Non-starch polysaccharides: Overview, classification, methods for estimation of non-starch polysaccharides and their properties

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**ABSTRACT**

Monosaccharide macromolecules joined by glycosidic linkages are known as polysaccharides. Non-glucan polysaccharides of the plant cell wall make up the majority of non-starch polysaccharides (NSP). They are a diverse category of polysaccharides that vary in size, structure, and water solubility. They are also referred to as hydrocolloids and disperse in water to create viscous dispersants or gels. These gels or dispersants alter colon absorption of nutrients and postprandial blood sugar levels by forming networks or films or by becoming viscouser. NSPs also have a variety of biological functions, including hypoglycemic, immunoregulatory, and antioxidant actions. Plant NSP concentration varies not only by species but also by genotype and cultivar within a given species. Additionally, the NSP content may be affected by the agronomic cultivation circumstances, which include environmental factors before harvesting and storage conditions following harvest. This chapter gives an outline of non-starch polysaccharide, its classification based on solubility and linkage, various methods for estimation of NSPs such as detergent method, chemical method, enzymatic method, gravimetric method and some properties it exhibits such as solubility, water binding capacity, viscosity.

**Keywords**- Non-starch polysaccharides, β-glucans, arabinoxylans, gravimetric, water-binding capacity

1. **INTRODUCTION**

The carbohydrate fractions known as non - starch polysaccharides (NSPs) do not contain starch or free sugars. These polymeric carbohydrates differ from amylase and amylopectin in terms of content and structure. They are the structural equivalents in plants to the skeletal system in the animal realm. NSPs are high-molecular-weight pentose and hexose polymers with -links that range in molecular weight from 8000 to a million. The majority of cell wall polysaccharides are made up of NSPs, which are also closely related to other polysaccharides and non-carbohydrate materials including lignin and protein [1]. These non-starch polysaccharides (NSPs) cannot be broken down by human endogenous enzymes. They disperse in water to create viscous dispersants or gels, also known as hydrocolloids, which affect intestinal nutrient absorption and postprandial blood glucose concentration by forming networks or films or by increasing viscosity [2]–[6]. NSPs also have a range of biological functions, including hypoglycemic, immunoregulatory, and antioxidant actions [3], [7]. For instance, xanthan gum slows down starch digestion by blocking glucoamylase in addition to absorbing heavy metals like lead, cadmium, and copper [3]. The main NSP found in cereal grains are cellulose, beta-glucan, arabinoxylans (pentosans), and xylans. Pectic polysaccharides are present in modest amounts in the stem and leaves. Only the hull and husk component of leguminous plants contains cellulose and xylans. Legumes have pectic polysaccharide in the cotyledon. Plant NSP concentration varies not only by species but also by genotype and cultivar within a given species. Additionally, the NSP content may be affected by the agronomic cultivation circumstances, such as environmental factors before harvest and storage conditions following harvest.

1. **Classification of Non-starch polysaccharides**

With the exception of α-glucans (starch), a wide range of polysaccharide molecules are referred to as NSP. NSPs have been categorized using a variety of factors. Historically, the process for isolating and extracting polysaccharides constituted the basis for the classification. Cellulose is the residue left over after a series of alkaline extractions of cell wall elements and the portion of the residue that is solubilized by alkali and is known as hemicellulose. Different solubilities led to another classification. Three types of NSP are included in this classification: crude fiber (CF), neutral detergent fiber (NDF), and acid detergent fiber (ADF). Crude fiber are the residues of the plant material after acid and alkali extraction which can contain varying amounts of insoluble NSP. In contrast to ADF, which refers to a portion of insoluble NSP primarily but not exclusively made up of cellulose and lignin, NDF is made up of the insoluble fraction of NSP plus lignin [8].

A more precise division of NSP into three major groups—cellulose, non-cellulosic polymers, and pectic polysaccharides—was suggested by Bailey (1973) (Table 1). Non-cellulosic polymers include arabinoxylans, mixed-linked β-glucans, mannans, and xyloglucan, while pectic polysaccharides are polygalacturonic acids replaced with arabinan, galactan, and arabinogalactan. Another classification is based on the basis of solubility and linkage. Cellulose is not soluble in water as well as in alkali or dilute acids. On the other hand, non-cellulosic polymers and pectic polysaccharides are partially soluble in water [9]. β-(1→4) glycosidic linkage backbones with β-(1→3) linkages are soluble or partially soluble in water whereas long sequences of β-(1→4) glycosidic unit are not soluble in water.

**Table 1. Classification of non-starch polysaccharide**

|  |  |  |  |
| --- | --- | --- | --- |
| Category  | Cellulose  | Non-cellulosic polymers  | Pectic polysaccharides  |
| Arabinoxylans  | Mixed link β-glucans  | Mannans  | Galactomannans  | Glucomannans  | Arabinans  | Galactans  | Arabinogalactans (Type I) | Arabinogalactans (Type II) |
| Monomeric Residue | Glucose  | Arabinose and xylose  | Glucose  | Mannose  | Galactose and mannans  | Glucose and mannans | Arabinose  | Galactose  | Arabinose and galactose  | Arabinose and galactose |
| Linkage  | β-(1→4) | β-(1→4)-linked xylose units | β-(1→3) and β-(1→4) | β-(1→4) | β-(1→4)-linking mannan chains with α-(1→6)-linked galactosyl side groups  | β-(1→4)-linked mannan chain with interspersed glucose residues in the main chain | α-(1→5) | β-(1→4) | β-(1→4) galactan backbone substituted with 5-linked and terminal arabinose | β-(1→3,6)-linked galactose polymer associated with 3- or 5- linked arabinose residue |
|  Sources  | Legumes and most cereals | Sorghum, wheat, oat, rye, barley, rice | Barley, oat | Coffee seed | Guar gum, locust bean gum | Lilies, pulp of sugar beet | Co-products of cereals  | Pulp of sugar beet, sugar bean meal | Grain legumes | Cotyledon of rapeseed |

Adapted from [8]

* 1. **CELLULOSE**

Cellulose is known to be a complex polysaccharide made up of at least 3000 or more linear unbranched chain of β-(1→4) linked D-glucose units. Due to the absence of the digestive tract enzyme cellulase in monogastric animals, this bond typically makes cellulose ingestible. About 33% of all vegetable components are composed of cellulose, which is the fundamental structural element of plant cell walls. It makes up more than half of all the carbon in vegetation, making it the most prevalent of all naturally produced organic compounds [8].

The amount of cellulose in whole grains varies depending on the species and is primarily a result of the husk and seed coat thickness. More cellulose in cells results in thicker, more robust cell walls. A well-filled grain should have a low cellulose to starch or any reserve polysaccharides ratio since seed endosperm cells consist of just thin cell walls [10].

The equatorial conformation of the residues of glucose enables the molecule adopt an extended and slightly stiff rod-like conformation since cellulose is a polymer made of straight chains that doesn't have coiling or branching. Numerous hydroxyl groups on the residues of glucose from a particular chain create bonds of hydrogen with oxygen molecules that are on the same or on an adjacent chain. This tightly holds the chains side by side. Cellulose is very insoluble in water due to the ability of the chains to stack up to create stronger microfibrils, nevertheless it can swell in excessive sodium hydroxide solutions. Cellulose is capable of being introduced into solution by using chemicals that disrupt hydrogen bonds, such as N-methylmorpholine N-oxide. Furthermore, through thermal and shear treatments, subsequently followed by alkaline peroxidation and shearing, cellulose-rich maize bran can be transformed into a cellulosic gel for use as a nutritional supplement [11]. In addition to water and matrix polysaccharides such (1, 3, 4)-D-glucans, heteroxylans (arabinoxylans), and glucomannans, cellulose microfibrils may also interact with these substances [12].

* 1. **NON-CELLULOSIC POLYMERS**
		1. **ARABINOXYLANS**

The polysaccharide arabinoxylan (AX), which is found in the cell walls of many cereals including oat, barley, corn, rice and wheat, has a linear backbone consisting of xylose units linked by arabinose units [13]. Despite these polysaccharides only make up a small portion of whole cereal grains, they play a significant role in plant cell walls. Arabinoxylans (60-70%) make up the majority of the thin walls that enclose the cells in the starchy endosperm and the layers of aleurone in the majority of cereals; the exceptions are the endosperm cell walls of rice (40%) and barley (20%) [11]. The pericarp and testa of wheat, in particular, contain a very high arabinoxylan content (64%) [14].

Wheat AXs have been found in endosperm (3–5% of the total endosperm), aleurone, and bran (60–70% of the total cell wall) [15], [16]. Since, they are attached to the cell walls by alkali-labile ester like cross linkages, the majority of the arabinoxylans in wheat grains are insoluble in water [17]. However, arabinoxylans that are not attached to the cell walls have the ability to generate extremely viscous solutions and can hold ten times their weight in water. Arabinoxylans can quickly form a gel network under the influence of oxidative agents, such as H2O2/peroxidase, as the outcome of the restoration of cross-links [18]. Arabinoxylans that are fully cross-linked are capable of holding as much as 100 g of water/g of polymer [16]. AXs make up 10.9 to 26% of all bran fractions in the particular case of wheat bran [19]–[22]. Barley AXs share the same fundamental makeup as wheat AXs, which are polysaccharides mostly made of xylose and arabinose. Though far less researched than AXs from barley or wheat, corn also serves as an ideal source of AXs [23]–[25]. AXs have been found in about 51% of maize bran, or 67% if residual starch is not taken into account [23]. Other researchers, however, have noted lower AX yields from corn bran (approximately 35–40%) [26].

Cereals can have AXs extracted from them utilizing a variety of methods from various grain sections. Cereal brans, which account for between 10% and 25% of all bran, are the most prevalent source from which AXs are derived [19], [21], [22], [27]. Enzymatic treatments, chemical treatments, water treatments, mechanical treatments, or a combination of these procedures can all be used to extract AXs [16], [28]–[31].

* + 1. **MANNANS**

The four types of mannans that are naturally occurring are linear mannan, glucomannan, galactomannan, and galactoglucomannan [32]. Linear chains of D-mannose residues connected by β-1,4-glycosidic linkages make up linear mannan. The linear mannan backbone is water-insoluble like cellulose because of its similarity [33]. Contrarily, glucomannan is made up of D-mannose and D-glucose residues joined together by β-1,4-glycosidic linkages. Cereal grains have been shown to contain trace amounts of glucomannans. Mannose and glucose units make up these NSPs. In glucomannans, the M: G (mannose: glucose) ratio ranges from about 1.5:1 to 4.2:1 [34]. Since, they are hydrophilic, glucomannans are very soluble in water [33]. On the other hand, galactomannans are made of linear chains of D-mannose residues that have had their galactose residues replaced by α-1,6-glycosidic linkages. Their mannose to galactose content ratios are different. The endosperm of the seeds of many dicotyledonous plants, particularly those belonging to the Leguminosae family, is where galactomannans are primarily found. The gums made from carob (27-33%), fenugreek seed (25.5-32.8%), and guar (28.6-34.6%) contain the highest concentrations of galactomannans and is also a contributor of the gum's viscosity and ability to form gels [32], [33]. Cereals' galactomannan content has not been documented. The most complicated mannans are galactoglucomannans, which have a glucomannan backbone with D-galactose replacements. According to reports, the molar ratio of the mannose, glucose, and galactose residues in galactoglucomannan is 3:1:1. Depending on where it comes from of the polysaccharide, galactoglucomannans are able to be acetylated at the C-2 and C-3 positions of mannose residues to varying degrees [35].

* 1. **PECTIC POLYSACCHARIDES**

Galacturonic acid molecules are the building blocks of pectic polysaccharides. These molecules are connected by α-(1→4) glycosidic linkages, frequently with rhamnose residues attached, but they can also contain glucuronic acid, galactose, fucose, arabinose, or xylose. In grains of wheat, corn, and rice, pectic polysaccharides typically make about 0.24–0.25% of the total grain weight [36]. It is 4.68% in quinoa grain and 2.41% in barley grain [37]. Two forms of pectins—high methoxyl and low methoxyl—are characterized by the presence of certain carboxyl groups in the galacturonic acid chain as methyl esters. Protopectin is also found, as well [38]–[40]. Low methoxyl pectins have less than 50% methanol-esterified carboxyl groups, while high methoxyl pectins have more than 50% [41]. Among cereal grains, high methoxyl pectins make up 28.7–36.4% of the overall pectin content, while low methoxyl pectins make up 30.9–35.2%. Protopectins, which are water-insoluble pectic compounds, make up the rest of the pectin content (32.3–36.5%) [42].

1. **METHODS USED FOR ESTIMATION OF NSPS**
	1. **GRAVIMETRIC METHODS**

After non-fiber materials have been chemically or enzymatically solubilized, gravimetric methods quantify the insoluble residue. Gravimetric techniques are simple to use and don't need any specialized tools [1].

* + 1. **CRUDE FIBER METHOD**

The crude fiber method is the oldest and most widely used method for fiber analysis. Since some of the structural polysaccharides such as cellulose and lignin can be solubilized, this approach can only measure a small portion of the fiber's constituents. The insoluble fraction is isolated using the crude fiber technique, which alternates between acid and alkaline digestion. In some parts of the world, as well as in the food sector, the crude fiber method is still in use. However, due to the loss of some insoluble polysaccharides, all soluble polysaccharides, some lignin, and the addition of some nitrogenous material to the residual residue, its utility is severely constrained.

* + 1. **DETERGENT METHOD**

Van Soest and associates pioneered the application of detergents to dissolve protein in the 1960s. Although these techniques were initially created for pasture fiber, detergent techniques are now more frequently employed for concentrate feeds. Strong acid is used in the Acid Detergent Fiber (ADF) process, which was used for animal feeds. All polysaccharides are hydrolyzed safeguard cellulose and lignin, which are the only components in ADF. This method, like the crude fiber method, has limitations regarding its applicability to human nutrition because it excludes other cell wall polysaccharides. Van Soest created the Neutral Detergent Fiber (NDF) method, for assessing all insoluble cell wall material, in response to the requirement to define and include additional cell wall elements. This turned out to be a more accurate predictor of the dietary fiber content of animal meals than the crude fiber technique. The NDF approach started to be used in human nutrition in the 1970s, but its applicability was still constrained because it did not incorporate soluble fiber components or completely eliminate starch. The fiber that is insoluble in acid detergent (ADF) and neutral detergent (NDF) can be measured using the detergent method in a more detailed way. While ADF only measures cellulose and lignin, allowing for the determination of hemicellulose by difference, NDF measures hemicellulose, cellulose, and lignin. Since both water-soluble and water-insoluble NSP might be lost during the NDF process, starch and protein can contaminate the NDF residue, and hemicellulose may remain in the ADF fraction, this computation may not provide a precise measurement of NSP. The difference between total dietary fiber and NDF can be used to determine NSP.

* 1. **COLORIMETRIC METHOD**

Strong acids that include orcinol, carbazole, and anthrone, which are generally selective for pentoses, uronic acid, and hexoses, respectively, cause carbohydrates to condense in a reaction. This reaction results in the production of spectrophotometrically measurable colored compounds. Methods were enhanced in the 1950s by adding a number of extraction processes, followed by polysaccharide hydrolysis and monosaccharide component colorimetric analysis. Southgate noted that removing all of the starch was essential since any remaining starch would cause the amount of dietary fiber derived from glucose to be overestimated. The Fourth Edition of McCance and Widdowson's The Composition of Foods included the United Kingdom nutritional tables when the Southgate technique was adjusted for human nutrition in the 1970s. Southgate acknowledged that a colorimetric assay did not distinguish individual monosaccharides but suggested that gas chromatography (GC) or high-performance liquid chromatography (HPLC) be used because the method established significant information on monosaccharide groups (pentoses, uronic acids, and hexoses). Additionally, there were still issues with the removal of starch, which resulted in exaggerated values for numerous dietary products with high starch contents, including grains, legumes, and starchy vegetables.

* 1. **CHROMATOGRAPHIC METHOD**

There are numerous chromatographic techniques used to estimate NSPs. A method for measuring non-starch polysaccharides using Gas Chromatography that extends Southgate's work was published by Englyst and colleagues. The technique required more thorough starch removal and made it possible to identify the various monosaccharides that make up dietary fiber in processed foods. Additionally, it enabled the separation of soluble from insoluble polysaccharides and cellulose from non-cellulosic polysaccharides. As a result, the approach offered a great deal of information about the polysaccharide components of diets for humans. The Englyst method is an upgraded version of McCance and Southgate's enzymatic-chemical approach for determining NSP. The enzyme completely breaks down starch, and NSP are calculated as the total of the component sugars liberated during acid hydrolysis. Gas-liquid chromatography (GLC), high-performance liquid chromatography (HPLC), colorimetric analysis, can all be used to assess the presence of carbohydrates. Data for total NSP, soluble NSP, and insoluble NSP can be determined. Cellulose can also be evaluated independently with a modest modification to the procedure. With its colorimetric version, the Englyst method can determine total, soluble, and insoluble NSP in 8 hours, or in one and a half days when using chromatographic techniques. NSP is calculated using GLC as the total of neutral carbohydrates, while uronic acids are calculated independently. Neutral sugars and uronic acids are the components of NSP as measured by HPLC. Monosaccharides and oligosaccharides are two examples of individual sugars that can be separated using thin layer chromatography (TLC). It is most frequently used for oligosaccharides in the raffinose series, including raffinose, stachyose, verbascose, etc. The various sugars are recognized, recovered, and then estimated spectrophotometrically from the ethanol extract that contains a combination of sugars and is spotted on the TLC plate (cellulose coated).

* 1. **ENZYMATIC METHOD**

The nineteenth century saw the invention of using enzymes to extract readily available carbohydrates by German researchers. In order to address issues with applying the approach to items with a high starch content, where the starch is not fully solubilized, Schaller added the amylase treatment in the neutral detergent technique developed by Van Soest & Wine. Mongeau and Brassard modified the technique and created a quick gravimetric approach with great precision, but it had the drawback of being unable to entirely extract the starch and/or protein in some samples. The non-enzymatic gravimetric method of Prosky and other more exact NSP analytical techniques, such as the enzymatic-chemical method, or Englyst method, have emerged as the primary methods for NSP assessment. Furda, Schweizer and Würsch, as well as Asp and Johansson separately created the first gravimetric techniques for measuring the soluble and insoluble parts of NSP. Together with DeVries, Prosky, and Harland, these writers created the first iteration of the AOAC's enzymatic gravimetric method. Later, the procedure was modified to work with both soluble and insoluble fractions before being made simpler by employing 4-morpholine-ethanesulfonic acid-TRIS buffer. The AOAC modified Prosky and Asp's approach. By enzymatically removing accessible starch and solubilizing and extracting a portion of the protein, the method calculates the overall amount of dietary fiber. The rest of the residue is then dried, weighed, and its crude protein and ash levels are adjusted. If there is at least 10% of fat present, a preliminary step is added to eliminate it. The procedure can be completed quickly and easily, and it has been mechanized to allow for the evaluation of many samples at once. Many nations have made it their official way of analyzing dietary fiber. This procedure used protease, amyloglucosidase, and thermostable amylase to break down the gelatinized material. Alcohol is used to precipitate the undigested fraction. With Nx6.25 and ash, the residue is corrected. The drawback of the AOAC method is that hydrolyzed byproducts stay in solution. Alcohol cannot dissolve the Na and Ca salts found in the samples and buffers, which results in an increase in ash. There exists a slight overestimation of polysaccharides at 525 °C due to the depletion of volatile components. Due to these issues, the process was altered to include urea-based dialysis, which forgoes the heat treatment and dialysis-based byproduct removal. The method's fundamental component is the unique activity of a thermostable enzyme in an 8M urea solution. Southgate and Bach Knudsen modified an approach created by Asp for the analysis and characterisation of dietary polysaccharides groups for feed.

1. **PROPERTIES OF NON-STARCH POLYSACCHARIDE**

NSPs' fundamental characteristics include their solubility, ability to bind to water, ability to create very viscous solutions, and capacity to cross-link and lower surface tension [1].

* 1. **SOLUBILITY**

The molecular structure of NSPs affects how soluble they are. Higher solubility is caused by any structural trait that prevents intermolecular interaction, such as molecular branching or the existence of carboxyl, sulfate, or phosphate groups [43]. The existence of linear chains within the molecule, high molar mass, and other common structural traits are examples of structural characteristics that encourage intermolecular interaction and cause poor solubility [44], [45].

AXs are often divided into two fractions: those that are soluble in water and those that are not. The degree and pattern of substitutions, the proportion of arabinose to xylose, and their molecular weight all affect how soluble AXs are in water. It has been established that the AX chain's solubility decreases when arabinose residues are removed [46]. AXs that are insoluble in water are coupled to components of the cell wall such cellulose, lignin, or proteins [46], [47]. The surface of the cell wall contains loosely attached water-soluble AXs [17], [46]. AX is typically 30–40% [48] soluble in wheat flour, compared to 18–23% [49] soluble in whole-grain rye flour. AXs were 10–18.5% [50] soluble in grain of barley. It should be noted, nonetheless, that the observed variations in the AXs' calculated solubility may be the result of different extraction procedures, preparations with different compositions, or solubility measurement techniques [49], [50].

The ratio of tri-saccharide to tetra-saccharide units influences the solubility of β-glucans; a smaller ratio indicates a higher solubility [51]. Since oat grains' β-glucans are more soluble in heated water than in cold one, food processing procedures that call for both heat as well as moisture are likely to do the same [52]. It has been demonstrated that baking bread increases the solubility of β-glucans as well [53]. However, it has been found that foods kept frozen for prolonged periods of time cause a reduction in the soluble capacity of β-glucans [54]. It was demonstrated that when the molecular weight of β-glucans decreased (from 2,200,000 g/mol to 400,000 g/mol), so did their solubility. Low molecular weight (120,000 g/mol) β-glucan molecules can, nevertheless, form insoluble clumps [55], [56]. Oat grain β-glucans are 27–78% soluble, whereas barley grain is 53–63% soluble [57], [58].

The degree to which mannose chains are replaced with galactose residues determines how soluble galactomannans are. The molecules are more soluble when there is a greater degree of substitution. Galactomannans, which have galactose residues linked to every mannose molecule, provide such a significant steric barrier that they disintegrate in cold water. In cold water, galactomannans, which have a galactose residue connected to every fourth mannose molecule, are difficult to dissolve, but in hot water, they dissolve with ease. The main reason galactomannan molecules are more soluble is that they contain more side chains, that maintain the primary mannose chains sufficiently apart. On the other hand, due to their lengthy sections of unsubstituted mannose units, galactomannans with less side chains (higher mannose-to-galactose ratio) are able to interact with other polysaccharides [59], [60]. Previous research studies have not provided information on the extent of solubility of galactomannans from cereal grains. However, a test of locust bean gum's solubility revealed a range of 62.7-82.7% [61].

The most common form in which arabinogalactans are extracted as NSPs is arabinogalactan peptide. About 92% of the polysaccharide is made up of arabinogalactan peptide, and the remaining 8% is made up of peptide [12]. There is no information on the solubility of arabinogalactans in cereal grains.

Pectins' degree of polymerization, quantity, as well as distribution of carboxyl groups all affect how soluble they are. Pectin's solubility rises as its molar mass falls and the esterification of its carboxyl groups increases. pH and temperature of the solution have a definite impact on pectin solubility as well [62]–[64]. The soluble state of cereal pectins is yet to be established.

Although xyloglucans have the ability to dissolve in water, there is no information on how xyloglucans in cereal grains are soluble [65].

* 1. **WATER BINDING CAPACITY**

NSPs possess hydrophilic characteristics that allow them to bind to water. The ability to bind water is the result of interactions between water and NSP molecules that produce in bonds of hydrogen or dipole interactions [66], [67].

Particularly the water-soluble AXs exhibit a great affinity to bind water [68]–[70]. In comparison to wheat flour with no inclusion of these polysaccharides, 11–12% more water was bound when water-soluble AXs in the range of 0.5–1.3% were added [70]. AXs that are water-soluble and made from wheat flour can bind, on average, 0.38 g of water per gram of dry basis [69], but AXs made from rye grains can bind, on average, 1.58 g of water per gram [68]. Additionally, it has been demonstrated in other research that AXs from flour made from wheat are capable of binding even 15 g of water/g [71]. AX from wheat bran, which is cellulose-rich, may bind 13.3 to 16.13 g of water [72].

The amount of water bound by β-glucans from barley grain varied depending on the extraction technique, from 2.91 g/g d.b. employing enzymatic treatment to 3.79 g/g d.b. employing hot water extraction [73]. According to other research in the literature, barley grain's β-glucans have a water holding capacity of 6.1 to 6.74 g water per 1 g of β-glucans [57]. The usage of additional barley grain kinds is likely what caused the large variances in the results that were achieved.

It is important to keep in mind that the outcomes of water-binding capacity that have been determined are closely related to and significantly influenced by the ways in which NSPs are extracted, as well as by variations in the procedures employed to assess this parameter.

* 1. **VISCOSITY**

The length of the molecule chains, their molar mass, the amount and sequence of arabinose substitution in the main chain (backbone), which is made up of xylose residues, and the presence of connected ferulic acid all affect how viscous water solutions of AXs are [46]. The soluble AXs come in two different varieties: arabinoxylan I and arabinoxylan II [74]. The first one has a series of xylose residues with over 50% replaced at the O-3 position by arabinose residues. Arabinoxylan II is made up of a series of xylose residues having 60–70% of their O-2 and O-3 locations replaced by arabinose residues [74]. Compared to arabinoxylan type I molecules, arabinoxylan type II molecules exhibit a greater association with viscosity. AXs' aqueous solutions' inherent viscosities range from 1.96 dL/g to 4.23 dL/g [75], [76].

Additionally, β-glucans have the power to make aqueous solutions viscous. According to the literature, the extraction technique, molar mass, temperature, solution pH, concentration, and aggregation capacity all have an impact on the viscosity of β-glucans [44], [77]–[79]. Typically, -glucan water solutions have inherent viscosities that range from 0.28 dL/g to 7.2 dL/g [80], [81].

At relatively low concentrations, galactomannans can produce extremely viscous aqueous solutions that are only marginally influenced by pH, ion concentration, and treatment with heat. Galactomannan solutions have high viscosity and are highly stable over a broad pH range (1–10.5), mostly because their molecules are neutral [59], [82]. Galactomannan aqueous solutions mentioned in the literature have inherent viscosities that range from 9.7 dL/g to 14.3 dL/g [83], [84].

The intrinsic viscosity of arabinogalactans in aqueous solutions ranged from 0.045 to 0.062 dL/g [75].

The pH, molar mass and structure, ionic strength, and polymer content of pectin polysaccharides all affect their capacity to generate very viscous solutions. As the molar mass of pectins increases, so does their viscosity in aqueous solutions [85]. Additionally, pH has an impact on the viscosity of pectic polysaccharide solutions. This is because the electrical charge of polysaccharides influences a shift in the molecular structure of the chains of those molecules [86]. The electrostatic repellent forces between the pectin chains are weaker in an acidic environment due to the reduced dissociation of the carboxyl groups that are part of the galacturonic acid residues, and as a result, the viscosity of an aqueous solution of such polysaccharides will be higher than that of an aqueous solution of polysaccharides with a neutral or alkaline pH [87]. High-methylated pectic polysaccharides gels at acidic pH (3.6), whereas low-methylated pectic polysaccharides gel at a wide pH range (3.5-8.5) [88], [89]. Fruit-derived pectic polysaccharides have intrinsic viscosities that range from 0.64 dL/g to 5.9 dL/g in aqueous solutions [90], [91]. The viscosity of aqueous solutions of xyloglucans, pectic polysaccharides, and arabinogalactans, from cereal grains is not well-documented in the literature.

* 1. **CROSS LINKING**

Nearby AX molecules can establish a covalent bond with ferulic acid residues under oxidizing circumstances and in the occurrence of free radicals, leading to cross-linking [92], [93]. The peroxidase/hydrogen peroxide systems (both of which exist natively in flour and yeast) or an enzyme called laccase are the two substances that are most frequently used to cross-link AX [93]. Monomeric ferulic acid is oxidized and transformed to the isomers of dehydrodiferulic acid or dehydrotriferulic acid during the enzymatic coupling reaction [94]. The molecular structure of AX, or their molar mass, the degree to which the xylan skeleton has been replaced by arabinose residues, and the amount and distribution of ferulic acid within the molecules all have an impact on how effectively they cross-link. More covalent cross-links are capable of being produced if there are more ferulic acid residues present in the polysaccharide backbone. It is estimated that the ferulic acid concentration of AX molecules derived from cereal grains ranges from 0.4 to 450 mg/100 g [31], [95]–[100]. Cross-linking produces NSPs with large molar masses and hence high viscosities [101]. Horseradish peroxidase and hydrogen peroxide cross-linked AX has a weight average molar mass that ranges from 191,000 g/mol to 720,000 g/mol [97], [102]–[104], while laccase cross-linked AX has a weight average molar mass that ranges from 159,000 g/mol to 508,000 g/mol [105]–[107].

By employing ethylene glycol diglycidyl ether (EDGE) in a mixture of 4% sodium hydroxide, β-glucans from euglenin cells and a strain of the bacteria Alcaligenes faecalis, kurdlan, were cross-linked to produce substances with higher hydrophilic properties (better capacity to form a gel). By severing the hydrogen bonds between the molecules' chains, cross-linked β-glucans are produced, which results in the formation of new hydroxyl groups [108].

There are currently no reports on the cross-linking of pectic polysaccharides, arabinogalactans, or xyloglucans, of cereal grain origin.

* 1. **SURFACE TENSION**

Cohesive interactions among water molecules produce surface tension. The surface tension of water is reduced as a result of active surfactants' disruption of the interactions of cohesive forces between water molecules [109]. This is crucial since the adhesion of dough, food emulsions, and liquid foods to packaging, processing machinery, and leftover wastes results in large financial losses [110].

According to research, adding AX to water in concentrations ranging from 0.2% to 1.6% lowers its surface tension from 72 mN/m to roughly 52 mN/m [75].

Water's surface tension is somewhat decreased by β-glucans, but not significantly. The surface tension drop is more apparent at larger concentrations of β-glucans. Surface tension decreased by about 10 mN/m in the case of 1% β-glucans, but it decreased by less than 1 mN/m in the the existence of 0.5% β-glucans [111].

The surface tension of water dropped from 72 mN/m to 61 mN/m in the presence of 0.4-0.5% galactomannans derived from fenugreek seeds [112].

Surface tension was similarly reduced by pectin polysaccharides from orange peel and pigeon pea (likely arabinogalactan) [113]. Surface tension dropped from 72 mN/m to roughly 50 mN/m with the incorporation of 1.5% pigeon pea polysaccharides, and from 72 mN/m to 53 mN/m with the inclusion of 1.5% citrus peel pectin [113].

There are no known effects of pectic polysaccharides, arabinogalactans, or xyloglucans, from cereal grains on water's surface tension.

* 1. **MOLAR MASS**

In terms of molar mass, NSPs derived from natural origin are polydisperse, meaning that the size of their molecules varies [114].

Size Exclusion Chromatography (SEC) is the primary method used to determine the weight average molar mass of cereal AX, which is typically between 197,800 and 2,000,000 g/mol for rye, 176,000,000 and 381,000 g/mol for wheat, 276,000 and 1,220,000 g/mol for barley grains, 244,000 and 491,000 g/mol for corn, and 24,400 and 232,000 g/mol for rice 6, 7, 9, 76, 92, [27], [102], [115]–[118].

Oat β-glucans have a molar mass ranging from 172,000 g/mol to 2,300,000 g/mol [77], [78], [119]–[125], while barley β-glucans have a molar mass ranging from 187,000 g/mol to 2,340,000 g/mol [57], [126]–[129]. It is estimated that the weight average molar mass of β-glucans in wheat grain ranges from 487,000 to 635,000 g/mol, while it is 970,000 g/mol in rye grain [122], [130], [131].

It has not been possible to determine the molar mass of pectins, xyloglucans, and arabinogalactans from cereals. Galactomannans produced from fenugreek seeds are thought to have an average weight molar mass of 1,170,000–1,810,000 g/mol [112], [132], [133]. Arabinogalactans had an average molar mass of 16,000 g/mol in Mongolian larch and 141,000 g/mol in *Polygonatum sibiricum* rhizome [104], [134]. The weight average molar mass of xyloglucans in azuki bean seeds ranges from 98,000 to 420,000 g/mol, while it is 480,000 to 2,400,000 g/mol in tamarind and *Detarium senegalense* seeds [65], [135], [136]. Fruit pectins' typical molar masses have been found to range from 61,000 g/mol to 247,000 g/mol [90], [137].

1. **INFLUENCE OF NSP ON HUMAN BODY**

As a result of their significant contribution to the quick movement of digestive contents, NSPs have a positive impact on how well the digestive system functions [138]. In addition, the fermentation of NSPs produces short-chain fatty acids (SCFAs), which have a number of health-promoting qualities, such as preventing or treating diarrhea and reducing the growth of pathogenic organisms [139], [140]. Because they influence the growth of bifidobacteria, or probiotic bacteria, in the colon, both AXs and β-glucans from cereal have a prebiotic impact [141], [142].

As immunomodulators, AXs and -glucans have an impact on both innate as well as acquired immunity [143]–[146]. Immune cells (including granulocytes, macrophages, monocytes, and natural killer cells) have pattern recognition receptors that can attach to -glucan molecules [147]–[149]. They exhibit anticancer action as a result of this property [150], [151]. Furthermore, AX molecules with ferulic acid in their molecular structure might have antioxidant properties [152]. Clinical studies have shown that the therapeutic immunostimulatory characteristics of -glucans from fungal cell walls include antibacterial, anti-inflammatory, anti-tumor, and faster wound healing [153], [154]. NSPs show promise in the management of diabetes and obesity, two common disorders in contemporary society.

AXs reduce postprandial levels of blood glucose, control insulin response, and promote the release of postprandial ghrelin, also known as "the hunger hormone" and produced by gastric cells [141], [155], [156]. Because AXs make aqueous solutions more viscous, bread that contains these polysaccharides in the baking process has a lower glycemic index [157].

In both the pharmaceutical and food sectors, morel (*Morchella esculenta*) galactomannans have the potential to operate as an immunomodulator.

1. **CONCLUSION**

This chapter summarizes the overview of non-starch polysaccharides, different types of non-starch polysaccharides, different ways to estimate them and their various properties. This also gives an insight of influence of non-starch polysaccharides on human body. A lot of literature on starch polysaccharides have been reported but very less literatures on non-starch polysaccharides have been reported till now. So, there is a scope for non-starch polysaccharides as they have some important physiochemical properties that can be used as a thickening, stabilizing, gelling and emulsifying agent in preparation of food products.

**REFERENCES**

[1] K. Sethy, S. K. Mishra, P. P. Mohanty, J. Agarawal, P. Meher, D. Satapathy, and S. M. Nayak, “An overview of non-starch polysaccharide,” *J Anim Nutr Physiol*, vol. 1, pp. 17-22, 2015.

[2] M. Chen, L. Guo, J. Nsor-Atindana, H. D. Goff, W. Zhang, “The effect of viscous soluble dietary fiber on nutrient digestion and metabolic responses Ⅰ: In vitro digestion process,” *Food Hydrocoll*, vol. 107, Oct. 2020, doi: 10.1016/j.foodhyd.2020.105971.

[3] L. Wang, B. Zhang, J. Xiao, Q. Huang, C. Li, and X. Fu, “Physicochemical, functional, and biological properties of water-soluble polysaccharides from *Rosa roxburghii* Tratt fruit,” *Food Chem*, vol. 249, pp. 127–135, May 2018, doi: 10.1016/j.foodchem.2018.01.011.

[4] Z. Zhou, F. Ye, L. Lei, S. Zhou, and G. Zhao, “Fabricating low glycaemic index foods: Enlightened by the impacts of soluble dietary fibre on starch digestibility,” *Trends in Food Science and Technology*, vol. 122. Elsevier Ltd, pp. 110–122, Apr. 01, 2022. doi: 10.1016/j.tifs.2022.02.016.

[5] D. A. Silva, G. C. M. Aires, and R. Silva Pena, “Gums characteristics and applications in the food industry,” in *Innovation in the food sector through the valorization of food and agro-food by-products*, 2020.

[6] Z., Wang, L., Yang, J., Wu, H., Zhang, L., Zhu, and X. Zhan, “Potential application of a low-viscosity and high-transparency xanthan gum produced from Xanthomonas campestris CCTCC M2015714 in foods.,” *Preparative Biochemistry and Biotechnology*, vol. 48, no. 5, pp. 402–407, 2018.

[7] A. Bordoloi, J. Singh, and L. Kaur, “*In vitro* digestibility of starch in cooked potatoes as affected by guar gum: Microstructural and rheological characteristics,” *Food Chem*, vol. 133, no. 4, pp. 1206–1213, Aug. 2012, doi: 10.1016/j.foodchem.2012.01.063.

[8] A. K. Sinha, V. Kumar, H. P. S. Makkar, G. De Boeck, and K. Becker, “Non-starch polysaccharides and their role in fish nutrition - A review,” *Food Chemistry*, vol. 127, no. 4. pp. 1409–1426, Aug. 15, 2011. doi: 10.1016/j.foodchem.2011.02.042.

[9] M. Choct, “Non-starch polysaccharides: effect on nutritive value.,” in *Poultry feedstuffs: supply, composition and nutritive value*, CABI Publishing, 2002, pp. 221–235. doi: 10.1079/9780851994642.0221.

[10] C. T. Brett and K. W. Waldron, *Physiology and biochemistry of plant cell walls*, 2nd ed., vol. 2. London: Chapman&Hall, 1996.

[11] G. Fincher and B. Stone, “Chemistry of nonstarch polysaccharides,” *Elsevier Academic Press*, 2004.

[12] B. G. B Fincher, W. Sawyer, and B. A. STONEt, “Chemical and Physical Properties of an Arabinogalactan-Peptide from Wheat Endosperm,” 1974.

[13] H. J., He, J., Qiao, Y., Liu, Q. Guo, X. , Ou, and X. Wang, “Isolation, Structural, Functional, and Bioactive Properties of Cereal Arabinoxylan─ A Critical Review,” *J Agric Food Chem*, vol. 69, no. 51, pp. 15437–15457, 2021.

[14] R. R., Selvendran and M. S. Du Pont, “An alternative method for the isolation and analysis of cell wall material from cereals,” *Cereal Chem*, vol. 57, no. 4, pp. 278–283, 1980.

[15] C. Barron, C. Bar-L’Helgouac’h, M. Champ, and L. Saulnier, “Arabinoxylan content and grain tissue distribution are good predictors of the dietary fibre content and their nutritional properties in wheat products,” *Food Chem*, vol. 328, Oct. 2020, doi: 10.1016/j.foodchem.2020.127111.

[16] M. S. Izydorczyk and C. G. Biliaderi, “Cereal arabinoxylans: advances in structure and physicochemical properties,” 1995.

[17] D. J. Mares and B. A. Stone, “Studies on wheat endosperm II. Properties of the wall components and studies on their organization in the wall,” *Aust J Biol Sci*, vol. 26, no. 4, pp. 813–830, 1973, doi: 10.1071/BI9730813.

[18] T., Geissmann and H. Neukom, “On the composition of the water-soluble wheat flour pentosans and their oxidative gelation,” 1973.

[19] E., Dornez, K., Gebruers, S., Wiame, J. A., Delcour, and C. M. Courtin, “Insight into the distribution of arabinoxylans, endoxylanases, and endoxylanase inhibitors in industrial wheat roller mill streams,” *J Agric Food Chem*, vol. 54, no. 22, pp. 8521–8529, 2006.

[20] K. Gebruers, E. Dornez, D. Boros, W. Dynkowska, Z. Bedő, M. Rakszegi, and C. M. Courtin, “Variation in the content of dietary fiber and components thereof in wheats in the HEALTHGRAIN diversity screen,” *Journal of Agricultural and Food Chemistry*, vol. 56, no. 21, pp. 9740-9749, 2008

[21] Y. Hemery, X. Rouau, V. Lullien-Pellerin, C. Barron, and J. Abecassis, “Dry processes to develop wheat fractions and products with enhanced nutritional quality,” *J Cereal Sci*, vol. 46, no. 3, pp. 327–347, Nov. 2007, doi: 10.1016/j.jcs.2007.09.008.

[22] A. Kaur, M. P. Yadav, B. Singh, S. Bhinder, S. Simon, and N. Singh, “Isolation and characterization of arabinoxylans from wheat bran and study of their contribution to wheat flour dough rheology,” *Carbohydr Polym*, vol. 221, pp. 166–173, Oct. 2019, doi: 10.1016/j.carbpol.2019.06.002.

[23] L. Saulniet, C. Marot, E. Chanliaud, and J.-F. Thibault, “Cell wall polysaccharide interactions in maize bran,” 1995.

[24] M. P. Yadav, D. B. Johnston, A. T. Hotchkiss, and K. B. Hicks, “Corn fiber gum: A potential gum arabic replacer for beverage flavor emulsification,” *Food Hydrocoll*, vol. 21, no. 7, pp. 1022–1030, Oct. 2007, doi: 10.1016/j.foodhyd.2006.07.009.

[25] M. P. Yadav, R. A. Moreau, and K. B. Hicks, “Phenolic acids, lipids, and proteins associated with purified corn fiber arabinoxylans,” *J Agric Food Chem*, vol. 55, no. 3, pp. 943–947, 2007.

[26] L. W. Doner, D. B. Johnston, and V. Singh, “Analysis and properties of arabinoxylans from discrete corn wet-milling fiber fractions,” *J Agric Food Chem*, vol. 49, no. 3, pp. 1266–1269, 2001.

[27] X. Zheng, L. Li, and X. Wang, “Molecular characterization of arabinoxylans from hull-less barley milling fractions,” *Molecules*, vol. 16, no. 4, pp. 2743–2753, Apr. 2011, doi: 10.3390/molecules16042743.

[28] H. Chen, Z. Chen, Y. Fu, J. Liu, S. Lin, Q. Zhang, and W. Qin, “Structure, antioxidant, and hypoglycemic activities of arabinoxylans extracted by multiple methods from triticale,” *Antioxidants*, vol. 8, no. 12, pp. 584, 2019

[29] Z. Zhang, C. Smith, and W. Li, “Extraction and modification technology of arabinoxylans from cereal by-products: A critical review,” *Food Research International*, vol. 65, no. PC, pp. 423–436, Nov. 2014, doi: 10.1016/j.foodres.2014.05.068.

[30] M. P. Yadav, M. S. Kale, K. B. Hicks, and K. Hanah, “Isolation, characterization and the functional properties of cellulosic arabinoxylan fiber isolated from agricultural processing by-products, agricultural residues and energy crops,” *Food Hydrocoll*, vol. 63, pp. 545–551, Feb. 2017, doi: 10.1016/j.foodhyd.2016.09.022.

[31] A. Fadel, A. M. Mahmoud, J. J. Ashworth, W. Li, Y. L. Ng, and A. Plunkett, “Health-related effects and improving extractability of cereal arabinoxylans,” *International Journal of Biological Macromolecules*, vol. 109. Elsevier B.V., pp. 819–831, Apr. 01, 2018. doi: 10.1016/j.ijbiomac.2017.11.055.

[32] S. Malgas, J. S. van Dyk, and B. I. Pletschke, “A review of the enzymatic hydrolysis of mannans and synergistic interactions between β-mannanase, β-mannosidase and α-galactosidase,” *World J Microbiol Biotechnol*, vol. 31, pp. 1167–1175, 2015.

[33] S. Singh, G. Singh, and S. K. Arya, “Mannans: An overview of properties and application in food products,” *International Journal of Biological Macromolecules*, vol. 119. Elsevier B.V., pp. 79–95, Nov. 01, 2018. doi: 10.1016/j.ijbiomac.2018.07.130.

[34] S. Dhawan and J. Kaur, “Microbial mannanases: an overview of production and applications,” *Crit Rev Biotechnol*, vol. 27, no. 4, pp. 197–216, 2007.

[35] L. R. S. Moreira and E. X. F. Filho, “An overview of mannan structure and mannan-degrading enzyme systems,” *Appl Microbiol Biotechnol*, vol. 79, pp. 165–178, 2008.

[36] L. Bailoni, M. Bonsembiante, S. Schiavon, G. Pagnin, and F. Tagliapietra, “Estimation of the content of pectins in feeds: Fractional extraction and quantitative determination,” *Vet Res Commun*, vol. 27, no. SUPPL. 1, pp. 249–251, Sep. 2003, doi: 10.1023/B:VERC.0000014152.80334.86.

[37] D. Zhang, L. Wang, B. Tan, and W. Zhang, “Dietary fibre extracted from different types of whole grains and beans: a comparative study,” *Int J Food Sci Technol*, vol. 55, no. 5, pp. 2188–2196, 2020.

[38] M. Abid, S. Cheikhrouhou, C. M. Renard, S. Bureau, G. Cuvelier, H. Attia, and M. A. Ayadi, “Characterization of pectins extracted from pomegranate peel and their gelling properties,” *Food Chemistry*, vol. 215, pp. 318-325, 2017.

[39] N. M. Ptitchkina, I. A. Danilova, G. Doxastakis, S. Kasapis, and E. R. Morris, “Pumpkin pectin: gel formation at unusually low concentration,” *Carbohydr Polym*, vol. 23, no. 4, pp. 265–273, 1994.

[40] S. M. Brejnholt, “Pectin,” *Food stabilisers, thickeners and gelling agents*, pp. 237–265, 2009.

[41] B. De Cindio, D. Gabriele, and F. R. Lupi, “Pectin: Properties Determination and Uses,” *De Cindio, B.; GaEncyclopedia of Food and Health*, pp. 294–300, 2016.

[42] L. Bailoni, S. Schiavon, G. Pagnin, F. Tagliapietra, and M. Bonsembiante, “Quanti-qualitative evaluation of pectins in the dietary fibre of 24 foods,” *Ital J Anim Sci*, vol. 4, no. 1, pp. 49–58, 2005, doi: 10.4081/ijas.2005.49.

[43] M. Q. Guo, X. Hu, C. Wang, and L. Ai, “Polysaccharides: structure and solubility,” *Solubility of polysaccharides*, vol. 2, pp. 8–21, 2017.

[44] M. Choct, “Feed Milling International,” 1997.

[45] G. Annison, “The role of wheat non-starch polysaccharides in broiler nutrition,” *Aust J Agric Res*, vol. 44, no. 3, pp. 405–422, 1993.

[46] C. M. Courtin and J. A. Delcour, “Arabinoxylans and endoxylanases in wheat flour bread-making,” *J Cereal Sci*, vol. 35, no. 3, pp. 225–243, 2002, doi: 10.1006/jcrs.2001.0433.

[47] K. liyama, T. Bach-Tuyet Lam, and B. A. Stone, “Covalent Cross-Links in the Cell Wall,” 1994.

[48] G. Cleemput, S. P. Roels, M. Van Oort, P. J. Grobet, and J. A. Delcour, “Heterogeneity in the structure of water-soluble arabinoxylans in European wheat flours of variable bread-making quality,” *Cereal Chem*, vol. 70, pp. 324–329, 1993.

[49] H.-U. Jürgens, G. Jansen, and C. B. Wegener, “Characterisation of Several Rye Cultivars with Respect to Arabinoxylans and Extract Viscosity,” *Journal of Agricultural Science*, vol. 4, no. 5, Mar. 2012, doi: 10.5539/jas.v4n5p1.

[50] M. S. Izydorczyk and J. E. Dexter, “Barley β-glucans and arabinoxylans: Molecular structure, physicochemical properties, and uses in food products-a Review,” *Food Research International*, vol. 41, no. 9, pp. 850–868, Nov. 2008, doi: 10.1016/j.foodres.2008.04.001.

[51] N. Böhm and W. M. Kulicke, “Rheological studies of barley (1→3) (1→4)-β-glucan in concentrated solution: Mechanistic and kinetic investigation of the gel formation,” *Carbohydrate Research*, vol. 315, pp. 302–311, 1999.

[52] S. M. Tosh, Y. Brummer, S. S. Miller, A. Regand, C. Defelice, R. Duss, and P. J. Wood, “Processing affects the physicochemical properties of β-glucan in oat bran cereal,” *Journal of agricultural and food chemistry*, vol. 58, no. 13, pp. 7723-7730, 2010.

[53] A. A. M. Andersson, N. Rüegg, and P. Åman, “Molecular weight distribution and content of water-extractable β-glucan in rye crisp bread,” *J Cereal Sci*, vol. 47, no. 3, pp. 399–406, May 2008, doi: 10.1016/j.jcs.2007.05.008.

[54] M. U. Beer, P. J. Wood, J. Weisz, and N. Fillion, “Effect of cooking and storage on the amount and molecular weight of (1→ 3) (1→ 4)‐β‐D‐glucan extracted from oat products by an in vitro digestion system,” *Cereal Chem*, vol. 74, no. 6, pp. 705–709, 1997.

[55] S. M. Tosh, Y. Brummer, T. M. S. Wolever, and P. J. Wood, “Glycemic response to oat bran muffins treated to vary molecular weight of β-glucan,” *Cereal Chem*, vol. 85, no. 2, pp. 211–217, 2008, doi: 10.1094/CCHEM-85-2-0211.

[56] A. Regand, Z. Chowdhury, S. M. Tosh, T. M. S. Wolever, and P. Wood, “The molecular weight, solubility and viscosity of oat beta-glucan affect human glycemic response by modifying starch digestibility,” *Food Chem*, vol. 129, no. 2, pp. 297–304, Nov. 2011, doi: 10.1016/j.foodchem.2011.04.053.

[57] S. H. Lee, G. Y. Jang, M. Y. Kim, I. G. Hwang, H. Y. Kim, K. S. Woo, “Physicochemical and *in vitro* binding properties of barley β-glucan treated with hydrogen peroxide,” *Food Chem*, vol. 192, pp. 729–735, Jul. 2016, doi: 10.1016/j.foodchem.2015.07.063.

[58] P. J. Wood, “Physiochemical characteristics and physiological properties of oat (1-3) (1-4)-ß-D-glucan in Oat Bran,” *American Association of Cereal Chemists*, p. 83, 1993.

[59] V. D. Prajapati, G. K. Jani, N. G. Moradiya, N. P. Randeria, B. J. Nagar, N. N. Naikwadi, and B. C. Variya, B. C, “Galactomannan: A versatile biodegradable seed polysaccharide,” *International journal of biological macromolecules*, vol. 60, pp. 83-92, 2013.

[60] M. Srivastava and V. P. Kapoor, “Seed galactomannans: an overview,” *Chem Biodivers*, vol. 2, no. 3, pp. 295–317, 2005.

[61] F. Garcia‐Ochoa and J. A. Casas, “Viscosity of locust bean (*Ceratonia siliqua*) gum solutions,” *J Sci Food Agric*, vol. 59, no. 1, pp. 97–100, 1992.

[62] D. Genene Demisu, “Production of Natural Pectin from Locally Available Fruit Waste and Its Applications as Commercially Value-added Product in Pharmaceuticals, Cosmetics and Food Processing Industries,” *WNOFNS*, vol. 20, pp. 1–11, 2018, [Online]. Available: [www.worldnewsnaturalsciences.com](http://www.worldnewsnaturalsciences.com)

[63] B. K. Simpson, K. B. Egyankor, and A. M. Martin, “Extraction, purification and determination of pectin in tropical fruits,” *J Food Process Preserv*, vol. 8, no. 2, pp. 63–72, 1984.

[64] J. Y. Chen, M. Piva, and T. P. Labuza, “Evaluation of water binding capacity (WBC) of food fiber sources,” *J Food Sci*, vol. 49, no. 1, pp. 59–63, 1984.

[65] D. R. Picout, S. B. Ross-Murphy, N. Errington, and S. E. Harding, “Pressure cell assisted solubilization of xyloglucans: Tamarind seed polysaccharide and detarium gum,” *Biomacromolecules*, vol. 4, no. 3, pp. 799–807, May 2003, doi: 10.1021/bm0257659.

[66] R. Căpriţă, A. Căpriţă, and C. Julean, “Biochemical Aspects of Non-Starch Polysaccharides,” 2010.

[67] C. G. Biliaderis, M. S. Izydorczyk, and O. Rattan, “Effect of arabinoxylans on bread-making quality of wheat flours,” 1995.

[68] D. Bender, R. Nemeth, G. Cavazzi, F. Turoczi, E. Schall, S. D'Amico, and R. Schoenlechner, “Characterization of rheological properties of rye arabinoxylans in buckwheat model systems,” *Food Hydrocoll*, vol. 80, pp. 33–41, Jul. 2018, doi: 10.1016/j.foodhyd.2018.01.035.

[69] K. A. Andrewartha, D. R. Phillips, and B. A. Stone, “Solution properties of wheat-flour arabinoxylans and enzymically modified arabinoxylans,” *Carbohydr Res*, vol. 77, no. 1, pp. 191–204, 1979.

[70] S. Bengtsson, P. Åman, and R. E. Andersson, “Structural studies on water-soluble arabinoxylans in rye grain using enzymatic hydrolysis,” *Carbohydr Polym*, vol. 17, no. 4, pp. 277–284, 1992.

[71] W. Bushuk, “Distribution of water in dough and bread,” in *The Bakers Digest*, 1996, pp. 38–40.

[72] A. Kaur, B. Singh, M. P. Yadav, S. Bhinder, and N. Singh, “Isolation of arabinoxylan and cellulose-rich arabinoxylan from wheat bran of different varieties and their functionalities,” *Food Hydrocoll*, vol. 112, Mar. 2021, doi: 10.1016/j.foodhyd.2020.106287.

[73] A. Ahmad, F. M. Anjum, T. Zahoor, H. Nawaz, and A. Din, “Physicochemical and functional properties of barley b-glucan as affected by different extraction procedures,” *Int J Food Sci Technol*, vol. 44, no. 1, pp. 181–187, Jan. 2009, doi: 10.1111/j.1365-2621.2008.01721.x.

[74] W. Sittikijyothin, D. Torres, and M. P. Gonçalves, “Modelling the rheological behaviour of galactomannan aqueous solutions,” *Carbohydr Polym*, pp. 339–350, 2005.

[75] M. Izydorczyk, C. G. Biliaderis, and W. Bushuk, “Physical properties of water-soluble pentosans from different wheat varieties,” *Cereal Chem*, vol. 68, pp. 145–150, 1991.

[76] K. Buksa, W. Praznik, R. Loeppert, and A. Nowotna, “Characterization of water and alkali extractable arabinoxylan from wheat and rye under standardized conditions,” *J Food Sci Technol*, vol. 53, pp. 1389–1398, 2016.

[77] S. W. Cui, “Polysaccharide Gums: Structures, Functional Properties, and Applications Characterizations of natural polysaccharides View project Effects of water-soluble forms of dietary fibre on postprandial meatbolism View project Marta S Izydorczyk Agriculture and Agri-Food Canada,” 2005. [Online]. Available: https://www.researchgate.net/publication/265671939

[78] A. Lazaridou, C. G. Biliaderis, and M. S. Izydorczyk, “Molecular size effects on rheological properties of oat β-glucans in solution and gels,” *Food Hydrocoll*, vol. 17, no. 5, pp. 693–712, 2003, doi: 10.1016/S0268-005X(03)00036-5.

[79] G. Annison, “The role of wheat non-starch polysaccharides in broiler nutrition,” *Aust J Agric Res*, vol. 44, no. 3, pp. 405–422, 1993.

[80] J. K. Agbenorhevi, V. Kontogiorgos, A. R. Kirby, V. J. Morris, and S. M. Tosh, “Rheological and microstructural investigation of oat β-glucan isolates varying in molecular weight,” *Int J Biol Macromol*, vol. 49, no. 3, pp. 369–377, 2011, doi: 10.1016/j.ijbiomac.2011.05.014.

[81] C. Gómez, A. Navarro, P. Manzanares, A. Horta, and J. V. Carbonell, “Physical and structural properties of barley (1→3), (1→4)-β-D-glucan. Part II. Viscosity, chain stiffness and macromolecular dimensions,” *Carbohydr Polym*, vol. 32, pp. 17–22, 1997.

[82] D. G. Rao, “Studies on viscosity-molecular weight relationship of chitosan solutions,” *J Food Sci Technol*, pp. 66–67, 1993.

[83] E. G. Azero and C. T. Andrade, “Testing procedures for galactomannan purification,” 2002. [Online]. Available: www.elsevier.com/locate/polytestMaterialProperties

[84] N. A. Thombre and P. S. Gide, “Rheological characterization of galactomannans extracted from seeds of Caesalpinia pulcherrima,” *Carbohydr Polym*, vol. 94, no. 1, pp. 547–554, Apr. 2013, doi: 10.1016/j.carbpol.2013.01.051.

[85] Y. Isobe, K. Endo, and H. Kawai, “Properties of a highly viscous polysaccharide produced by a Bacillus strain isolated from soil,” *Bioscience, Biotechnology & Biochemistry*, vol. 56, pp. 636–639, 1992.

[86] P. Sriamornsak, “Chemistry of pectin and its pharmaceutical uses: A review,” *Silpakorn University International Journal*, vol. 3, pp. 206–228, 2003.

[87] D. Oakenfull and A. Scott, “Hydrophobic Interaction in the Gelation of High Methoxyl Pectins.”

[88] X. Yang, T. Nisar, Y. Hou, X. Gou, L. Sun, and Y. Guo, “Pomegranate peel pectin can be used as an effective emulsifier,” *Food Hydrocoll*, vol. 85, pp. 30–38, Dec. 2018, doi: 10.1016/j.foodhyd.2018.06.042.

[89] T. Geissmann and H. Neukom, “On the composition of the water-soluble wheat flour pentosans and their oxidative gelation,” *Lebensmittel-Wissenschaft & Technologie*, vol. 6, pp. 59–62, 1973.

[90] M. L. Fishman, D. T. Gillespie, S. M. Sondey, and Y. S. El-Atawy, “Intrinsic viscosity and molecular weight of pectin components\*,” 1991.

[91] Z. K. Muhidinov, M. L. Fishman, K. K. Avloev, M. T. Norova, A. S. , Nasriddinov, and D. K. Khalikov, “Effect of temperature on the intrinsic viscosity and conformation of different pectins,” *Polymer Science Series A*, vol. 52, pp. 1257–1263, 2010.

[92] M. C. Figueroa-Espinoza and X. Rouau, “Oxidative cross-linking of pentosans by a fungal laccase and horseradish peroxidase: Mechanism of linkage between feruloylated arabinoxylans,” *Cereal Chem*, vol. 75, no. 2, pp. 259–265, 1998, doi: 10.1094/CCHEM.1998.75.2.259.

[93] E. Carvajal-Millan, V. Landillon, M. H. Morel, X. Rouau, J. L. Doublier, and V. Micard, “Arabinoxylan gels: Impact of the feruloylation degree on their structure and properties,” *Biomacromolecules*, vol. 6, no. 1, pp. 309–317, 2005.

[94] G. Hartmann, M. Piber, and P. Koehler, “Isolation and chemical characterisation of water-extractable arabinoxylans from wheat and rye during breadmaking,” *European Food Research and Technology*, vol. 221, pp. 487–492, 2005.

[95] S. Zhou, X. Liu, Y. Guo, Q. Wang, D. Peng, and L. Cao, “Comparison of the immunological activities of arabinoxylans from wheat bran with alkali and xylanase-aided extraction,” *Carbohydr Polym*, vol. 81, no. 4, pp. 784–789, Jul. 2010, doi: 10.1016/j.carbpol.2010.03.040.

[96] R. Guo, Z. Xu, S. Wu, X. Li, J. Li, H. Hu, and L. Ai, “Molecular properties and structural characterization of an alkaline extractable arabinoxylan from hull-less barley bran,” *Carbohydr Polym*, vol. 218, pp. 250–260, Aug. 2019, doi: 10.1016/j.carbpol.2019.04.093.

[97] K. Buksa, R. Ziobro, A. Nowotna, W. Praznik, and H. Gambuś, “Isolation, modification and characterization of soluble arabinoxylan fractions from rye grain,” *European Food Research and Technology*, vol. 235, pp. 385–395, 2012.

[98] T. Verwimp, V. Van Craeyveld, C. M. Courtin, and J. A. Delcour, “Variability in the structure of rye flour alkali-extractable arabinoxylans,” *J Agric Food Chem*, vol. 55, no. 5, pp. 1985–1992, 2007.

[99] P. Yuwang, I. Sulaeva, J. Hell, U. Henniges, S. Böhmdorfer, T. Rosenau, and S. Tongta, “Phenolic compounds and antioxidant properties of arabinoxylan hydrolysates from defatted rice bran,” *J Sci Food Agric*, vol. 98, no. 1, pp. 140–146, 2018.

[100] B. Vogel, D. D. Gallaher, and M. Bunzel, “Influence of cross-linked arabinoxylans on the postprandial blood glucose response in rats,” *J Agric Food Chem*, vol. 60, no. 15, pp. 3847–3852, 2012.

[101] R. Aveyard and D. A. Haydon, *An introduction to the principles of surface chemistry*. Cambridge University Press, 1973.

[102] K. Buksa, A. Nowotna, and R. Ziobro, “Application of cross-linked and hydrolyzed arabinoxylans in baking of model rye bread,” *Food Chem*, vol. 192, pp. 991–996, Jul. 2016, doi: 10.1016/j.foodchem.2015.07.104.

[103] M. E. F. Schooneveld-Bergmans, M. J. W. Dignum, J. H. Grabber, G. Beldman, and A. G. J. Voragen, “Studies on the oxidative cross-linking of feruloylated arabinoxylans from wheat flour and wheat bran.”

[104] O. Rattan, M. S. Izydorczyk, and C. G. Biliaderis, “Structure and rheological behaviour of arabinoxylans from Canadian bread wheat flours,” *J Food Sci Technol*, vol. 27, no. 6, pp. 550–555, 1994.

[105] R. González-Estrada, M. Calderón-Santoyo, E. Carvajal-Millan, F. D. J. Ascencio Valle, J. A. Ragazzo-Sánchez, F. Brown-Bojorquez, and A. Rascón-Chu, “Covalently cross-linked arabinoxylans films for Debaryomyces hansenii entrapment,” *Molecules*, vol. 20, no. 6, pp. 11373–11386, Jun. 2015, doi: 10.3390/molecules200611373.

[106] X. Li, Q. Chen, G. Liu, H. Xu, and X. Zhang, “Chemical elucidation of an arabinogalactan from rhizome of Polygonatum sibiricum with antioxidant activities,” *Int J Biol Macromol*, vol. 190, pp. 730–738, Nov. 2021, doi: 10.1016/j.ijbiomac.2021.09.038.

[107] S. Yilmaz-Turan, P. Lopez-Sanchez, A. Jiménez-Quero, T. S. Plivelic, and F. Vilaplana, “Revealing the mechanisms of hydrogel formation by laccase crosslinking and regeneration of feruloylated arabinoxylan from wheat bran,” *Food Hydrocoll*, vol. 128, Jul. 2022, doi: 10.1016/j.foodhyd.2022.107575.

[108] Y. Matsumoto, Y. Enomoto, S. Kimura, and T. Iwata, “Highly deformable and recoverable cross-linked hydrogels of 1,3-α-D and 1,3-β-D-glucans,” *Carbohydr Polym*, vol. 251, Jan. 2021, doi: 10.1016/j.carbpol.2020.116794.

[109] B. Adhikari, T. Howes, A. Shrestha, and B. R. Bhandari, “Effect of surface tension and viscosity on the surface stickiness of carbohydrate and protein solutions,” *J Food Eng*, vol. 79, no. 4, pp. 1136–1143, Apr. 2007, doi: 10.1016/j.jfoodeng.2006.04.002.

[110] K. Buksa, A. Nowotna, R. Ziobro, and H. Gambus̈, “Rye flour enriched with arabinoxylans in rye bread making,” *Food Science and Technology International*, vol. 21, no. 1, pp. 45–54, Jan. 2015, doi: 10.1177/1082013213504771.

[111] Z. Burkus and F. Temelli, “Stabilization of emulsions and foams using barley β-glucan.” [Online]. Available: www.elsevier.com/locate/foodres

[112] M. K. Youssef, Q. Wang, S. W. Cui, and S. Barbut, “Purification and partial physicochemical characteristics of protein free fenugreek gums,” *Food Hydrocoll*, vol. 23, no. 8, pp. 2049–2053, Dec. 2009, doi: 10.1016/j.foodhyd.2009.03.017.

[113] R. Syed, H. H. Ding, D. Hui, and Y. Wu, “Physicochemical and functional properties of pigeon pea (*Cajanus cajan*) protein and non-starch polysaccharides,” *Bioactive Carbohydrates and Dietary Fibre*, vol. 28, Nov. 2022, doi: 10.1016/j.bcdf.2022.100317.

[114] M. Q. Guo, X. Hu, C. Wang, and L. Ai, “Polysaccharides: Structure and solubility,” in *Solubility of Polysaccharides*, Rijeka, Croatia, 2017, pp. 7–20.

[115] J. M. Storsley, M. S. Izydorczyk, S. You, C. G. Biliaderis, and B. Rossnagel, “Structure and physicochemical properties of β-glucans and arabinoxylans isolated from hull-less barley,” in *Food Hydrocoll*, Elsevier, 2003, pp. 831–844. doi: 10.1016/S0268-005X(03)00104-8.

[116] Y. Sun, S. W. Cui, X. Gu, and J. Zhang, “Isolation and structural characterization of water unextractable arabinoxylans from Chinese black-grained wheat bran,” *Carbohydr Polym*, vol. 85, no. 3, pp. 615–621, Jun. 2011, doi: 10.1016/j.carbpol.2011.03.021.

[117] M. S. Kale, M. P. Yadav, H. K. Chau, and A. T. Hotchkiss, “Molecular and functional properties of a xylanase hydrolysate of corn bran arabinoxylan,” *Carbohydr Polym*, vol. 181, pp. 119–123, Feb. 2018, doi: 10.1016/j.carbpol.2017.10.008.

[118] R. S. P. Rao and G. Muralikrishna, “Structural characteristics of water-soluble feruloyl arabinoxylans from rice (*Oryza sativa*) and ragi (finger millet, *Eleusine coracana*): Variations upon malting,” *Food Chem*, vol. 104, no. 3, pp. 1160–1170, 2007, doi: 10.1016/j.foodchem.2007.01.015.

[119] J.-L. Doublier and P. J. Wood, “Rheological Properties of Aqueous Solutions of (1→3), (1→4)-β-D-Glucan from Oats (*Avena sativa* L.) 1,” 1995.

[120] A. Skendi, C. G. Biliaderis, A. Lazaridou, and M. S. Izydorczyk, “Structure and rheological properties of water soluble β-glucans from oat cultivars of *Avena sativa* and *Avena bysantina,” J Cereal Sci, vol. 38, no. 1, pp. 15–31, 2003, doi: 10.1016/S0733-5210(02)00137-6.*

[121] A. Lazaridou, C. G. Biliaderis, M. Micha-Screttas, and B. R. Steele, “A comparative study on structure-function relations of mixed-linkage (1→3), (1→4) linear β-D-glucans,” *Food Hydrocoll*, vol. 18, no. 5, pp. 837–855, Sep. 2004, doi: 10.1016/j.foodhyd.2004.01.002.

[122] Q. Zhao, X. Hu, Q. Guo, S. W. Cui, Y. Xian, S. You, and X. Gao, “Physicochemical properties and regulatory effects on db/db diabetic mice of β-glucans extracted from oat, wheat and barley,” *Food Hydrocoll*, vol. 37, pp. 60–68, Jun. 2014, doi: 10.1016/j.foodhyd.2013.10.007.

[123] K. Autio, O. Myllymäki, T. Suortti, M. Saastamoinen, and K. Poutanen, “Physical properties of (1→ 3), (1→ 4)-β-D-glucan preparates isolated from Finnish oat varieties,” *Food Hydrocoll*, vol. 5, no. 6, pp. 513–522, 1992.

[124] M. U. Beer, P. J. Wood, and J. Weisz, “Molecular weight distribution and (1→ 3), (1→ 4)‐β‐D‐glucan content of consecutive extracts of various oat and barley cultivars,” *Cereal Chem*, vol. 74, no. 4, pp. 476–480, 1997.

[125] P. Åman, L. Rimsten, and R. Andersson, “Molecular weight distribution of β‐glucan in oat‐based foods,” *Cereal Chem*, vol. 81, no. 3, pp. 356–360, 2004.

[126] H. Vaikousi, C. G. Biliaderis, and M. S. Izydorczyk, “Solution flow behavior and gelling properties of water-soluble barley (1 → 3,1 → 4)-β-glucans varying in molecular size,” *J Cereal Sci*, vol. 39, no. 1, pp. 119–137, 2004, doi: 10.1016/j.jcs.2003.09.001.

[127] S. W. Cui, “Processing, Structures and Functionality,” in *Polysaccharide Gums from Agricultural Products*, FL, USA: CRC Press., 2001, pp. 1–284.

[128] M. Irakli, C. G. Biliaderis, M. S. Izydorczyk, and I. N. Papadoyannis, “Isolation, structural features and rheological properties of water‐extractable β‐glucans from different Greek barley cultivars,” *J Sci Food Agric*, vol. 84, no. 10, pp. 1170–1178, 2004.

[129] H. Vaikousi, C. G. Biliaderis, and M. S. Izydorczyk, “Solution flow behavior and gelling properties of water-soluble barley (1→3,1→4)-β-glucans varying in molecular size,” *Journal of Cereal Science* , vol. 39, pp. 119–137, 2004.

[130] W. Li, S. W. Cui, and Y. Kakuda, “Extraction, fractionation, structural and physical characterization of wheat β-d-glucans,” *Carbohydr Polym*, vol. 63, no. 3, pp. 408–416, Mar. 2006, doi: 10.1016/j.carbpol.2005.09.025.

[131] R. Andersson, G. Fransson, M. Tietjen, and P. Åman, “Content and molecular-weight distribution of dietary fiber components in whole-grain rye flour and bread,” *J Agric Food Chem*, vol. 57, no. 5, pp. 2004–2008, 2009.

[132] M. A. Cerqueira, A. I. Bourbon, A. C. Pinheiro, J. T. Martins, B. W. S. Souza, J. A. Teixeira, and A. A. Vicente, “Galactomannans use in the development of edible films/coatings for food applications,” *Trends in Food Science and Technology*, vol. 22, no. 12. pp. 662–671, Dec. 2011. doi: 10.1016/j.tifs.2011.07.002.

[133] Y. Brummer, W. Cui, and Q. Wang, “Extraction, purification and physicochemical characterization of fenugreek gum.” [Online]. Available: www.elsevier.com/locate/foodhyd

[134] P. Odonmažig, A. Ebringerová, E. Machová, and J. Alföldi, “Structural and molecular properties of the arabinogalactan isolated from Mongolian larchwood (Larix dahurica L.),” *Carbohydrate Research*, vol. 252, pp. 317–324, 1994.

[135] K. Soga, K. Wakabayashi, T. Hoson, and S. Kamisaka, “Hypergravity Increases the Molecular Mass of Xyloglucans by Decreasing Xyloglucan-Degrading Activity in Azuki Bean Epicotyls,” 1999. [Online]. Available: https://academic.oup.com/pcp/article/40/6/581/1925923

[136] K. Nishitani and R. Tominaga, “In vitro molecular weight increase in xyloglucans by an apoplastic enzyme preparation from epicotyls of Vigna angularis,” *Physiol Plant*, vol. 82, pp. 490–497, 1991.

[137] M. Y. Sayah, R. Chabir, H. Benyahia, Y. Rodi Kandri, F. Ouazzani Chahdi, H. Touzani, and F. Errachidi, “Yield, esterification degree and molecular weight evaluation of pectins isolated from orange and grapefruit peels under different conditions. ,” *PLoS One*, vol. 11, no. 9, 2016.

[138] K. P. Scott, S. H. Duncan, and H. J. Flint, “Dietary fibre and the gut microbiota,” *Nutrition Bulletin*, vol. 33, pp. 201–211, 2008.

[139] V. Kumar, A. K. Sinha, H. P. S. Makkar, G. de Boeck, and K. Becker, “Dietary roles of non-starch polysachharides in human nutrition: A review,” *Crit Rev Food Sci Nutr*, vol. 52, pp. 899–935, 2012.

[140] C. Grootaert, J. A. Delcour, C. M. Courtin, W. F. Broekaert, W. Verstraete, and T. Van deWiele, “Microbial metabolism and prebiotic potency of arabinoxylan oligosaccharides in the human intestine,” *Trends Food Science and Technology*, vol. 18, pp. 64–71, 2007.

[141] B. R. Hamaker and Y. E. Tuncil, “A perspective on the complexity of dietary fiber structures and their potential effect on the gut microbiota,” *J Mol Biol*, vol. 426, pp. 3838–3850, 2014.

[142] A. Estrada, C.-H. Yun, A. Van Kessel, B. Li, S. Hauta, and B. Laarveld, “Immunomodulatory Activities of Oat P-Glucan In Vitro and In Vivo,” 1997.

[143] L. Cao, X. Liu, T. Qian, G. Sun, Y. Guo, F. Chang, and X. Sun, “Antitumor and immunomodulatory activity of arabinoxylans: A major constituent of wheat bran,” *Int J Biol Macromol*, vol. 48, no. 1, pp. 160–164, Jan. 2011, doi: 10.1016/j.ijbiomac.2010.10.014.

[144] M. Akhtar, A. F. Tariq, M. M. Awais, Z. Iqbal, F. Muhammad, M. Shahid, and E. Hiszczynska-Sawicka, “Studies on wheat bran Arabinoxylan for its immunostimulatory and protective effects against avian coccidiosis,” *Carbohydr Polym*, vol. 90, no. 1, pp. 333–339, Sep. 2012, doi: 10.1016/j.carbpol.2012.05.048.

[145] M. R. Savitha Prashanth, R. R. Shruthi, and G. Muralikrishna, “Immunomodulatory activity of purified arabinoxylans from finger millet (Eleusine coracana, v. Indaf 15) bran,” *J Food Sci Technol*, vol. 52, pp. 6049–6054, 2015.

[146] F. Hong, J. Yan, J. T. Baran, D. J. Allendorf, R. D. Hansen, G. R. Ostroff, P. X. Xing, N. K. V. Cheung, G. D. Ross, “Mechanism by which orally administered  β-1,3-glucans enhance the tumoricidal activity of antitumor monoclonal antibodies in murine tumor models,” *Journal of Immunology*, vol. 173, pp. 797–806, 2004.

[147] J. M. Gaullier, J. Sleboda, E. S. Ofjord, E. Ulvestad, M. Nurminiemi, C. Moe, and O. Gudmundsen, “Supplementation with a Soluble Beta-Glucan Exported from Shiitake Medicinal mushroom, Lentinus edodes (Berk.) Singer Mycelium: A Crossover, Placebo-Controlled Study in Healthy Elderly,” 2011. [Online]. Available: [www.begellhouse.com](http://www.begellhouse.com)

[148] M. F. Ahmad, F. A. Ahmad, M. I. Khan, A. A. Alsayegh, S. Wahab, M. I. Alam, and F. Ahmed, “Ganoderma lucidum: A potential source to surmount viral infections through β-glucans immunomodulatory and triterpenoids antiviral properties,” *International Journal of Biological Macromolecules*, vol. 187. Elsevier B.V., pp. 769–779, Sep. 30, 2021. doi: 10.1016/j.ijbiomac.2021.06.122.

[149] A. L. Garcia, B. Otto, S. C. Reich, M. O. Weickert, J. Steiniger, A. Machowetz, and C. Koebnick, “ Arabinoxylan consumption decreases postprandial serum glucose, serum insulin and plasma total ghrelin response in subjects with impaired glucose tolerance,” *European Journal of Clinical Nutrition*, vol. 61, pp. 334–341, 2007.

[150] Z. Hromádková, B. S. Paulsen, M. Polovka, Z. Košťálová, and A. Ebringerová, “Structural features of two heteroxylan polysaccharide fractions from wheat bran with anti-complementary and antioxidant activities,” in *Carbohydrate Polymers*, Mar. 2013, pp. 22–30. doi: 10.1016/j.carbpol.2012.05.021.

[151] A. Mpofu, H. D. Sapirstein, and T. Beta, “Genotype and environmental variation in phenolic content, phenolic acid composition, and antioxidant activity of hard spring wheat,” *J Agric Food Chem*, vol. 54, no. 4, pp. 1265–1270, Feb. 2006, doi: 10.1021/jf052683d.

[152] G. D. Brown, S. Gordon, and S. William, “Minireview Fungal-Glucans and Mammalian Immunity,” 2003.

[153] J. Chen and R. Seviour, “Medicinal importance of fungal β-(1→3), (1→6)-glucans,” *Mycological Research*, vol. 111, no. 6. pp. 635–652, Jun. 2007. doi: 10.1016/j.mycres.2007.02.011

[154] Z. X. Lu, K. Z. Walker, J. G. Muir, T. Mascara, and K. O’Dea, “Arabinoxylan fiber, a byproduct of wheat flour processing, reduces the postprandial glucose response in normoglycemic subjects,” *The American Journal of Clinical Nutrition*, pp. 1123–1128, 2000.

[155] M. Möhlig, C. Koebnick, M. O. Weickert, W. Lueder, B. Otto, J. Steiniger, and H. J. Zunft, “Arabinoxylan-enriched meal increases serum ghrelin levels in healthy humans,” *Hormone and Metabolic Research*, vol. 37, no. 5, pp. 303–308, May 2005, doi: 10.1055/s-2005-861474.

[156] D. J. Jenkins, C. W. Kendall, L. S. Augustin, S. Franceschi, M. Hamidi, A. Marchie, and M. Axelsen, “Glycemic index: Overview of implications in health and disease,” *The American Journal of Clinical Nutrition*, vol. 76, pp. 266–273, 2002.

[157] S. Zhang, Z. Lin, D. Wang, X. Xu, C. Song, L. Sun, and Y. Zhou, Y, “Galactofuranose side chains in galactomannans from Penicillium spp. modulate galectin-8-mediated bioactivity,” *Carbohydr Polym*, vol. 292, Sep. 2022, doi: 10.1016/j.carbpol.2022.119677.