Functional and nutraceutical properties of maize bran cell wall non-starch polysaccharides

Farhan Saeed\textsuperscript{a}, Muzzamal Hussain\textsuperscript{a}, Muhammad Sajid Arshad\textsuperscript{a}, Muhammad Afzaal\textsuperscript{a}, Haroon Munir\textsuperscript{a}, Muhammad Imran\textsuperscript{b}, Tabussam Tufail\textsuperscript{b}, and Faqir Muhammad Anjum\textsuperscript{c}

\textsuperscript{a}Department of Food Sciences, Government College University, Faisalabad, Pakistan; \textsuperscript{b}University Institute of Diet & Nutritional Sciences, The University of Lahore, Lahore, Pakistan; \textsuperscript{c}Administration department, University of the Gambia, Serrekunda, Gambia

\begin{abstract}
In most of the countries around the world, the ever increase in food processing industries around the world is producing various types of by-products including peel, bran, pomace, refused pulp, shells, hull, husk, pods, seeds. With increasing activity in health-promoting functional foods, increase in the demand for natural bioactive moieties and new areas of research are on the way. Many by-products have been explored for health endorsing properties however, maize bran cell walls (MBCWs) and their various components (non-starch polysaccharides) are of chief importance. In this review, efforts are focused to illustrate the functional and nutraceutical importance of maize bran cell walls. Maize bran cell wall is made up of non-starch polysaccharide materials including arabinoxylans, heteroxylans, and hemicellulose. It holds various bioactive compounds such as ferulic acid, diferulic acid, and \textit{p}-coumaric acid, having enormous nutraceutical properties, like antioxidant, anticancer, anti-inflammatory, anti-microbial, antiaging, cardioprotective, prebiotic and antiviral effects. These bioactive compounds are protecting against various disorders, like hypercholesterolemia, diabetes, cancer, neurodegenerative, cardiovascular, and thrombosis diseases. Furthermore, extraction, functional and nutraceutical properties, possible uses, and industrial applications of MBCW are the limelight of this article.
\end{abstract}

\section*{INTRODUCTION}
Agricultural residues are rich in bioactive compounds and despite their health benefits, they have not been sufficiently used in the food system.\textsuperscript{[1]} These residues may be used directly for the manufacturing of specific foods or after certain modifications, separation, and purification of various components.\textsuperscript{[2]} The recovery and modification of industrial residues in the food industry are becoming ever more necessary. The aim is to use the raw material more effectively and reduce pollution and waste management problems.\textsuperscript{[3]} The practice of agro-industrial waste as raw materials contributes to decrease the environmental pollution load and also minimizes the cost of production.\textsuperscript{[4]} Therefore, they are treated as waste. Being the non-product raw material sources, their economic value is lower than the production and reuse recovery costs. However, these wastes could be considered useful by-products if the value of the subsequent products is to exceed the cost of reprocessing and using suitable technical resources for recycling them. Agro-industrial by-products are used by isolation or purification for the production of nutrients, animal feed, biofuels, antioxidants, antibiotics, and other chemicals.\textsuperscript{[5]} Table 1

\section*{CONTACT}
Faqir Muhammad Anjum \textsuperscript{c} dranjum@utg.edu.gm \textsuperscript{c} Vice-Chancellor Sectriate, The University of Gambia, Serrekunda, Gambia, +220.

Published with license by Taylor & Francis Group, LLC.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
Cereal brans have high nutritional value with functional ingredients and enormous health properties. Despite their health benefits, cereal brans have not been completely used in food production. Cereal brans are obtained through the process of milling which also involves germ, aleurone layer, testa, pericarp, and a small portion of the starchy endosperm. Wheat, maize, rice, barley, oat, rye, millet, and sorghum are the major cereals consumed worldwide. The bran represents around 3–30% of the dried kernel weight, depending on the form of cereal kernel. Cereal brans differ in composition depending on the variety of the plant, kernel (maturity period, size, shape, outermost layer thickness) before milling, grain conditioning, and grain storage condition.

### Table 1. Composition of Maize Kernel composition of maize kernel per 100 g.

| Components       | Quantity       |
|------------------|----------------|
| Carbohydrate     | 72.63 g        |
| Protein          | 9.86 g         |
| Fat              | 5.00 g         |
| Fiber            | 2.26 g         |
| Ash              | 3.32 g         |
| Moisture         | 9.24 g         |
| Minerals         | 1.6 g          |
| Phosphorus       | 358 mg         |
| Sulfur           | 116 mg         |
| Iron             | 2.4 mg         |
| Magnesium        | 138 mg         |
| Amino acid       | 1.76 mg        |
| Calcium          | 11 mg          |
| Sodium           | 14.8 mg        |
| Potassium        | 298 mg         |
| Thiamine         | 0.44 mg        |
| Vitamin C        | 0.14 mg        |
| Riboflavin       | 0.11 mg        |
| Copper           | 0.16 mg        |

### Table 2. Maize Bran composition.

| Maize Bran components | Percentage [w/w] | References |
|-----------------------|------------------|------------|
| Heteroxylans          | 50% Approx.      | [49]       |
| Cellulose             | 20% approx.      | [44]       |
| Phenolic acids        | 6%               | [46]       |
| Starch                | 4–9%             | [33]       |
| Protein               | 10–13%           | [50]       |
| Lipids                | 2–3%             | [37]       |
| Ash                   | 2%               | [44]       |
| Fiber                 | 12.2%            | [51]       |

### Table 3. Components percentage in maize bran cell wall.

| Components                   | Percentage % | References |
|------------------------------|--------------|------------|
| Non-starch polysaccharides   | 67.5%        | [49]       |
| Heteroxylans (arabinose, xylose galactose and glucuronic acid) | 22.5% |          |
| Cellulose                    |              |            |
| Phenolics components         | 4.4%         | [69]       |
| (Ferulic acid and diferulic acid) |            |            |
| Acetic acid                  | 3.5%         | [49]       |
| Protein (Zain)               | 2.4%         | [70]       |
**Background**

Maize or corn is a worldwide important seasonal cereal crop belonging to the *Poaceae* family.\[10\] Maize was cultivated more than 7,200 years before in Mexico and has spread rapidly as a primary crop all over North and South America.\[11\] Maize is a worldwide high production and productivity chief cereal. It is farmed all over the world under diverse agro-climatic conditions.\[12\] In Developing countries, maize utilization for human beings is diminished nowadays. However, its consumption within the feed livestock and its applications in the wet-milling industry are growing fastly.\[13\] The feed sector is followed by the wet-milling process, which is the major requirement for maize originated.\[14\] The wet-milling process of maize kernel produced an array of food products, food by-products, and value addition of food items.\[15\] In the new world, maize kernel is the prime and most important staple cereal food product.\[16\] Maize produced a capsule, known as caryopsis which is also called maize kernel.\[17\] Maize kernel is a nutritive and also edible part of the plant. The maize kernel is formed from four leading structures, the bran (pericarp), endosperm, germ and tip cap, making up to 5%, 83%, 11%, and 1%, respectively.\[18\] Chemically, dried maize kernel comprises about 10.5% moisture, 7% to 11% protein, 4% lipid, 2.0% fiber, 1.2% ash and 72% to 75% carbohydrate. Maize kernel also contains water-soluble vitamins, Tocopherol, Phyloquinone. Se, N-ferrulyl tryptamine, N-p-coumaryl tryptamine, and folic acid. Maize plays an important role in macro-nutrients deficiencies as it is a rich source of potassium.\[19\] Shortly it contains macro and micronutrients such as vitamins and minerals. These will vary due to hybrid, variety, soil conditions, and growing seasons.\[20\] The composition of the maize kernel, as is the case with other cereals, varies depending on cultural practices, the variety used and soil type, weather conditions and other factors.\[21\] Maize is considered to be higher in nutrition than other cereals except in protein value. Maize relates very well to nutritive value with wheat and rice. It is superior in fiber, fat, and iron content.\[22\] Maize plays a key role in Pakistani people’s nutrition. In the absence of cereal grains, it can be used as an alternative source of food.\[23\]

**Maize production and utilization**

Currently, the total production of maize (Zea mays) is approximately 1099.6 (1133.8) million tons; the USA, China, Mexico, France, Brazil, Ukraine, India, Argentina, Canada, South Africa, Italy, and Indonesia produce 79% of the world maize production as shown in Figure 1.\[24\] Worldwide 60–70% of maize production is utilized commercially as animal feed, and the other 30–40% is utilized for human consumption food product production.\[25\]

Maize is chief yielding cereal harvest within the world, was of substantial rank for countries similar to Pakistan, where supply from quickly growing inhabitants has previously outstripped the accessible food, feed, and fodder supplies. Maize grades 3rd most grownup cereal in the world within an area of more than 122 million hectares with around 610 million metric tons production. In Pakistan, maize contributes 2.8% to the value-added in agriculture and 0.5% GDP (Gross Domestic Product). It is the third major cereal after wheat and rice which is used as cattle feed.\[26\] Pakistan ranked 31st in the area under maize farming, and in total maize production ranked 29th and 68th in yield among the world’s maize-growing countries.\[27\] The formed area of maize crop has increased to 1.334 million hectares, during 2016–17 showing an increase of 0.2% over the last year’s area of 1.142 million hectares. During 2016–17, maize production stood at 5.920 million tons, showing a decrease of 0.3% over the last year’s production of 4937 thousand tons. Maize appreciates a major role in the current crop systems of Pakistan.\[26\] Eighty-nine percent of the cereal crop is grownup in Khyber Pakhtunkhwa and Punjab. Ninety-nine percent of the total production of maize bulk originates from two major provinces, within Punjab contributing 48% of the area and KPK accounting for 51% of the overall area, but 69% in Punjab and 31% in KPK total maize kernel production. A less quantity of 1.1% is produced in the provinces of Baluchistan and Sindh.\[28\] Total maize production used approximately poultry feeds 60%, industries 25% and the remaining are used as food for humans and animals.\[26\]
Maize requirement is mostly from the livestock and poultry subsectors, is anticipated to enhance and further can be done to enhance value to maize crop in Pakistan. Maize is principally a carbohydrate plant, and hence it is the primary source of nutrition in different food products for humans and animals. The expansion in livestock and poultry division, in accumulation to other industrial
applications and human utilization, more stimulated the requirement which facilitated the foods and feed industry to offer focused costs to maize cultivator.\[^{31}\] The profitable wet-milling products are the oil (germ) and starch from the maize kernel. The oil present in maize (germ) is far and wide used for cooking and manufacture of soaps. It is used for the production of ethanol and malt as a biofuel.\[^{32}\] Maize kernel is economically important as it is used in the production of corn syrup and corn starch. Currently, maize bran has less value and however, is mostly used as feed for animals.\[^{33}\]

In Pakistan, the maize utilization in different industries is lesser as compared to its usage in animal feed including poultry, livestock. Wet-milling cereal industries are increased by using the latest
In composition technologies in food industries. Maize is commonly consumed for animal feed like livestock and poultry. Maize starch is a principal ingredient used as a feedstock for a host of industrial products, also utilize human and animal diets. Maize grains are consumed in a raw and cooked form that serves as a good origin of carbohydrates. Maize is extensively processed into numerous kinds of food products, for instance, cornmeal, flour, starch, tortillas, grits, breakfast cereal products and snacks. Maize flour is used to make flatbread or chapatis, which are eaten.

Composition of maize bran

In the developing world, the organized sector of the fast-growing food processing industry is expected to produce far more by-products in the coming years. These by-products are identified as good sources of several bioactive compounds as well as dietary fiber. The utilization of industrial by-products for the development of different human foods as dietary fiber, functional or innovative components have generated the huge potential for waste diminution and indirect revenue generation. During the maize milling process, maize bran is acquired as a byproduct. In the processing of maize, the milling process produces maize bran about 60–70 g/kg. Maize bran is a lavishly existing byproduct of the maize starch industry, most of that was utilized as feed or waste. The commercial maize dry milling process produced a by-product, maize bran. Maize bran is containing thick-walled cells initiating from the pericarp, pericarp, testa and aleurone layer remaining endosperm tissues. The main elements of maize bran are cellulose, hemicellulose, and phenolics. Maize bran is a novel origin of dietary fiber and phenolics antioxidant, plenteous origin of total dietary fiber TDF and phenolics. In a circumstance, of the main cereal kernel brans, maize bran is that the maximum in each of those components. The main part of the maize bran is hemicellulose, which is additionally a complex heteroxylan containing primarily of a xylans backbone with arabinosyl facet elements. A maize kernel integrates weight around 350 mg, and also the maize bran is concerning 5–7% of the overall bulk of the grain. The results of maize processing are immense quantities of maize bran which are utilized in the main for feed because of the fascinating constitution of the maize bran for this function. Maize bran composed of cellulose (22%), starch (9–22%), protein (10–12%), phenolics (4%), lipid (2–3%) and ash (1–2%). Maize bran insoluble substantial was mostly arabinoxylan and
heteroxylans, employing these two sugars started partial of the dry mass of the significant.\textsuperscript{[36]} Maize bran is comprising primarily of heteroxylans and cellulose and virtually lacking lignin. Heteroxylans are usually unextractable water and are supposed to be associated with cellulose-concluded hydrogen bonding and physical involvement within the cell wall.\textsuperscript{[37,43]} The milling process throughout the processing of maize generates 65 to 75 g/kg of maize bran. The 55% of the overall amount of the maize grain is heteroxylans, the bulk being arabinoxylan.\textsuperscript{[37,44]} Maize bran conjointly comprises a comparatively high mass of ferulic acid, that is involved in the heteroxylan through an ester linkage to arabinoxylan units. Each ferulic acid FA 3.2% and its dehydrodimers 1.9% were discharged from maize bran by alkaline treatment. Those (5–5’), (8–O’), (8–5’) dimers prevailed, however (a8–8’) dimer was additionally indicated.\textsuperscript{[45]} The maximum limit of ferulic acid FA was extracted from maize bran.\textsuperscript{[46]} Ferulic acid esterification developed oxidative cross-linkages, that is together with different intramolecular relations, produces insoluble compounds.\textsuperscript{[41]} It has a very high energy value and an appreciable level of crude protein.\textsuperscript{[45]} Maize bran contains possibly appreciated components, including dietary fiber, phenolic antioxidants, oil, and phytosterol esters.\textsuperscript{[36]} Maize bran is additionally rich in phenolics, Inglett & Chen,\textsuperscript{[47]} have involved wide research efforts as a result of several chronic diseases are thought to be strictly joined to the method of oxidative mutilation to special bio-molecules like deoxyribonucleic acid (DNA), membrane proteins, and lipids through various mechanisms.\textsuperscript{[48]}

**Application of maize bran as co-product**

Maize bran is less priced, food level cereal dietary fiber and antioxidant supplier, Maize bran is considered as less priced cereal dietary fiber that contains potentially valuable components, including oil, phytosterol esters, policosinol and phenolics.\textsuperscript{[49,50,51]} Maize bran has significant functional properties to decrease calorie products.\textsuperscript{[52]} Investigation on the application of maize milling coproducts in different food items initiated with the accumulation of maize bran to cakes,\textsuperscript{[53]} muffins, and bread to enhance the dietary fiber content of widely consumed foods.\textsuperscript{[54]} It improves emulsion and oxidative stability, can help as water enhancers or water absorption capacity, bulking agents (non-caloric), and oil retention agents.\textsuperscript{[55]} Consumption of those coproducts for food applications could raise the worth of these mill streams, decrease agricultural waste, and decline the cost of major maize products. Maize bran addition in snack foods may decrease the caloric value of the product. It is also utilized in home cooking to enhance the fiber content of several foods and to improve texture. Food applications of such coproducts may also deliver additional desirability.\textsuperscript{[56]} Maize bran could also be used as a preserved, like supplements, as cross-linking agents, or as material to natural vanillin manufacturing. It is used as a dietary fiber ingredient in breakfast cereal products.\textsuperscript{[41]}

**Maize bran cell wall**

The cell wall is an innovative multifunctional structure.\textsuperscript{[57]} Maize bran is containing thick-walled cells initiating from the pericarp, pericarp, testa, and aleurone layer remaining endosperm tissues.\textsuperscript{[38]} Pericarp and testa are non-living tissues and involve mainly of lignified cell walls, although the aleurone is metabolically active with thick, resistant cell walls. The starchy endosperm is a storage tissue with thin un-lignified cell walls which are easily degraded, when required and releases stored energy.\textsuperscript{[58]} The cell wall of maize bran was an excellent source of cellulose and anti-oxidant compounds. Maize cells have a distinctive primary cell wall in which cellulose microfibrils enclosed in a matrix of arabinoxylans (AXs) containing cell wall phenolics are included in the primary structural array.\textsuperscript{[59]} The main components of the cell wall are non-starch polysaccharides (Heteroxylans, arabinoxylans galactose, and glucuronic acid), cell wall protein, and phenolics compounds like ferulic acid, di-ferulic acid, and \( p \)-coumaric acid.\textsuperscript{[60]}
Cell walls extraction techniques

Alkali treatment has been broadly reported as a technique of extraction of arabinoxylans from cereal kernel brans, mostly maize kernel bran. [61] Saulnier et al. [49] isolated the maize bran cell wall by sequential extraction method. Partial enzymic or acid hydrolysis of cell walls and consequent chromatographic fractional process have permissible the separation from bran tissues of numerous oligosaccharides ester-linked to hydroxycinnamic acids and their structures were assessed by using NMR (Nuclear Magnetic Resonance) spectroscopy enzymic degradation, acetylation, and Methylation. Gartaula et al. [62] isolate the cell wall from wheat endosperm by enzymatic treatment and small feruloylated oligosaccharides and free phenolic acids, which are loosely bound to the cell wall surface and less cross-linked to other components [63] can be isolated by microwave irradiation or by ultrasound of samples containing 60–80% methanol [64] or ethanol. [65] Some reports have followed an enzymatic protocol for the preparation of soluble and insoluble dietary fibers, according to the study of bound phenolic compounds and feruloylated oligosaccharides, using the heat-stable amylase, protease, and amylloglucosidase sequence to eliminate starch and protein, and quantified the feruloylated arabinoxylan side chains from the cell wall. [66] Bader Ul Ain, et al. [67] isolated the cell wall from different cereals (wheat, sorghum, and barley) through enzymatic treatment. The cell wall content in wheat, sorghum, and barley were 5.68 ± 0.15, 4.02 ± 0.12 g/100 g, and 8.32 ± 0.21 g/100 g, respectively.

Maize bran cell walls constituents

Cell walls of the maize bran are in the main constitute of heteroxylans and cellulose however conjointly comprise important amounts of phenolics, some proteins, for example, the pericarp is mainly comprised of about 55% heteroxylans. [49] It has a very small lignin content about 2%, and around ferulic acid 6%, the maximum level of ferulic acid content present in maize bran cell wall. [68] The cell walls of maize bran are non-starch polysaccharides, known as arabinoxylan, and also an important constituent of the TDF (total dietary fiber) in cereals. [42]

Ferulic acid has an important result on the functionality of AXs, each inside the cell wall and when extraction. Dimers and trimers of ferulic acid, which are crosslink arabinoxylans molecules, normally present within the cell walls. [69] Higher amounts of ferulates are present chiefly in cereal brans, maize bran being a specific origin. [70] It represents about up to 4% of the maize bran cell wall. [71] Cell walls are widely utilized in a large number of foods, feed, and non-food sectors. [72] The main constituent of maize bran is non-starch polysaccharides, and 50% of that are Ferulated arabinoxylans (FAXs). [73] Such structural features of FAXs play a crucial role in their functional properties and thus gelling ability.

Although existing in moderately low amounts, ferulic acid has an important result on the functionality of AXs, each inside the cell wall and when extraction. Dimers and trimers of ferulic acid, which are crosslink arabinoxylans molecules, normally present within the cell walls. This is often one in all explanations for the water unextractable arabinoxylans WUAXs naturally. Water extractable arabinoxylans (WEAXs), on the opposite hand, are not cross-linked inside the cell walls and hence, WUAXs are water-soluble. [74] This non-starch polysaccharide conjointly generated research concentration within the world, because of their nutritive interest as soluble and insoluble fiber and therefore the occurrence of ferulic acids in the molecule which also has certain antioxidant activities. [75]

In cell wall of maize bran, Arabinoxylan gels have possible applications as sturdy, texturizing agents, stable food gels, and food preserver. [76] Covalently cross-linked arabinoxylans gels are generally strong, form quickly and are not temperature dependent. Moreover, these exhibit no syneresis after long time storage. [74] Arabinoxylans form highly viscous solutions. Under the action of certain oxidizing agents, AXs can form a gel-like structure. [73] Carvajal-Millan et al. [37] indicated that AXs stabilize emulsions by enhancing continuous stage in viscosity. The non-starch
polysaccharide is a novel constituent of herbal medicine and functional food. Quality assurance is an issue due to the complexity of non-starch polysaccharides.\cite{77} Ferulic acid in maize bran cell wall also acts as an antimicrobial agent in the bread industry to inhibit microbial growth on the bread slice and increase its shelf life. Ferulic acid’s potential to prevent fatty acid peroxidation allows it to be known as a natural preservative in different food products.\cite{21} The cross-linkages of phenolic acids are responsible for the insolubility of cereal dietary fibers, the gelling properties of arabinoxylans, and their indigestibility. Arabinoxylans are also used as food thickness and stabilizing agents, because of their water-holding capacity and high viscous property.\cite{63}

**Arabinoxylans**

Maize bran cell wall is made up of cellulose, substantial arabinoxylans, and roughly pectin.\cite{78} Zhu,\cite{79} described the interactions of cereal bran cell wall components and heteroxylans, the heteroxylan section covers the gaps between the cellulotic microfibrils, which are cross-linked with cell wall components and each other through di- and trifururate bridges, solidifying the structure of the cell wall and identifying the insoluble heteroxylan\". It contains around 45% (weight/weight) of heteroxylans comprised of a backbone of 1,4- related (3-D-xylene) residues exceedingly substituted at O-2 or O-3 by single units of xylose, arabinose, and glucuronic acid and by side chains of 2 or 3 units of arabinose, xylose, and galactose. Arabinoxylan is hemicellulose existing within the cereals’ cell walls as well as maize and wheat.\cite{63,80} It made up of pentose sugars, especially (xylose and arabinose) residues are often discussed as pentosans.\cite{81} Additionally, monosaccharides like arabinose, xylose, glucuronic acid, and galactose comprise variable volumes of phenolics, primarily trans ferulic acid. The arabinoxylans from maize kernels have an extremely branched structure.\cite{82} High molecular weight AXs also assembled cross-linked hydrogels because of their improved WHC (water holding capacities).\cite{83} These non-starch polysaccharides (arabinoxylans) are contained within the cell walls of the aleurone layer, the bran, and the endosperm tissues. Also, the content of arabinoxylan may vary based on environmental and genetic factors. Entire arabinoxylan content in grains ranges from 30.82% in maize bran.\cite{84}

**Ferulic acid**

Ferulic acid, the foremost galore hydroxycinnamic acid in cell wall non-starch polysaccharides, is extensively allocated in higher plants. Microbial enzymes, called Feruloyl esterase can also extract ferulic acid from the maize bran.\cite{116-118} Feruloyl esterase catalyzes the cleavage of the ester bond between ferulic acid and arabinosyl moiety on arabinoxylans.\cite{36} Ferulic acid FA in maize bran is sometimes connected to cell wall polymers by ester bond through their carboxylic acid group with the hydroxyl of the Alpha-L-arabino Syl side chains of xylans.\cite{57} Ferulic acid is identified as a strong phenolic antioxidant.\cite{36} Phenolic compounds in the biological system may scavenge free radicals,\cite{85} and also inhibit food spoilage.\cite{86} Natural antioxidants, for instance phenolic acids, tocopherols, and flavonoids, may improve food quality to prevent lipid peroxidation in food.\cite{87} P-coumaric, Ferulic and vanillin acids are the most prevalent free phenolic acids in wheat that revealing antioxidant activities.\cite{88} Feruloylated oligosaccharides from the facet chains of heteroxylans are antecedently extracted from maize bran by acid hydrolysis (reaction), and also the cross-linking of heteroxylan chains through ferulic acid is powerfully maintained by the occurrence of di-ferulic acid in bran.\cite{49} The maximum amount of ferulic acid is often present in maize bran.\cite{46} Ester-bound ferulic acid is often simply discharged by alkaline treatment.\cite{89,90}

**Industrial applications of maize bran cell wall**

The cell wall is generally utilized in different food sectors, non-food, and feed industries.\cite{75} Cell walls have a positive effect on the agricultural field (pathogenic resistance, silage digestibility), food
manufacturing sector (bread quality, biomass conversion), and dietary fiber for human health. Tabussam et al. explored that baking product quality has been enhanced with the addition of cereal bran cell wall during processing. Water-extractable arabinoxylans (WEAXs) are not crosslinked within the cell walls and soluble in water. WEAXs are known not only for their ability to develop viscous solutions, as well as for their gelling strength When treated with an oxidizing agent. The cell walls of maize bran are highly tolerant to enzymatic degradation, reasonable because of the highly branched character of the heteroxylan, then likewise due to the high level of cross-linking by differential bridges and the high level of ferulic acid esterified to arabinoxylan, which may limit the accessibility of enzymes. Additionally, ferulic acid can be extracted by enzymatic and chemical method and can be utilized as an antioxidant (precursor to many useful aromatic chemicals) including vanillin.

**Health benefits of maize bran cell wall**

The cell wall of maize bran is linked with ferulic acid and p-coumaric acid with hemicellulosic non-starch polysaccharides, specifically arabinoxylans. Non-starch polysaccharides with several biological activities have been thoroughly studied and health advantages are usually regarded as the main functional components of food and medicine. Conjugated phenolics (free or bound form), that are generally linked to cell wall components in maize bran. Specially, ferulic acid is mainly present in the maize bran cell walls, found in hemicellulosic non-starch polysaccharides, esterified with arabinose residues. In fact, ferulic acid has cross-linked with non-starch polysaccharide chains, due to this reason ferulic acid is essential for the cell wall structure and function. In medicinal and pharmaceutical uses, the biological properties of AXs such as antioxidant, anticancer, and prebiotic, in addition to its gelling ability result in significant interest. AXs is distinguished by rising the levels of butyric acid, which play a significant role in sustaining health and gastrointestinal function. Therefore, AXs specific features and functional properties make these non-starch polysaccharides interesting for biopharmaceutical applications.

Ferulic acid is a natural antioxidant that has the ability to cure numerous disorders including diabetes, cancer, cardiovascular and neurodegenerative diseases. Ferulic acid ridiculous herbs were used to treat thrombosis in China for many years. Platelet aggregation, one of the processes elaborated in the healing of blood vessel injuries, is interrelated to diseases like thrombosis. Kim et al. confirmed the cholesterol-lowering effect of the ferulic acid. It was reported that ferulic acid prevented cholesterol formation by aggressively preventing the action of hydroxymethylglutaryl CoA reductase in the liver and by enhancing the acidic sterol excretion. Feruloylated arabinoxylans in human diets containing whole grains bran (especially cell wall) comprise a significant portion of the health-promoting dietary fiber chain, in which they can generate both prebiotic and (effectively) antioxidative health benefits. These components in maize bran cell wall have positive health effects. Some health benefits of maize bran cell wall are discussed in the following sections:

**Antioxidant**

The arabinoxylan antioxidant activity in the cell wall was mainly associated with its phenolic acid content, especially ferulic acid. Arabinoxylan (as dietary fiber) also helps against cardiovascular diseases, obesity, cancer, and diabetes type II. Ferulic acid is a derivative of caffeic acid that are present in cell wall and studied with numerous advantageous health effects, especially cardiovascular, anti-carcinogenic and neuro-protective properties, anti-inflammatory, and free radical scavenging activities. Also it helps to prevent lower serum, increased hepatic cholesterol and increased sperm viability, diabetes, and aging. Ferulic acid exhibits its antioxidant ability through various mechanisms, like free radical scavenging, blocking the free radical chain, metal chelation, reducing potential, modulating enzymatic activity, and altering signal transduction pathways. Ferulic acid has significant antioxidant effects in both free and conjugate forms. FA released through the action of FAEs from the maize bran cell wall is an active natural antioxidant with
potential applications in the food industries and pharmaceutical. FAEs could be utilized in paper processing, pulp, and as animal feed additives to facilitate nutrient accommodation. FAEs play a vital role in polysaccharide chains’ delignification and depolymerization as cross-linking through the FA ester bond significantly increases biomass recalcitrance and enzymatic hydrolysis resistance.

The key role of antioxidants is to inhibit or prevent the oxidation of free radicals. Free radicals are produced by various factors, including normal diet, metabolic activity, and the environment. As a natural way, the body uses antioxidant endogenous enzymes as a defense mechanism against free radicals. The increase in the accumulation of free radicals and other reactive oxygen species that exceeds normal levels in the body causes oxidative stress. This imbalance causes damage to biomolecules, including lipoproteins, membrane lipids, and DNA (increases the risk of developing chronic diseases). Consequently, the use of antioxidants helps to becoming sufficient to reduce the influence of free radicals and the risk of chronic diseases, like cancer.\textsuperscript{[73]}

While AXs antioxidant activity is associated with the presence of phenolic acids, some studies indicate this activity is related specifically to FA. Its structural features are due to the antioxidant activity of FA. The existence on its benzene ring of electron-donating groups gives it the ability of terminating the free radical chain reactions. Furthermore, the COOH group may bind to the lipid bilayer, offering protection against lipid peroxidation and the attack of free radicals.\textsuperscript{[100]} The most abundant phenolic acid in AXs is ferulic acid, it may be the most responsible for the polysaccharide antioxidant function, as has been reported in numerous studies. FA content and appearance assess AXs antioxidant capacity. Higher FA (tri-FA) trimmer content in AXs leads to increased antioxidant activity.\textsuperscript{[101]} This activity is due to three units of FA, which enhance the ability of the hydrogen donor, supply higher amounts of OH–groups, thereby protecting against radical scavenging.\textsuperscript{[73]} Thus, when describing the antioxidant potential of AXs, consideration should be given not only to the FA content but also to how it is contained in the molecule. Knowledge of these structural features will help to predict AXs antioxidant activity to be considered for various applications.

**Anticancer**

Cancer cells contain large amounts of hydrogen peroxide which can promote mutations, destruction, and other tissue invasion. Then, the proliferation of cancer cells impacts directly on the antioxidant mechanism and certain anticancer agents may act as antioxidants accordingly.\textsuperscript{[102]} Some researcher has shown the AXs capacity of anticancer. This ability is due to both the prebiotic and antioxidant ability of polysaccharide. Additionally, it is indicated that AXs impose their anticancer effect through a mechanism involving its ability to immune-modulate. Studies in vitro as well as in vivo have shown AXs anticancer activity on various forms of cancer. However, most studies illustrate their beneficial role in colon cancer prevention, due to the advantages of their and immunostimulatory function prebiotic activity.\textsuperscript{[73]} The colon is also an important site of metabolism of the ferulic acid. The ferulic acid is efficiently metabolized into phenyl propionic acids by the intestinal microbiota, which can be absorbed.\textsuperscript{[66]}

AXs demonstrate protective effects against colon cancer that were associated with its prebiotic effect. Femia et al.\textsuperscript{[103]} found that preneoplastic lesions in rat colon were decreased by the administration of AXs. The researchers suggest that because of their prebiotic behavior, Arabinoxylan-Oligosaccharides AXOS has shown a chemo-preventive effect on colon carcinogenesis. In addition, Glei et al.\textsuperscript{[104]} showed that wheat AXs short-chain fatty acid (SCFA) fermentation products prevented the development of colon cancer cells (HT29). AXs as a prebiotic also result from producing helpful bacterial metabolites, like short-chain fatty acids (SCFA). Ferulated AXs exhibit prebiotic and antioxidant properties which provide the polysaccharide to anticancer potential. While AXs gels retain their prebiotic and antioxidant properties, antiproliferative activity should also be exerted. High cross-linking density AXs gels in the treatment of colon cancer may be a suitable option for drug delivery of targeted colon cells.\textsuperscript{[73]}
Antimicrobial and anti-inflammatory agent

Ferulic acid also has a specific antimicrobial potential against different pathogens in the maize bran cell wall. It has an activity on Gram-negative, Gram-positive bacteria and yeasts. It demonstrated a strong inhibitory effect against the *Helicobacter pylori*, *Escherichia coli*, *Enterobacter aerogenes*, *Citrobacter koseri*, *Shigella sonnei*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae*, having an effect on the human gastrointestinal microflora, that’s already present in the anti-inflammatory drug composition.\(^{105}\) However, it is emphasized that ferulic acid has revealed antibacterial activity against *Streptococcus pneumoniae* and *Bacillus subtilis*.\(^{106}\) It is stated that ferulic acid has the highest antifungal activity among 12 phenolic acids against *Alternaria sp.*, *Sclerotinia sclerotiorum*, *Penicillium digitatum*, *Botrytis cinerea*, and *Fusarium oxysporum*.\(^{94}\) Galvez Ranilla, et al.\(^{107}\) showed the antimicrobial activity of free and bound phenolics fraction from maize accession. In fact, as potentially effective alternatives to conventional anti-inflammatory drugs, phenolic compounds like flavonoids, cinnamic acids, and lignans are assessed.\(^{88}\) Kim et al.\(^{95}\) reported that the extracted phenolic amides in maize bran a valuable preventive and therapeutic agent against inflammatory responses.

Conclusion

In the discipline of nutrition, plentiful priority has been requited to functional and nutraceutical foods. These functional foods have sanctioned to vigorous components. These components are pivotal for appropriate physiological functionality of whole-body organs. Among these components, maize bran cell wall holds the potential to act as both functional as well as nutraceutical components. Moreover, with the addition of different levels of cell wall in flour during processing, rheological characteristics are enhanced, thus baking product quality is also improved. It is also used as a venerable source of bioactive compounds including FA, di-FA and p-coumaric acid. FA is a powerful antioxidant, promotes proper gastrointestinal function, inhibits platelet aggregation and thrombosis, and serves as cholesterol-lowering agent. FAXs contain health-promoting dietary fiber chain and also prevent cholesterol formation by enhancing the acidic sterol excretion. These phenolics compounds having higher antioxidant activity are used to increase the shelf life of different food products. FA acts as an antimicrobial agent and also inhibits food spoilage. The cross-linkages of phenolic acids are responsible for the insolubility of cereal dietary fibers, the gelling properties of arabinoxylans, and their indigestibility used as prebiotic Arabinoxylans can be used as stable food gels, food thickness and stabilizing agents, because of their water-holding capacity and high viscous property.

Abbreviations

Ferulic acid (FA), Arabinoxylans (AXs), Feruloylated arabinoxylans (FAXs), Feruloyl esterase’s (FAEs), Total dietary fiber (TDF), Nuclear Magnetic Resonance (NMR), Water extractable arabinoxylans (WEAXs), Water unextractable arabinoxylans (WUAXs).

References

[1] Luithui, Y.; Nisha, R. B.; Meera, M. S. Cereal By-products as an Important Functional Ingredient: Effect of Processing. *J. Food Sci. Technol.* 2019, 56(1), 1–11. DOI: 10.1007/s13197-018-3461-y.
[2] Jablonský, M.; Škulcová, A.; Malvis, A.; Šima, J. Extraction of Value-added Components from Food Industry Based and Agro-forest Biowastes by Deep Eutectic Solvents. *J. Biotechnol.* 2018, 282, 46–66.
[3] Ravindran, R.; Jaiswal, A. K. Exploitation of Food Industry Waste for High-value Products. *Trends Biotechnol.* 2016, 34, 58–69.
[4] Sadh, P. K.; Duhan, S.; Duhan, J. S. Agro-industrial Wastes and Their Utilization Using Solid State Fermentation: A Review. *Bioresour. Bioprocess.* 2018, 5, 1.
[34] James, M. G.; Denyer, K.; Myers, A. M. Starch Synthesis in the Cereal Endosperm. Curr. Opin. Plant Biol. 2003, 6, 215–222.

[35] Sharma, S. K.; Bansal, S.; Mangal, M.; Dixit, A. K.; Gupta, R. K.; Mangal, A. Utilization of Food Processing By-products as Dietary, Functional, and Novel Fiber: A Review. Crit. Rev. Food Sci. Nutr. 2016, 56, 1647–1661.

[36] Rose, D. J.; Inglett, G. E. Production of Feruloylated Arabinoxyl-o-oligosaccharides from Maize (Zea Mays) Bran by Microwave-assisted Autohydrolysis. Food Chem. 2010, 119, 1613–1618.

[37] Carvajal-Millán, E.; Rascón-Chu, A.; Márquez-Escalante, J. A.; Micard, V.; de León, N. P.; Gardea, A. Maize Bran Gum: Extraction, Characterization and Functional Properties. Carbohydr. Polym. 2007, 69, 280–285. DOI: 10.1016/j.carbpol.2006.10.006.

[38] Tufail, T.; Saeed, F.; Arshad, M. U.; Afzaal, M.; Rasheed, R.; Bader Ul Ain, H.; Imran, M.; Abrar, M.; Farooq, M. A.; Shahid, M. Z. Exploring the Effect of Cereal Bran Cell Wall on Rheological Properties of Wheat Flour. J. Food Proc. Pres. 2019, 44(3). e14345.

[39] Benkó, Z.; Andersson, A.; Szengyel, Z.; Gáspár, M.; Réczey, K.; Stålbrand, H. Heat Extraction of Corn Fiber Hemicellulose. Appl. Biochem. Biotechnol. 2007, 137, 253–265. Springer.

[40] Vitaglione, P.; Napolitano, A.; Fogliano, V. Cereal Dietary Fibre: A Natural Functional Ingredient to Deliver Phenolic Compounds into the Gut. Trends Food Sci. Tech. 2008, 19, 451–463.

[41] Saulnier, L.; Thibault, J. F. Ferulic Acid and Diferulic Acids as Components of Sugar-beet Pectins and Maize Bran Heteroxylans. J. Sci. Food Agric. 1999, 79, 396–402.

[42] Anderson, C.; Simsek, S. Mechanical Properties and Topographical Profiles of Fibre-rich Polymers Made from Alkaline Extracted Arabinoxylans from Wheat Bran, Maize Bran, or Dried Distillers’ Grain. Food Hydrocoll. 2019, 86, 78–86.

[43] Joseleau, J.; Comtat, J.; Ruel, K. Chemical Structure of Xylans and Their Interaction in the Plant Cell Walls. Prog. Biotechnol. 1991, 7, 1–15.

[44] Agger, J.; Vikso-Nielsen, A.; Meyer, A. S. Enzymatic Xylose Release from Pretreated Corn Bran Arabinoxylan: Differential Effects of Deacetylation and Deferuloylation on Insoluble and Soluble Substrate Fractions. J. Agric. Food Chem. 2010, 58, 6141–6148.

[45] Allerdings, E.; Ralph, J.; Steinhart, H.; Bunzel, M. Isolation and Structural Identification of Complex Feruloylated Heteroxylan Side-chains from Maize Bran. Phytochem. 2006, 67, 1276–1286.

[46] Zhao, S.; Yao, S.; Ou, S.; Lin, J.; Wang, Y.; Peng, X.; Li, A.; Yu, B. Preparation of Ferulic Acid from Corn Bran: Its Improved Extraction and Purification by Membrane Separation. Food Bioprod. Process. 2014, 92(3), 309–313.

[47] Inglett, G. E.; Chen, D. Antioxidant Activity and Phenolic Content of Air-classified Corn Bran. Cereal Chem. 2011, 88, 36–40.

[48] Willcox, J. K.; Ash, S. L.; Catignani, G. L. Antioxidants and Prevention of Chronic Disease. Crit. Rev. Food Sci. Nutr. 2004, 44, 275–295.

[49] Saulnier, L.; Marot, C.; Chanliaud, E.; Thibault, J. F. Cell Wall Polysaccharide Interactions in Maize Bran. Carbohydr. Polym. 1995, 26, 279–287.

[50] Berlanga-Reyes, C. M.; Carvajal-Millán, E.; Lizardi-Mendoza, J.; Rascón-Chu, A.; Marquez-Escalante, J. A.; Martínez-López, A. L. Maize Arabinoxylan Gels as Protein Delivery Matrices. Molecules. 2009, 14, 1475–1482.

[51] Noblej, J.; Le Goff, G. Effect of Dietary Fibre on the Energy Value of Feeds for Pigs. Anim. Feed Sci. Technol. 2001, 90, 35–50.

[52] Singh, M.; Liu, S. X.; Vaughn, S. F. Effect of Corn Bran as Dietary Fiber Addition on Baking and Sensory Quality. Biocatal. Agric. Biotechnol. 2012, 1, 348–352.

[53] Sosulski, F.; Wu, K. High-fiber Breads Containing Field Pea Hulls, Wheat, Corn, and Wild Oat Brans. Cereal Chem. 1988, 65(3), 186–191.

[54] Byamukama, J. Nutritional Composition and Sensoric Acceptability of Wheat Bread Supplemented with Soybean Flour, Maize Bran and Maize Germ. Doctoral dissertation, Makerere University, 2019.

[55] Elleuch, M.; Bedigian, D.; Roseaux, O.; Besbes, S.; Blecker, C.; Attia, H. Dietary Fibre and Fibre-rich By-products of Food Processing: Characterisation, Technological Functionality and Commercial Applications: A Review. Food Chem. 2011, 124, 411–421.

[56] Schaffer-Lequart, C.; Lehmann, U.; Ross, A. B.; Roger, O.; Eldridge, A. L.; Ananta, E.; Bietry, M. F.; King, L. R.; Moroni, A. V.; Srichuwong, S.; et al. Whole Grain in Manufactured Foods: Current Use, Challenges and the Way Forward. Crit. Rev. Food Sci. Food. 2017, 57, 1562–1568.

[57] Marcia, M. D. O.; Feruloylation in Grasses: Current and Future Perspectives. Mol. plant. 2009, 2, 861–872.

[58] Anderson, B.; Almeida, H. Corn Dry Milling: Processes, Products, and Applications Corn; Elsevier, 2019; pp 405–433. AACI International Press.

[59] Melida, H.; Garcia-Angulo, P.; Alonso-Simón, A.; Álvarez, J. M.; Acebes, J. L.; Encina, A. The Phenolic Profile of Maize Primary Cell Wall Changes in Cellulose-deficient Cell Cultures. Phytochem. 2010, 71, 1684–1689.

[60] Andersson, R.; Áman, P. Cereal Arabinoxylan: Occurrence, Structure and Properties. Adv. Diet. Fibre Technol. 2008, 27, 301.
[61] Herrera-Balandrano, D. D.; Báez-González, J. G.; Carvajal-Millán, E.; Muy-Rangel, D.; Urias-Onora, V.; Martínez-López, A. L.; Márquez-Escalante, J. A.; Heredia, J. B.; Beta, T.; Niño-Medina, G. Alkali-extracted Feruloylated Arabinoxylans from Nixtamalized Maize Bran Byproduct: A Synonymous with Soluble Antioxidant Dietary Fiber. *Waste Biomass Valorization*. 2020, 11, 403–409.

[62] Gartaula, G.; Dhital, S.; Pleming, D.; Gidley, M. J. Isolation of Wheat Endosperm Cell Walls: Effects of Non-endosperm Flour Components on Structural Analyses. *J. Cereal Sci*. 2017, 74, 165–173.

[63] Zhang, Z.; Smith, C.; Li, W. Extraction and Modification of Arabinoxylans from Cereal By-products: A Critical Review. *Food Res. Int.* 2014, 65, 423–436.

[64] Barros-Rios, J.; Santiago, R.; Jung, H. J. G.; Malvar, R. A. Covalent Cross-linking of Cell-wall Polysaccharides through Esterified Diferulates as a Maize Resistance Mechanism against Corn Borers. *J. Agric. Food Chem*. 2015, 63, 2206–2214. DOI: 10.1021/jf505341d.

[65] Malunga, L. N.; Beta, T. Isolation and Identification of Feruloylated Arabinoxylan Mono-and Oligosaccharides from Undigested and Digested Maize and Wheat. *Heliyon*. 2016, 2, e00106. DOI: 10.1016/j.heliyon.2016.e00106.

[66] Sneijers, J.; Olaerts, H.; Dornez, E.; Van-de-Wiele, T.; Aura, A. M.; Vanhaecke, L.; Delcour, J. A.; Courtin, C. M. Structural Features and Feruloylation Modulate the Fermentability and Evolution of Antioxidant Properties of Arabinogalactanoligosaccharides during in Vitro Fermentation by Human Gut Derived Microbiota. *J. Funct. Foods*. 2014, 10, 1–12. DOI: 10.1016/j.jff.2014.05.011.

[67] Bader Ul Ain, H.; Saeed, F.; Asif Khan, M.; Niaz, B.; Tufail, T.; Anjum, F. M.; Hussain, S.; Rohi, M. Isolation and Characterization of Cereal Cell Walls. *Int. J. Food Prop*. 2019, 22, 130–137. DOI: 10.1080/10942912.2019.1573832.

[68] Chateigné-Boutin, A. L.; Ordraz-Ortiz, J. J.; Alvarado, C.; Bouchet, B.; Durand, S.; Verheertbruggen, Y.; Barrière, Y.; Saulnier, L. Developing Pericarp of Maize: A Model to Study Arabinoxylan Synthesis and Feruloylation. *Front. Plant Sci*. 2016, 7, 1476.

[69] Dobberstein, D.; Bunzel, M. Separation and Detection of Cell Wall-bound Ferulic Acid Dehydrodimers and Dehydrotrimeres in Cereals and Other Plant Materials by Reversed Phase High-performance Liquid Chromatography with Ultraviolet Detection. *J. Agr. Food Chem*. 2010, 58, 8927–8935.

[70] Bunzel, M.; Ralph, J.; Marita, J. M.; Hatfield, R. D.; Steinhardt, H. Diferulates as Structural Components in Soluble and Insoluble Cereal Dietary Fibre. *J. Sci. Food Agric*. 2001, 81, 653–660.

[71] Hatfield, R. D.; Jung, H.; Morita, J. M.; Kim, H. Cell Wall Characteristics of a Maize Mutant Selected for Decreased Ferulates. *Am. J. Plant Sci*. 2018, 9, 446.

[72] Pena, M. J.; Kulkarni, A. R.; Backe, J.; Boyd, M.; Neill, M. A.; York, W. S. Structural Diversity of Xylans in the Cell Walls of Monocots. *Planta*. 2016, 244, 589–606.

[73] Mendez-Encinas, M. A.; Carvajal-Millan, E.; Rascon-Chu, A.; Astiazaran-Garcia, H. F.; Valencia-Rivera, D. E. Ferulated Arabinoxylans and Their Gels: Functional Properties and Potential Application as Antioxidant and Anticancer Agent. *Oxid. Med. Cell. Longev.* 2018. DOI: 10.1155/2018/2314759.

[74] Vansteenwisse, E.; Babot, C.; Rouau, X.; Micard, V. Oxidative Gelation of Feruloylated Arabinoxylan as Affected by Protein. Influence on Protein Enzymatic Hydrolysis. *Food Hydrocoll*. 2004, 18, 557–564.

[75] Katapodis, P.; Vardakou, M.; Kalogeris, E.; Kekos, D.; Macris, B. J.; Christakopoulos, P. Enzymic Production of a Feruloylated Oligosaccharide with Antioxidant Activity from Wheat Flour Arabinoxylan. *Eur. J. Nutr.* 2003, 42, 55–60.

[76] Kale, M. S.; Hamaker, B. R.; Campanella, O. H. Alkaline Extraction Conditions Determine Gelling Properties of Corn Bran Arabinoxylans. *Food Hydrocoll*. 2013, 31, 121–126.

[77] Zhao, J.; Deng, Y.; Li, S. P. Advanced Analysis of Polysaccharides, Novel Functional Components in Food and Medicine Dual Purposes Chinese Herbs. *TRAC-Trend Anal. Chem*. 2017, 96, 138–150.

[78] Jung, H.; Phillips, R. Putative Seedling Ferulate Ester (Sfe) Maize Mutant: Morphology, Biomass Yield, and Stover Cell Wall Composition and Rumen Degradability. *Crop Sci*. 2010, 50, 403–418.

[79] Zhu, F.; Interactions between Cell Wall Polysaccharides and Polyphenols. *Crit. Rev. Food Sci. Nutr.* 2018, 58, 1808–1831.

[80] Saeed, F.; Pasha, I.; Anjum, F. M.; Sultan, M. T. Arabinoxylans and Arabinogalactans: A Comprehensive Treatise. *Crit. Rev. Food Sci. Nutr.* 2011, 51, 467–476.

[81] Berlanga Reyes, C.; Carvajal Millán, E.; Niño Medina, G.; Rascón Chu, A.; Ramírez Wong, B.; Magaña Barajas, E. Low-value Maize and Wheat By-products as a Source of Ferulolated Arabinoxylans. *Waste Water-Treat Reutilization* (1st edition). INTECH, 2011, 341–352.

[82] Martínez-López, A. L.; Carvajal-Millán, E.; Micard, V.; Rascón-Chu, A.; Brown-Bojorquez, F.; Sotelo-Cruz, N.; López-Franco, Y. L.; Lizardi-Mendoza, J. In Vitro Degradation of Covalently Cross-linked Arabinoxylan Hydrogels by Bifidobacteria. *Carbohydr. Polym.* 2016, 144, 76–82.

[83] Zhang, X.; Chen, T.; Lim, J.; Gu, F.; Fang, F.; Cheng, L.; Campanella, O. H.; Hamaker, B. R. Acid Gelation of Soluble Laccase-crosslinked Corn Bran Arabinoxylans and Possible Gel Formation Mechanism. *Food Hydrocoll*. 2019, 92, 1–9.

[84] Izydorczyk, M. *Arabinoxylans Handbook of Hydrocolloids*; Elsevier, Woodhead Publishing UK. 2009; pp 653–692.
[85] Bilgiçi, N.; Ibanog’lu, Ş.; Herken, E. N. Effect of Dietary Fibre Addition on the Selected Nutritional Properties of Cookies. *J. Food Eng.* 2007, 78, 86–89.

[86] Pokorný, J.; Yanishlieva, N.; Gordon, M. *Antioxidants in Food: Practical Applications*; Burlington Elsevier Science, 2001.

[87] Fan, L.; Zhang, S.; Yu, L.; Ma, L. Evaluation of Antioxidant Property and Quality of Breads Containing Auricularia Auricula Polysaccharide Flour. *Food Chem.* 2007, 101, 1158–1163.

[88] Zielinski, H.; Kozlowska, H. Antioxidant Activity and Total Phenolics in Selected Cereal Grains and Their Different Morphological Fractions. *J. Agric. Food Chem.* 2000, 48, 2008–2016.

[89] Mussatto, S. I.; Dragone, G.; Roberto, I. C. Ferulic and P-coumaric Acids Extraction by Alkaline Hydrolysis of Brewer’s Spent Grain. *Ind. Crops Prod.* 2007, 25, 231–237.

[90] Torre, P.; Alakbarian, B.; Rivas, B.; Dominguez, J. M.; Converti, A. Release of Ferulic Acid from Corn Cobs by Alkaline Hydrolysis. *Biochem. Eng. J.* 2008, 40, 500–506.

[91] TuFAIL, T.; Saeed, F.; Arshad, M. U.; Afzaal, M.; Rasheed, R.; Bader Ul Ain, H.; Imran, M.; Abrar, M.; Farooq, M. A.; Shahid, M. Z. Exploring the Effect of Cereal Bran Cell Wall on Rheological Properties of Wheat Flour. *J. Food Process. Preserv.* 2020, 44, e14345.

[92] Singh, S.; Dwivedi, O. P.; Mishra, S. Recent Development in Ferulic Acid Esterase for Industrial Production. Molina, G.; Gupta, V. K.; Singh, B. N.; Gathergood, N. *Bioprocessing for Biomolecules Production*. John Wiley & Sons. Bioprocessing for Biomolecules Production, 2019, 373–382.

[93] Bach Knudsen, K. E.; Microbial Degradation of Whole-grain Complex Carbohydrates and Impact on Short-chain Fatty Acids and Health. *Adv. Nutr.* 2015, 6, 206–213. DOI: 10.3945/an.114.007450.

[94] Ou, S.; Kwok, K. C. Ferulic Acid: Pharmaceutical Functions, Preparation and Applications in Foods. *J. Sci. Food Agric.* 2004, 84, 1261–1269. DOI: 10.1002/jsfa.1873.

[95] Kim, H. K.; Jeong, T. S.; Lee, M. K.; Park, Y. B.; Choi, M. S. Lipid-lowering Efficacy of Hesperetin Metabolites in High-cholesterol Fed Rats. *Clin. Chim Acta.* 2003, 327, 129–137. DOI: 10.1016/S0009-8981(02)00344-3.

[96] Schendel, R. R.; Meyer, M. R.; Bunzel, M. Quantitative Profiling of Feruloylated Arabinoxylans Side-chains from Graminaceous Cell Walls. *Front. Plant Sci.* 2016, 6, 1249. DOI: 10.3389/fpls.2015.01249.

[97] Mancuso, C.; Santangelo, R. Ferulic Acid: Pharmacological and Toxicological Aspects. *Food Chem. Toxicol.* 2014, 65, 185–195. DOI: 10.1016/j.fct.2013.12.024.

[98] Cheng, J.-C.; Dai, F.; Zhou, B.; Yang, L.; Liu, Z.-L. Antioxidant Activity of Hydroxycinnamic Acid Derivatives in Human low Density Lipoprotein: Mechanism and Structure–activity Relationship. *Food Chem.* 2007, 104(1), 132–139. DOI: 10.1016/j.foodchem.2006.11.012.

[99] Lappi, J.; Kolehmainen, M.; Mykkänen, H.; Poutanen, K. Do Large Intestinal Events Explain the Protective Effects of Whole Grain Foods against Type 2 Diabetes? *Crit. Rev. Food Sci. Nutr.* 2013, 53(6), 631–640. DOI: 10.1080/10408398.2010.550388.

[100] SriniVASAn, M.; Sudheer, A. R.; Menon, V. P. Ferulic Acid: Therapeutic Potential through Its Antioxidant Property. *J. Clin. Biochem. Nutr.* 2007, 40(2), 92–100. DOI: 10.3164/jcbn.40.92.

[101] Ayala-Soto, F. E.; Serna-Saldivar, S. O.; Garcia-Lara, S.; Pérez-Carrillo, E. Hydroxycinnamic Acids, Sugar Composition and Antioxidant Capacity of Arabinoxylans Extracted from Different Maize Fiber Sources. *Food Hydrocolloids.* 2014, 35, 471–475. DOI: 10.1016/j.foodhyd.2013.07.004.

[102] Noaman, E.; El-Din, N. K.; Bibars, M. A.; Mossalam, A. A. A.; Ghoneum, M. Antioxidant Potential by Arabinoxylan Rice Bran, MGN-3/biobran, Represents a Mechanism for Its Oncostatic Effect against Murine Solid Ehrlich Carcinoma. *Cancer Lett.* 2008, 268(2), 348–359. DOI: 10.1016/j.canlet.2008.04.012.

[103] Fernia, A. P.; Salvadori, M.; Broekaert, W. F.; Francois, I. E. J. A.; Delcour, J. A.; Courtin, C. M.; Caderni, G. Arabinoxylan-oligosaccharides (AXOS) Reduce Preneoplastic Lesions in the Colon of Rats Treated with 1,2-dimethylhydrazine (DMH). *Eur. J. Nutr.* 2010, 49(2), 127–132. DOI: 10.1007/s00394-009-0050-x.

[104] Glei, M.; Hofmann, T.; Küster, K.; Hollmann, J.; Lindhauer, M. G.; Pool-Zobel, B. L. Both Wheat (Triticum aestivum) Bran Arabinoxylans and Gut Flora-Mediated Fermentation Products Protect Human Colon Cells from Genotoxic Activities of 4-Hydroxynonenal and Hydrogen Peroxide. *J. Agric. Food Chem.* 2006, 54(6), 2088–2095. DOI: 10.1021/jf052768e.

[105] Boz, H.; Ferulic Acid in Cereals—a Review. *Czech J. Food Sci.* 2015, 33, 1–7.

[106] Mathew, S.; Abraham, T. E. Ferulic Acid: An Antioxidant Found Naturally in Plant Cell Walls and Feruloyl Esterases Involved in Its Release and Their Applications. *Crit. Rev. Biotechnol.* 2004, 24, 59–83.

[107] Galvez Ranilla, L.; Christopher, A.; Sarkar, D.; Shetty, K.; Chirinos, R.; Campos, D. Phenolic Composition and Evaluation of the Antimicrobial Activity of Free and Bound Phenolic Fractions from a Peruvian Purple Corn (Zea Mays L.) Accession. *J. Food Sci.* 2017, 82, 2968–2976. DOI: 10.1111/1750-3841.13973.