Cereal β-glucans and their Significance for the Preparation of Functional Foods – A Review

Michaela HAVRLENTOVÁ[1], Zuzana PETRULÁKOVÁ[2], Alena BURGÁROVÁ[2], František GAGO[3], Andrea HLINKOVÁ[1,3] and Ernest ŠTURDÍK[2,3]

[1]Plant Production Research Centre, Research Institute of Plant Production, Piešťany, Slovak Republic; [2]Slovak University of Technology, Faculty of Chemistry and Food Technology, Department of Nutrition and Food Evaluation, Bratislava, Slovak Republic; [3]University of SS. Cyril and Methodius in Trnava, Faculty of Natural Sciences, Department of Biotechnologies, Trnava, Slovak Republic

Abstract

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Cereals are generally known to have a positive influence on the general state of the human organism. The attention of the nutritional experts is paid especially to oats and barley. Besides their accessibility, these cereals are interesting due to their relatively high contents of soluble non-starch polysaccharides (fibrous material), out of which β-glucans have a dominant position from the aspect of health benefit. This paper presents a brief review of the latest knowledge on the positive effects of β-glucans on the consumer's health. The structure, occurrence, sources, and positive physiological effects of β-glucans on the cardiovascular system but also their antibacterial, antitumoral, immunomodulant, and radioprotective properties are mentioned. In the paper are given examples of β-glucans exploitation as functional ingredients in food, cosmetic, and pharmaceutical industries and as food additives on the basis of cereal fibres and cereal β-glucans.

Keywords: cereals; oats; β-glucans; fibre; functional food; health benefit; application

Food industry aims at the development of new products towards functional foods and ingredients with regard to the consumer's demands on healthy nutrition. Functional foods are eatables which besides their initial function (satiation and nutrition of the organism) provide also a health benefit to the consumer. Such foods affect the organism by improving the functions of individual organs, by decreasing the risk of becoming ill with respect to their prophylactic action, and also by optimising the weight and influencing the mental state. Functional foods are aliments diminishing the risk of many chronic and infectious diseases. They are traditional foods modified so as to achieve their favourable health effects which are not present in the non-modified products. Contrary to conventional foods where the emphasis is laid primarily on the nutritive and sensory functions, the functional foods are characterised by giving preference to the physiological functions, i.e. to the regulation of the protective mechanisms, physical condition, prevention of ageing, and to the prevention and medical treatment of diseases associated with the diet. The functional food must fulfil the follow-

ing requirements: it must be a food consisting of natural components, not a tablet or powder; it can and should be consumed as part of the daily meals; its special regulation lies in the regulation of the particular process ongoing in the human organism. When preparing functional foods, a certain portion should consist of food naturally enriched with vitamins, minerals, antioxidants, suitable enzymes, etc.

Functional foods are composed of the carrier and the active component, which has a proven health effect. The carrier is a common basis of food which must fulfil the prescribed criteria. The food must be suitable for regular and repeated consumption. From the technological aspect, it must be suitable for the application of the active component which must not react with it undesirably. From the practical point of view, the functional food can be: (*i*) natural food, some component of which was enriched via special cultivation conditions, (*ii*) food to which the component with an evident favourable action was added, (*iii*) food from which the respective component was removed to reduce the negative health effect, (*iv*) food in which the nature of one or more components was chemically modified to reach a better absorption of the beneficial component, and (*v*) combination of the above-mentioned possibilities (Andlauer & Furst 2002; Charalampopoulos *et al*. 2002; Bressani 2003).

The best-known examples of functional foods are fermented milks and yogurts containing a special kind of bacterium that positively affects human intestines. Moreover, fermented milk products have recently become popular because of their low cholesterol content. In the European market, energetic drinks are also very popular.

Another alternative of functional foods is cereals due to their wide accessibility. Cereals or the cereal components may be applied into functional foods as: (*i*) fermented substrates for the growth of probiotic microorganisms, especially *Lactobacillus* and *Bifidobacterium* strains, (*ii*) fibrous material supporting some favourable physiological effects, (*iii*) prebiotics (due to the content of specific indigestible saccharides), (*iv*) encapsulating material for probiotics to improve their stability (Andlauer & Furst 2002; Charalampopoulos *et al*. 2002).

In this study, attention is paid to an important part of the fibre – β-glucans and their significance in maintaining favourable effects on human health. The work offers approximately 10-year review of the knowledge gathered from local and foreign

literature sources and from the research carried out mainly into cereal β-glucans (sources, medical aspects, detection methods, etc.). The possibilities of their application as functional ingredients in the production of cereal foods are also discussed.

Dietary fibre

Fibrous material is the edible part of plants which is resistant to the hydrolysis by enzymes in the digestive tract. A part of it is metabolised into volatile fatty acids in the gastrointestinal tract. Following its water solubility, fibrous material can be divided into two categories. Each category insures different therapeutic effects. Water-soluble fibre predominantly consists of non-starch polysaccharides, mainly β-glucans and arabinoxylan. It produces a viscous solution. Soluble fibre inhibits passing of the chyme through the intestines, hampers the stomach discharge, reduces the absorption of glucose and sterols in the intestines, and decreases serum cholesterol, blood glucose, and the content of insulin in the human body. The water-insoluble fibre contains lignin, cellulose, hemicellulose, and non-starch polysaccharides such as the water-extractable arabinoxylan. It is not fermented in the large intestine (AACC 2001; Andlauer & Furst 2002; Charalampopoulos *et al*. 2002).

Cereal grains have different fibre contents. In cereal grain, a majority of fibre is found (at a decreasing rate) from the outer coat to the endosperm. This does not apply to arabinoxylan, which is a principal component of the endosperm cell wall. The methods of the fibre isolation and purification as well as the techniques implying quantitative and structural analyses have been developed to isolate the fibre from the common cereal fractions obtained in the grinding process. The elaborated procedure of the cereals processing (grinding) makes it possible to obtain products from the particular structural grain layer (Bressani 2003; Lambo *et al*. 2005).

It is however necessary to mention also some negative aspects of food fibre in human nutrition. The exploitation of the outer part of the grain also brings about certain risks of contamination with heavy metals, radioactive elements, and residua of pesticides used either in the period of vegetation or during the processing and warehousing. Proportionally to the increase of the fibre content in the cereal products, a growing proportion of phytic acid is observed. This acid together with

calcium and magnesium, but also with iron, zinc, and copper generates water-insoluble complexes and thereby unfavourably influences their efficiency (for review see Rodriguez & Saura-Calixto 1991). The potential negative effects of dietary fibre include reduced absorption of vitamins, minerals, proteins, and calories (Marlett *et al.* 2002). Excessive amounts of dietary fibre caused diarrhea (Saibil 1989) and its fermentation by anaerobic bacteria in the large intestine produces gas, including hydrogen, methane, and carbon dioxide, which may be related to the complaints of distention and flatulence (Marlett *et al.* 2002). A higher intake of whole grain breakfast cereals can be also associated with a lower risk of the heart failure (Djoussé & Gaziano *et al.* 2007) while the beneficial blood pressure regulating effect is valid only for patients with mild hypertension (Keenan *et al.* 2002). Vega-Lopez *et al.* (2001, 2002) have reported that the positive effect of psyllium intake on triglycerides and lipoproteins metabolism, respectively, was not detected in pre-menopausal women in comparison with men, with whom this dietary fibre component shows to decrease plasma insulin, apolipoprotein CIII, and apolipoprotein E.

It follows that the problem of the food fibre has not been sufficiently investigated so far and the opinions on its role in the human nutrition differ. What can be considered as definitive is the opinion of experts who claim that the content of soluble non-starch fibrous polysaccharides represented by the β-glucans group is most important for the healthy nutrition directed mainly to oats and barley (AACC 2001; Lambo *et al.* 2005). The interest in a single component may further our understanding of the whole but should not suggest supremacy of any one item. An analogy is the orchestra: It is important to discuss and understand each instrument, yet we must also recognise how the instruments interrelate (Eastwood & Kritchevsky 2005).

β-glucans – structure, occurrence, and sources

β-glucans are indigestible polysaccharides occurring naturally in various organic sources such as corn grains, yeasts, bacteria, algae. They are important components of the fibres containing unbranched polysaccharides consisting of β-D-glucopyranose units linked through (1→4) and (1→3) glycosidic bonds in cereals (Figure 1) and (1→6) glycosidic bonds in fungal sources (Figure 2), respectively. The structure has an impact on the water solubility of β-glucans. Extensive research has been done into the structure and properties of water-soluble β-glucans in contrast to water-insoluble β-glucans (Johansson *et al.* 2000; Ren *et al.* 2003). Generally, no sharp distinction exists between the soluble and insoluble fractions and the ratio is highly dependent on the extraction conditions of the soluble fibre (Virkki *et al.* 2005). Glucans are usually concentrated in the internal aleurone and subaleurone endosperm cells walls (Charalampopoulos *et al.* 2002; Demirbas 2005; Holtekjølen *et al.* 2006). Out of cereals, the highest amounts of β-glucans are found in barley and oat grains (Havrlentová & Kraic 2006, Table 1). Literature data indicating the yields of β-glucans in different cereal-based food sources are listed in Table 2.

Currently, a renaissance of barley for human food and nutrition can be observed in many countries of the world (Ehrenbergerová *et al.* 2008) and barley fiber plays several beneficial roles in improving human health (Newman *et al.* 1989; Newman & Newman 1991; Ehrenbergerová *et al.* 1999). Increased levels of β-glucan have been reported in hull-les *waxy* barley (Ehrenbergerová et al. 2003, 2008; Procházková *et al.* 2004), its content being affected by the enrironmental conditions and their interactions with varieties (Ehrenbergerová *et al.* 2008). Hull-les barley has been successfully used
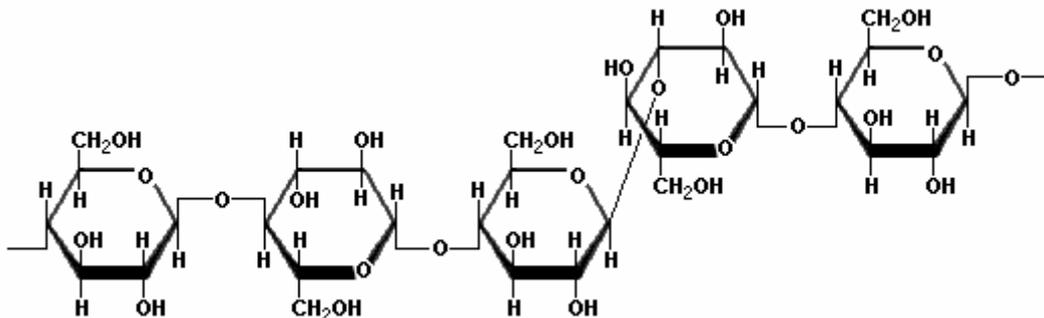

Figure 1. Basic structure of β-glucans in cereals with combined bonds β-(1→3) and β-(1→4)
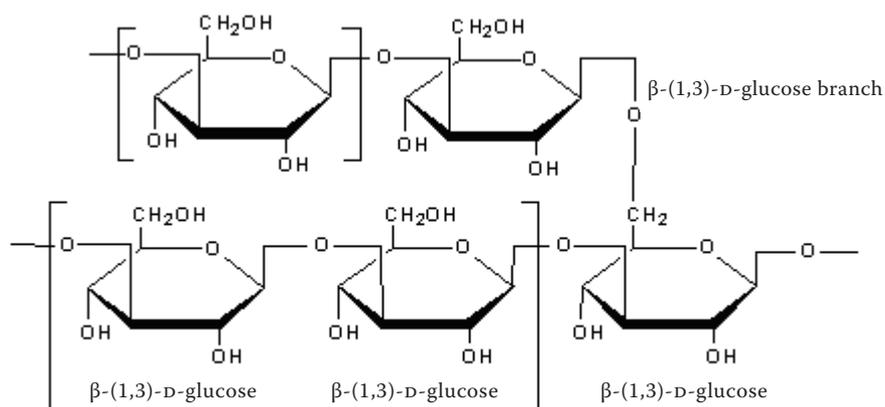
Figure 2. Basic structure of β-glucans with combined bonds (1→3) and (1→6) in yeast sources

in food, feed, and industrial applications (Bhatty 1986) and the effects on the baking properties of flour used in bakery products and bread have been determined (Newman *et al.* 1990; Andersson *et al.* 2004).

The potential use of oats in the production of functional foods is bound to the nutritional value of the grain, in particular to the content and composition of dietary fibre, proteins, and lipids, respectively (Demirbas 2005). Thanks to dietary fibre, especially soluble β-glucan, a health claim was published about the beneficial effects of oats (FDA 1997). Higher amounts of β-glucans are observed in naked oats compared to hulled ones (Grausgruber *et al.* 2004; Havrlentová 2009), their content being affected by the genotype and environment (Ames *et al.* 2006; Havrlentová 2009).

Microbial glucans can be found generally inside or on the surface of microbial cells or are excreted by microbial cells into the neighbouring environment extracellularly. Surface glucans are carriers of the immunochemical specificity. Some of them, such as (1→3)-β-ᴅ-glucans, can stimulate the immune mechanisms of the host and have also antitumour and antimicrobial effects (Ooi & Liu 2000; Větvička *et al.* 2002; Větvička & Yvin 2004). The most frequently studied β-glucans obtained from mushrooms include lentinan from *Lentinus edodes*, grifolan (also called GRN and grifolan LE) from *Grifola frondosa*, schizophyllan (called also SPG, sonifilan, sizofiran, and sizofilan) from *Schizophyllum commune*, SSG from *Sclerotinia sclerotiorum*, PSK (called also crestin), and PSP (polysaccharide peptide) from *Coriolus versicolor* (Chang 1996), and β-glucan isolated from *Pleurotus ostreatus* called pleuran.

According to the experimental results and clinical studies, fungal β-glucans are characterised by antibacterial, antiviral, and immunomodulating

properties utilisable for the prevention and therapy in human medicine (macrophage stimulation through the β-glucans receptors located on their surfaces) (Karácsonyi & Kuniak 1994; Kubala *et al.* 2003; Tsukada *et al.* 2003). Further biological effects of β-glucans, which may be prospectively utilised in the clinical practice, can reside in the stimulative action on the haematopoiesis of the bone marrow, and also in the radioactive and antimutagenic effects (scavengers of free radicals) (Hirasawa *et al.* 1999).

Detection methods

Based on the new knowledge gathered in the last eight years on the detection of β-glucans in cereals, especially oats (Ren *et al.* 2003; Johansson *et al.* 2004; Tosh *et al.* 2004) and barley (Zhang *et al.* 2002; Burkus & Temelli 2003; Rimsten 2003), frequently applied methods are predominantly the enzymatic ones using α-amylase, 1,-3 and 1,4-β-ᴅ-glucanase, and β-ᴅ-glucosidase, cellulase, or lichenase (Genc *et al.* 2001; Johansson *et al.* 2004; Tosh *et al.* 2004; Demirbas 2005; Lambo *et al.* 2005; McCleary 2006) but also physical methods (centrifugation-dialysis filtration) (Lambo *et al.* 2005) or extraction using NaOH (Bhatty 1995). The detection of β-glucans is carried out via HPLC (Pérez-Vendrel *et al.* 1995) and HPEC-PAD (Johansson *et al.* 2004), or via spectrophotometry in the UV (Demirbas 2005) and IR spectral regions (PN 01/01 Fungal glucan, 2001), respectively.

Physiological effects of cereal β-glucans

The influence of oat and barley β-glucans on the animal organism has a multifunctional character. Phagocytosis stimulation experiments showed that

Table 1. Content of β-glucans in cereals according to literature data

Cereals	β-glucans (g/100g dry wt)	Method of determination	Reference
Oats	10.9–1.0[b]	enzymic	Lambo *et al.* (2005)
	4.0 ± 0.1[a]	enzymic + HPAEC-PAD	Johansson *et al.* (2004)
	4.1 ± 0.19[a]	enzymic	Genç *et al.* (2001)
	10.37[b]	enzymic	Dongowski *et al.* (2003)
	8.5 [b]	alkaline extraction	Bhatty (1995)
	4.0[a]	enzymic	Virkki *et al.* (2005)
	3–5[a]	–	Anttila *et al.* (2004)
	2.47–3.45[a]	enzymic	Weightman *et al.* (2004)
	1.73–5.7[a]	enzymic	Havrlentová and Kraic (2006)
	13.79–33.73[b]	enzymatic-gravimetric	Gajdošová (2007)
Barley	2.41–8.25[a]	enzymic	Holtekjølen *et al.* (2006)
	1.86–5.37[a]	enzymic	Havrlentová and Kraic (2006)
	3.24–4.62[a]	enzymic	Zhang *et al.* (2002)
	6.0–8.0[a]	enzymic	Lambo *et al.* (2005)
	3.7 ± 0.1[a]	enzymic + HPAEC-PAD	Johansson *et al.* (2004)
	3.6 ± 0.1[a]	enzymic	Genç *et al.* (2001)
	15.4[b]	alkaline extraction	Bhatty (1995)
	3.7[a]	enzymic	Virkki *et al.* (2005)
	3.91–4.95[a]	enzymic	Zhang *et al.* (2001)
	10.89–19.7[b]	enzymatic-gravimetric	Gajdošová (2007)
Wheat	0.8 ± 0.3[a]	enzymic	Genç *et al.* (2001);
	0.31–0.9[a]	enzymic	Grausgruber *et al.* (2004)
	0.19–0.67[a]	enzymic	Havrlentová and Kraic (2006)
	8.48–16.19[b]	enzymatic-gravimetric	Gajdošová (2007)
Rye	1.20–2.90[a]	enzymic	Genç *et al.* (2001
	2.26[a]	enzymatic-gravimetric	Gajdošová (2007)
	3.0–6.9[b]	enzymic + HPAEC-PAD	Roubroeks *et al.* (2000)
	7.45[b]	enzymatic-gravimetric	Gajdošová (2007)
	2.21[a]	enzymic	Grausgruber *et al.* (2004)
Buckwheat	0.02–0.15[a]	enzymic	Havrlentová (unpublished data)
Amaranth	0.03–0.11[a]	enzymic	Havrlentová (unpublished data)
Millet	0.01–0.11[a]	enzymic	Havrlentová (unpublished data)

[a]soluble β-glucan, [b]total β-glucan; HPAEC-PAD – high performance anion exchange chromatography with pulsed amperometric detection

β-glucans are important agents for the maintenance of some blood biochemical parameters. They are responsible for decreasing total and LDL-cholesterol, the ratio of total to HDL-cholesterol (Uusitupa *et al.* 1992; Asp *et al.* 1993; Behall 1997; Behall *et al.* 1997; Bell *et al.* 1999; Karla & Jood, 2000; Freiburger & Gallamer 2001; Kerckhoffs *et al.* 2003; Naumann *et al.* 2006; Queenan *et al.* 2007; Kapur *et al.* 2008; Ruxton & Derbyshire 2008; Cui *et al.* 2009), and so they may reduce the risk of coronary and ischemic heart diseases (Maki *et al.* 2007). This property may result from the ability to increase the viscosity of the intestinal content (Mälkki 2004; Butt *et al.* 2008). The recommended amount of fibre needed to affect cholesterol levels in humans is about 3 g a day, to be taken as four

Table 2. Fibre content in different cereal-based food products

Cereal	Cereal food source	Soluble β-glucans (g/100 g dry wt)	Reference
Wheat	whole meal	0.39	Gajdošová (2007)
	bran	1.38	Gajdošová (2007)
	groat	0.42	Gajdošová (2007)
Barley	whole meal	3.95	Gajdošová (2007)
	groat	3.35–3.74	Havrlentová and Kraic (2006)
		4.14	Gajdošová (2007)
	bran	5.28	Gajdošová (2007)
Oats	whole meal	2.66	Gajdošová (2007)
	groat	4.51	Grausgruber et al. (2004)
		3.16	Gajdošová (2007)
		3.5–5.0	Mälkki and Virtanen (2001)
	bran concentrate	7.48	Gajdošová (2007)
		11.5–17.0	Mälkki and Virtanen (2001)
	flakes	2.64–4.6	Havrlentová and Kraic (2006)

times at least 0.75 g per serving (FDA 1997). However, some authors (e.g. Brown *et al.* 1999; Keogh *et al.* 2003; Robitaille *et al.* 2005) reported no significant changes in the cholesterol levels after the fibre diet.

β-glucans show also positive cardio- (Keogh *et al.* 2003; Stephens 2005) and subsequently glycaemic reactions (Cavallero *et al.* 2002; Tappy 2006; Alminger & Eklund-Jonsson 2008; Nazare *et al.* 2009) beneficial for the overweight humans and patients with type 2 diabetes (Kim *et al.* 2009). The decrease in glucose content can be reached by 10% concentration of oat β-glucans in dairy products (Granfeldt *et al.* 2008; Kim *et al.* 2009). On the other hand, reports of Lovergrove *et al.* (2000), Juntunen *et al.* (2002), and Li *et al.* (2003) show that barley, oats, etc. do not have any significant effects on the blood sugar in people whose glucose tolerance is normal.

There has been little randomised research on whether β-glucans are effective against infection. Cheol-Heui *et al.* (2003) studied the effect of β-glucans extracted from oats on the increase of resistance to infections caused by *Staphylococcus aureus* and *Eimeria vermiformis* in mice. The *in vitro* study in which macrophages isolated from the peritoneal cavity were used showed that the administration of β-glucans considerably increased the activity of phagocytes. Furthermore, the *in vivo* study on mice showed that the administration of β-glucans led to a significant protection against *S. aureus* bacteria. Oral or parenteral administration of β-glucans significantly increased the resistance to infections caused by *S. aureus* or *E. vermiformis* in mice.

Further, β-glucans are potent inducers of humoral and cell-mediated immunity, and their regular daily consumption significantly increases the immunological activity (Estrada *et al.* 1997). *In vitro* addition of oat β-glucans to cultivated macrophages increases the production of interleukin IL-1 and tumor-necrosis factor TNF-α. The authors reported that an intraperitoneal administration of β-glucans to mice increased both the number and activity of peritoneal macrophages.

As active compounds of the soluble dietary fibre, β-glucans have an important role in gut physiology. The probiotic effect of cereal β-glucans was studied in the work of Vasiljevic *et al.* (2007). The diets treated with β-glucans significantly reduced the body weight in model mice organism (Bae *et al.* 2009). However, in another study, no significant effect on the weight was observed in 68 hyperlipidemic patients given a high β-glucan diet in comparison with a control group (Jenkins *et al.* 2002). It is also documented that oat β-glucans may be a potential adjunct to the prevention of colonic diseases, ulcerative colitis, and colon cancer (Nilsson *et al.* 2008; for review see Kim *et al.* 2006). Oatmeal whole grain, high fibre, and protein attributes are believed to be the primary factors influencing the spatial memory performance of children (Samuel 2002).

A large number of experimental investigations aimed at testing barley and oat β-glucans were conducted from the aspect of health benefit.

Utilisation of cereal β-glucans
in the industrial practice

The physical and physiological properties of cereal β-glucans are of commercial and nutritional importance (Mälkki & Virtanen 2001; for review see Vasanthan & Temelli 2008). The increasing interest during the last two decades has been largely due to their acceptance as functional, bio-active ingredients (Cui & Wood 2000). Lately, consumers have shown increased interest in the purchasing and consuming such products, which are considered to be healthier. The foods with higher concentrations of complex saccharides and fibrous material, for example, are becoming more and more popular. This category involves also cereal-based products with a certain potential for the production of quick meals, cereal breakfasts, pasta, tortillas, puddings, oat yogurts, and yogurt milks (Brennan & Cleary 2005). OatLife (concentrated β-glucan made from oat bran) was the crucial ingredient in Primaliv, yoghurt and muesli combination, the first foodstuff labelled as "functional food" according to the new rules in Sweden.

Thanks to the excellent rheological properties related to the high viscosity of β-glucans at relatively low concentrations (Butt *et al.* 2008) can this polysaccharide be applied as a food ingredient in the form of hydrocolloids (Lazaridou *et al.* 2004; Lee *et al.* 2009) or as powder using microparticulation (Hunter *et al.* 2002). The incorporation of β-glucans into various products (baking products, muffins and cakes, pasta, noodles, muesli cereals, milk products, soups, salad dressings, beverages, reduced-fat dairy, and meat products) showed that the attributes, such as breadmaking performance, water binding and emulsion stabilising capacity (Kalinga & Mishra 2009), thickening ability, texture, and appearance appear to be related to the concentration, molecular weight, and structure of the polysaccharide (Lazaridou & Biliaderis 2007; Tiwari & Cummins 2009). Besides enhancing the nutritional value, β-glucans also improve the sensoric and gustatory properties of the final product (Gajdošová *et al.* 2007), for example of beverages (Lyly *et al.* 2003), where the expansion in the functional drink sector has been tremendous over the last few years (Sloan 2002). C-Trim-20 and C-Trim-30 with 20% and 30% of oat β-glucans, respectively, in 10–30% amounts are successfully used as thickening agents regulating the structural and taste properties of functional food products (Kalinga & Mishra 2009; Lee *et al.* 2009) in the development of calorie-reduced foods (Inglett 2000).

In the food industry can β-glucans be used also for the purpose of impermeable coating on the food product surface. Current research confirms the application of the fibre sources as crystallic and recrystallic regulator in frozen milk products (Soukoulis *et al.* 2009).

Cereal breakfast

Oats are frequently used as an additive in the preparation of various cereal products and delicacies. Cereal preparations for breakfast, or various cereal delicacies with fruit flavour as well as the products with coffee, cocoa, and chocolate flavour in the shape of flakes have already experienced a great success on the market. The decrease of the water activity is known to prolong the durability of foods. This principle is employed also in the production of cereal products from oats.

Lehrack and Volk (1999) described new possibilities of the thermal processing of cereals and cereal products by means of the microwave technology, warm air, and pressing in rice, wheat bran, and oat flakes processing. The microwave technology provides products with a relatively low reduction of the nutritional value and minimises the colour reactions typical for the pre-boiled rice.

Tested was also the addition of oat β-glucans with the aim to stabilise *Lactobacillus rhamnosus* cells in chocolate breakfast flakes. The effect of the polysaccharide led to the cell stability higher by 20°C (Saarela *et al.* 2006).

Baking products (bread, baked goods, dough)

Using the enzymatic and gravimetric methods, Plaami and Kumpulainen (1994) monitored the concentrations of soluble and insoluble dietary fibre materials in 128 samples, which represented twelve various kinds of bread, rusks (local as well as imported), and dough. The highest concentration of total dietary fibre (totally, soluble, and insoluble) was detected in rusks. Very high levels of fibres were monitored in the bread sample produced from rye flour, also in potato bread, oat-flour bread, brown dough produced from the durum wheat, and in the four-cereal dough prepared from

the durum wheat, oats, rye, and rice (Plaami & Kumpulanen 1994).

A research team from Ireland observed the influence of the addition of commercial oat-flour and oat-flake preparations on the quality of brown and white fermented bread. Control flours were produced from wholemeal and fine wheat flours. As a substitution for the fine wheat flour, oat flour in the amount of 2%, 4%, 6%, 8%, and 10% was added into the samples tested. The optimum amount needed for the brown bread quality, which was improved not only in the crust colour and bread softness but also in the taste itself, was achieved by adding 10% of oat flour (Gormley & Morrisey 1999). The addition influenced positively not only the sensoric properties and stronger taste but also the structure and health benefit of the final product (Flander et al. 2007; Škrbic et al. 2009).

The current study shows a positive effect of oat β-glucan on the sensoric properties of oat biscuits. The addition of hydrocolloids Nutrim O-B (10% of β-glucan) and C-Trim-20 (20% of β-glucan) increases the taste, adhesiveness, and moisture content (Lee et al. 2009).

The purpose of the latest co-operation established between the American and Thai scientists was to employ the oat component called Nutrim-5 in the prolongation of durability of rice flour in the Asian pasta. Nutrim-5 is one of the preparations of β-glucans in the form of a hydrocolloid, which is produced by treating the oat grain or flour using a thermal process. The rheological properties of the dough flour indicate that Nutrim-5 contributes to the overall strength of the material. 20 kg of pasta from the rice and wheat flours mixture together with Nutrim-5, salt, and eggs were prepared. The results showed that the optimal amount of Nutrim-5 was 10% of the total pasta weight; with neither the quality nor the sensory properties being negatively affected when comparing it to the pasta without β-glucans addition (Inglett et al. 2005).

Milk products

Oats are also known as additives used in the production of yogurts with increased amounts of fibre. The presence of 1–2% of the fibre results in an increased production of acetic and propionic acids during fermentation. Moreover, the fibre addition increased the solidity ratio and texture of unsweetened yogurts, but these parameters were decreased in sweetened yogurts (Fernandez-Garcia et al. 1998). Seven kinds of yogurts were tested. The addition of the fibre caused accelerated acidification in the experimental group and the majority of the enriched yogurts showed increased viscosity. Also, cereal flavour was observed (Fernández-García & McGregor 1997).

In 2002 in Sweden, the yogurt Primaliv was approved as the first Swedish functional food. This type of yogurt containing "muesli" and the oat fibre affects the balanced sugar level in blood, the low insulin reaction after meals, and the reduction of cholesterol. Clinical tests confirmed that the group of healthy people consuming Primaliv as a part of their diet had the blood sugar and insulin levels lower by 36% and 44%, respectively, when compared with the reference group (Skänemejerier´s 2002).

Konuklar et al. (2004) studied the structural properties of 3-month-old low-fat Cheddar cheeses produced with a β-glucans hydrocolloid component named Nutrim (nutraceutic substitution of fat) using instrumental methods and sensory evaluation. Using the detection methods, the texture (fragility, coherence, and elasticity) and melting point were measured. The studied sensory features involved odour, and taste and texture estimated by a 15-member commission of experienced assessors providing the results of these tests. Low-fat control cheeses (fat content of 11.2%) were compared with the Nutrim-I (6.8% of fat) and Nutrim-II (3.47% of fat) cheeses. The results showed that the elasticity and coherence values were the same for all cheeses. The majority of the sensory features were similar, the low-fat control cheeses being less bitter, more butter-like and creamy, and also less starchy than the Nutrim cheeses. In general, it can be concluded that a significant substitution of fat by Nutrim component resulted in softer Cheddar cheeses characterised by decreased melting time and lowered sensory properties.

Volikalis et al. (2004) determined the influence of oat β-glucans concentrate on the chemical, physicochemical, and sensory properties of white low-fat cheese products in the salt brine. The white low-fat cheeses in the salt brine were produced by the traditional procedure from cow milk (70% reduction of fat) containing two levels of oat β-glucans concentrate (0.7% and 1.4% w/w). As references, full-fat and low-fat products without the addition of β-glucans concentrate were investigated. HPLC analysis revealed that the addition of β-glucans concentrate into milk led to a remarkable increase of the production of lactic, acetic, and butyric acids

during the cheese curing. In the hydrocolloid enriched samples, the extent of proteolysis was significantly increased when compared to the control samples, especially on day 60 and 90. With respect to the rheological properties of the cheeses, the incorporation of β-glucans concentrate resulted in the improvement of all parameters of the low-fat products texture in comparison with the results obtained by both the large-scale deformation mechanical analysis and sensory analysis; remarkable correlations ($P < 0.01$) were found between the instrumental and sensory parameters for the "rigidity" descriptor. However, the addition of the preparation unfavourably affected the appearance, taste, and odour of cheeses when compared with the control samples (Volikalis *et al.* 2004).

The probiotic effect of cereal β-glucans has also been studied. The polysaccharide selectively supports the growth of *Lactobacilli* and *Bifidobacteria*, which are antagonists of many pathogenic bacteria in the digestive system (Charalampopoulus *et al.* 2002; Lambo *et al.* 2005). In probiotic drinks, the addition of oat β-glucans increases the health benefit and also the stability of the drink (Angelov *et al.* 2006). The amount of fibre did not change.

Meat products

Oat fibre is one of the most effective ingredients in the cooked low-fat meat products with the ability to mimic fat characteristics. The beef burgers were tested for the cooking yield, water-holding capacity, retention of shape, sensory, and mechanical texture. The study shows that this ingredient can be used to offset the poor quality associated with low-fat beef burgers (Troy *et al.* 1999). The addition of oat fibre improves the taste and total quality of the final food products (Desmond *et al.* 1998). The influence of oat fibre addition into sausages as a substitution for fats and sugars was also studied. Different fibre concentrations influenced differently the hydratation-binding properties, colour, and taste characteristics of sausages. By decreasing the content of fat from 30% to 5%, the losses occurring during boiling considerably increased, the emulsion stability decreased, and the sensory quality of the products deteriorated. The products with the decreased content of fat were darker and more reddish in comparison with the control. The results have shown that the addition of oat fibre into sausages can partially compensate for the taste changes that occur in the low-fat sausages

where fat is substituted with bound water (Hughes *et al.* 1997).

Other products (desserts, sauces, drinks)

Different forms of oats may be used as alternatives to the oat flour, for example pressed oat grains, partially milled oats, or oat porridge. Their fractions rich in the soluble fibre, including wholemeal oat flour and oat porridge, provide very smooth and relatively "dry" texture of the dessert; whereas the application of the above-mentioned flour with a higher content of starch gives a sweeter resulting effect. With the steady enzyme concentration, the sweetness of the product can be regulated by the duration of the saccharification process. When reaching the desired sweetness, the syrup is cooled to approximately 10°C. Then it can be flavoured with various admixtures such as vanilla, cocoa, chocolate, etc., or the milk or cream flavour may be added making the dessert more like an ice cream. After adding the flavours, the product is deep-frozen. Besides the already mentioned parameters, the product is also characterised by good viscosity, which results from the contents of fibre and gums in the starch sources. The product texture depends on the content of β-glucans. Thus β-glucans serve as stabilisers and texture agents; and the final product gives results comparable to ice-cream, frozen yogurts, and other similar frozen desserts (Whalen & Maxwell 1998).

Oats can serve as a substitute for soya in the production of flavouring sauces similar to the soya sauce. Weeded and soaked oat grains are processed and mixed with salt water containing NaCl in the concentration of 7–8% and subjected to a multi-step fermentation. This fermentation implies the hydrolytic process of milk and ethanol fermentation exploiting microorganisms *Aspergillus oryzae* or *Aspergillus soyae* (for the production of "kojic" products), the osmotolerant strain of lactococci *Pediococcus halophilus* or the yeast *Zygosaccharomyces rouxii* during the fermentation phase. The fermentation proceeds in several steps at temperatures gradually decreasing from 40–45°C. The result of this process is a flavouring sauce similar to soya sauce which, however, is of lighter colour, is not so spicy, and is more neutral and delicious. The total taste is better adapted to the Western trend, which is characterised by less salty and spicy meals than are those from the Eastern kitchen. Another advantage is the shortening

of the whole process to a time period shorter than 3 months (Muller *et al.* 1995).

The application of the nettle extract and oats as additives into food products and products of the pharmaceutical industry described by Kovacs (1989) is also of great interest. The admixtures containing the nettle extract and oat products serve as additives to the fruit juices and drinks and increase the nutrition value of these products. Similarly, in the pharmaceutical industry the oat products are processed into the forms of dried mixtures, tablets, capsules, and gels, giving the drug another positive effect besides the antibiotic or chemotherapeutic effects (Morgan & Ofman 1998).

Future trends

Some food components can help to protect individuals against mainly coronary heart diseases, which increased the public awareness and demand for functional admixtures. For this reason, European consumer prefers foods which are natural, nutritive, safe, and visually attractive and which display the properties strengthening human health. These trends present a challenge to the food researchers whose task is to develop and identify the sources of raw foods with properties increasing the level of health-improving ingredients. Cereals (such as barley and oats) are good sources for functional ingredients and various studies have confirmed their potential nutritional benefits. One of the active substances which, according to the results of the recent research, shows immunomodulating and glucan-associated effects is the cereal β-glucans. This review has focused on various possibilities of exploitation of cereal β-glucans as important functional ingredients for the development of new cereal products in food industry.

References

AACC (2001): The definition of dietary fibre. Cereal Foods World, **46**: 112–129.

Alminger M., Eklund-Jonsson Ch. (2008): Whole-grain cereal products based on a high-fibre barley or oat genotype lower post-prandial glucose and insulin responses in healthy humans. European Journal of Nutrition, **47**: 294–300.

Ames N., Rhymes C., Rossnagel B. (2006): Genotype and environment effects on oat β-glucan, total dietary fiber and antioxidant activity. Agriculture and Agri-Food Canada, **15**: 1–9.

Anderson A.A.M., Armö E., Rangeon E., Fredriksson H., Andersson R., Åman P. (2004): Molecular weight and structure units of (1→3, 1→4)-β-glucans in dough and bread made from hull-less barley milling fractions. Journal of Cereal Science, **40**: 195–204.

Andlauer W., Furst P. (2002): Nutraceuticals: a piece of history, present status and outlook. Food Research International, **35**: 171–176.

Angelov A., Gotcheva V., Kuncheva R., Hristozova T. (2006): Development of a new oat-based probiotic drink. International Journal of Food Microbiology, **112**: 75–80.

Anttila H., Sontag-Strohm T., Salovaara H. (2004): Viscosity of beta-glucan in oat products. Agricultural and Food Science, **13**: 80–87.

Asp N.G., Bjorck I., Nyman M. (1993): Physiological effects of cereal dietary fibre. Carbohydrate Polymers, **21**: 183–187.

Bae I.Y., Lee S., Kim S.M., Lee H.G. (2009): Effect of partially hydrolyzed oat beta-glucan on the weight gain and lipid profile of mice. Food Hydrocolloids, **23**: 2016–2021.

Beer M.U., Arrigoni E., Amado R. (1995): Effects of oat gum on blood cholesterol levels in healthy young men. European Journal of Clinical Nutrition, **49**: 517–522.

Behall K.M. (1997): Oat fibre decreases cholesterol levels. Food and Chemical Toxicology, **35**: 528–529.

Behall K.M., Scholfield D.J., Hallfrisch J. (1997): Effect of beta-glucan level in oat fiber extracts on blood lipids in men and women. Journal of the American College of Nutrition, **16**: 46–55.

Bell S., Goldman V.M., Bistrian B.R. (1999): Effect of beta-glucan from oats and yeast on serum lipid. Critical Reviews in Food Science and Nutrition, **39**: 189–200.

Bhatty R.S. (1986): The potential of hull-les barley – a review. Cereal Chemistry, **63**: 97–103.

Bhatty R.S. (1995): Laboratory and pilot plant extraction and purification of beta-glucans from hull-less barley and oat brans. Journal of Cereal Science, **22**: 163–170.

Brennan Ch.S., Cleary J. (2005): The potential use of cereal (1,3)(1,4)-beta-D-glucans as functional food ingredients. Journal of Cereal Science, **42**: 1–13.

Bressani R. (2003): Amaranth. Encyclopedia of Food Science and Nutrition. Academic Press, Oxford: 166–173.

Brown L., Rosner B., Willett W.W., Sacks F.M. (1999): Cholesterol-lowering effects of dietary fiber: a meta-analysis. American Journal of Clinical Nutrition, **69**: 30–42.

Burkus Z., Temelli F. (2003): Determination of the molecular weight of barley β-glucan using intrinsic viscosity measurements. Carbohydrate Polymers, **54**: 51–57.

Butt M.S., Tahir-Nadeem M., Khan M.K.I., Shabir R., Butt M.S. (2008): Oat: unique among the cereals. European Journal of Nutrition, **47**: 68–79.

Cavallero A., Empilli S., Brighenti F., Stanca A.M. (2002): High (1→3, 1→4)-β-glucan barley fractions in bread making and their effects on human glycemic response. Journal of Cereal Science, **36**: 59–66.

Chang R. (1996): Functional properties of edible mushrooms. Nutrition Reviews, **54**: 91–93.

Charalampopoulos D., Wang R., Pandella S.S., Webb C. (2002): Application of cereals and cereal components in functional food: a review. International Journal of Food Microbiology, **79**: 131–141.

Cheol-Heui Y., Estrada A., Van Kessel A., Byung-Chul P.I., Laarveld B. (2003): Beta-glucan, extracted from oat, enhances disease resistance against bacterial and parasitic infection. FEMS Immunology and Medical Microbiology, **35**: 67–75.

Cui S.W., Wang Q. (2009): Cell wall polysaccharides in cereals: chemical structure and functional properties. Structural Chemistry, **20**: 291–297.

Cui W., Wood P.J. (2000): Hydrocolloids. Relationship between Structural ˇFeatures, Molecular Weight and Rheological Properties of Cereal β-ᴅ-Glucan. Elsevier, Amsterdam: 159–168.

Demirbas A. (2005): β-Glucan and mineral nutrient contents of cereals grown in Turkey. Food Chemistry, **90**: 773–777.

Desmond E.M., Troy D.J., Buckley D.J. (1998): Comparative studies of nonmeat adjuncts used in the manufacture of low-fat beef burgers. Journal of Muscle Foods, **9**: 221–241.

Djoussé L., Gaziano J.M. (2007): Breakfast cereals and risk of heart failure in the physicians' health study I. Archives of Internal Medicine, **167**: 2080–2085.

Dongowski G., Huth M., Gebhardt E. (2003): Steroids in the intestinal tract of rats are affected by dietary fibre-rich barley-based diets. British Journal of Nutrition, **90**: 895–906.

Eastwood M., Kritchevsky D. (2005): Dietary fiber: How did we get where we are? Annual Review of Nutrition, **25**: 1–8.

Ehrenbergerová J., Vaculová K., Zimolka J., Müllerová E. (1999): Yield characters and their correlations with quality indicators of hull-less spring barley grain. Plant Production, **45**: 53–59.

Ehrenbergerová J., Vaculová K., Psota V., Havlová P., Šerhantová V. (2003): Effects of cropping system and genotype on variability in important phytonutrients content of the barley grain for direct food use. Plant Soil and Environment, **49**: 443–450.

Ehrenbergerová J., Březinová Belcredi N., Psota V., Hrstková P., Cerkal R., Newman C.W. (2008): Changes caused by genotype and environmental conditions in beta-glucan content of spring barley for dietetically beneficial human nutrition. Plant Foods for Human Nutrition, **63**: 111–117.

Estrada A., Yun C.H., VanKessel A., Li B., Hauta S., Laarveld B. (1997): Immunomodulatory activities of oat beta-glucan *in vitro* and *in vivo*. Microbiology and Immunology, **41**: 991–998.

FDA. (1997): FDA allows whole oat foods to make heath claim on reducing the risk of heart disease. [online]. 31 March 1997. Available at http://www.fda.gov/Food/LabelingNutrition/LabelClaims/HealthClaimsMeetingSignificantScientificAgreementSSA/ucm074514.htm (accessed 10. 1. 2005)

Fernández-García E., McGregor J.U. (1997): Fortification of sweetened plain yogurt with insoluble dietary fiber. Food Research and Technology, **204**: 433–437.

Fernández-García E., McGregor J.U., Traylor S. (1998): The addition of oat fiber and natural alternative sweeteners in the manufacture of plain yogurt. Journal of Dairy Science, **81**: 655–663.

Flander L., Salmenkallio-Marttila M., Suortti T., Autio K. (2007): Optimization of ingredients and baking process for improved wholemeal oat bread quality, LWT–Food Science and Technology, **40**: 860–870.

Freiburger L.M., Gallamer D.D. (2001): Association between intestinal contents viscosity and cholesterol lowering in rats fed fermentable and nonfermentable dietary fiber. FASEB Journal, **14**: A291.

Gajdošová A. (2007): Hodnotenie, výber a využitie cereálií pre prípravu funkčných potravín so zvýšeným obsahom β-glukánov. [Dizertačná práca.] FCHPT STU, Bratislava: 64–108.

Gajdošová A., Petruláková Z., Havrlentová M., Červená V., Hozová B., Šturdík E., Kogan G. (2007): The content of water-soluble and water-insoluble β-ᴅ-glucans in selected oats and barley varieties. Carbohydrate Polymers, **70**: 46–52.

Genç H., Ozdemir M., Demirbas A. (2001): Analysis of mixed-linked (1→3), (1→4)-β-ᴅ-glucans in cereal grain from Turkey. Food Chemistry, **73**: 221–224.

Gormley T.R., Morrissey A. (1999): A note on the evaluation of wheaten breads containing oat flour or oat flakes. Irish Journal of Agricultural and Food Research, **32**: 205–209.

Granfeldt Y., Nyberg L., Björck I. (2008): Muesli with 4 g oat β-glucans lowers glucose and insulin responses after a bread meal. European Journal of Clinical Nutrition, **62**: 600–607.

Grausgruber H., Sailer C., Ghambashidze G., Bolyos L., Ruckenbauer P. (2004): Genetic Variation in Agronomic and Qualitative Traits of Ancient Wheats. Genetic Variation for Plant Breeding. EUCARPIA & BOKU, Wien, Austria: 19–22.

Havrlentová M. (2009): Variabilita v obsahu polysacharidov bunkovej steny a v dĺžke mikrosatelitnej DNA ovsa siateho. [Doktorandská dizertačná práca.] FPV UKF, Nitra: 57–99.

Havrlentová M., Kraic J. (2006): Content of beta-ᴅ-glucan in cereal grains. Journal of Food Research and Nutrition, **45**: 97–103.

Hirasawa M., Shouji N., Neta T., Fokushima K., Takada K. (1999): Three kinds of antibacterial substances from *Lentinus edodes* (Berk.) Sing. (Shiitake, an edible mushroom). International Journal of Antimicrobial Agents, **11**: 151–157.

Holtekjølen A.K., Uhlen A.K., Brathen E.S., Sahlstrom S., Knutsen S.H. (2006): Contents of starch and non-starch polysaccharides in barley varieties of different origin. Food Chemistry, **94**: 348–358.

Hughes E., Cofrades S., Troy D.J. (1997): Effect of fat level, oat fibre and carrageenan on frankfurters formulated with 5, 12 or 30% fat. Meat Science, **45**: 273–281.

Hunter K.W.Jr., Gault R.A., Berner M.D. (2002): Preparation of microparticulate beta-glucan from *Saccharomyces cerevisiae* for use in immune potentiation. Letters in Applied Microbiology, **35**: 267–271.

Inglett G.E. (2000): USA's oatrim replaces fat in many food products. Food Technology, **44**: 100.

Inglett G.E., Peterson S.C., Carriere C.J., Maneepun S. (2005): Rheological, textural, and sensory properties of Asian noodles containing an oat cereal hydrocolloid. Food Chemistry, **90**: 1–8.

Jenkins A.L., Jenkins D.J., Zdravkovic U., Wursch P., Vuksan V. (2002): Depresion of the glycemic index by high levels of beta-glucan fiber in two functional foods tested in type 2 diabetes. European Journal of Clinical Nutrition, **56**: 622–628.

Johansson L., Tuomainen P., Ylinen M., Ekholm P., Virkki L. (2004): Structural analysis of water-soluble and -insoluble β-glucans of whole-grain oats and barley. Carbohydrate Polymers, **58**: 267–274.

Johansson L., Virkki L., Maunu S., Lehto M., Ekholm P., Varo P. (2000): Structural characterization of water soluble beta-glucan of oat bran. Carbohydrate Polymers, **42**: 143–148.

Juntunen K.S., Niskanen L.K., Liukkonen K.H., Poutanen K.S., Holst J.J., Mykkanen H.M. (2002): Postprandial glucose, insulin, and incretin responses to grain products in healthy subjects. American Journal of Clinical Nutrition, **75**: 254–262.

Kalinga D., Mishra V.K. (2009): Rheological and physical properties of low fat cakes produced by addition of cereal beta-glucan concentrates. Journal of Food Processing Preservation, **33**: 384–400.

Kapur N.K., Ashen D., Blumenthal R.S. (2008): High density lipoprotein cholesterol: an evolving target of therapy in the management of cardiovascular disease. Vascular Health and Risk Management, **4**: 39–57.

Karácsonyi Š., Kuniak Ľ. (1994): Polysaccharides of *Pleurotus ostreatus*: Isolation and structure of pleuran, an alkali-insoluble β-d-glucan. Carbohydrate Polymers, **24**: 107–111.

Karla S., Jood S. (2000): Effect of dietary fibre β-glucan on cholesterol and lipoprotein fractions in rat. Journal of Cereal Science, **31**: 141–145.

Keenan J.M., Pins J.J., Frazel Ch., Moran A., Turnquist L. (2002): Oat ingestion reduces systolic and diastolic blood pressure in patients with mild or borderline hypertension: a pilot trial. The Journal of Family Practice, **51**: 369–374.

Keogh G.F., Cooper G.J.S., Mulvey T.B., McArdle B.H., Coles G.D., Monro J.A., Poppitt S.D. (2003): Randomized controlled crossover study of the effect of a highly β-glucan-enriched barley on cardiovascular disease risk factors in mildly hypercholesterolemic men. American Journal of Clinical Nutrition, **78**: 711–718.

Kerckhoffs D.A.J.M., Hornstra G., Mensink R.P. (2003): Cholesterol-lowering effect of β-glucan from oat bran in mildly hypercholesterolemic subjects may decrease when β-glucan is incorporated into bread and cookies. American Journal of Clinical Nutrition, **78**: 221–227.

Kim S.Y., Song H.J., Lee Y.Y., Cho K.-H., Roh Y.K. (2006): Biomedical issues of dietary fiber β-glucan. Journal of Korean Medical Science, **21**: 781–789.

Kim H., Stote K.S., Behall K.M., Spears K., Vinyard B., Conway J.M. (2009): Glucose and insulin responses to whole grain breakfasts varying in soluble fiber, beta-glucan. European Journal of Nutrition, **48**: 170–175.

Konuklar G., Inglett G.E., Warner K., Carriere C.J. (2004): Use of a β-glucan hydrocolloidal suspension in the manufacture of low-fat Cheddar cheeses: textural, properties by instrumental methods and sensory panels. Food Hydrocolloids, **18**: 535–545.

Kovacs J. (1989): Composition of oats and nettle extracts to be used as a food additive or pharmaceutical preparation in human health care. US Patent No. 4886665.

Kubala L., Ružičkova J., Nickova K., Sandula J., Ciz M., Lojek A. (2003): The effect of (1,3)-β-glucans, carboxymethylglucan and schizophyllan on human leukocytes *in vitro*. Carbohydrate Research, **338**: 2835–2840.

Lambo A.M., Oste R., Nyman M.E.G. (2005): Dietary fibre in fermented oat and barley β-glucan rich concentrates. Food Chemistry, **89**: 283–293.

Lazaridou A., Biliaderis C.G. (2007): Molecular aspects of cereal beta-glucan functionality: Physical properties, technological applications and physiological effects. Journal of Cereal Science, **46**: 101–118.

Lazaridou A., Biliaderis C.G., Micha-Screttas M., Steele B.R. (2004): A comparative study on structure-function relations of mixed-linkage (1→3), (1→4) linear β-d-glucans. Food Hydrocolloids, **18**: 837–855.

Lee S., Inglett G.E., Palmquist D., Warner K. (2009): Flavor and texture attributes of foods containing beta-glucan-rich hydrocolloids from oats. LWT–Food Science and Technology, **42**: 350–357.

Lehrack U., Volk J. (1999): New possibilities for the hydrothermal treatment of cereals and cereal products. Getreide, Mehl und Brot, **46**: 268–273.

Li J., Kaneko T., Qin L.Q., Wang J., Wang Y. (2003): Effects of barley intake on glucose tolerance, lipid metabolism, and bowel function in women. Nutrition, **19**: 926–929.

Lovegrove J.A., Clohessy A., Milon H., Williams C.M. (2000): Modest doses of beta-glucan do not reduce concentrations of potentially atherogenic lipoproteins. American Journal of Clinical Nutrition, **72**: 49–55.

Lyly K., Salmenkallio-Marttila M., Suortti T., Autio K., Poutanen K., Lahteenmaki L. (2003): Influence of oat β-D-glucan preparations on the perception of mouth-feel and rheological properties in beverage prototypes. Cereal Chemistry, **80**: 536–541.

Maki K.C., Davidson M.H., Witcher M.S., Dicklin M.R., Subbaiah P.V. (2007): Effects of high-fiber oat and wheat cereals on postprandial glucose and lipid responses in healthy men. International Journal of Vitamin and Nutrition Research, **77**: 347–356.

Marlett J.A., McBurney M.I., Slavin J.L. (2002): Position of the American dietetic association: Health implications of dietary fiber. Journal of the American Dietetic Association, **102**: 993–1000.

Mälkki Y. (2004): Trends in dietary fibre research and development. Acta Alimentaria, **33**: 39–62.

Mälkki Y., Virtanen E. (2001): Gastrointestinal effect of oat bran and oat glum: a review. Lebensmittel-Wissenschaft und -Technologie, **34**: 337–347.

McCleary B.V. (2006): Megazyme: Mixed-linkage Beta-glucan Assay Procedure (McCleary method). Bray Business Park, Bray, Ireland: 1–15.

Morgan K.R., Ofman D.J. (1998): Glucagel, a gelling beta-glucan from barley. Cereal Chemistry, **75**: 876–881.

Muller R., Bohatiel J., Blortz D., Frank B. (1995): Process for the production of a seasoning sauce based on oat. US Patent No. 5407690.

Naumann E., VanRees A.B., Onning G., Oste R., Wydra M., Mensink R.P. (2006): Beta-glucan incorporated into a fruit drink effectively lowers serum LDL-cholesterol concentrations. The American Journal of Clinical Nutrition, **83**: 601–605.

Nazare J.A., Normand S., Triantafyllou A.O., DeLa-Perriere A.B., Desage M., Laville M. (2009): Modulation of the postprandial phase by beta-glucan in overweight subjects: Effects on glucose and insulin kinetics. Molecular Nutrition and Food Research, **53**: 361–369.

Newman R.K., McGuire C.F., Newman C.W. (1990): Composition and muffin-baking characteristics of flours from barley cultivars. Cereal Foods World, **35**: 563–566.

Newman R.K., Newman C.W. (1991): Barley as a food grain. Cereal Foods World, **36**: 800–805.

Newman R.K., Newman C.W., Graham H. (1989): The hypocholesterolemic function of barley β-glucans. Cereal Foods World, **34**: 883–886.

Nilsson U., Johansson M., Nilssson A., Björck I., Nyman M. (2008): Dietary supplementation with beta-glucan enriched oat bran increases faecal concentration of carboxylic acids in healthy subjects. European Journal of Clinical Nutrition, **62**: 978–984.

Ooi V.E., Liu F. (2000): Immunomodulation and anti-cancer activity of polysaccharide-protein complexes. Current Medicinal Chemistry, **7**: 715–729.

Pérez-Vendrell A., Guash J., Frances M., Molina-Cano J.L., Brufau J. (1995): Determination of β-(1→3), (1→4)-D-glucans in barley by reverse-phase high performance liquid chromatography. Journal of Chromatography A, 718: 291–297.

Plaami S., Kumpulanen J. (1994): Soluble and insoluble dietary fiber contents of various breads, pastas and rye flours on the Finnish market. Journal of Food Composition and Analysis, **7**: 134–143.

PN 01/01 Fungal glucan (2001): Pleuran, Ltd., Bratislava.

Procházková J., Pipalová S., Ehrenbergerová J., Vaculová K. (2004): Verification of nutritive value and hypocholesterolemic effect of spring barley lines. In: 9th International Barley Genetics Symposium, Brno, Czech Republic, 20–26 June 2004: 574–578.

Queenan K.m., Stewart M.l., Smith K.n., Thomas W., Fulcher R.g., Slavin J.L. (2007): Concentrated oat β-glucan, a fermentable fiber, lowers serum cholesterol in hypercholesterolemic adults in a randomized controlled trial. Nutrition Journal, **6**: 6–13.

Ren Y., Ellis P.R., Ross-Murphy S.B., Wang Q., Wood B.J. (2003): Dilute and semi-dilute solution properties of (1→3),(1→4)-β-D-glucan, the endosperm cell wall polysaccharide of oats (*Avena sativa* L.). Carbohydrate Polymers, **53**: 401–408.

Rimsten L. (2003): Extractable cell-wall polysaccharides in cereals with emphasis on beta-glucan in steeped and germinated barley. [Doctoral Thesis.]: Swedish University of Agricultural Sciences, Uppsala, Sweden 7–48.

Robitaille J., Fontaine-Bisson B., Couture P., Tchernof A., Vohl M.C. (2005): Effect of an oat bran rich supplement on the metabolic profile of overweight premenopusal women. Annals of Nutrition and Metabolism, **49**: 141–148.

Rodriguez T.M., Saura-Calixto F. (1991): Effects of dietary fibre and phytic acid on mineral availability. Critical Review in Food Science and Nutrition, **30**: 1–22.

Roubroeks J.P., Andersson R., Åman P. (2000): Structural features of (1→3),(1→4)-β-D-glucan and arabinoxylan fractions isolated from rye bran. Carbohydrate Polymers, **42**: 3–11.

Ruxton C.H.S., Derbyshire E. (2008): A systematic review of the association between cardiovascular risk factors and regular consumption of oats. British Food Journal, **110**: 1119–1127.

Saarela M., Virkajärvi I., Nohynek L., Vaari A., Mättö J. (2006): Fibres as carriers for *Lactobacillus rhamnosus* during freeze-drying and storage in apple juice and

chocolate-coated breakfast cereals. International Journal of Food Microbiology, **112**: 171–178.

Saibil F. (1989): Diarrhea due to fiber overload. The New England Journal of Medicine, **320**: 599.

Samuel P. (2002): Getting their oats helps kids perform better. Availabe at http://www.nutraingredients.com/news/ng.asp?id=35877 (accessed 1.5.2005)

Skänemejerier's (2002): Primaliv first food product in sweden to be approved and labelled as a functional food. extract from press release from Skänemejerier. Available at http://www.creanutrition-sof.com/pages/primaliv.htm (accessed 14.11.2003)

Sloan A.E. (2002): The top 10 functional food trends: The next generation. Food Technology, **56**: 32–57.

Soukoulis Ch., Lebesi D., Tzia C. (2009): Enrichment of ice cream with dietary fibre: Effects on rheological properties, ice crystallisation and glass transition phenomena. Food Chemistry, **115**: 665–671.

Stephens G. (2005): Optimising cardio health with oat beta-glucans. Functional Foods Nutraceuticals, **32**: 32–34.

Škrbic B., Milovac S., Dodig D., Filipčev B. (2009): Effects of hull-less barley flour and flakes on bread nutritional composition and sensory properties. Food Chemistry, **115**: 982–988.

Tappy L. (2006): Effects of break fast cereals containing various amounts of beta-glucan fibres on plasma glucose and insulin responses in NIDDM subjects. Diabetes Care, **19**: 831–834.

Tiwari U., Cummins E. (2009): Factors influencing β-glucan levels and molecular weight in cereal-based products. Cereal Chemistry, **86**: 290–301.

Tosh S.M., Wood P.J., Wang Q., Wesz J. (2004): Structural characteristics and rheological properties of partially hydrolysed oat β-glucan: the effect of molecular weight and hydrolysis method. Carbohydrate Polymers, **55**: 425–436.

Troy D.J., Desmond E.M., Buckley D.J. (1999): Eating quality of low-fat beef burgers containing fat-replacing functional blends. Journal of the Science of Food and Agriculture, **79**: 507–516.

Tsukada C., Yokohama H., Miyaji C., Ishimoto Y., Kawamura H., Abo T. (2003): Immunopotentiation of intraepithelial lymphocytes in the intestine by oral administration of β-glucan. Cellular Immunology, **221**: 1–5.

Uusitupa M.I., Ruuskanen E., Makinen E. (1992): A controlled study on the effect of beta-glucan-rich oat bran on serum lipids in hypercholesterolemic subjects: relation to apolipoprotein E phenotype. Journal of the American College of Nutrition, **11**: 651–659.

Vasanthan T., Temelli F. (2008): Grain fractionation technologies for cereal beta-glucan concentration. Food Research International, **41**: 876–881.

Vasiljevic T., Kealy T., Mishra V.K. (2007): Effects of beta-glucan addition to a probiotic containing yogurt. Journal of Food Science, **72**: C405–C411.

Vega-Lopez S., Conde-Knape K., Vidal-Quintanar R.L. (2002): Sex and hormonal status influence the effects of psyllium on lipoprotein remodelling and composition. Metabolism – Clinical & Experimental, **51**: 500–507.

Vega-Lopez S., Vidal-Quintanar R.L., Fernandez M.L. (2001): Sex and hormonal status influence plasma lipid responses to psyllium. American Journal of Clinical Nutrition, **74**: 435–441.

Větvička V., Yvin J.C. (2004): Effects of marine β-1,3-glucan on immune reaction. International Immunopharmacology, **4**: 721–730.

Větvička V., Terayama K., Mandeville R., Brousseau P., Kournikakis B., Ostroff G. (2002): Beta-glucan as immunomodulator. The Journal of the American Nutraceutical Association, **2**:16–20.

Virkki L., Johansson L., Ylinen M., Maunu S., Ekholm P. (2005): Structural characterization of water-insoluble nonstarchy polysaccharides of oats and barley. Carbohydrate Polymers, **59**: 357–366.

Volikalis P., Billiaderis C.G., Vamvakas C., Zerfiridis C. (2004): Effects of a commercial oat-β-glucan concentrate on the chemical, physico-chemical and sensory attributes of low-fat white-brined cheese product. Food Research International, **37**: 83–94.

Weightman R.M., Heywood C., Wade A., South J.B. (2004): Relationship between grain (1→3,1→4)-β-glucan concentration and response of winter-sown oats to contrasting forms of applied nitrogen. Journal of Cereal Science, **40**: 81–86.

Whalen P.J., Maxwell D.L. (1998): Oat-based frozen confection. US Patent 5,723,162.

Zhang G., Chen J., Wang J., Ding S. (2001): Cultivar and environmental effects on (1→3,1→4)-β-D-glucan and protein content in malting barley. Journal of Cereal Science, **34**: 295–301.

Zhang G., Wang J., Chen J. (2002): Analysis of β-glucan content in barley cultivars from different locations of China. Food Chemistry, **79**: 251–254.

Corresponding author:

RNDr. Michaela Havrlentová, Ph.D., Výskumný ústav rastlinnej výroby CVRV, Bratislavská cesta 122, SK 921 68 Piešťany, Slovak Republic

tel.: + 421 33 772 23 11, e-mail: havrlentova@vurv.sk