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DIETARY FIBRE IN CEREAL GRAINS – A REVIEW

ABSTRACT

The article presents basic information on dietary fibre, including its current definition and characteristics of individual components. The physiological and health-promoting effects of soluble and insoluble fractions of fibre, are also presented. The characteristics of dietary fibre are discussed, taking as examples the selected cereal species most popular in Poland and in Europe which make up a significant part of the diet and, as such, are an important source of this component.

Key words: arabinoxylans; β-glucan; cereals; dietary fibre; polysaccharides.

INTRODUCTION

The health situation of the population in highly developed countries has been constantly changing in the recent years. There has been a significant increase in the incidence of lifestyle diseases such as obesity, diabetes, certain types of cancer or hypertension. These diseases are caused by unhealthy lifestyle involving low physical activity, use of stimulants, excessive stress and, above all else, an unhealthy diet too high in calories (Kotradyova *et al.* 2013; Carrera Bastos *et al.* 2011). High-quality, non-processed products rich in nutrients and bioactive components, prominent among which is dietary fibre, are crucial to proper nutrition. This complex compound has numerous health-promoting effects, confirmed by many years of research, and plays an important role in preventing diet-related diseases (Anderson *et al.* 2009). Products rich in fibre are an important element of the food pyramid. Apart from vegetables and fruit, cereals and products processed from cereals are also important sources of fibre in the diet, consumed mainly

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as bread, as well as pasta, groats and flakes. The most frequently consumed cereal species are wheat and rye. However, non-bread cereals, such as oat and barley, have recently become increasingly popular. Oat is particularly notable for its high dietary fibre content, with a high concentration of soluble β-glucan, which gives oat grains the most powerful health-promoting effects of all cereals (Gibiński 2008; Kawka 2010; Havrlentova *et al.* 2011). However, during last few years a continuous downward trend in all categories of bread consumption is observed in many countries, which is a serious problem, resulting in a growing number of diet-related diseases in a society (Kendall *et al.*, 2010; Pal *et al.*, 2011; GUS 2017). Due to poor dietary habits, as a result of which dietary fibre intake is still too low, it is crucial to constantly broaden the public knowledge and awareness of the structure and properties of individual nutrients, including dietary fibre, in order to prevent this type of diseases. For this reason, the present paper discusses the structure and physiological effects of dietary fibre and its individual components, taking as examples selected cereal species which make up a significant part of the diet and, as such, are an important source of this component.

DEFINITION OF DIETARY FIBRE

The worldwide discussion on the definition of dietary fibre ended in 2009, when the FAO/WHO Codex Alimentarius Commission adopted the final version of that definition and its two footnotes as follows:

"Dietary fibre means carbohydrate polymers[1] with 10 or more monomeric units[2], which are not hydrolysed by the endogenous enzymes in the small intestine of humans and belong to the following categories:

Edible carbohydrates polymers naturally occurring in the food as consumed.

Carbohydrate polymers, which have been obtained from food raw material by physical, enzymatic or chemical means and which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities.

Synthetic carbohydrate polymers, which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities.

Footnote 1 states, "when derived from plant origin, dietary fibre may include fractions of lignin and/or other compounds associated with polysaccharides in the plant cell walls. These compounds also may be measured by certain analytical method(s) for dietary fibre."

Footnote 2 states, "Decision on whether to include carbohydrates of 3 to 9 monomeric units should be left up to national authorities" (Codex Alimentarius Commision 2009; Westenbrink *et al.*, 2013; Jones 2014).

In Europe, Commission Directive 2008/100/EC (Commision of the European Communities 2008) and Statement by the European Food Safety Authority EFSA-Q-2007-121 (EFSA 2008) provide that dietary fibre may have one or more beneficial physiological effects, such as decreasing intestinal transit time, increasing stool bulk, being fermentable by gastrointestinal microflora, reducing total blood cholesterol and/or LDL cholesterol levels, reducing post-prandial blood glucose and/

or insulin levels. These documents are open to new physiological effects which could have a positive impact on health (Lupton *et al.* 2009, Philips 2011).

DIETARY FIBRE COMPONENTS

In accordance with applicable regulations (EFSA 2010; Westenbrink *et al.* 2013), dietary fibre is composed of the following groups of compounds:

- Non-starch polysaccharides
- Non-digestible oligosaccharides
- Resistant starch
- Lignin naturally linked to fibre polysaccharides

Table 1

Dietary fibre content in different cereal species

Kind of cereal	Dietary fibre content [g × 100 g^{-1}]
Wheat	8.8 - 17.0
Rye	10.0 - 22.0
Barley	14.6 - 27.1
Oat	11.5 - 32.9
Triticale	11.9 – 14.3

The dietary fibre content, as well as the amount and proportions of its individual components and fractions, vary depending on the cereal species, and may also differ greatly within the same species. The dietary fibre content in different cereal species is presented in Table 1, whereas the dietary fibre composition is presented on Fig. 1.

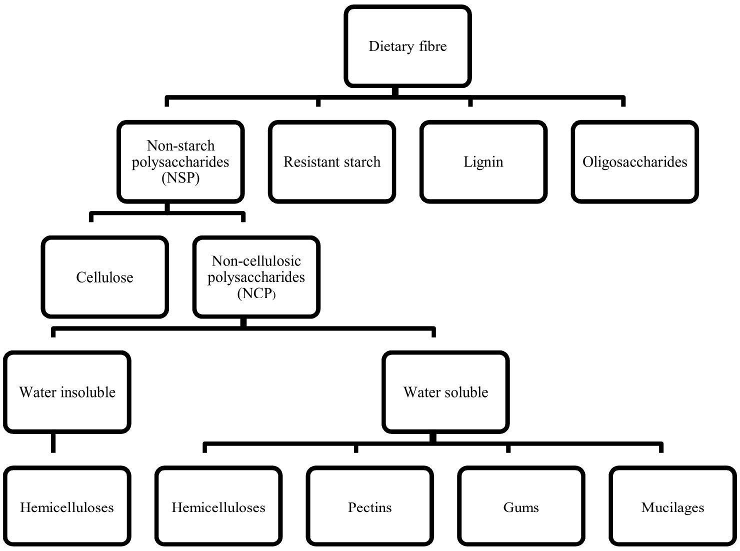

Fig. 1. Dietary fibre composition

Non-starch polysaccharides

Non-starch polysaccharides (NSPs) are polysaccharides which make up plant cell walls (Selvendran 1991). These compounds are divided into cellulose and non-cellulosic polysaccharides (NCPs), which are frequently referred to as hemicelluloses in literature. They are mainly arabinoxylans and β-glucan and, to a lesser extent, mannans, galactomannans, arabinogalactans, pectins, and plant gums and mucilages (Hasik and Bartnikowska, 1987; Asp 1996; Maes and Delcour, 2002; Egi *et al.*, 2004; Smeets *et al.*, 2014).

Cellulose is a plant structural polysaccharide which is the main structural component of cell walls. This polymer is made up of many β-D-glucopyranose (glucose) units linked by β-1,4-glycosidic bonds (Fig. 2). Cellulose chains contain approximately 10 thousand glucose residues and are linked together by hydrogen bonds to form elementary fibrils, which in turn form aggregates described as micelles. There is a significant number of gaps in cellulose micelles, which are filled with water in young tissue and undergo lignification in old tissue. In cereal grains, cellulose is present mainly in the bran fraction (Oscarsson *et al.*, 1996; Andersson *et al.*, 2006). The content of this component in individual cereal species is as follows: 2% in wheat, 1.6% in rye, 4.3% in barley with husk, 1.0% in dehusked barley, 8.2% in oat with husk and 1.4% in dehusked oat (Bach Knudsen 2001; Górecka 2008).

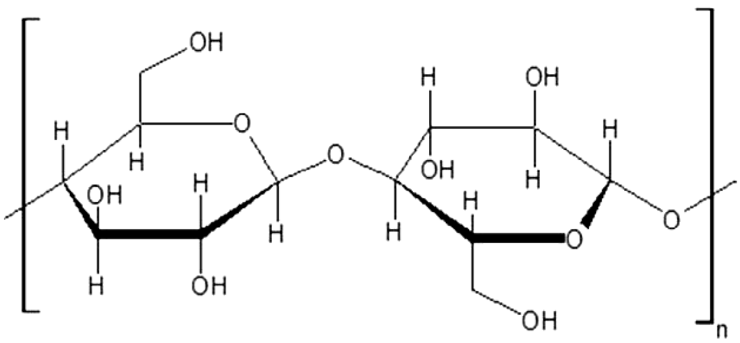

Fig. 2. Cellulose structure

Arabinoxylans (AXs) are the main polymers in the cell walls of wheat and rye grains. They consist of a linear backbone of 1,4-β-D-xylopyranose (xylose, Xyl) units linked by a glycosidic bond. The backbone can be unsubstituted, monosubstituted at the O2 or O3 position or disubstituted at the O3 and O2 positions with α-L-arabinofuranose (arabinose, Ara) residues (Fig. 3). Because they contain five carbon atoms in a monomeric unit, arabinoxylans are frequently called pentosans. β-D-glucuronic acid and its methyl esters substituted at the O2 position or hydroxycinnamic and ferulic acids covalently linked by an ester bond to the O5 position of arabinose may also be substituents in an arabinoxylan chain. Arabinoxylan chains are cross-linked by diferulic bridges formed between ferulic acid residues (Izydorczyk *et al.*, 1991; Izydorczyk and Biliaderis, 1995; Edwards *et al.*, 2003; Ordaz-Ortis and Saulnier, 2005; Saulnier *et al.*, 2007; Revanappa *et al.*, 2015). The degree of substitution of a xylan chain affects the structure and behaviour of an arabinoxylan molecule.

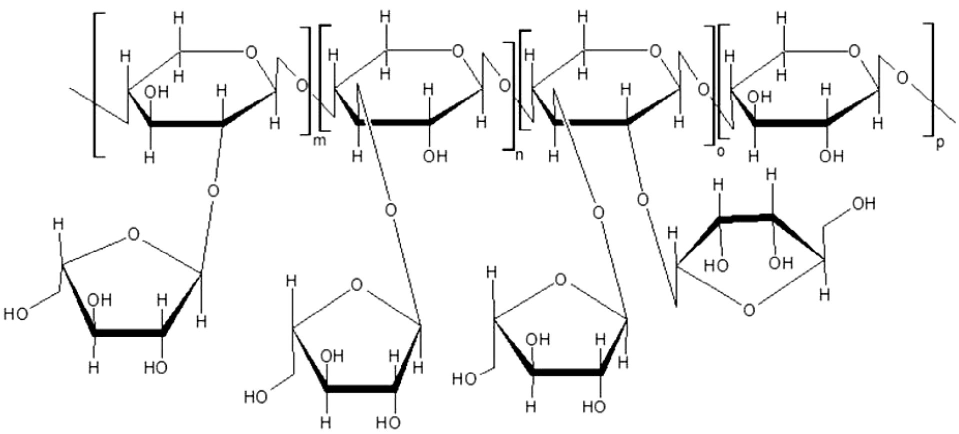

Fig. 3 Arabinoxylans structure

Unsubstituted 1,4-β-xylan chains form left-handed helices with three xylose residues per turn. The helices are flexible when linked by a single hydrogen bond between two adjacent xylose residues. 1,4-β-xylan in the unsubstituted form aggregates into insoluble complexes stabilised by intermolecular hydrogen bonds. The linking of arabinoxylan molecules is limited by a spatial barrier in the form of arabinose residues protruding from a xylan chain (Izydorczyk and Biliaderis, 1995; Saulnier *et al.*, 2007). Arabinoxylans can be divided into two fractions: water -extractable, forming highly viscous solutions, and water-unextractable. The ratio of arabinose residues to xylose is also an important parameter used to characterise the structure and degree of substitution of arabinoxylans. The higher the Ara/Xyl ratio, the higher the degree of polymerisation of a xylan chain (Cleemput *et al.*, 1993; Andersson *et al.*, 1994; Ordaz-Ortis and Saulnier, 2005; Barron *et al.*, 2007; Saulnier *et al.*, 2007; Gebruers *et al.*, 2008). The content of arabinoxylans in the following cereal species ranges from: 4.8-6.9% for wheat, 6.5-12.2% for rye, 4-11% for barley and 2.7-7.2% for oat (Aman and Hesselman, 1984; Hasimoto *et al.*, 1987; Hasimoto *et al.*, 1987a; Oscarsson *et al.*, 1996; Vinx and Delcour, 1996; Izydorczyk and Biliaderis, 2007; Saulnier *et al.*, 2007; Skendi *et al.*, 2011).

β-D-glucan is a linear homopolymer in the cell walls of cereal grains, present in the endosperm (oat and barley grains) and in aleurone and sub-aleurone layer (rye and wheat grains). It is made up of β-D-glucopyranose (glucose) residues linked by β-1,4-glycosidic bonds, which are separated by single β-1,3-glycosidic bonds (Fig. 4). A β-D-glucan chain is made up primarily of tri- and tetrasaccharides. The two main units are β-1,3-cellotriosyl (55-72%) and cellotetraosyl (20-34%), which are formed by lichenase enzyme action ((1,3)(1,4)-β-D-glucan-4-glucanohydrolase) (Izydorczyk and MacGregor, 2000; Jin *et al.*, 2004; Johansson *et al.*, 2004; Li *et al.*, 2006; Lazaridou and Biliaderis, 2007; Gebruers *et al.*, 2008). Significant structural differences in β-D-glucan depend on the ratio of trisaccharides to tetrasaccharides, which is at a level of 3.0-4.5 for wheat grains, 1.9-3.0 for rye grains, 1.5-2.3 for oat grains and 1.8-3.5 for barley grains (Li *et al.*, 2006; Lazaridou and Biliaderis, 2007). According to literature data, the β-D-glucan content in individual cereals ranges from: 1.7–7.2% in barley, 2.2-6.6% in oat, 1.2-2.9% in rye and 0.5-1.4% in wheat (Genc *et al.*, 2001; Gajdosova *et al.*, 2007).

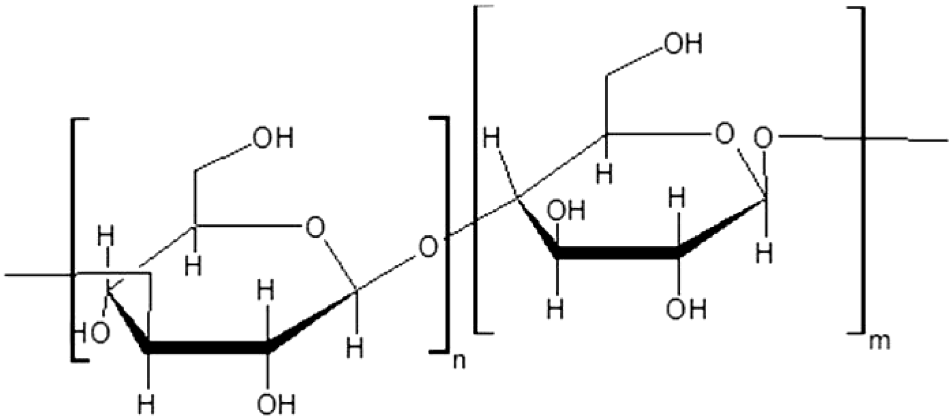

Fig. 4. β-glucan structure

Pectic substances are branched polysaccharides containing a backbone partially esterified by D-galacturonic acid. The side chains of a pectin molecule are made up of neutral saccharides, such as D-galactose, L-arabinose and D-xylose. Pectic substances include pectins, protopectin and pectic acids, which are formed by protopectin hydrolysis. Plant gums are complexes of highly branched polysaccharides containing glucuronic and galacturonic acids as well as neutral saccharides, such as arabinose, xylose and mannose. These compounds are formed when a plant is damaged, and produce a hard film after drying. Plant mucilages are branched polysaccharides present mainly in the endosperm. Their role is to retain water and prevent seeds from drying (Hasik and Bartnikowska, 1987; Oscarsson *et al.*, 1996; Philips *et al.*, 2008).

Resistant starch

Resistant starch is defined as the sum of starch and products of starch degradation not digested in the small intestine of a healthy individual (Englyst *et al.*, 1992). Resistant starch is divided into four types, depending on the causes of resistance to digestion: RS1 — starch that is physically inaccessible to digestive enzymes as a result of being enclosed in an indigestible matrix; RS2 — starch granules resistant to amylases during gelatinisation, present in some plant species (e.g. bananas, potatoes); RS3 — retrograded starch; RS4 — chemically modified starch (Englyst *et al.*, 1992; Haralampu 2000; Tungland and Meyer, 2002; Woo and Seib 2002; Thompson 2007). The RS3 form, which remains stable during the thermal processing of food, is most common in cereal products. This form is obtained when starch granules are heated and starch is gelatinised, after which the granules are cooled and amylose chains form double helices stabilised by hydrogen bonds, creating a form resistant to digestive enzymes (retrogradation) (Haralampu 2000).

Non-digestible oligosaccharides

Oligosaccharides are carbohydrates with a low degree of polymerisation, containing 3 or more saccharide units. Non-digestible oligosaccharides include, among others, fructo-oligosaccharides (FOS) and galacto-oligosaccharides (GOS). These compounds are not digested by enzymes of the gastrointestinal tract, but are broken down by microbial enzymes in the large intestine (Tungland and Meyer 2002; Lunn and Buttris 2007; Mussato and Mancihla 2007; Philips 2011).

Lignin and associated substances

Lignin is an aromatic phenylpropane polymer whose units form a highly complex network. The following three monomeric units are precursors of lignin: coniferyl alcohol, sinapyl alcohol and p-coumaryl alcohol (Selvendran 1991; Wallace *et al.*, 1991; Bunzel *et al.*, 2004). Lignin is partially bound by covalent bonds to cellulose in cell walls and cross-linked to non-cellulosic polysaccharides, in particular arabinoxylans, through ferulic acid (Bach Knudsen 1997; Bunzel *et al.*, 2004). Lignin cements and anchors fibrils of cellulose and other polysaccharides in cell walls to increase the rigidity of walls and protect them against biochemical degradation and physical damage. The lignin content is approximately 1.9% in wheat grains, 2.1% in rye grains, 3.5% in barley grains and 6.6% in oat grains (Bach Knudsen 1997). Apart from lignin, dietary fibre includes substances associated with lignin and non-starch polysaccharides, which include, among others, waxes, cutins, suberins, phytates, tannins and saponins.

Physiological role of dietary fibre

Dietary fibre is a specific complex of substances with diverse physical and chemical properties and a variety of physiological effects. In terms of water solubility, dietary fibre can be divided into two fractions: soluble and insoluble. Each of them has different physiological and health-promoting effects (Andersson 1985; Dikeman *et al.*, 2006; Lunn and Buttris 2007; Galisteo *et al.*, 2008).

The soluble fraction of dietary fibre consists mainly of soluble arabinoxylan fractions and β-glucan, as well as pectic substances, inulin, gums and mucilages. Among different cereal species, large amounts of this fraction are present in oat, barley and rye grains (Guillon and Champ 2000; Dikeman *et al.*, 2006; Lunn and Buttris 2007; Galisteo *et al.*, 2008). The soluble fraction of dietary fibre can bind water and form viscous solutions in the aquatic environment. The viscous properties of fibre have a beneficial effect, among others, on metabolism, control blood glucose levels and bind bile acids, thus reducing lipid absorption and improving cholesterol and lipid metabolism and, in consequence, reducing total and LDL cholesterol (Schneeman 1998; Guillon and Champ 2000; Bosaeus 2004; Jenkins *et al.*, 2004; Dikeman *et al.*, 2006; Gebruers *et al.*, 2008; Kristensen and Jensen 2011). The ability to form viscous solutions as the main factor contributing to the reduction of postprandial blood glucose and insulin was discussed in literature by Dikeman and Fahey (2006) and Hallfrish and Behall (2000). The soluble fibre fraction slows down the passage of food through the stomach, while at the same time improving digestibility and absorption, and produces a feeling of satiety more quickly and for a longer time. In the small intestine, viscous and dense food constitutes a barrier to hydrolytic enzymes and hinders the circulation of nutrients released as a result of hydrolysis. Additionally, this fraction changes food resistance to contractions in the gastrointestinal tract, thus reducing glucose transport to absorption areas. Soluble fibre fractions can also slow down the absorption of minerals, especially calcium, iron and zinc, in the human body (Andersson 1985; Hasik and Bartnikowska 1987; Davidson and MacDonald 1998; Guillon and Champ 2000; Bach Knudsen 2001; Dikeman and Fahey 2006; Górecka 2008). In the large intestine, the soluble fibre fraction is fermented by the microflora into short-chain fatty acids: acetic and butyric. These acids stimulate the growth of the beneficial gut flora and reduce the number of harmful bacteria, as well as inhibit cholesterol synthesis and prevent colorectal and anal cancer by protecting intestinal walls (Davidson and MacDonald 1998; Moore *et al.*, 1998; Schneeman 1998; Guillon and Champ 2000; Haralampu 2000; Bach Knudsen 2001; Topping and Clifton 2001).

The insoluble fibre fraction consists mainly of cellulose, insoluble hemicelluloses, lignin, resistant starch, waxes, cutin and suberin (Davidson and MacDonald 1998; Guillon and Champ 2000; Lunn and Buttris 2007; Galisteo *et al.*, 2008). The highest content of the insoluble fibre fraction can be found in whole grains of barley and then oat, wheat and rye. For grinding fractions, the highest content can be found in bran (Galisteo *et al.*, 2008; Górecka 2008). The insoluble fraction is not hydrolysed by digestive enzymes in the human gastrointestinal tract, but is partially digested by the microflora of the large intestine (Lunn and Buttris 2007). The insoluble fibre fraction is characterised by passive water binding properties, which increases stool bulk and frequency, and decreases intestinal transit time (Davidson and MacDonald 1998; Lunn and Buttris 2007; Gebruers *et al.*, 2008; Górecka 2008). According to literature data, the insoluble fraction of dietary fibre may offer protection against colorectal cancer through the ability to form complexes with carcinogenic substances (Hasik and Bartnikowska 1987; Ferguson *et al.*, 1995; Moore *et al.*, 1998). Cuticular substances that form part of this fraction increase the lipid content in faeces. Lignin, which binds substantial amounts of bile acids and cholesterol, improves the absorption of vitamin A and prevents intestinal cancer, also has beneficial health-promoting properties (Flint and Camire 1992; Górecka 2008). Resistant starch is fermented by the microflora of the large intestine, what is related to greater short-chain fatty acids (SCFA) production, which support proper intestinal function (Haralampu 2000; Toping and Clifton 2001).

CONCLUSION

The knowledge of dietary fibre has increased significantly over the last few decades. A universal definition of dietary fibre has been adopted. It offers worldwide benefits, making it possible to determine the fibre content, label food and determine the reference nutritional value and health claims. Dietary fibre has also been shown to have a range of beneficial physiological effects. The list compiled is still open to new health-promoting effects. Despite the high incidence of diet-related diseases and the continuing decline in bread consumption, consumer research reveals a growing public awareness of healthy eating habits. Consumers are increasingly opting for cereal products which are enriched with healthy natural additives and rich in dietary fibre. For this reason, easy access to basic information on dietary fibre is of crucial importance.

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