Functional and health-endorsing properties of wheat and barley cell wall’s non-starch polysaccharides

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ABSTRACT
Cereals have captured global importance owing to the presence of bioactive moieties in cell wall. Numerous components have been considered but non-starch polysaccharides (NSP) of cereals cell wall are of prime concern. In this comprehensive review, the basic aim is to elaborate the functional and nutritional importance of cereals cell wall with special reference to NSP. Among bioactive components of cell wall, NSP, such as arabinoxylans, β-glucans, and arabinogalactans of wheat and barley, have gained much importance. Moreover, literature revealed that NSP have greater role as prebiotic, immunomodulator, antioxidant, anti-diabetic, and cardio-protector as well as major food applications.

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Introduction
Cereals are the widespread crop throughout the temperate and tropical regions of the world, whereas the species, i.e. wheat, rice, and maize, provide over 50% of the world’s plant-derived food energy. According to Eurostat statistics, wheat is the largest crop, followed by barley, with oats in the third place among the cereals cultivated in Europe.[1] Cereals are the most widely consumed staple food in most countries.[2] The cereal grain consists of three major portions: the germ (responsible for the production of new plants), the endosperm (which serves as food for the germinating seed), and the bran (consisting of various layers to protect the grain). Although the proportions vary, all cereal grains follow the same general pattern.[3] Among cereals, wheat is the most widely grown, accounting for 17% of the total cultivated land worldwide.[4]

Wheat (Triticum aestivum L.) is one of the substantial staple cereal grains belonging to the family Gramineae. Its’ worldwide production is about 672 million tons in 2012.[5,6] A wheat kernel comprises on three principal fractions—85% endosperm, 13% bran, and 2% germ.[3,7] Wheat contains many nutrients and phytochemicals, which make wheat important in functional and nutritional aspects. It is consumed worldwide after milling, mainly in the form of breads, and is a major supply of nutrients.[8] Wheat is a leading cereal crop utilized for human consumption and livestock feed.[9] Ferreira et al.[10] described that functional properties of wheat are obliged to the grain hardness, composition, and protein content. Along with these nutritional perspectives, wheat possesses some anti-nutritional effects due to the presence of anti-nutrients, such as wheat gluten and wheat lectin, which can reduce dysfunction and disease in humans.[6] Climatic changes reduce the yield and quality of wheat production by creating environmental stress.[11,12] A by-product of the industrial roller milling of wheat is known as wheat bran, which is important for its nutritional composition and physiological effects, and is added progressively to the food products. In cereal-
based products, such as bread, inclusion of bread bran leads to noteworthy losses in organoleptic qualities, such as textural changes, decreased bread volumes, and decreased sensory acceptance.\textsuperscript{13} The formation of three-dimensional structures on mixing in water makes wheat flour unique among cereals. Therefore, it is the main vital structural constituent for baking bread.\textsuperscript{14}

Barley (\textit{Hordeum vulgare} L.) is the fourth cereal crop in worldwide production, and it is under-utilized in the food industry, with just two applications: feed or malt.\textsuperscript{15} Barley has been an important foodstuff in the Arabian Peninsula since ancient times.\textsuperscript{16} Barley is classified in many types based on seed rows number on each spike (spring and winter wheat), hull adherence to the grain (hulled or hullless) and grain composition (normal, waxy, or high amylase starch types, high $\beta$-glucan- and proanthocyanidin-free types).\textsuperscript{17,18} Nevertheless, in the last decade, an increasing interest in barley research as a food source has occurred, mainly because barley flour contains a large amount of soluble dietary fibers, especially $\beta$-glucans. Barley is rich in fiber, especially soluble fibers $\beta$-glucan, pectin, and arabinoxylans.\textsuperscript{19,20} This fact makes barley an important cereal because of its nutritional and functional properties but barley in spite of all these functional ingredients is rarely used in the food industry.\textsuperscript{21,22} Barley grains have highest amount of $\beta$-glucans among all cereals. Barley contains about 10.89–19.7 g/100g dry wt of $\beta$-glucan.\textsuperscript{23,24} Hull-less waxy barley contains increased levels of $\beta$-glucan, making it successfully applicable in food, feed, and industrial applications.\textsuperscript{25} Various factors such as environmental conditions and their interactions with varieties affect the levels of $\beta$-glucans in hull-less waxy barley.\textsuperscript{26–28}

**Cell wall**

Cereal grain is a complex structure possessing cell wall. The composition and properties of cell wall vary widely. The major components of grain are starch (70–80%) and proteins (10–15%) along with non-starch polysaccharides (NSP) derived from the cell wall accounting for about 3–8% approximately. These components of cell wall have varying degree of structural and functional complexities. The main non-cellulosic components are arabinoxylans and (1,3;1,4)-$\beta$-D-glucans, with lower levels of glucomannans, xylolignans, and pectic polysaccharides. $\beta$-glucans and arabinoxylans are structural components of cell wall of many cereals, such as wheat, oat, barley, and rye. Their relative quantities vary with species and growing environments. Rich sources of $\beta$-glucans are barley and oats cell wall, whereas rye and wheat cell wall are rich in arabinoxylans. In most dicot species, the major non-cellulosic cell wall constituents are pectic polysaccharides and xyloglucans, whereas $\beta$-glucans are generally absent and arabinoxylans are found at relatively low levels. The type and composition of these polysaccharides is of increasing interest in both human and animal nutrition.\textsuperscript{29–35}

These polysaccharides are determined by the strength of the grain shells, forming crosslinks in the matrix structure of the cell wall.\textsuperscript{36,37} These highly molecular mass polysaccharides are even soluble in aqueous media, at least slight. Then, they take on highly asymmetrical conformations and as a result form high viscosity solutions. The molecular size, solubility, and viscosity of the polysaccharides vary widely in cereal to cereal and even with single specie.\textsuperscript{38,39} The physicochemical properties of arabinoxylans and $\beta$-glucans are influenced by the variation in their structural features, which in turn influence many aspects of the end uses of cereals.\textsuperscript{40} They are known to have beneficial effects in alleviating disease symptoms, such as diabetes, cardiovascular disease, atherosclerosis, and colon cancer.\textsuperscript{40–45} Comino \textit{et al.}\textsuperscript{46} characterized the cell wall polysaccharides functionally and structurally by an appropriate method. The study was aimed to separate the soluble polymer and the residual cell wall fraction without using organic solvents, and the fractionation of soluble polymers into arabinoxylans- and $\beta$-glucans-rich fractions for subsequent analysis. This methodology was applied to endosperms flours from wheat, hull-less barley, and rye.

Cellulosic components of cereals cell wall are cellulose and lignins. Cellulose and lignin content in the cell wall of grains are higher than in the cell wall of endosperm. In the mature grain, there is possibility of low cellulose and lignin content owing to the no load-bearing ability of endospermic
walls and consequently for the safety of wall, low levels of these relatively intractable wall components are necessary because there is a chance of rapid degradation of the germinated grain wall.\textsuperscript{31,47}

**Cell wall of wheat grain**

Cell wall residue in the wheat endosperm is about 2–7%, which consists largely of NSP.\textsuperscript{48} Wheat grain cell walls contain about 31.7 to 136.7 g/kg NSP. Among these NSP, 23.7 to 107.5 g/kg is arabinoxylans content and 1.8 to 18.0 g/kg is mixed linked \( \beta \)-glucans content.\textsuperscript{49–51} The content and types of dietary fiber vary widely with the types and varieties of wheat. The main types of wheat are winter wheat and spring wheat (both *Triticum aestivum* L., also known as common wheat), durum wheat (*Triticum durum* Desf.), spelt wheat (*Triticum spelta* L.), einkorn wheat (*T. monococcum* L.), and emmer wheat (*Triticum dicoccum Schubler*) having 131, 20, 10, 5, 5, and 5 varieties, respectively. The level of dietary fiber in common wheat, einkorn and emmer wheat, durum and spelt wheat is 11.5–18.3% of dry matter (dm), 7.2–12.8% of dm, and 10.7–15.5% of dm, respectively. Whereas, arabinoxylans content in bran portion of different types of wheat ranges from 12.7 to 22.1% of dm, 6.1 to 14.4% of dm, and 10.9 to 13.9% of dm in common wheat, einkorn and emmer wheat, and durum and spelt wheat, respectively. Content of NSP, such as arabinoxylose, xylose, and galactose, in different spring wheat is about 21.66 to 40.02 g/100 g, 23.95 to 48.09 g/100 g, and 37.44 to 50.02 g/100 g, respectively. In whole wheat flour, the arabinoxylans and arabinogalactans content ranged from 6.1 to 14.4% of dm, 20.4 to 43.2% of dm, and 10.7 to 15.5% of dm in common wheat, einkorn and emmer wheat, and durum and spelt wheat, respectively. On average, arabinoxylans of bran is about 29% of the total dietary fiber content of wheat. Moreover, the arabinoxylans content in wheat flour is about 1.35 and 2.75% of dm. The studies about the arabinoxylans and dietary fiber content in wheat revealed that bran yield negatively affects the arabinoxylans contents in bran; whereas, dietary fiber contents in whole wheat are positively correlated with bran yield. As far as the mixed-linkage \( \beta \)-glucans is concerned, its’ content in einkorn, emmer, and durum wheat (0.25–0.45% of dm) is about half the level in the winter, spring, and spelt wheat (0.50–0.95% of dm).\textsuperscript{33} Wheat bran is a by-product of milling containing high nutrient content including 15% high-quality proteins. These proteins are good source of amino acids and bioactive peptides and are known to be inhibitors of enzymes of industrial interest for their fortifying nature, nutritional, and functional properties. This bran fraction contains around 44% dietary fiber.\textsuperscript{53,54} The reason behind their low consumption by humans and more wastage is that cell wall polysaccharides matrix encloses most of the wheat bran proteins, which are poorly digested resulting in the annual waste of 15.5 million tons of usable protein.\textsuperscript{55–57} At the inner site of bran, there is a single cell layer known as aleurone that is micronutrient-rich fiber fraction having most of minerals, vitamins, lignans, and phenolics antioxidants of the wheat grain.\textsuperscript{58}

**Cell wall of barley**

Starchy endospermic cell wall of barley contains about 75% of \( \beta \)-glucans, 20% of arabinoxylans, 2% of cellulose, and 2% of glucomannan. Whereas the aleurone cell wall consists of about 71% of arabinoxylans, 26% of \( \beta \)-glucans, and 3% of cellulose and glucomannan.\textsuperscript{59,60} On the basis of solubility and insolubility in water, \( \beta \)-glucans exist in two forms.\textsuperscript{61} Arabinxylans (AX) comprises of ~ 20% total cell wall polysaccharides of the starchy endosperm in barley. barley cell wall contains about 3–4% cellulose and same quantity of glucomannans. Barley endospermic cell wall contains polymers of very high molecular weight (MW) (about 4 \times 10^7 daltons) \( \beta \)-glucans consisting of firmly linked peptide sequences, which are the essential parts in the structure of \( \beta \)-glucans complex as it exists in the cell wall. \( \beta \)-glucans get similar size to those from short-grown green malts (with MW about 10^6 daltons) through rupturing of peptide bonds by hydrazinolysis or by proteolytic enzyme thermolysin. Consequently, proteolysis is the initial step in \( \beta \)-glucan degradation. Kernel hardness and water uptake are significantly affected by the endospermic cell wall components.\textsuperscript{62} The
solubility and digestibility of endosperm cell wall polysaccharides has large differences, which are related to the composition. The environment of growing barley grain effects the composition.\textsuperscript{[63]}

**Non-starch polysaccharides**

Polysaccharides are macromolecules of monosaccharides linked by glycosidic bonds. The NSP are heterogeneous group of polysaccharides that consist of β-glucans, cellulose, pectin, and hemicelluloses, varying widely in size, structure, and solubility and are the significant constituents of the plant cell wall. They are also known as non-α-glucan polysaccharides.\textsuperscript{[64,65]} The NSPs are heterogeneous group of polysaccharides naturally occurring in many foods, predominantly in cereals. They are known as building blocks of cell walls of many cereals.\textsuperscript{[66]} The main sources of NSP are cereal grains, which contain large amount of arabininoxylans (pentosans), β-glucans, and cellulose.\textsuperscript{[67]} Unripe banana flour also contains higher content of NSP.\textsuperscript{[68]} The NSP on the basis of solubility in aqueous solution are classified into two categories, such as water soluble NSP and water insoluble NSP. This classification possesses various practical advantages.\textsuperscript{[69–71]}

Cellulose, lignin, xylans, xyloglucans, and galactomannans are known as water insoluble NSP; whereas, pectins, arabinoxylans, arabinogalactans, and β-(1,3)(1,4)-D-glucans (β-glucans) are called water soluble NSP.\textsuperscript{[67]} Substantial amounts of soluble and insoluble NSP are present in wheat and barley. In wheat, main water soluble NSP is arabininoxylans (6–8%); whereas, in barley, the major water soluble NSP is β-glucans (7.6%). The NSP contain large spectrum of physicochemical properties, such as viscosity, solubility in water, cation exchange capacity, bulk, fermentability to beneficial short chain fatty acids (SCFAs), and absorptive properties of organic compounds making them nutritionally improvement. Among all NSP, water soluble NSP are more viscous. Various factors, such as chemical composition, molecular size, and composition of the extraction media, affect the viscosity of NSP. The viscosity, biological, and physiochemical properties of these polysaccharides are oblige of their beneficial physiological effects in the small and large intestine.\textsuperscript{[38,72]}

Generally, cell walls of cereal grains (2–8%) contain arabininoxylans, (1, 3; 1, 4)-β-glucans, arabinogalactan, and pectins.\textsuperscript{[35,72,73]} Whereas, literature revealed that among cereals, barley and oats are rich in mixed linked β-glucans, while wheat, rye, and triticale contain arabinoxylans (Pentosans).\textsuperscript{[74]} They are not digested by human’s small intestinal enzymes and so contribute to total dietary fiber intake.\textsuperscript{[38]} In corn, sorghum and wheat, NSP content is less and starch is more, whereas, in co-products of these cereals, NSP content is less more and starch. In grains, the cellulose, arabinoxylans, and other hemicelluloses are about 22, 49, and 29%, (dm basis) respectively; whereas, in their co-products, these carbohydrates are about 25, 43, and 32% (DM basis), respectively. As far as the wheat is concerned, its grains and co-products contain about 16, 64, and 20% (DM basis) cellulose, arabinoxylans, and other hemicelluloses, respectively. Moreover, the lignin content is between 0.8 and 1.8% (DM basis) in grains, while co-products contain about 2.2–11.5% (DM basis) lignin.\textsuperscript{[75]}

Among all these NSP, arabininoxylans and β-glucans are most important polysaccharides and they have attracted the most attention due to their increasing functional and nutritional properties. The composition and type of these polysaccharides is important. Both types of enzymatic and monosaccharide methods are used to analyze these polysaccharides in grains. The predominant, rapid, and inexpensive protocol of analysis is near-infrared reflectance spectroscopy.\textsuperscript{[34,35]} Knudsen\textsuperscript{[30]} found that β-glucans and arabinoxylans contribute to the viscosity of the extract but β-glucan is higher in MW than arabinoxylan but less resistant to degradation. So the use of more resistant arabinoxylans-rich grains in broiler diets is usually more problematic than those containing high concentrations of β-glucans.

**Arabinoxylans**

Arabinoxylans are paramount component of the dietary fiber in cereals and belong to the group of NSP.\textsuperscript{[76,77]} They are major NSP present in endosperm and outer layers of cereals mainly wheat grains constituting cell wall of various types of cereal grains.\textsuperscript{[54,78–81]} About 70% of the cell wall’s NSP are
The efficacy of barley and oats in containing a high level of β-glucan with respect to their general structure. Despite their structural heterogeneity among arabinoxylans originating from different botanical sources. Various factors including tissues, wheat cultivars, genotype, environment, and genotype x environment interactions affect the content and structure of arabinoxylans in whole grain. Among all these factors, the occurrence of genotype x environment interactions to the total variability is considered lower than all other factors. The resultant variation in the content and structure affects the nutritional quality and end-use of the grain. The main sources of arabinoxylans are wheat, barley, rice, rye, oat, and sorghum. Some other sources include psyllium husk, pangola grass, and bamboo shoots etc. Whole wheat flour and bran of different wheat varieties contain about 2.93 to 4.68% and 11.71 to 18.38% arabinoxylans content, respectively. While another study showed that the arabinoxylans contents in bran and starchy endosperm ranged from 11 to 16.4% (w/w) and 1.5 to 1.8%, respectively. Thirty-seven percentage of starchy endosperm arabinoxylans was soluble in water. 

Arabinoxylans on the basis of structural and conformational-based extraction properties is classified into two categories including water-extractable arabinoxylans (WEAX) and water-unextractable arabinoxylans (WUEAX). Total arabinoxylans and water-extractable arabinoxylans content in common wheat are 6.7% and 0.7%, respectively, and the hard wheat varieties possess considerably higher contents than soft wheat cultivars. Moreover, the content of water-extractable arabinoxylans in winter wheat varieties is more as compared to spring wheat cultivars. Content of total arabinoxylans and water-extractable arabinoxylans vary widely in grains depending upon the genetic differences and environment. The ferulic acid moieties also consent to oxidative cross-linking between arabinoxylans molecules or the tyrosine residues of proteins. The efficacy of water-extractable arabinoxylans is providing resistance against various ailments and is more than water-unextractable arabinoxylans. This efficiency is based on the MWs, solubility, and cross-linkages of arabinoxylans. Arabinoxylans affect the quality of end-use wheat in many ways. Chen et al. reported that most vital attribute of arabinoxylans is its role in the upgrading of an assortment of functional components of the intestinal barrier function and the involvement of microbiota changes. Owing to the viscosity, arabinoxylans have considerable impact on the technological properties of wheat and assess the physiologically positive influence in consumption. 

Beta-glucans

β-glucan is the most important bioactive substance, characteristics hemicelluloses, and predominant polymer in the cell wall of cereals. Internal aleurone and subaleurone endospermic cell walls are concentrated by glucans. Among cereals, barley and oats contain a high level of β-glucan with highest solubility. β-glucans can also be present mainly in rye and wheat brans. β-glucans content in barley, wheat, rye, and oat is 10.89–19.7, 8.48–16.19, 7.45, and 13.79–33.73 g/100g dm, respectively, as determined by enzymatic gravimetric method. The structure of β-glucans is a linear chain polysaccharide made of units of β-D-glucopyranosyl residues linked by 1, 3, and 1, 4 glycosidic bonds. Temperature, pH, extraction time, particle size, solvent and the raw material, environmental conditions, processing technology, and extraction methods are used to determine the extraction yield, purity, structure, rheological properties, and physiological properties of β-glucans.

The physiological and physicochemical properties depend upon the molecular structure of β-glucans. Hence, there is a growing interest in the production of various foods containing β-glucans. The occurrence of wheat with high cell wall contents together with barley with high β-glucans contents is well known. The β-glucans content of barley and the impact of β-glucans content on starch digestibility are affected by extrusion types (Collet and cooking) and parameters (moisture content, screw speed, and temperature). Extrusion significantly reduces the total β-glucans (TBG) content of barley as a raw material.
**Arabinogalactans**

Arabinogalactans are long, highly branched, abundant class of cell surface water-soluble proteoglycans (the combination of protein and sugar molecules) having high MW. They are found abundantly in flowering plants, between cells of most plants, larch, tamarack, and certain other herbs. Some important dietary sources of arabinogalactans include coffee beans, soy beans, broad beans, and cereals. Whole wheat flour and bran of different wheat varieties contain about 0.47 to 0.93% and 1.07 to 4.43% arabinogalactan content, respectively. They have highly complex structure comprising β-(1→3)-D-galactan backbone along with the side chains of β-(1→6)-D-galactose, which are further modified with a-arabinose as well as other sugars, including b-(methyl)glucuronic acid, a-rhamnose, and a-fucose. They are important component of gums.

Hydrolysis of arabinogalactans by the action of arabinogalactan protein-specific enzymes resulted in the formation of oligosaccharides. The structure of these oligosaccharides exposed the highly complex and branched nature of arabinogalactan of wheat endosperm arabinogalactan proteins (AGPs). Among NSP of cereals cell wall, arabinogalactans are less important than arabinoxylans. But arabinogalactan proteins have gained pervasive consideration from plant biologists due to their role in plant development (root regeneration and seed germination) since the late 1980s. Arabinogalactan proteins are highly soluble, ubiquitous cell wall components, and probably take part in cell–cell interactions during development. They are widely post-translationally customized by exchange of proline to hydroxyproline (Hyp) and by adding arabinogalactan (AG) polysaccharides to Hyp residues. Tryfona et al. described that about 90% of arabinogalactan is arabinogalactan proteins making arabinogalactan a functional molecule.

**Health-endorsing effects**

Wheat grains, when introduced in the human diet, can reduce the risk of a bundle of diseases, such as coronary heart disease, tumor formation, mineral-related abnormalities, colorectal cancer, inflammatory bowel disease, breast cancer, tumor and disordered laxation due to the presence of nutritional compounds. Thus, the consumption of wheat could possibly be used as a remedy against an array of aberrations and as meliorating their complications due to the presence of NSP (arabinoxylans and arabinogalactans) in its cell wall. There are various modes of action of NSP as therapeutic agent. The effectiveness of non-cellulosic cell wall polysaccharides in improving health outcomes is related to the fine structure and associated physicochemical properties. The significant properties of dietary NSP are water dispersibility, viscosity effect, bulk, and fermentability into SCFAs. These features may lead to reduced risk of serious diet-related diseases, which are major problems in Western countries and are emerging in developing countries with greater affluence.

Arabinoxylans are one group of dietary fiber components in cereal grains, and specific health benefits have been linked with their molecular fine structures and hence with physicochemical properties, such as solubility in aqueous media. β-glucan is a very valuable functional ingredient and which distributes widely in various cereals, such as oat, barley, and wheat. It is clear that in some cases, these (1,3;1,4)-β-glucans function as a major store of metabolizable glucose in the grain. The nutraceutical potential of β-D-glucan is largely dependent on its structure, size, viscosity, extraction techniques, quality, rheological properties, MW, and synthesis. Moreover, health benefits of arabinogalactan have been given in Table 1. A brief description for health benefits is described herein after.

**Prebiotic activity**

Arabinoxylans (arabinoxylan oligosaccharides & xylooligosaccharides) exert prebiotic effects in the colon of humans and animals through selective stimulation of beneficial intestinal microbiota. The prebiotic potential and fermentation characteristics of cereal arabinoxylans depend strongly on
A specific concentrate of long-chain water extractable arabinoxylans (LC-AX) stimulates specific intestinal microbes (e.g. Bifidobacterium longum) and launches specific fermentation patterns in humans and animals through selective stimulation of beneficial benefits for the host (e.g. propionate production). \cite{80,107–109}

β-glucans favors the growth of beneficial intestinal bacteria through the production of SCFAs. Decomposition of β-glucans occur in the large intestine. As the microbial cells increase, dry weight of colon contents increases. The water retention capacity of microbial cell material is more than insoluble fiber, which increases the bulking effect of insoluble fiber. \cite{112–114}

The prebiotic activity of arabinogalactans is of prime consideration. They pay resistant to the human digestive processes and are not broken. \cite{115} For intestinal microorganism, they play important role as prebiotic. The intestinal microorganism break these complex compounds/complex structures of arabinogalactans, and as a result, SCFAs are produced which are metabolic by-products. These SCFAs, owing to their role as energy reservoir for cells forming a colon endothelial layer, are important for mucosal health. They are also important for cancer and inflammatory disorders. \cite{116}

### Immunomodulatory properties

Arabinoxylans are of significant importance to human health due to their potential to modulate both the adaptive and innate immune systems. The immunomodulatory properties of arabinoxylan depend upon their structural features. Arabinoxylans of cereals have been shown to affect different immune cells to augment a wide range of immune responses in vitro and in vivo in animals and humans. \cite{79,117}

The relationship between molecular structure and physicochemical properties, as well as physiological properties, should be clarified, especially the mechanism of β-glucan enhancing the immune system. \cite{98,118} β-glucans are known as biological response modifiers (BMS) as they are believed to modulate the immune response. \cite{119} These substances increase host immune defense by activating complement system, enhancing macrophages and natural killer cell function. \cite{120} In addition, β-glucans can stimulate immune functions by activating monocytes/macrophages and increasing the amounts of

| Health-endorsing perspectives | Mechanism and Outcomes | References |
|-------------------------------|------------------------|-----------|
| Anti-diabetic effect | Reducing glycemic index of foods. Positively reduces the glucose levels and insulin resistance. | \cite{141} |
| In turn mitigates the chance of diabetes. Immunomodulatory effects | Boost up the natural killer cells and macrophages as well as the secretion of pro-inflammatory cytokines. Boost up the immune responses and in turn mitigate the chance of tumor progression, viruses, and bacteria infiltration. | \cite{99} |
| Anti-infectious potential | Inhibiting the adherence of toxic bacteria to the intestinal wall | \cite{139,140} |
| Prebiotic effect | Not broken by human digestive processes. Act as prebiotic for intestinal microorganisms. Broken down into short chain fatty acids. | \cite{115,116} |
| Ability of short chain fatty acids to protect the mucosal health by providing energy reservoir to the colon endothelial layer forming cells. | Important for cancer and inflammatory disorders Broken down into short chain fatty acids. | \cite{115,116} |
| Portal-systemic Encephalopathy (a disease characterized by ammonia buildup in the liver) | Significant reduction in the ammonia level. In turns helps in protection and cure portal-systemic encephalopathy | \cite{139} |
immunoglobulin, NK cells, killer T-cells, and so on, which will improve resistance to cancer and infectious and parasitic diseases, as well as increase biological therapies and their prevention.\textsuperscript{121}

Arabinogalactan acts as an important immunomodulator owing to its ability to boost up the immune responses that in turn mitigate the chances of tumor progression and virus and bacteria infiltration. The prime and most important reason behind their immunomodulatory activity is their ability to increase the natural killer cells and macrophages as well as the secretion of pro-inflammatory cytokines.\textsuperscript{99}

**Antioxidant properties**

Arabinoxylans have some antioxidant properties due to the presence of phenolics moieties in their molecular structures.\textsuperscript{20,109,122–125} Arabinoxylans are capable of donating both electron and hydrogen atom during redox reactions. Their antioxidant potential is highly influenced by ferulic acid content, degree of xylose substitution, dietary sources, and pattern of substitution.\textsuperscript{126–128} Arabinoxylan oligosaccharides with higher content of esterified ferulic acid and degree of substitution are better antioxidants. Owing to this antioxidant potential, arabinoxylan reduced the risk of colorectal cancers and diabetes. Two steps may be involved for arabinoxylan to exert these health benefits. They include: a) water extractable arabinoxylans donate electrons or hydrogen atoms to neutralize dietary-free radicals (implicated in the initiation and/or development of chronic diseases) as they traverse through the gastrointestinal tract; and b) arabinoxylans noncompetitively inhibit intestinal \( \alpha \)-glucosidase and glucose transporter thereby attenuating postprandial blood glucose levels.\textsuperscript{129,130} Ferulic acid and feruloylated arabinoxylan mono-/oligosaccharides have potential for use in diabetes management.\textsuperscript{131} Arabinoxylan added to wheat bread can have beneficial effects on glycemic control in type II diabetes\textsuperscript{111,131,132}

\( \beta \)-glucans captured great interest for their antioxidant capacity. \( \beta \)-glucan participated in the glucoregulation and consequently decreases the serum cholesterol levels in humans.\textsuperscript{22,133–138} Arabinogalactan plays an important role as antioxidant. Various potential health effect associated with arabinogalactan are gastroprotection\textsuperscript{139}, membrane-tropic, anti-inflammation, and immunity enhancements.\textsuperscript{139,140}

**Anti-diabetic effect**

Arabinoxylan has significant effect on cholesterol level and glycemic index in human’s FDA,\textsuperscript{85} but their mode of action is still unknown. It may be owing to its excellent rheological features, i.e. high viscosity and soluble nature. Moreover, the viscous substances slow the rate of gastric emptying and reduce small intestinal motility thus resulting in delayed glucose absorption.\textsuperscript{141} \( \beta \)-glucan of cereals is effective in prevention, treatment, and control of diabetes by attenuating blood glucose and insulin levels. The ability of cereal \( \beta \)-glucan to attenuating blood glucose, insulin levels is linked to the viscosity produced by cereal \( \beta \)-glucans in a linear relationship. \( \beta \)-glucan lowers the glycemic index.\textsuperscript{20,36,121,142–147} Arabinogalactans are known as important NSP for their anti-diabetic effect. Arabinogalactan plays anti-diabetic role in many ways, i.e. reduces the glycemic index of foods, positively affects the reduction of glucose level and insulin resistance, and in turn reduces the chances of diabetes.

**Cardiovascular disease**

Studies revealed that arabinoxylans have cardioprotective effect due to its prebiotic nature. As a result, it reduces the mortality cases and death from cardiovascular diseases, cancer, diabetes, respiratory disease, and infections.\textsuperscript{148} Same is in the case of arabinogalactans owing to its prebiotic nature. \( \beta \)-glucans from the endosperm cell walls of wheat, barley, and oat lower the risk of coronary heart disease, colorectal cancer, and obesity by lowering blood cholesterol.\textsuperscript{20,50,143,149,150} Increased total and low-density lipoprotein (LDL) cholesterol levels are considered as major risk factors for
cardiovascular disease. β-glucans have ability to lower the total blood cholesterol, LDL cholesterol and to improve the high-density lipoprotein (HDL) cholesterol and blood lipid profile as well as to maintain body weight. This in turn lowers the risk of cardiovascular diseases.[32,121,151]

Food applications

Arabinoxylans

Arabinoxylans have been revealed to considerably affect cereal-based processes such as milling, brewing, and bread-making. Furthermore, arabinoxylans offer nutritional benefits of soluble and insoluble fiber, and, because of the presence of phenolic moieties in their molecular structures, they may also have some antioxidant properties.[20] Addition of water extractable arabinoxylans in bread formulation results in significant increase in volume and improvement in texture of the final product. Water extractable arabinoxylans hold potential to be extracted and utilized in cereal-based products for best quality and value addition.[89] Similar to dietary fiber, purified arabinoxylans also affects dough and bread properties as would be expected because of its high water-holding capacity. In the past, research has been aimed in understanding the functional role of endogenous arabinoxylans (present in the flour) and the effect of modification on their function. The extraction of arabinoxylans from cereals, however, has been aimed at different applications than functional foods. The potential industrial application of arabinoxylans is currently focused in the packaging industry for the production of biodegradable films and as additive in papermaking to replace other cationic polymers.[152] It also has the potential in biomedical and pharmaceutical industries for adhesion and drug delivery.[153,154] The major obstacle for these potential applications is production of highly pure arabinoxylans and the development of a commercially viable extraction and purification process.

Arabinoxylans as food additive

Wheat and rye arabinoxylans act as functional ingredients in baked products and affect the water-binding and holding, rheology and starch retrogradation. Their viscous nature keeps the gas retention in dough by influencing the gluten-starch films.[82,155] Once isolated and included as food additive, arabinoxylans affect foodstuff attributes and have positive effects on human health.[156] Arabinoxylans, owing to their highly water-absorbing capacity, play a considerable role in the shaping of physical and chemical properties of products obtained from this raw material. As far as its’ role in the cereal industry is concerned, it is used in the biotechnological processes including baking, brewing, production of glucose hydrolysates, and animal feed, and plays an important role in imparting quality in the products. Buksa et al.[157] investigated the effect of water-soluble arabinoxylans on the properties of rye dough and bread. It was found that the addition of arabinoxylan resulted in an increase of water absorption, greater volume of bread, and decreased crumb hardness.[158]

Arabinoxylans as high value co-product

Extraction of arabinoxylans from the low-value animal feed produced during wheat milling has the potential to provide a high-value co-product. This is only achievable if a market is available for the arabinoxylans extract produced. The functional properties of arabinoxylan open up a wide range of possibilities for its use in both food and non-food applications.[54,159]

Not only arabinoxylans can be used as functional food ingredient but it also has the potential as a nutritional food additive by exhibiting prebiotic effects.[160] In the large intestine, undigested arabinoxylans are thought to change the composition of the microbial flora, which affects the activity of the bacterial enzymes present, influencing the end products of bacterial fermentation, promoting colonic health.[161] Potential uses of arabinoxylan as a prebiotic in the food industry could be the production of
health-promoting cereal-based food products, including bread, biscuits, and pasta.\textsuperscript{162} With both technological and nutritional functional properties, it is clear that many opportunities become available for differing industries to take advantage of the beneficial properties of arabinoxylan, thus making it a sought after, high-value product.

The indigestibility of arabinoxylan is associated with high MW, which exhibit high viscosities in solution, preventing the breakdown of nutrients and their uptake.\textsuperscript{163} Monogastric animals are deficient in the necessary enzymes to degrade AX, but improvements to digestibility can be made by supplementing animal feeds with particular microbial xylanases, which depolymerize arabinoxylans, reducing their viscosity, and increasing nutrient uptake.\textsuperscript{163} Removing arabinoxylans as a high-value functional food ingredient, rather than degrading them as an inconvenience in animal feed, offers a commercially beneficial alternative.

**Arabinoxylan as partial flour replacer**

Crude arabinoxylan extracted from the animal feed co-product, wheat bran, is a feasible candidate for application in the bread-making process as a partial flour replacer.

**β-glucans**

**β-glucans as food ingredient:** In recent era, β-glucans are of commercial and nutritional importance owing to their physical and physiological characteristics.\textsuperscript{164} The escalating significance of β-glucans is due to their recognition as functional, bioactive ingredients.\textsuperscript{165} Recently, consumers have been made to understand the augmented importance in purchasing and consuming such products, which are well thought-out to be healthier. High saccharides and fibrous material foods are becoming more and more popular. This group involves the cereal-based products with a certain potential for the quick meals production, pasta, cereal breakfast, tortillas, puddings, oat yogurts, and yogurt milk.\textsuperscript{166} β-glucan is used as a functional food ingredient in the form of hydrocolloids or as powder using microparticulation owing to its excellent rheological properties, i.e. high viscosity, of β-glucan at relatively low concentration.\textsuperscript{167,168}

Various features including water-binding and emulsion-stabilizing capacity, texture and appearance, thickening ability, bread-making performance, MW, and the structure of polysaccharide are shown while incorporating the β-glucans in various products, such as meat products, milk products, soup, salad dressings, baking products, muffins and cakes, pasta, noodles, beverages, reduced-fat dairy, and muesli cereals.\textsuperscript{166,170} Gajdosova et al.\textsuperscript{[23]} explicated that β-glucans, when incorporated into the product, can augment the sensorial and gustatory characteristics along with the nutritional importance, e.g. of beverages\textsuperscript{[133]}, where the extension in the functional drink sector has been incredible over the last few years.\textsuperscript{[171]}

β-glucans possess a broad spectrum of food applications as active food ingredient. It can be used in the fortification of wheat bread.\textsuperscript{[93]} It could be used as thickening agent, regulating the structural and taste properties of functional food products, in the development of calorie-reduced foods\textsuperscript{[167,172]} followed by its applications in food industry for the impermeable food product surface coating and as crystallic and recrystallic regulator in frozen milk products.\textsuperscript{[173]} As far as the applications of β-glucans are concerned in the baking industry, it is used to fortify the wheat bread as described earlier.\textsuperscript{[93]} It significantly increases the firmness of bread and maintains the higher moisture content. It could result in the development of hydrogel structure, which gives stiffness to the dough and bread and has high water absorption capacity.\textsuperscript{[174]} It was examined that β-glucans can weaken the dough by negatively affecting the bread volume due to CO\textsubscript{2} gas retention.\textsuperscript{[175]} Consequently, β-glucans are used as food ingredient with dual roles, i.e. for increasing the fiber content in the food products and ameliorating the health-endorsing effects.\textsuperscript{[176]}

**Arabinogalactans**

Arabinogalactans, by adding into dough during mixing and leavening, play an important role in different ways. It promotes the alteration in the structure of developing wheat dough, put impact on
Farinographic parameters, and significantly increase the dough humidity.\textsuperscript{[177]} When arabinogalactans are added into flour, it affects the Farinographic parameter, i.e. increases the water absorption capacity and dough development time.\textsuperscript{[177]} Arabinogalactan slightly decreases the bread volume, and its' addition decreases the baking absorption.\textsuperscript{[117,118]} It lowers the gluten yield.\textsuperscript{[117,118]}

**Conclusion**

A brief overview of functional and health-endorsing perspectives of NSP in wheat and barley cell wall has been reported. Three basic NSP including arabinoxylans, β-glucans and arabinogalactans are found to be the source of many potential health effects, such as prebiotic, immune modulatory, antioxidant, anti-diabetic, and cardio protective. As far as the functional aspects of NSP are concerned, it has been seen that they are chief functional food ingredients showing number of significantly positive effects. This opens the door to potential health claims as well as functional aspects and provides an option for consumers looking for foods that are excellent food ingredients and are beneficial in maintaining health. Until now, there is brief discussion regarding functional and health-related benefits of NSP. Therefore, further research studies are needed to elucidate their role as nutraceutical and recent advances to incorporate them into products so that people can have more and more of these functional foods for various frequently increasing health disorders.

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