheat flour) into bread achieved limited success due to its poor baking quality [23,24]. As reported by Baik and Ullrich [2], gray and dark colours development has been one of the major obstacles in the use of barley in food products, e.g., pasta. The successful development, targeted either traditional or new products, however, needs lot of research through innovative processing which can bypass the undesirable traits in the developed food. Additionally, since the influence of genotype of barley is much greater than those of environment, discolouration of barley food products may be envisaged to be controlled through genetic improvement [2]. Since during last two decades the knowledge of dietary influence on health and well-being has highly increased, several whole grain food products are now getting popularized even with sacrifice of desirable colors. It is appreciated that barley, underutilized in recent years, will fetch its status as a prized food for good nutrition and health.

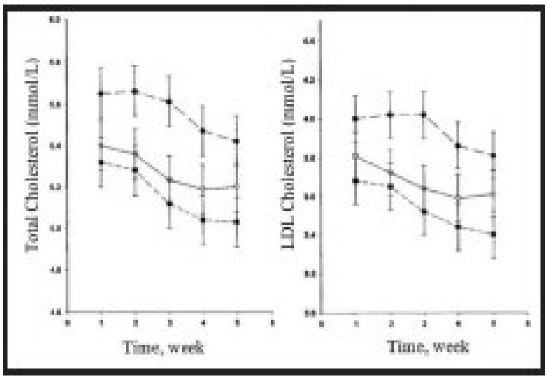

Figure 1. Mean (n=25; 7 men, 9 premenopausal women, 9 postmenopausal women) weekly total and LDL cholesterol by: low β-glucans diet, (●); medium β-glucans diet, (∇); high β-glucans diet.

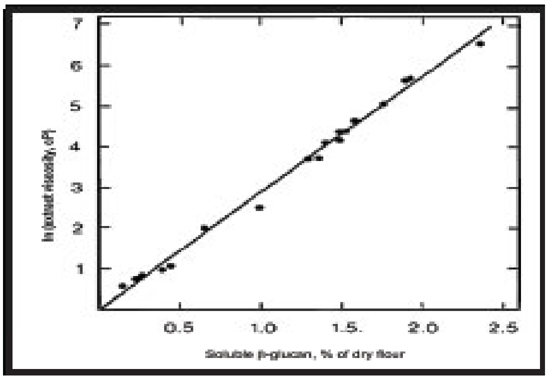

Figure 2. Relationship between viscosity and β-glucans content of the flour extracts from 18 barley genotypes.

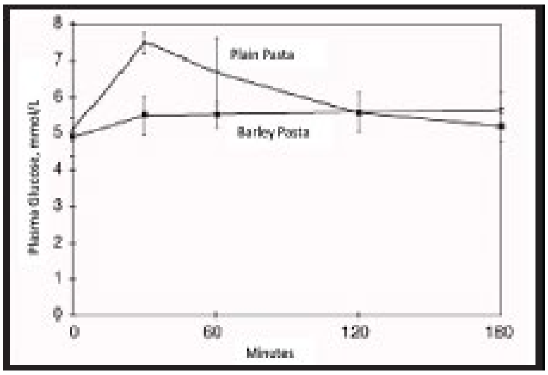

Figure 3. Plasma glucose measurements of fasted subjects (n = 5, 4 men, 1 women) after consumption of plain pasta containing durum wheat flour that had negligible β-glucans content and of barley pasta containing a blend of β-glucans-enriched barley flour and durum wheat flour.

CONCLUSION

Barley occupies the fourth position among the cereal crops in the world. However, presently, barley remains underutilized as human food, only three percent of the total produce being used for the said purpose. Recent researches have established several health benefits of barley, predominantly because of its β-glucans content. The documented benefits are hypocholesterolemic, hypoglycemic, obesity controlling, prebiotic, and anticancerous effects. These beneficial contributions are helpful to control the life style disorders of the present generation. Therefore, incorporation of barley in human food should be highly encouraged. Though inclusion of barley in some foods may incur a slight deviation from the most wanted traits, but it can be sacrificed with the positive contribution. It is a good sign that people are now getting more and more inclined to whole grain products with sacrifice of colour. Simultaneously, research should be motivated towards innovative processing which can overcome this problem.

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