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REVIEW

Oat: unique among the cereals

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Abstract This review is intended to focus on the composition of oat and its therapeutic potential in the pharmacology that supports its use to cure various maladies. Oat (*Avena sativa*) is distinct among the cereals due to its multifunctional characteristics and nutritional profile. Recent advancement in food and nutrition has revealed the importance of its various components. It is a good source of dietary fiber especially β-glucan, minerals and other nutrients. Oat and oat by products have been proven to be helpful in the treatment of diabetes and cardiovascular disorders. Oat bran in particular, is good source of B complex vitamins, protein, fat, minerals besides heart healthy soluble fiber β-glucan. The β-glucan has outstanding functional properties and is of immense importance in human nutrition. Different physiological effects of β-glucan are related to its viscosity, attenuation of postprandial plasma glucose and insulin responses, high transport of bile acids towards lower parts of the intestinal tract and high excretion of bile acids thereby lowering of serum cholesterol levels. Moreover, it is helpful against coeliac disease. The incorporation of oat grains and oat bran in the food products improves not only the nutrition but also a therapy against various maladies.

Key words oat – oat bran – β-glucan – dietary fiber – cardiovascular diseases – hyperglycemia

Introduction

Oat, like all other grain varieties, belongs to the Poaceae family and is known as "Jai" or "Javi" in Indian subcontinent. *Avena sativa* L (common oat) is the most important among the cultivated oats (Table 1). Like wheat, it is an annual grass that is believed to be Asiatic in origin. During early growth, the oat plant consists of leaves and a shortened stem, giving a rosette type of plant. The tillers grow into additional "branch plants" or tillers and under favorable conditions, the plant can form up to 30 tillers. The main stem and tillers can reach up to 2 or more ft, depending on variety and growing condition. These stems terminate in a large panicle that bears flowers and seeds or kernels. Each main and lateral stem as well as branch stem terminates in a spikelet that is removed during threshing. Generally two kernels, but occasionally one, are produced per spikelet. The oat kernel, also termed caryopsis or groat, is the part after the removal of palea and lemma. It is elon-

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Table 1 Taxonomic information

Botanical name	*Avena sativa*
Kingdom	Plantae: plants
Subkingdom	Tracheobionta: vascular plants
Superdivision	Spermatophyta: seed plants
Division	Magnoliophyta: flowering plants
Class	Liliopsida: monocotyledons
Subclass	Commelinidae
Order	Cyperales
Family	Poaceae: grass family
Genus	Avena: oat
Species	*A. sativa*: common oat, *A. byzantina*, *A. fatua*, *A. diffusa*, *A. orientalis*

gated—spindle shaped, up to about 0.5 in. in length and 0.125 in. or less in width. It is generally covered with fine, silky hairs and includes the seed coat layers of cells, starchy endosperm and the embryo. Oat is an important food grain in temperate regions of the world. Modern oat probably originated from the Asian wild red oat, which grew as a weed in other grain crops [76].

It is an annual crop used both for human and animal nutrition. Before being used as a food, it was used for medicinal purposes. With the development in field of nutrition, oat was recognized as a healthy food in the mid 1980s signifying that a substance in it helped prevent heart disease and therefore it became more popular for human nutrition [114]. Since oats are not suitable for bread making due to lack of gluten therefore often served as a porridge, flakes or breakfast cereals made from crushed or rolled oats. As oat flour or oatmeal, it is utilized in a variety of baked items like composite bread made from mixture of oatmeal and wheat flour. When the objective is to utilize oat flour, millers are more conscious about its protein contents. While oat cultivars are characterized as to their relative protein concentration, little is known about genetic differences in elemental composition, which may also be of nutritional significance for food and feed. Oat has a couple of traits that causes it to be less favored than other grains—a bland taste and a tendency to spoil. Despite these issues, oat is a staple in Germany, Ireland, Scotland, and the Scandinavian countries [102].

Grain

Oat grain has soft kernel and lipid distributed throughout the seed, which makes its milling process more difficult than wheat and corn. To prevent from atmospheric oxidation, the oat is given a hydrothermic treatment before processing. Hull (husk) of oat grain is about 25–30% of the seed (Fig. 1)

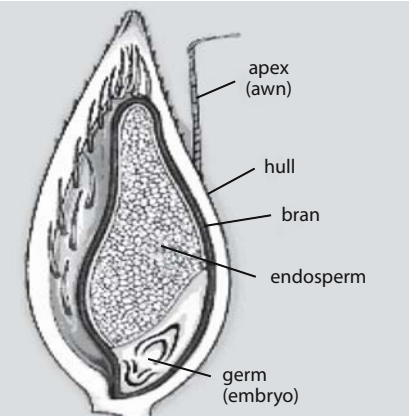


Fig. 1 Cross section of oat grain. By courtesy of Encyclopedia Britannica Inc., copyright 1996; used with permission

The grain is dehulled before use, whereas husk after processing may be used in food industry. Unprocessed hull contain silicate particles, which have barbed nature and can irritate the mouth, esophagus and gastrointestinal tract. Whole oat groat contains high amounts of valuable nutrients such as soluble fibers, proteins, unsaturated fatty acids, vitamins, minerals, and phytochemicals (Table 2). The dietary fiber complex with its antioxidants and other phytochemicals is effective against cardiovascular disease and some types of cancer [49, 50, 51, 101, 108].

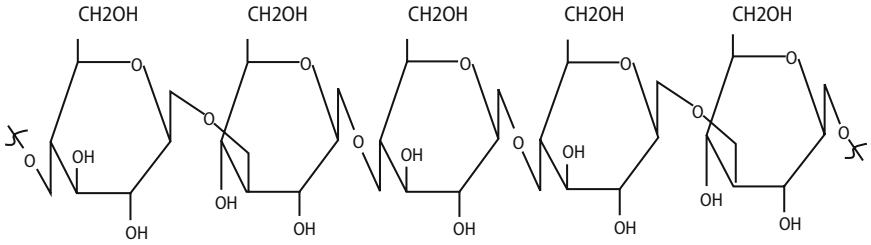
Oat groat contains significant amounts of β-glucan that varies between 2.3 and 8.5 g/100 g [113]. β-glucan in oat is distributed through the endosperm and is located in the endosperm cell walls constituting about 75% of the endosperm cell walls. It is also present in the aleurone cell wall lesser than in endosperm [80].

Table 2 Oat grain composition

Component	% Age
Moisture	13.3
Protein	13
Lipids	7.5
Fiber	10.3
Ash	3.1
Calcium (mg/100 g)	60
Phosphorus (mg/100 g)	372
Iron (mg/100 g)	3.8
Zinc (mg/100 g)	3.9
Iodine (mg/100 g)	16
Thiamin (mg/100 g)	0.50
Riboflavin (mg/100 g)	0.14
Niacin (mg/100 g)	1.3
Energy (MJ/100 g)	1.61

Kirk and Sawyer [71]

Fig. 2 β-glucan



Bran

Bran is the edible, outermost layer of the oat kernel and is produced by grinding clean groats or rolled oats for separating the resulting flour by sieving, bolting and other suitable means into fraction such that the oat bran is not more than 50% of the starting material. It has total *β*-glucan and dietary fiber not less than 5.5 and 16.0% respectively with at least one third of total dietary fiber is soluble fiber [8]. Like oatmeal, oat bran contains B complex vitamins, protein, fat, minerals, and heart healthy soluble fiber called *β*-glucan. Oat bran contains 17.1% protein, 67.9% carbohydrates, 8.6% fat, 15–22% dietary fiber, 10.4% *β*-glucan, 1.3 mg niacin, 171 mg magnesium, 6.4 mg iron, 0.17 mg copper, 441 mg potassium and α-tocopherol less than 0.5 mg [78, 98].

Dietary fiber

Dietary fiber is found only in plant foods. It is the remnant of the edible part of plants that are resistant to human digestion system [1]. It consists of both soluble and insoluble fiber. Soluble fiber dissolves while insoluble fiber does not dissolve in water. Both types are important to health in different ways. Soluble fiber includes gums, mucilages, pectin and some hemicelluloses. Cellulose, lignin (polymerized *p*-coumaryl alcohols) and the rest of the hemicelluloses, are all insoluble fibers. Water-soluble fiber in cereals is composed of non-starchy polysaccharides such as *β*-glucan. Water-soluble dietary fiber can form viscous solutions. Increased viscosity in the intestine slows intestinal transit, delays gastric emptying [2, 116], and slows glucose and sterol absorption in the intestine. The soluble fiber from oatmeal and oat bran is very effective to lower blood cholesterol and normalize blood sugar levels [58, 118, 120]. Insoluble fiber contains lignin as well as non-starchy polysaccharides. Lignin is not a polysaccharide but is a lipophilic, phenolic polymer, which can absorb bile acids. Insoluble dietary fibers usually have high water-holding capacity, which contributes to increased fecal bulk.

Associated with dietary fiber are antinutrients, such as phytic acid and oxalic acid, and proteins which could affect to a certain extent mineral bioavailability by binding and trapping minerals within dietary fiber particles or shortening the transit time of nutrients through the intestine. There are several in vivo and in vitro studies which indicate that dietary fiber might have important impacts on mineral balance [45, 48].

β-glucan

Dietary fiber has important component *β*-D-glucan. Purified oat *β*-glucan is linear, unbranched polysaccharide composed of 1-4-*O*-linked (70%) and 1-3-*O*-linked (30%) *β*-D-glucopyranosyl units (Fig. 2). The 1-3-linkages occur singly and most of the 1-4-linkages occur in groups of two or three leading predominantly to a structure of *β*-(1-3)-linked cellotriosyl and cellotetraosyl units [28, 83, 118]. On the basis of linkage analysis oat *β*-glucan and non-cereal *β*-glucan appear identical but analysis of oligosaccharides fragments released by enzymatic hydrolysis reveals differences.

β-glucan has outstanding functional and nutritional properties exhibiting high viscosities at relatively low concentrations. *β*-glucan solutions (concentration: 1%) have a low flow behavior index and a high consistency index in the power law model [9]. Its viscosity is stable over a wide range of pH (2–10) but it decreased with increasing temperature [29] Because of its viscosity, *β*-glucan may disturb the brewing process or limit the nutritive value of oat-based feeds for animals [23]. On the other hand, *β*-glucan can be used as a thickening agent in food industry [117]; it may influence the sensory quality of beverages [75] and is of particular importance in human nutrition [82].

Different physiological effects of *β*-glucan in isolated form or as a constituent of oat and barley products are related to its viscosity: attenuation of postprandial plasma glucose and insulin responses [121], high transport of bile acids towards lower parts of the intestinal tract and high excretion of bile acids [74] or lowering of serum cholesterol levels [17, 79].

Molecular weight and concentration have a great influence on the viscosity and the rheological behavior of β-glucans in aqueous solution and in the intestinal tract. Difference in rheological properties of β-glucan from several oat varieties was found at the same β-glucan concentration due to difference in molecular weight [10].

β-Glucans extracted from oat bran has higher viscosities than those from oat endosperm [115]. Similarly β-glucans extracted from enhanced oat lines are more viscous than those from traditional lines [26]. In order to be physiologically active and form viscous solutions in the gut, β-glucan must be soluble, and the concentration and molecular weight must be sufficiently high and vary between 2.68×10^4 and 3×10^6 g/mol [3, 28, 35]. The molecular weight of β-glucan in oat/barley products is reported to be smaller than the molecular weight of β-glucan in the raw material [3, 13, 66, 106]. The molecular weight of β-glucan in oat bread, for example, was reduced as compared with the molecular weight of β-glucan in oat bran. Raw material, endogenous β-glucanase activity, processing, and storage conditions affect the amount, solubility, molecular weight, and structure of β-glucan in the products [13, 31, 123].

There are some indications that the molecular weight of β-glucan may partly be reduced during its passage through the upper gastrointestinal tract [56, 92]. However controversial reports are available that shows no quantitative losses of β-glucan from oat flour or bran in the stomach and in upper parts of the small intestine in ileum-cannulated pigs [11].

β-glucan containing extrudates from oat affect bile acid binding and fermentation in vitro [37]. Oat products of different composition, e.g. oat meal, oat bran etc. pre-treated by different methods, e.g. extrusion, autoclavation or even untreated when used in diets, have shown beneficial effects in nutritional studies with humans and rats [36]. During passage through the stomach and small intestine, insoluble β-glucans are partly converted into soluble form, and can form viscous solutions in the gut. There is only limited information on the flow behavior of β-glucans from different oat sources used in nutrition [34].

Oat and diabetes

Oat contains β-glucan that controls blood glucose and cardiovascular diseases. Different researchers have investigated the effects of high β-glucan oat bran flour on patients with Type II diabetes [54, 107]. Twelve patients, for example, were administered oat bran flour, oat bran crisp and a glucose load providing 12.5 g glycemic carbohydrate (Series 1), and 25 g glucose load alone and 25 g glucose load with 30 g oat bran flour (Series 2). Study participants undertook five 2-h meal glucose tolerance tests on separate occasions. Oat bran flour high in β-glucan had a low glycemic response and decreased postprandial glycemic response of an oral glucose load in subjects. Canadian researchers similarly evaluated the long-term effects of oat bran concentrate on free-living subjects with Type II diabetes, in which eight subjects were fed bread containing oat bran concentrate (soluble fiber β-glucan content = 22.8%), followed by a white bread control in the second phase of the trial [55].

Test subjects' mean total plasma cholesterol and LDL cholesterol levels were lower in the oat bran concentrate period than in the white bread period of the study, and the mean ratio of LDL cholesterol to HDL cholesterol was reduced by 24% in the oat bran concentrate phase of the trial. The oat bran concentrate bread products improved lipidemic as well as glycemic and insulinemic responses through its ability to lower total and LDL cholesterol. Consumption of oat extracts containing soluble glucans causes decline in glucose, insulin and glucagon responses to carbohydrates loads. Incorporation of very modest amounts of the soluble oat extract (50–75 g/day) into foods affects risk factors for disease without altering the acceptability or palatability of diets [57]. While comparing acute responses of healthy subjects to glucose or foods containing glucose plus oat gum, the oat gum shows more palatability [17].

Normally glucagon value is expected to decline after a carbohydrate load; however, in patients with non-insulin dependent diabetes, glucagon secretion has been reported to increase inappropriately after a carbohydrate meal. Although subjects in the study were not diabetic, hyperinsulinemia suggests an abnormality of glucose metabolism, which is supported by the increased glucagon concentrations after the carbohydrate load. The comparative reduction of glucagon response after the oat extracts may be partially responsible for the reduction in glucose concentrations [57].

Cholesterol and cardiovascular diseases

Coronary artery disease is the major cause of death in the United States and in most Western countries and blood cholesterol is a major risk factor [64]. Dietary and pharmacologic reductions in total and LDL cholesterol decrease the risk of the malady [22, 94], and dietary intervention is the first-line approach. Increasing dietary fiber has been recommended as a safe and practical approach for cholesterol reduction [110]. On the basis of numer-

ous clinical studies, the US Food and Drug Administration (FDA) permitted the use of a claim that oat-soluble fiber has the ability to reduce the risk of heart disease. The required dose of β-glucan for a single food is 0.75 g/serving. In literature, the highly viscous β-glucan fraction of oat has been reported to lower blood cholesterol and the intestinal absorption of glucose [81, 119]. Similar behavior has been observed for other soluble fibers such as psyllium, pectin, and guar gum [41, 111].

Oat bran exerts a small but potentially useful effect on plasma lipoprotein risk factors for cardiovascular disease. In subjects with mild hypercholesterolemia and normal blood pressure when receive different diets containing dietary fiber from wheat, oat, and rice bran; the oat bran has been found to be the only fiber source that significantly lowered total and low-density-lipoprotein (LDL) cholesterol levels. Although all three brans were found to slightly increase high-density-lipoprotein (HDL) cholesterol levels there were no significant changes in blood pressure, blood glucose, or serum insulin responses to a test meal on any of the bran-supplemented diets. However, this potential benefit may be limited by the amount of fiber that individuals would need to consume [67].

Water insoluble wheat fiber and cellulose have no effect on the cholesterol levels unless they displace foods supplying saturated fats and cholesterol. Although soluble fibers are more effective in lowering blood cholesterol levels, there is debate as to the degree of cholesterol reduction caused by them. The cholesterol lowering potential varies extensively among different fiber sources. The reasons for such ample variations include small sample sizes, different dosages of fiber, different background diets, concurrent changes in body weight, varying dietary control, and different types of subjects. Certain fibers lower cholesterol more effectively than others and oat is an example in this regard [4, 14, 72, 91].

Concurrent changes in fat and cholesterol caused by inadequate dietary control can confound the relation between increased fiber intake and blood cholesterol concentrations. For this reason, quantitating the direct effect of soluble fiber on cholesterol lowering, in addition to that attributed to displacement of saturated and trans-unsaturated fat in the diet, is difficult. Oat bran due to high content of soluble fiber is recommended as a potentially beneficial adjunct to lipid-lowering diets [99]. This recommendation is supported by the results of studies that demonstrate significant, although variable, reductions in serum cholesterol after ingestion of various oat bran-containing products [6, 70, 91].

Kahlon et al. [62] reported significant plasma cholesterol reductions with rice bran and oat bran diets in growing hamsters fed 10% fat and 0.5% cholesterol diets for 3 weeks. LDL values in hamsters fed cellulose + soy protein + vitamin E; Rice bran, OB, and oat bran + vitamin diets were significantly lower than in those fed the control diet, resulting in reduced atherogenic risk in those animals. Animals fed on oat bran and oat bran + vitamin E diets had significantly lower liver cholesterol concentrations when compared with all other groups, suggesting oat bran diets more effective to lower liver cholesterol accumulation as well as for reduced fatty infiltration of the liver. A mechanism for cholesterol reduction with oat bran diets can include an increased excretion of bile acid [30], which in turn stimulates liver to utilize available cholesterol to produce more bile acid [59, 60, 62, 63]. Intake of oat bran results in increased lipid excretion and percent digestibility. Lipid excretion may be different among various dietary fiber sources. Diets containing rice bran and oat bran significantly diminished the atherogenicity of 20% fat, 0.5% cholesterol diets in hamsters as manifested by a 45–65% reduction in foam cell formation in the aortic arch of the animals. The effect is apparently influenced by reduction in the plasma LDL level and LDL / HDL ratios [61].

Cereal-fiber sources decrease the chylomicron cholesterol concentration. The postprandial serum triglyceride response is significantly lowered with the addition of oat bran. Several mechanisms can be involved, such as impaired dietary triglyceride absorption from the small intestine, increased clearance of chylomicron particles and chylomicron remnant uptake, reduced liver very-low-density lipoprotein (VLDL) secretion, or increased VLDL catabolic rate [77].

If some food source causes interruption in the synthesis of cholesterol by the body it can lower cholesterolemia. Foods containing high doses of cholesterol can decrease cholesterolemia for several hours as compared with the fasting value [24]. Several complementary mechanisms are likely to be involved. First, a single amount of cholesterol from intestinal origin, on entering the blood stream causes the liver to quickly reduce the endogenous synthesis of cholesterol. This lowers postprandial cholesterolemia early after the meal intake. This effect results from the inhibition of the activity of key enzyme involved in cholesterol synthesis, HMG-CoA reductase, as shown in laboratory animals [21]. Fiber sources are able to decrease the chylomicron cholesterol secretion and a marked reduction of cholesterolemia is observed.

The lowering effect of rice bran on chylomicron cholesterol (22.2%) has been found not to be sufficient to significantly lower postprandial cholesterolemia whereas oat bran, which decreased chylomicron

cholesterol by 43.3%, significantly reduced postprandial cholesterolemia. Oat bran containing high amounts of soluble fibers which repeatedly displayed a hypo cholesterolemia effect after chronic intake [7] exhibited the most marked influence on postprandial cholesterolemia. Another mechanism possibly involved in the reduction of postprandial cholesterolemia can be an inhibition of the HMG-CoA reductase activity by fiber sources. This has been shown to occur with various cereal fractions in animal models [86]. In the presence of oat bran, the mean area of variation of serum cholesterol minus chylomicron cholesterol (−2.67 mmol/L h) has been found significantly lower than that given by the control test meal (−1.71 mmol/L h).

Oat and lipids

Dietary fiber reduces fasting lipoproteins and postprandial lipoproteins [5, 87]. Oat bran significantly decreases serum total cholesterol and LDL cholesterol compared with control values. Anderson et al. [5] compared the effects of soluble-fiber (oat bran) and insoluble fiber (wheat bran) intakes on serum lipids, apolipoproteins, and lipoprotein fractions for 20 hypercholesterolemic men on a metabolic ward for 21 day. They postulated that the interactions of four separate processes may contribute to the hypocholesterolemic effect of oat bran. First, oat bran significantly increases fecal bile acid excretion and alters bile acid metabolism. Second, oat bran may alter lipoprotein metabolism, possibly by increasing hepatic LDL receptors. Oat bran tends to selectively lower LDL cholesterol to a greater extent than does HDL cholesterol. Third, oat bran is fermented in the colon into short chain fatty acids such as acetate, propionate, and butyrate and after absorption into the portal vein, propionate may inhibit hepatic cholesterol synthesis [122]. Fourth, decreases in insulin secretion associated with fiber such as oat bran could lead to reduction in cholesterol synthesis [55]. A daily intake of 106 g oat bran providing 15.3 g TDF (total dietary fiber) and 7.6 g soluble-fiber over 21 day was accompanied by significant reduction in total cholesterol, LDL cholesterol, and apolipoprotein B-100 in hypercholesterolemic men. An equivalent intake of TDF from wheat bran providing 1.3 g soluble-fiber did not significantly reduce these contents.

In humans, acetate is an important large bowel digestion product of diets containing oat products. Susan et al. [18] compared the oat bran and wheat bran along with control for the production of serum acetate in human body. They got the serum acetate concentrations at 0800 hours ranged from 52 to 83 μmol/L for all subjects that were similar to the values for fasting serum acetate in humans as reported by Guynn and Veech [44]. Fasting serum acetate values were significantly higher after the oat-bran than after the control diets. Serum acetate concentration was significantly higher in subjects fed oat bran than in subjects fed wheat bran. Serum acetate concentrations for the oat-bran group peaked at 1400 (109 ± 12 μmol/L) and 1600 hours (113 ± 13 μmol/L) [18].

Similar diet-induced differences in short chain fatty acids (SCFA) concentrations in both cecal contents and hepatic portal venous plasma have been noted previously in animals fed highly degradable fibers such as pectin, beans, and oat bran and marginally degradable fibers such as cellulose and wheat bran [39, 104]. It was reported that although acetate was the principal SCFA produced in rats by oat bran and cellulose diets, propionate was significantly higher in the portal vein of rats fed oat-bran diets compared with cellulose diets [25].

Significantly higher concentration of SCFAs have been reported both in hepatic portal venous plasma and facial contents of rats fed oat-bran diets compared with cellulose diets. Acetate was the major SCFA produced by both diets. However, the animals fed oat bran had proportionately less acetate and more propionate and butyrate than in animals fed cellulose. This finding may be due to the fermentation of complex carbohydrates, such as the hemi-cellulose present in oat bran, leading to fermentation of longer-chain acids [89].

Concentrations of SCFAs have been shown to decrease in the blood as they pass from the portal to hepatic to peripheral sites. At all sites acetate is the principal anion but molar ratios of the three principal SCFAs change at various sites, indicating greater uptake of butyrate by the colonic epithelium and of propionate by the liver [27]. Increases in peripheral serum acetate in humans, therefore, are likely accompanied by increases in portal vein acetate and propionate as well. Peripheral serum acetate was also noted to be significantly higher in oat-bran fed subjects than in wheat-bran fed subjects [7]. Both acetate [15] and propionate [122] have been reported to inhibit cholesterol synthesis in animals. Thus, significant increases in SCFAs in humans may contribute to the hypocholesterolemic effects of oat bran and other sources of soluble-fiber.

Oat bran is effective in reducing the risk for CHD because it favorably alters atherogenic fasting and postprandial serum lipids and other lipoprotein fractions, independent of other dietary changes. Carefully controlled studies of longer duration are needed to determine if the hypocholesterolemic effect of oat bran is sustained [5].

Oat and coeliac disease

Coeliac disease is an autoimmune hereditary disorder of the small intestine that occurs in people of all ages from middle infancy because of sensitivity to gluten in food. Normally the lining of the small intestine has a fluffy velvety texture, but in coeliac disorder it becomes smooth and flat. This reduces its ability to absorb nutrients, including sugars, proteins, vital minerals and vitamins from food. When persons with celiac disease take foods containing gluten, their immune system responds by damaging the small intestine lining. Tiny fingerlike protrusions, called villi are attacked by the immune system and are eventually destroyed. Malnutrition occurs without these villi, no matter how much food a person consumes because the nutrients from food pass the gut without being absorbed (malabsorption), leading to diarrhoea, vitamin and mineral deficiencies, anaemia and osteoporosis. Children usually develop it at between six and 18 months of age. However, the onset of the disorder can be delayed and it can occur at any age, when the symptoms come on slowly, perhaps over years, making early diagnosis difficult [38, 100].

Presently, the only effective treatment of coeliac disease is a life-long rely on gluten-free diet [73]. No medication exists that will prevent damage, or keep the body from attacking the gut when gluten is present. Strict adherence to the gluten free diet allows the intestines to heal, leading to resolution of all symptoms in the vast majority of cases and, depending on how soon the diet is begun, can also eliminate the heightened risk of osteoporosis and intestinal cancer [109].

The work of Dicke in 1950 has proved that wheat and rye damage the small-intestinal mucosa of patients with celiac disease. The injurious constituent of wheat in patients with celiac disease is α-gliadin in the prolamin fraction of wheat gluten [32]. Oats do not contain gliadin but its counterpart avenin [12]. In wheat, rye, and barley, prolamins constitute 40–50, 30–50, and 35–45% of total proteins, respectively. However, in case of oats, prolamins constitute only 10–15% of total proteins and sixty grams of oats is estimated to contain 1.2 g of avenin [20].

Generally, it is recommended that coeliac patients should avoid wheat, rye, and barley. The removal of gluten from their diet results in epithelial healing and the gradual reformation of intestinal villi. Although the inclusion of oats in the gluten free diet was controversial until 1996, several later studies indicate that oats are not unsafe for those either with celiac disease or dermatitis herpetiformis. Moreover, adherence to a strict gluten-free diet is difficult and any relief of dietary restrictions, such as those on oats, can make the diet more acceptable to patients [65]. Oats improve the nutritional value of the gluten-free diet without any negative effects on nutritional status and are appreciated by the patients. Therefore, oats can help coeliac patients following a strict gluten-free diet [105].

The safety of oats in individuals with celiac disease has been extensively investigated. Clinical evidence confirms that consumption of pure, uncontaminated oats is safe up to 50–70 g/day by adults and 20 to 25 g/day for children. Studies looking at the consumption of oats over 5 years have confirmed their safety. Such studies have increased the possibility of adding oats to a gluten-free diet, as this would permit a wider choice of foods for individuals with celiac disease and provide an additional source of carbohydrates, proteins and fiber. However, some people with celiac disease show no improvement on the gluten-free diet, the condition called unresponsive celiac disease. The most common reason for poor response is that small amount of gluten fraction is still present in the diet. Pure oats are being grown and produced following good agricultural practices to minimize the presence of other cereals. This helps to make sure that gluten from other grains is not mixed with the pure oats [42].

The effects of gluten-free diets with and without oats (50–70 g/day) in adults with celiac disease have been studied [53]. The oat and control groups did not differ significantly in nutritional status, symptoms, or in vitro testing. Patients in remission, regardless of diet, did not have worsening effect on the duodenal villi. All the patients with new diagnoses were in remission at 1 year, except for one in the control group. It is likely that the results apply to children as well, because the toxicity of oats in children would be difficult to test owing to the extended time span required for relapse. Therefore, many patients with celiac disease can include moderate amounts of oats to their gluten-free diets without harmful effects as supported by other studies as well [46, 52, 90, 103].

In a long-term study, 32 children with coeliac disease were either challenged with oats or with gluten. When relapse was evident after gluten challenge, a gluten-free diet including oats was started to this group. At the end, in coeliac children in remission, oats had no detrimental effect on intestinal histology or serology. In contrast, the gluten challenge group relapsed after 3–12 months. Complete recovery from the disease was accomplished in all relapsed and newly detected patients on an oat-containing gluten-free diet. After the trial, 86% of the children preferred to consume oats and all of them remained in remission [47]. Similar results have been described previously in the adults [52].

Some in vitro studies also indicate lack of oats toxicity in coeliac disease patients. It is well documented that the wheat protein gliadin triggers inflammation in coeliac patients. However, the potential toxicity of avenin, the corresponding protein in oats has been evaluated and the results showed that the immunogenic sequences present in gliadin are missing in avenin [68].

Picarelli et al. [84] cultured intestinal biopsy tissue specimens from subjects with quiescent celiac disease to determine if oats were a source of toxicity. Samples of duodenal mucosa that were obtained by biopsy were cultured in media containing immunologically active components of wheat (gliadin) or oats (avenin). Tissue cultures produced celiac-specific antibodies only to gliadin, whereas there was no antibody response to avenin or its most toxic fraction. These results suggest that oats can be included safely in a gluten-free diet for celiac disease.

Kilmartin et al. [69] examined the immune response of celiac mucosal T-cell lines to prolamin fractions from wheat, rye, barley, and oats. They isolated mucosal T-cells from coeliac patients and investigated their interaction with the prolamin fraction of the four cereals. The T-cell lines demonstrated immunoreactivity to protein fractions from the four related cereals. However, despite oats stimulation of T cell lines, it did not activate mucosal lesion in celiac patients. The treatment with tTG enhanced the response to gliadin, secalin, and hordein, but the enzyme caused little or no enhancement of avenin responsiveness. The lower number of proline residues in avenin makes the protein less suitable substrate for tTG, and that the binding of avenin to HLA-DQ2 is less efficient than the r prolamins of other cereals.

A few studies have been performed to investigate the nutritional quality of the gluten free diet. These studies reported that the gluten free diet could be deficient in fiber, vitamins and minerals, especially for women [43]. Inclusion of oats in the gluten free diet is advantageous, since oats are a good source of dietary fiber and of several vitamins and minerals. Nevertheless, there could be some negative nutritional impacts in relation to its high intake, as insoluble dietary fiber may interact with needed mineral elements resulting their lower bioavailability [85, 93, 112] and increased risk of mineral deficiencies [33, 88]. The effects of complex carbohydrates on the absorption of minerals have been reviewed in an array of foods [19].

The decreased absorption of minerals is not only related to ion binding capacity of fiber components but some other factors such as intestinal transit time, degree of bacterial fiber degradation in gut and potential for the absorption of minerals in the large intestine may contribute in this progression. Moreover, impaired mineral availability may not be entirely due to fiber but phytate in unrefined foods may also be a causative factor [16, 97]. During food processing and digestion, phytate may be degraded to inositol phosphates with a lower phosphorylation degree thus reducing the adverse effect of phytic acid on mineral absorption. However, it should be considerate that both, dietary fiber and phytic acid are present in fiber-rich diets thus it is rather difficult to separate the effects of fiber and phytate in the binding of essential polyvalent metallic ions [95, 96]. While oats are considered to have low phytase activity, heat treatment of oats aimed to protect against fat oxidation further decreases the activity of enzyme [40].

Conclusion

Various strategies are used to combat diseases and potential health risks. In addition to pharmaceutical approach, diet based strategies are also considered suitable to prevent various disorders. In the developing countries, increased cost of medication and their side effects are of great concern to general public; opening new channels of pharmacological investigations focusing on natural medication and diverting human trends toward natural cure. Manipulation of different foods can be helpful to control different diseases. Oat grains are good source of B complex vitamins, protein, fat, minerals, and heart healthy soluble- fiber β-glucan. Moreover it is also useful for the control of diabetes and lipid profile. The incorporation of oat in daily diet is not only important from the nutrition standpoint but also for its therapeutic potential. However, the health claims associated with oats are achieved only when oat products are consumed regularly for longer time and the amount in the diet overcomes certain threshold values set for β-glucan.

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