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Contents of β-Glucan in Various Cereals and Its Functional Properties

– Review –

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Abstract

A soluble dietary fiber, β-glucan, contained in oat and barley has nutritional benefits such as hypocholesterolemic effects and influences blood glucose regulation. The contents of β-glucan in both cereals range from 3 to 7% with the exception of a certain barley genotype which contains up to 16% β-glucan. β-Glucan is distributed mainly in the cell walls of endosperm and the distal (bran) portion of the kernel. Various procedures have been developed for increasing the extraction yield of β-glucan. Oat gum prepared with weak alkali extraction and alcohol precipitation following protein removal usually contains 80% β-glucan. The most commonly used method for β-glucan quantitation is an enzymatic procedure combining lichenase plus β-glucosidase followed by measuring the amount of glucose released by glucose oxidase-peroxidase treatment. The increase in foam-and emulsion-stabilizing capacity of β-glucan is due to the increase in viscosity of the aqueous phase. Therefore, β-glucan shows great potentials as a thickener and a stabilizer.

Key words: β-glucan, hypocholesterolemic effect, blood glucose regulation, viscosity, stabilizer

INTRODUCTION

Among cereals, barley and oat are rich sources of β-glucan, a soluble dietary fiber. The content of β-glucan ranges from 3.0 to 6.9% in barley (1), 3.0 to 6.8% in whole oat kernel (2) and 5.8 to 8.9% in oat bran (3). Rye has 1.7 to 2.9% β-glucan but the other cereals such as rice, sorghum and wheat have less than 1% (Table 1). This soluble gum is the major cell-wall polysaccharide in the endosperm of oats and barley (4,5). β-Glucan is a linear, unbranched non-starch polysaccharide composed of 4-O-linked β-D-glucopyranosyl units (70%) and 3-O-linked β-D-glucopyranosyl units (30%). It was suggested that (1→3) linkages occur singly and most of the (1→4) linkages occur in groups of two or three. The resultant structure, therfore, is a polysaccharide built mainly from β (1→3)-linked cellotriosyl and cellotetrosyl units (3).

From the mid 1980s, consumers became aware of the physiological significances of β-glucan: improvement of glucose and insulin regulation and its hypocholesterolemic effect (6-8). Additionally, the possibilities of utilization of β-glucan as a food hydrocolloid, thickener or stabilizer have recently been suggested (8-10). These benefits have pushed up the amount of consumption of the β-glucan-enriched fraction from barley and oat. This article reviews (1) various attempts to increase the content of β-glucan through different processing steps (2), the methods to quantify this gum and (3) the commercial utilizations of β-glucan.

Table 1. Content of β-glucan in various cereals (% dry wt)

Sample	Mean (Range)	Literature cited
Oat	3.0 ~ 6.8	Wood et al. (2)
Oat groat	3.9 ~ 6.8	Wood et al. (2)
Oat breakfast cereals	2.5 ~ 4.6	Carr et al. (9)
Oat bran	5.8 ~ 8.9	Wood et al. (3)
Malting barleys	4.5 ~ 8.2	Prentice et al. (43)
Feed barleys	5.1 ~ 7.2	Prentice et al. (43)
Barleys	3.0 ~ 6.9	Kahlon et al. (1)
Rice	0.1	Henry (44)
Rye	1.7 ~ 2.9	Prentice et al. (43), Henry (44)
Sorghum	1.0	Prentice et al. (43)
Triticale	0.4 ~ 1.2	Prentice et al. (43), Henry (44)
Wheat	0.5 ~ 1.4	Prentice et al. (43), Henry (44)

DISTRIBUTION OF β-GLUCAN

The sources of variation in β-glucan content of oat and barley are genetic and environmental. The contents of β-glucan in oats vary with cultivars ranging from 3 to 7% (5) while similar ranges of β-glucan content have been reported for commercial barley varieties (10-12) with the exception of a certain barley genotype containing β-glucan up to 16% (12). These values are destined to be diluted when these grains are processed into ready-to-eat cereals. Some waxy barley cultivars with more than 10% β-glucan have been developed but these cultivars have lower fertility and yield (5).

The relative fluorescence intensity (RFI) of Calcofluor bound to β-glucan in various portions of oat kernels was measured (3,5). The RFI of bound Calcofluor is approximately proportional to the amount of β-glucan present (3). In the central and distal (bran) portions of oat OA516-2 (4% β-glucan), the β-glucan content was the highest in the subaleurone layer around the periphery of the kernel and up into the crease (5). The pattern was different in the central and distal regions of the cultivar Marion (6.3% β-glucan). The RFI was high throughout, but higher concentration of β-glucan in the distal

region was found. The difference in β-glucan content with these 2 cultivars reflected differences in cell size and wall thickness. In OA516-2, the cells in the endosperm were larger than those of Marion and the cell walls in the endosperm of Marion were thicker than those of OA516-2 (3,5,12).

Results of the examination on β-glucan content of various barley cultivars suggested that, regardless of β-glucan level, the distribution of β-glucan in barley was similar to that in the central region of Marion oat. The difference in cell wall thickness in the endosperm observed in barley cultivars were also good indicators of different levels of β-glucan (3,5).

THE CONTENT OF β-GLUCAN IN CEREALS WITH VARIOUS PROCESSING PROCEDURES

Dry milling

Oat bran is not an anatomically pure bran but rather a sieved fraction enriched in β-glucan (3). After realizing the nutritional and clinical advantages of β-glucan, there has been a continous effort to yield fractions enriched in this component. The general oat processing steps begin with cleaning of the seeds and proceed with dehulling, aspirating to remove the hull, kilning, steaming and flaking (3). The first commercial oat bran was produced by Quaker Oats Co. in the late 70s by steaming, flaking and hammer milling oat groats. The milled material was sifted to give a coarse fraction (oat bran) comprising 40~50% of the starting material and a β-glucan content of 8~12% that is twice the content of starting groat (3). Later, this company employed a dry-milling and air classification procedure (13) from hexane-defatted oat flake and obtained coarse bran fraction from the cultivar Dal (27.7%). This fraction was extracted with sodium carbonate (pH 9.2) and after discarding starch by centrifugation, the protein was precipitated at the isoelectric point and removed. The remaining aqueous phase was neutralized, concentrated and precipitated with 2-propanol to yield an oat gum that contained 66% β-glucan. This procedure is now widely accepted in extracting oat gum in the laboratory (Fig. 1). The roller-milling method used to make wheat and corn bran has a yield of oat bran of 18.6~25%, which is considered to be inefficient (3,14).

Aqueous processing

A process developed by Burrows et al. (15) steeps oat groats in water for up to 28 hr at 50°C followed by wet-milling the steeped mixture to produce bran. The bran and flour fractions were unacceptable because of the free fatty acids produced, but yielded a primary bran of 15.07% and β-glucan of 14.7% which is three times as high as the content of the groat (4.7%). Inglett (16) introduced a process to produce an oat soluble dietary fiber (SDF) fraction. Oat flour or bran is subjected to α-amylase to remove starch and the insoluble residues were removed and the extract was dried to give a substance known by the trade name Oatrim (fat replacer) which contains 7~8% SDF (mainly β-glucan). Homogenization of oat groat in cold water (<10°C) followed by wet screening

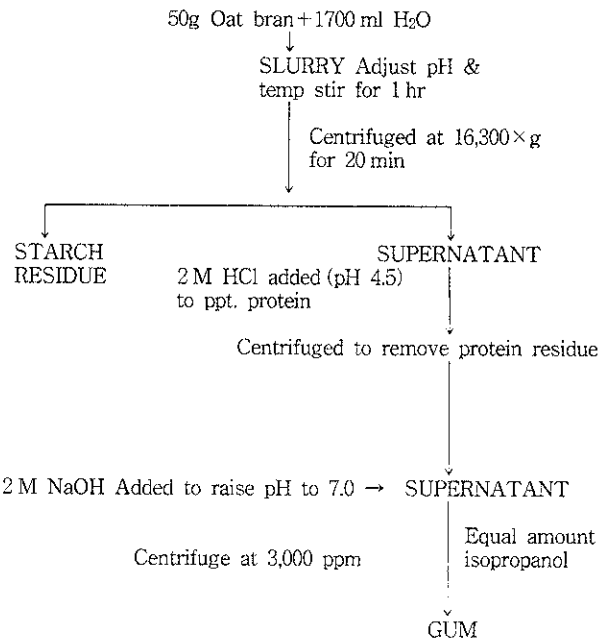

Fig 1. Procedure for the extraction of oat gum.

and sieving gives a β-glucan content of the bran in the range of 15~30% (w/w) (17).

Nonaqueous processing

Oughton (18) fractionated oat slurries in nonaqueous organic solvents using liquid cyclones with a screening technique to yield a bran of 28.5%. Later, this process was further developed by Boczewski (19) to pass oat groats between several paired smooth rolls, crush the oats and mix with hexane. The mixture was screened and processed with hydrocyclones to yield the bran of oat cultivar Hinoat 26~53% (w/w).

Nonaqueous plus aqueous processing

Wood et al. (20) developed a hexane-extraction and air-classification process of extracting bran fraction. The oat bran fraction was 38% having a β-glucan content of 11.2%. The process described by Myllymaki et al. (21) smooth rolls oat groats which is followed by screening, refluxing the coarse bran in isopropanol and wet grinding and screening. This produced oat bran enriched in β-glucan (oat bran 20%, β-glucan 17~18%).

EXTRACTION AND QUANTITATION OF β-GLUCAN

Extraction of β-glucan

Dry milling, sieving (22-24) and solvent extraction (20,25, 26) were employed for production of β-glucan concentrates from oats and barley. β-Glucan concentration obtained were 31% for dry milling and air classification (24) and 89% for solvent extraction (26). It was reported that the yields of gum (wt. gum/50 g flour) were 1.6 and 2.5% for products containing 52.9 and 64.8% β-glucan from Waxiro and Cameo barley cultivars, respectively, after extraction with water at 40°C (27). Wood et al. (28) prepared an oat gum containing

78% β-glucan from oat bran at the piolot plant scale with sodium carbonate extraction at pH 10. When they applied this procedure on extracted oat gum, 75 to 86% yield of precipitate containing 98% β-glucan was achieved. Dawkins and Nnanna (26) used 2 M sodium hydroxide instead of sodium carbonate and extracted 70 to 89% β-glucan from oat bran and 50 to 69% β-glucan from rolled oats. Generally, oat gum prepared with weak alkali extraction plus alcohol precipitation following protein removal contains approximately 80% β-glucan in the laboratory (3). Production of further purified gum could be achieved by two additional precipitations with 20% ammonium salt and 2-propanol, respectively (7). When the highly pure β-glucan is to be extracted, extraction with minimum starch contamination is necessary. However, care is needed not to underestimate the content of β-glucan because mild conditions are employed so as not to be contaminated with starch and this results in an incomplete extraction.

Quantitation of β-glucan

It is impossible to directly analyze the content of β-glucan itself and therfore, acid or alkali extraction followed by enzymatic hydrolysis is required. In one method (29), starch was completely degraded by α-amylase and amyloglucosidase and solubilized β-glucan was precipitated. The precipitates were then treated with a crude β-glucanase to hydrolyze β-glucan to glucose. In another method, a crude cellulase could be used to convert β-glucan to glucose after a prior extraction of interfering cellulose and amylase (9,26). The released glucose was measured by a glucose oxidase-peroxidase procedure (30).

Treatment of β-glucan with lichenase, (1→3), (1→4)-β-D-glucan-4-glucanohydrolase, plus β-glucosidase that converts the oligosaccharides released by lichenase to glucose are currently the most widely used method for β-glucan quantitation. Commercial products with these enzyme kits from Biocon (Lexington, KY) and Megazyme (Aust. Pty. Ltd. North Rocks, Sydney, NSW) are now available.

A nonenzymatic, fluorometric method that uses the optical brightener, Calcofluour, disodium 4, 4′-bis {4-anilino-6- [bis (2-hydroxyethyl)-amino]-1, 3, 5-triazin-2-yl} amino-2-2′-stilbenedisulfonate to bind to β-glucan (31) has been developed. An automatic flow injection analysis (FIA) system based on the complex formation between these two compounds is a very useful technique for the β-glucan analysis. An assay using Congo red instead of Calcofluor to bind to β-glucan was also developed (3).

NUTRITIONAL BENEFITS OF β-GLUCAN

Hypocholesterolemic effect

Numerous reports have been published concerning the effect of oat β-glucan on its cholesterol-lowering properties in animals and human beings. In human beings, a significant reduction of blood cholesterol could be achieved with a daily dose corresponding to 1.3-8 g of β-glucan (32-34) even though the quantity seemed unrealistic to take on a continual basis. Both oat bran- and oat gum-supplemented synthetic diets lowered plasma cholesterol levels in cholesterol-fed rats (35-37). The oat gum diet containing 66% β-glucan (a concentrated form) was more effective than the oat bran diet in lowering the serum cholestrol in hypercholesterol rats (37). Rats fed with the β-glucan-enriched breads had lower serum and liver cholesterol levels at 35 days of feeding and lower serum triglyceride levels at 25 days of feeding (38,39). It was concluded that β-glucan-enriched breads and baked products could be useful in the dietary control of blood cholesterol levels (38). The cholesterol-lowering activity of β-glucan is mainly due to binding or trapping of cholesterol and its metabolites in the digestive tract (39,40). This trapping is caused by the ability of the gum to increase the viscosity of the tract, thereby reduce diffusion of cholesterol leading to a reduced absorption of cholesterol and bile acids (41).

Hypoglycemic effect

It was reported that feeding with β-glucan partly causes poor growth performance in monogastric animals (9) and aggravation of mineral absorption efficiency in diabetics (39). Recently, however, the postprandial rises in blood glucose and insulin were reported to be significantly reduced by oat gum with a 50 g glucose load compared with the effects of a same glucose load but without added gum (3). In further experiments, the oat bran meal (14.6% β-glucan) gave a significantly lower rise in postprandial glucose and insulin levels than a cream of wheat meal (3). Some diabetics, fed with diets high in oat bran could be taken off insulin therapy or insulin dosage could be decreased in almost all cases (33,39).

FUNCTIONAL PROPERTIES OF β-GLUCAN

Higher viscosity of β-glucan is responsible for retardation of malting, poor wort separation, difficulties in beer filtration and formation of undesirable beer precipitates (9) but recently, other advantageous functional properties of β-glucan have been reported (8). One percent dispersions of barley β-glucan in water (w/v) had a maximum whippability of 185% at pH 7.0/45°C. Whippability decreased with an increase in temperature above 45°C and with increasing pH (8). Emulsion-stabilizing capacities of 1% β-glucan dispersions were at best 63.4%, stable at pH 7.0 and 55°C after centrifugation. With the increase in pH and temperature, emulsion-stabilizing capacity decreased (8).

The contribution to the increase in stability of foam and emulsion is mainly due to the increase in viscosity of β-glucan in the aqueous phase. Coalescence of air bubbles and oil droplets is hindered by a viscous aqueous phase (3,12). Viscosity of 1% barley β-glucan increased with extraction temperature and at 55°C, the viscosity was the highest whereas viscosity increased with pH, reaching a maximum at pH 9.0 (8). Acid buffer (82.8 ml of 1 N HCl+7.46 g of KCl) extracts of barley had slightly higher viscosity than water extracts and the soluble β-glucan was a major contributor to acid-

extract viscosity (12). The performance of β-glucan show great potential as a thickener and a stabilizer in products such as soups, sauces, desserts and salad dressings (8-10, 26,42). Experimental breads containing 7% β-glucan had a light cream color crumb and medium to dark brown crust. Textures and densities of the breads were similar to those of several multi-grain breads now on the market (39).

SUMMARY

Barley and oat are the two major cereals which contain the soluble dietary fiber, β-glucan. It exerts hypocholesterolemic and hypoglycemic effect along with other desirable functional properties such as emulsion-and foam-stabilizing capacity caused by its formation of a viscous gel. From the mid 1980s, after consumers became conscious of these physiological significances, oat bran was no longer considered a by-product and became a sought-after commodity (3). Most of the studies performed on β-glucan in Western countries have focused on oats because the barleys grown in these countries were used for malting and feeding (39).

In Korea, even though per capita consumption of barley has decreased recently (12), the significance that this crop takes in the diet is still high and its physiological advantages have potentials for triggering a reincrease in consumption. A scientifically supported feasible process to extract and concentrate β-glucan in barley to utilize it for human consumption needs to be developed.

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