XYLOOLIGOSACCHARIDES FROM AGRICULTURAL BY-PRODUCTS: CHARACTERISATION, PRODUCTION AND PHYSIOLOGICAL EFFECTS

L. Kaprelyants, Doctor of Science, professor, E-mail: leonid@onaft.edu.ua
O. Zhurlova, Doctor of Philosophy, assistant of professor, E-mail: e.zhurlova@gmail.com
T. Shpyrko, Doctor of Philosophy, associate professor, E-mail: tatjana-shpirko@rambler.ru
L. Pozhitkova, Doctor of Philosophy, assistant of professor, E-mail: odessiotchka@gmail.com

Department of Biochemistry, Microbiology and Nutrition Physiology
Odessa National Academy of Food Technologies, Odessa, Kanatnyaya str. 112, 65039

Abstract. The current study is a review of characteristics, production, physiological properties and application of xylooligosaccharides (XOS). XOS are the carbohydrates, their molecules are built from xylose residues linked mainly by β-(1→4)-glycoside bonds. Xylan is important for plant cell walls and is widely spread component in agricultural by-products. XOS are products of xylan hydrolytic degradation, and exhibiting the high prebiotic potential. The XOS preparation of wheat and rye bran stimulated the cells accumulation - 1,4×10^10 CFU/cm^3 of L. acidophilus and 9,2×10^6 CFU/cm^3 of B. bifidum. A difference in XOS molecules branching causes a wide range of their physiological properties: antioxidant, immunomodulation, antimicrobial, anti-inflammatory, anticarcinogenic. XOS can reduce high cholesterol level and triglycerides in blood plasma. XOS application reviewed in this article opens new perspectives on its potential use for human consumption. The rich sources of xylan are wheat, rye and barley bran, rice husk, wheat straw, corn cobs, cotton stalk. Industrial way of XOS production includes chemical or enzymatic hydrolysis with following purification. Chemical methods are based on hydrothermal pretreatment and acidic or alkaline extraction. Obtained oligosaccharides have a wide range of polymerization degree (DP) from 2 to 20. Enzymatic methods include fermentation with xylanase that allow controlling the XOS accumulation with certain DP. The different chromatographic purification after hydrolysis is used for analytical purposes. There are anion-exchange, size-exclusion, affinity, size-exclusion high-performance liquid chromatography. In addition, biomethods are preferred for XOS used in food, because such preparations do not contain monosaccharides and furfural as contaminants. XOS are stable in a wide range of temperature and pH, justifying the development of new synbiotics generation. Most widely XOS are used in production of functional products and pharmaceutical preparations. But they are also applied in cosmetic, agricultural and mixed feed industries.

Keywords: xylooligosaccharides, xylan, prebiotics, enzymatic hydrolysis

Copyright © 2015 by author and the journal “Food Science and Technology”.

DOI: http://dx.doi.org/10.15673/fst.v11i3.606
fect on the human body, preventing a number of widespread diseases: cardiovascular system, gastrointestinal tract, oncology and the endocrine system. BAS can be used both separately and by adding to food products, thus providing them with functional properties.

Considering the increased demand for dietary supplements, the scientific community was faced with the problem of raw materials for these supplements production. In this context, the studies were carried out to define the chemical composition of agro-industrial wastes, which are underutilized and disposed of billions of tons [1,2].

Cereals are an integral part of nutrition and a source of important nutrients. Scientists, those engaged in nutrition problems, drew attention to the special physiological role of cereals in the diet as a source of dietary fiber, digestible carbohydrates, proteins, vitamins, mineral and other BAS [3]. The by-products of grain processing contain a large amount of hemicelluloses, cellulose, lignin, minerals and so on. Hemicelluloses are heteropolysaccharides, which are mainly based on xylan, as well as monosaccharides: xylose, arabinose, galactose, mannose and glucose [4]. Xylan is a homopolysaccharide that includes such important components as xylose and xylitol, which are the parts of xylo-oligosaccharides (XOS). Interest in oligosaccharides as a prebiotics, XOS in particular, has arisen relatively recently. It is based on their numerous technological and physiological properties, as well as on a low cost and abundance of raw materials for the XOS preparation.

The aim of the review were 1) to study the chemical structure, sources, physiological properties of XOS, 2) to analyze the XOS production methods and application.

Chemical structure and properties of xylooligosaccharides

Xylooligosaccharides are the carbohydrates, their molecules are built from xylose residues linked mainly by \(\beta-(1\rightarrow4)\)-glycoside bonds. XOS are obtained from xylans by way of hydrolysis. Fig. 1 shows the molecular structure of xylene and XOS [1].

The number of xylose residues in XOS varies from 2 to 10. But many scientists refer oligosaccharides with polymerization degree (DP) up to 20 to XOS [5,6]. In addition to xylose residues, xylans usually include side groups in their polysaccharide chain. There are 6-D-xlyopyranosyluronic acids or their 4-O-methyl derivatives, acetyl groups or arabinofuranosyl residues. Thereby, the hydrolysis of xylan allows obtaining the branched XOS. Such cross-bonding explains a variety of their physiological effects [7].

The mass fraction of secondary cell walls in lignocellulose plant raw materials is much larger than of the primary fraction. Therefore, the XOS produced during the hydrolysis of heteroxylans are considered dominant oligosaccharides. XOS have important prebiotic properties which makes it possible to use them in medicine, food and health products [8]. The chemical and biological properties of XOS are shown in table 1 [9].

Chemical structure and properties of xylooligosaccharides

\[ X_1 = \text{xylose} \]

\[ X_2 = \text{xylobiose} \]

\[ n = 1: X_3 = \text{xylotriose} \]

\[ n = 2: X_4 = \text{xyloctetraose} \]

\[ n = 3: X_5 = \text{xylopentaose} \]

\[ n = 4: X_6 = \text{xylohexaose} \]

\[ n = 5: X_7 = \text{xyloheptaose} \]

Fig. 1. The molecular structure of xylose and XOS.
Table 1 – The chemical and biological properties of XOS.

| Property                        | Value/nature                                                                 |
|---------------------------------|------------------------------------------------------------------------------|
| Common name                     | Xylooligosaccharides                                                         |
| Synonym                         | D-xylose-hexulose                                                            |
| Molecular formula                | C₅ₙ H₈ₙ+₂ O₄ₙ+₁, n=2 to 6                                                   |
| Chemical family                  | Carbohydrate; xylobiase (DP 2), xylotriose (DP 3), xylotetrose (DP 4), xylo-
                                     | lopentose (DP 5) and xylohexose (DP 6)                                      |
| Molecular weight                | 282 to 810 (X₂ to X₆)                                                      |
| Physical status                 | Crystalline solid, colour depends on source xylan or purification or process |
|                                 | of drying.                                                                   |
| Odour                           | Nil                                                                          |
| Melting temperature             | 134 °C                                                                       |
| Decomposition temperature       | 120 °C                                                                       |
| Solubility                      | 58% w/w at 21 °C                                                            |
| pH stability                    | 2 to 7                                                                       |
| Relative sweetness              | 92% of sucrose when compared in 10% solutions                                |
| Profile of sweetness            | Emulates sucrose having faster onset like sucrose                           |
| Cooling effect                  | Nil                                                                          |
| Energy value                    | 1.5 kcal/g                                                                   |
| Carcinogenicity                 | Nil                                                                          |
| Flavor enhancer                 | Synergistic with high intensity sweeteners                                  |
| Humectants                      | Similar to sorbitol                                                          |
| Hygroscopicity                  | Less than fructose                                                           |
| Absorbability at gastrointestinal tract | Malabsorption sugar in human                                               |
| Maillard reactions and caramelization | Browns similar to sucrose                                                |
| Advantages of consumption       | Low calorie sugar alcohol having prebiotic effects                          |
|                                 | No elevation of blood glucose; suitable for diabetic patients               |
|                                 | Antioxidant, cyto-protective                                                 |
|                                 | Offers scope for dietary supplements, beneficial drug or drug adjuvant      |
| Recommended consumption dose    | 8–12 g/day for healthy adult                                                 |
| Side effects of excess dose     | Distension of intestine, nausea, flatulence, diarrhea etc.                  |
| Regulatory status               | Excipient in drugs and non-foods: Generally Recognized as Safe (GRAS)       |
|                                 | Excipient use in animal feeds: Generally Recognized as Safe (GRAS)          |
|                                 | Application as antidiabetic drug: Under clinical trial                      |

Agrycultural by-products as the sources of xylooligosaccharides

Hemicelluloses are the second globally spread polysaccharides in plant raw materials. The content of hemicelluloses at the plants cell wall varies from 20 to 30% of the total mass. They have a heterogeneous composition of various sugar units. Usually hemicelluloses are classified depend on side groups’ types and substitution degree [10,11]:
- Homoxylans are linear polysaccharides common in some seaweeds.
- Glucuronylans can be partly acetylated and have units substituted with β (1→2)-4-Omethyl-D-
glucopyranosyl uronic acid (MeGlcUA). They are found in hardwood, depending on the treatment.
- (Arabino)glucuronoxylans have a substitution with β (1→3)-L-arabinofuranosyl (ArbF) next to MeGlcUA. They are typical for softwoods.
- Arabinoxylans with a substitution of the β (1→4)-D-xylopyranose backbone at position 2 or 3 with ArbF can be esterified partly with phenolic acids. This type is frequently found in the starchy endosperm and the outer layers of cereal grains.
- (Glucuron) arabinoxylans can be disubstituted with ArbF units, acetylated, and esterified with ferulic acid. This form is typical of lignified tissues of grasses and cereals.
- Heteroxylans are heavily substituted with various mono- or oligosaccharides and are present in cereal bran, seed, and gum exudates.

As hemicelluloses are the source of XOS, it was useful to study their content in different agricultural by-products. The content of arabinoxylans in cereal grains is (% of dry matter): barley - 4.2 – 5.4, oats – 4.1 – 14.5, rye – 8.0 – 12.1, triticale – 3.4 – 5.2, wheat – 4.4 – 6.9 [12]. Wheat and rye bran also contain arabinoxylan in quantity of 30% and 23% of dry matter, respectively [13].

Heteroxylan is present in barley coleoptiles – 32 %, barley aleurone – 71 %, barley starchy endo-
spor – 20 %, maize internodes – 46 %, *Brachypodium* whole grain – 4.7, rice endosperm – 32 %. Xy-
loglucan is contained in barley coleoptiles – 10 and maize internodes – 6% [14].
Xylan is contained also in tobacco stalk – 19.95 %, cotton stalk – 19.76 %, wheat straw – 20.9 % and rice husk – 22.7 % [15,16]. Soluble and insoluble xylan is present in soybean meal (5; 16 %), barely (5; 43 %), rye (26; 42 %), wheat (17; 61 %) and corn (1; 68 %) respectively [17].

The xylooligosaccharides production by chemical and enzymatic hydrolysis

XOS are obtained by chemical, enzymatic or mix hydrolytic methods from the lignocellulosic raw material. A simple method for producing XOS is the steam or hot water processing of raw material in the presence of a catalyst. The hydrolytic decomposition of xylan is called autohydrolysis, hydrothermolysis or water pretreatment. The polymerization degree and the yield of obtained XOS depend on the conditions of the raw material processing and its nature [18].

Microwave oven milled aspen wood (Populus tremula) processing at 180 °C for 10 min allows extracting water-soluble hemicelluloses. Then XOS were subject to fractionated on oligo- and polysaccharides by size-exclusion chromatography. Polysaccharides O-acetyl-(4-O-methylglucurono)xylan were eluted in the first two fractions. In the 3rd fraction, there were present acetylated XOS as the product of acetylated 4-O-methylglucuronoxylan hydrolytic decomposition [8,19].

High yields (65 – 92 %) of XOS is obtained by diluting of raw material (Calamagrostis acutiflora, Miscanthus sinensis, Panicum virgatum and bagasse) in acid at lower temperature (60 °C) for about 12 h, followed by authohydrolysis at high temperature (temperature 100 °C for 1 h). Such preparation could be used as prebiotic on commercial scale. The application in food is inadmissible because of monomeric sugar contained with furfural and HMF as contaminants [20].

Partially acetylated XOS were obtained from the almond husks by autohydrolysis. It is a mixture of neutral and acid oligomers and low-molecular polymers (4-O-methyl-D-glucuronoxylan). Almond husks was treated at the temperature range from 150 °C to 190 °C. The results of studies showed that the highest XOS yield was about 43 % (treated at 150 °C for 300 min) and 63 % (treated at 190 °C for 19 min) [21,22].

The influence of various bagasse concentrations (0.5 %, 1 %, 3 %, 7 % and 10 %) has been studied on the xylose and XOS yield under reactor conditions at 200 °C without the use of acids and other reagents. It was demonstrated that XOS yield decreases with an increase of dry substances concentration in the reaction medium. It is linked with an increase of pH and, as a result, with XOS hydrolysis to xylose [23].

Alternatively, the depolymerized hemicelluloses can be extracted from the lignocellulosic material with alkalis (KOH, NaOH, Ca(OH)₂, NH₄OH or with their mixture). Xylan, depolymerized in such condition, loses acetyl and uronic acids by saponification during extraction. That is why it has a very limited degree of solubility in neutral aqueous solutions. In this case, a general technology of XOS obtaining represents an alkaline hydrolysis and the following termal treatment. The extraction of xylan: from corn stalks (10 % NaOH and 1 % NaHBH₄ at 20 °C) gives a yield – 54 % [24], from wheat straw (0.5 M NaOH at 55 °C) gives a yield of 49.3 % [25], from wheat straw (24 % KOH and 1 % NaHBH₄) gives a yield of 20.6 % [26], from corn cobs (12 % NaOH with steam) gives a yield of 84 % [27].

As distinct from autohydrolysis and chemical methods, enzymatic hydrolysis does not require high temperature and pressure equipment. It allows avoiding the production of by-products or high concentrations of monosaccharides in XOS production.

An acid hydrolysis of xylans is preferable in the XOS production with a DP from 2 to 15. At the same time, the application of purified endoxylanase made it possible to obtain XOS mainly with xylotriose composition. Xylotriose and xylotetrose, obviously, almost resistant to xylanases hydrolytic decomposition, probably due to bonds with arabinosyl residues. Commercial xylanase preparations contain low concentrations of α-xylanosidase, which allows xylose accumulation in XOS [28].

Wheat bran was subjected to enzymatic hydrolysis with XOS obtained. A preparation obtained from Bacillus subtilis was used as the enzyme – xylanase. Insoluble dietary fiber of wheat bran was treated with 1 % xylanase solution at 50 °C, pH 5.0 for 60 hours, with constant stirring. Hydrolysate was purified at an Amberlite XAD-2 column. The oligosaccharides were separated by paper chromatography with the following identification. Hydrolysate of insoluble wheat bran polysaccharides contained XOS (xylobiose, xylotriose, xylotetrose), as well as xylose [29].

XOS production from corn xylan was compared between using of immobilized and free endo-xylanases in Bacillus halodurans. Enzymatic hydrolysis was carried out for 24 h at 50 °C, pH 8.0, 12.8 U/g of xylan and 2 % of substrate. The immobilized endo-xylanases proved more efficient in XOS production. The free enzyme has converted xylan to oligomers of higher-level with DP>4, as well as 32.5 % to xylobiose and xylotriose. The immobilized xylanase has converted xylan to XOS with shorter length and 25.2 % of the mixture were xylobiose and xylotriose [30].

XOS production from rice husk included authophydrolysis (180 °C for 20 min), the nanofiltration of liquid phase in diafiltration mode, nanofiltration of retentate in concentration mode. The retentate, obtained from the second nanofiltration, was treated in two ways. In the first one, the retentate was purified at ion exchange chromatography (IRA-96, LSR 15(g/g) and freeze-dried. In the second one, the retentate was treated by enzymatic hydrolysis (using Pentocon Mon BG 350 XU/kg liquor) with following purification at ion exchange chromatography (IRA-96, LSR 15 (g/g))
and freeze-dried. As a result, the second way was longer but more efficient in XOS production [16].

The possibility of enzymatic synthesis shown of various alkyl-α-xylosides by using reactions of transglycosylation of α-xylosidase enzymes have been shown in a number of studies [29,31]. Nowadays, the glycosyntases becomes increasing popular in XOS production. Glycosyntases are synthetic enzymes - derivatives of glycosidases. They are widely applied for the synthesis of useful oligosaccharide-prebiotics. The catalytic domain of endo-1,4-α-xylanase from Cellulomonos fimi was successfully converted into the corresponding glycosynthese by catalytic nucleophile mutating into the glycine residue. The obtained enzyme is capable to catalyze the transfer of xylobiose residues from α-xylobiosyl fluoride to ether n-nitrophenyl-α-xylobiose or benzylthio-α-xylobiose. It makes it possible to synthesize oligosaccharides with DP from 4 to 10. The obtained products are purified by using HPLC [32]. The obtaining XOS is subjected to purification after chemical or enzymatic methods. Multi-stage processing and fractionation are used to purify and separate XOS. Various physicochemical methods of treatment are used depending on the required degree of the XOS purity. It involves as follows: solvent extraction and XOS precipitation, surface active substances absorption, chromatographic separation and purification, membrane technologies.

Ethanol, acetone, and 2-propanol are usually used for the solvent extraction and XOS precipitation [32]. As the absorption substances the most popular is activated carbon in a constant concentration of 20 g/L of crude XOS [33]. The different chromatographic purification is used for analytical purposes. There are anion-exchange, size-exclusion, affinity, size-exclusion high-performance liquid chromatography [8].

Vacuum evaporation is used to concentrate the primary XOS solution after an autothermal treatment and volatile components removal. A solvent extraction is usually used to extract the XOS and the raw material pretreatment before enzymatic or chemical treatment.

Nanofiltration allows concentrating the liquids and removing the low-molecular compounds such as monosaccharides or phenolic substances. It facilitates for purification of oligosaccharides mixtures. Oligosaccharides with different molecular weight and polymerization degree are separated by ultrafiltration.

Fig. 2. Scheme of prebiotic health benefits in human body.
Physiological effects of xyooligosaccharides

As it has been reported, a salubrious XOS influences differ. Food products with XOS reduce the risk of colon cancer and cardiovascular diseases due to the formation of short-chain fatty acids, improve an intestinal function and calcium absorption, prevent of dental caries, provide anti-inflammatory and prebiotic effect [8,34-37]. The comparison study in vitro of oligosaccharides prebiotical effect showed a high index of XOS preparation compared with others. For example, fructooligosaccharides (FOS) were less effective than XOS at increase in numbers of bifidobacteria and lactate production [38]. Influence of prebiotic components on the colon microorganisms can be illustrated by fig. 2 [39]. The XOS preparation of wheat and rye bran stimulates the cells accumulation – 1,4∙10¹⁰ CFU/cm³ of L. acidophilus and 9,2∙10¹⁰ CFU/cm³ of B. bifidum [40].

The XOS effect from oat bran at the utilization and fermentation of Lactobacillus rhamnosus, L. plantarum and L. lactis testified to the fact that all three microorganisms have fermented β-glyco-oligosaccharides. Only L. plantarum has fermented XOS. The main fermentation products were lactic acid, acetic acid, formic acid and ethanol [41].

The antimicrobial activity was conformed in combination of L. Plantarum and L. pentosus with XOS, inulin and FOS, which proved effective inhibitors of growth of E. coli and Salmonella enteritidis [42]. Preparations of acidic XOS showed an average activity against Staphylococcus aureus. But XOS were not affected against Pseudomonas aeruginosa and Proteus mirabilis. Compared with ampicillin, aldehyde acids showed an inhibitory effect on the growth of Helicobacter pylori at much higher concentrations [43]. It was observed, that antioxidant activity of XOS from ragi (12ons [43]. It was observed, that as compared to XOS derived from wheat, rice and maize (70d, that as coxidant af c acid, formic acid and eted by fig. 2 [39]. The XO[44].

XOS anti-inflammatory and antiallergic properties allow using these substances in the cosmetic industry. XOS can reduce high cholesterol in the blood. As it has been reported, that consumption of XOS in dose of 2.7 g/day significantly reduces cholesterol level and triglycerides in serum [9,37].

Conclusion

As it has already been reviewed, XOS are widely used in different fields including cosmetic, agriculture, pharmaceutical and others, but the largest and most advanced is the food industry. Their unique combination of technological properties and health benefits allow including XOS in food products without changing the organoleptic characteristics. Stability in a wide range of temperatures and pH, and high prebiotic effect allow using XOS as an ingredient of symbiotic foods. The non-digestible oligosaccharides is the matrix for the probiotic bacteria immobilization. The obtained symbiotic preparations are delivered in colon intact [46].

In pharmaceutical industry, XOS are used being a part of antiviral and antitumor drugs. They are added in preparation of micro- and nanoparticles and hydrogels intended for drug delivery, as well as for treatment and prevention of gastrointestinal disorders [47]. Immunomodulatory, anticarcinogenic and anti-allergic activities give an opportunity to include the XOS as a component of the relevant preparations.

XOS are also added in feed for domestic animals and fishes. They are used in agricultural as yield enhancer, ripening agents enhancer, and the growth stimulator and accelerator [48].

Application of xyooligosaccharides

Oligosaccharides have been used in the food industry since 1980s. The subsequent study of their technological and physiological properties led to the extension of the XOS application. Today they are used in the food, pharmaceutical, cosmetic and other industries.

Most widely XOS are applied as ingredients in functional foods. They are added to soft drinks, tea, dairy products, confectionery, jam products of beekeeping, gerodietic and other products for children [23]. The XOS application is shown in fig. 3 and demonstrates the wide range of their application [45].

In food industry, XOS are used in production of low calorie sweeteners as xylitol. Thus, they enhance sweet flavor without changing the other organoleptic characteristics. Stability in a wide range of temperatures and pH, and high prebiotic effect allow using XOS as an ingredient of symbiotic foods. The non-digestible oligosaccharides is the matrix for the probiotic bacteria immobilization. The obtained symbiotic preparations are delivered in colon intact [46].

In pharmaceutical industry, XOS are used being a part of antiviral and antitumor drugs. They are added in preparation of micro- and nanoparticles and hydrogels intended for drug delivery, as well as for treatment and prevention of gastrointestinal disorders [47]. Immunomodulatory, anticarcinogenic and anti-allergic activities give an opportunity to include the XOS as a component of the relevant preparations.

XOS are also added in feed for domestic animals and fishes. They are used in agricultural as yield enhancer, ripening agents enhancer, and the growth stimulator and accelerator [48].
Fig. 3. Applications of xylooligosaccharides

References

1. Carvalho AFA, de Oliva Neto P, da Silva DF, Pastore GM. Xylo-oligosaccharides from lignocellulosic materials: Chemical structure, health benefits and production by chemical and enzymatic hydrolysis. Food Research International. 2013 Apr; 51(1): 75–85. doi: 10.1016/j.foodres.2012.11.021

2. O’Shea N, Arendt EK, and Galagher E. Dietary Fibre and phytochemical characteristics of fruits and vegetables byproducts and their recent applications as novel ingredients in food products. Innovative Food Science and Emerging Technologies. 2012; 16: 1-10. doi: 10.1026/1/j.frit.1-3-1

3. Iorgacheva EG, Kaprelyants LV, Velichko TA. Fermentirovannyie osaaharennyie zernovyie produktyi – multifunktsionalnyie pischevyie ingrediyenti. Khranenie zerna i pererabotka. 2003; 9(51): 49-52.

4. Varques MJ, Alonso J, Dominguez H. Xylooligosaccharides: manufacture and applications. Ntrends Food Sci. Technol. 2000; 11: 3981-3988

5. Moure A, Gullуn P, Domнnguez H. Xylooligosaccharides: manufacture and applications. Ntrends Food Sci. Technol. 2000; 11: 3981-3988

6. Jain I, Kumar V, Satyanarayana T . Xylooligosaccharides: an economical prebiotic from agroresidue s and their health benefit. Indian Journal of Experimental Biology. 2015; 53: 131-142

7. Elsevier BV. Cereal straw as a resource for sustainable biomaterials and biofuels. Amsterdam; 2010.

8. Aachary AA, Prapulla SG. Xylooligosaccharides (XOS) as an Emerging Prebiotic: Microbial Synthesis, Utilization, Structural Characterization, Bioactive Properties, and Applications. Food Science and Food Safety. 2011; 10(1): 2–16. doi: 10.1111/j.1541-4337.2010.00135.x

9. Samanta AK, Jayapal N, Jayaram C, Sohini R, Kolte AP, Senani S, Sridhar M. Xylooligosaccharides as prebiotics from agricultural by-products: Production and applications. Bioactive Carbohydrates and Dietary Fibre. 2015; 5: 62-71. doi: 10.1016/j.bcdf.2014.12.003

10. Ebringerovб A. Structural diversity and application potential of hemicelluloses. Macromolecular Symposia. 2005 Feb; 232(1): 1-12.

11. Ebringerovб A. Structural diversity and application potential of hemicelluloses. Macromolecular Symposia. 2005 Feb; 232(1): 1-12.

12. Burton RA, Fincher GB. Evolution and development of cell walls in cereal grains. Front Plant Sci. 2014; 5: 1-15. doi: 10.3389/fpls.2014.00456

13. Gullуn P, Gonzбlez-Muсoz MJ, Parajу JC. Manufacture and prebiotic potential of oligosaccharides derived from industrial solid wastes. Bioresourc Technol. 2011 May;102(10):6112-9. doi: 10.1016/j.biortech.2011.02.059.

14. Gullуn P, Salazar N, Gonzбlez-Muсoz M J, Gueimonde M, Ruiz-Madiedo P, de los Reyes-Gavilбn CG., Parajу JC. Assessment on the fermentibility of xylooligosaccharides from rice husks. BioResources. 2011; 6(3): 3096-3114.

15. McNab JM, Boorman KN. Poultry feedstuffs. Supply, composition and nutritive value. Poultry Science Symposium Series. England: Carfax Publishing Company; 2002.

16. Garrote G, Domнnguez H, Parajу JC. Autohydrolysis of corncob: study of non-isothermal operation for xylo-oligosaccharide production wood. Journal of Food Engineering. 2002; 52(3): 211–218.

17. Teleman A, Lundqvist J, Tjerneld F, Stalbrand H, Dahlman O. Characterization of acetylated 4-O-methylglucuronoxylan isolated from aspen employing 1H and 13C NMR spectroscopy. Carbohydr. Res. 2000 Dec; 329(4): 807–815.

18. Otieno DO, Ahring BK. A thermochemical pretreatment process to produce xylooligosaccharides (XOS), arabinoooligosaccharides (AOS) and mannoooligosaccharides (MOS) from lignocellulosic biomasses. Biore. Technol. 2012 May;112: 285-292. doi: 10.1016/j.biortech.2012.01.162.
СИЛОЛОГОСАХАРИДЫ ИЗ СЕЛЬСКОХОЗЯЙСТВЕННОГО СЫРЬЯ: ХАРАКТЕРИСТИКА, ПОЛУЧЕНИЕ И ФИЗИОЛОГИЧЕСКИЕ ЭФФЕКТЫ

Л.В. Капрельянц, доктор техн. наук, профессор, E-mail: leonid@onaft.edu.ua
О.Д. Журлова, доктор философии, канд. техн. наук, E-mail: e.zhurlova@gmail.com
Т.В. Шпырко, доктор философии, канд. техн. наук, доцент, E-mail: tatjana-shpirko@rambler.ru
Л.Г. Пожицкова, доктор философии, канд. техн. наук, E-mail: odesstiochka@gmail.com

Аннотация. Данная статья - это критический обзор ксилоолигосахаридов (КОС), их характеристики, производства, физиологических свойств и применения. Ксила важен для растительных клеточных стенок и широко распространен в сельскохозяйственном сырье. КОС - это продукты гидролитической деградации ксила, обладают высоким пребиотическим потенциалом. Отличие в разветвлении молекул КОС объясняет широкий спектр их физиологических свойств: антиоксидантные, иммуномодулирующие, противомикробные, противовоспалительные, антиканцерогенные и другие. Применение КОС, рассмотренное в этой статье, открывают новые перспективы их потенциального использования.

Кисло-лозо-саха-риды из сельскохозяйственного сырья: характеристика, получение и физиологические эффекты

Л.В. Капрельянц, доктор техн. наук, профессор, E-mail: leonid@onaft.edu.ua
О.Д. Журлова, доктор философии, канд. техн. наук, E-mail: e.zhurlova@gmail.com
Т.В. Шпырко, доктор философии, канд. техн. наук, доцент, E-mail: tatjana-shpirko@rambler.ru
Л.Г. Пожицкова, доктор философии, канд. техн. наук, E-mail: odesstiochka@gmail.com

Аннотация. Данная статья - это критический обзор ксилоолигосахаридов (КОС), их характеристики, производства, физиологических свойств и применения. Ксила важен для растительных клеточных стенок и широко распространен в сельскохозяйственном сырье. КОС - это продукты гидролитической деградации ксила, обладают высоким пребиотическим потенциалом. Отличие в разветвлении молекул КОС объясняет широкий спектр их физиологических свойств: антиоксидантные, иммуномодулирующие, противомикробные, противовоспалительные, антиканцерогенные и другие. Применение КОС, рассмотренное в этой статье, открывают новые перспективы их потенциального использования.

Кисло-лозо-саха-риды из сельскохозяйственного сырья: характеристика, получение и физиологические эффекты

Л.В. Капрельянц, доктор техн. наук, профессор, E-mail: leonid@onaft.edu.ua
О.Д. Журлова, доктор философии, канд. техн. наук, E-mail: e.zhurlova@gmail.com
Т.В. Шпырко, доктор философии, канд. техн. наук, доцент, E-mail: tatjana-shpirko@rambler.ru
Л.Г. Пожицкова, доктор философии, канд. техн. наук, E-mail: odesstiochka@gmail.com

Аннотация. Данная статья - это критический обзор ксилоолигосахаридов (КОС), их характеристики, производства, физиологических свойств и применения. Ксила важен для растительных клеточных стенок и широко распространен в сельскохозяйственном сырье. КОС - это продукты гидролитической деградации ксила, обладают высоким пребиотическим потенциалом. Отличие в разветвлении молекул КОС объясняет широкий спектр их физиологических свойств: антиоксидантные, иммуномодулирующие, противомикробные, противовоспалительные, антиканцерогенные и другие. Применение КОС, рассмотренное в этой статье, открывают новые перспективы их потенциального использования.

Кисло-лозо-саха-риды из сельскохозяйственного сырья: характеристика, получение и физиологические эффекты

Л.В. Капрельянц, доктор техн. наук, профессор, E-mail: leonid@onaft.edu.ua
О.Д. Журлова, доктор философии, канд. техн. наук, E-mail: e.zhurlova@gmail.com
Т.В. Шпырко, доктор философии, канд. техн. наук, доцент, E-mail: tatjana-shpirko@rambler.ru
Л.Г. Пожицкова, доктор философии, канд. техн. наук, E-mail: odesstiochka@gmail.com

Аннотация. Данная статья - это критический обзор ксилоолигосахаридов (КОС), их характеристики, производства, физиологических свойств и применения. Ксила важен для растительных клеточных стенок и широко распространен в сельскохозяйственном сырье. КОС - это продукты гидролитической деградации ксила, обладают высоким пребиотическим потенциалом. Отличие в разветвлении молекул КОС объясняет широкий спектр их физиологических свойств: антиоксидантные, иммуномодулирующие, противомикробные, противовоспалительные, антиканцерогенные и другие. Применение КОС, рассмотренное в этой статье, открывают новые перспективы их потенциального использования.

Кисло-лозо-саха-риды из сельскохозяйственного сырья: характеристика, получение и физиологические эффекты

Л.В. Капрельянц, доктор техн. наук, профессор, E-mail: leonid@onaft.edu.ua
О.Д. Журлова, доктор философии, канд. техн. наук, E-mail: e.zhurlova@gmail.com
Т.В. Шпырко, доктор философии, канд. техн. наук, доцент, E-mail: tatjana-shpirko@rambler.ru
Л.Г. Пожицкова, доктор философии, канд. техн. наук, E-mail: odesstiochka@gmail.com

Аннотация. Данная статья - это критический обзор ксилоолигосахаридов (КОС), их характеристики, производства, физиологических свойств и применения. Ксила важен для растительных клеточных стенок и широко распространен в сельскохозяйственном сырье. КОС - это продукты гидролитической деградации ксила, обладают высоким пребиотическим потенциалом. Отличие в разветвлении молекул КОС объясняет широкий спектр их физиологических свойств: антиоксидантные, иммуномодулирующие, противомикробные, противовоспалительные, антиканцерогенные и другие. Применение КОС, рассмотренное в этой статье, открывают новые перспективы их потенциального использования.
предварительной обработке и кислотной или щелочной экстракции. Полученные олигосахариды имеют широкий диапазон теплостабильны в широком диапазоне температур и рН, что обосновывает развитие нового поколения синбиотиков. Наиболее широко КОС используются в производстве функциональных продуктов и фармацевтических препаратов. Но они также применены в косметической, сельскохозяйственной и комбикормовой промышленности.

**Ключевые слова:** кисло-олигосахариды, кислые, предбиотики, ферментативный гидролиз

**References**

1. Carvalho A.F.A. Xylo-oligosaccharides from lignocellulosic materials: Chemical structure, health benefits and production by chemical and enzymatic hydrolysis [Text] / A.F.A. Carvalho, P. de Oliva Neto, D.F. da Silva, G.M. Pastore // Food Research International. – 2013. – Vol. 51, No 1. – P. 75–85. doi: 10.1016/j.foodres.2012.11.021

2. O’Shea N. Dietary Fibre and phytochemical characteristics of fruits and vegetables byproducts and their recent applications as novel ingredients in food products [Text] / N. O’Shea, E. A. Arendt and E. Galagar // Innovative Food Science and Emerging Technologies. – 2012. – No 16. – P. 1-10. doi: 10.1016/j.ifset.1-3-1

3. Иоргачаева Е. Г. Ферментированные осахаренные зерновые продукты – мультифункциональные пищевые ингредиенты [Текст] / Е. Г. Иоргачаева, Л. В. Капрельянц, Т. А. Величко // Хранение зерна и переработка. – 2003. – № 9(51). – С. 49-52.

4. Vanues M.J. Xylooligosaccharides: manufacture and applications [Text] / M.J. Vanues, J. Alonso, H. Domingu // Trends Food Sci. Technol. – 2000. – No 11. – P. 3981-3988.

5. More A. Advances in the manufacture, purification and applications of xylo-oligosaccharides as food additives and nutraceuticals [Text] / A. More, P. Gullon, H. Domingu, J. C. Paraj // Process Biochemistry. – 2006. – No 41. – P. 1913-1923. doi:10.1016/j.proch.2006.05.011

6. Jain I. Xylooligosaccharides: an economical prebiotic from agroresidues and their health benefit [Text] / I. Jain, V. Kumar, T. Satyana-rayana // Indian Journal of Experimental Biology. – 2015. – No 53. – P. 131-142

7. Elsevier BV. Cereal straw as a resource for sustainable biomaterials and biofuels. Amsterdam. – 2010. – P. 300.

8. Aachary A. A. Xylo-oligosaccharides (XOS) as an Emerging Prebiotic: Microbial Synthesis, Utilization, Structural Characterization, Bioactive Properties, and Applications [Text] / A. A. Aachary, S. G. Prappula // Food Science and Food Safety. – 2011. – Vol.10, No 1. – P. 2-16. doi: 10.1111/j.1541-4337.2010.00135.x

9. Samanta A. K. Xylo-oligosaccharides as prebiotics from agricultural by-products: Production and applications [Text] / A. K. Samanta, N. Jayapal, C. Jayaram, R. Sohini, A. P. Kolte, S. Senani, M. Srithar // Bioactive Carbohydrates and Dietary Fibre. – 2015. – No 5. – P. 62-71. doi: 10.1016/j.bdfc.2014.12.003

10. Ebringerova A. Structural diversity and application potential of hemicelluloses [Text] / A. Ebringerova // Macromolecular Symposia. – 2005. – Vol. 232, No 1. – P. 1-12.

11. Sedlmeyer FB. Xylan as by-product of biorefineries: characteristics and potential use for food applications [Text] / F. B. Sedlmeyer // Food Hydrocolloids. – 2011. – Vol. 25, No 8. – P. 1891-1898. doi: 10.1016/j.foodhyd.2011.04.005

12. Rakha A. Characterisation of Dietary Fibre in Cereal Grains and Products Emphasis on Triticale and Rye Faculty of Natural Resources and Agricultural Sciences [Text] / A. Rakha // Thesis of Ph.D. - Department of Food Science Uppsala: Sweden. - 2011. – P. 80.

13. Johansson M. Dietary fibre composition and sensory analysis of heat treated wheat and rye bran [Electronic resources] / Second cycle, A2E. Uppsala: SLU, Dept. of Food Science. Sep 07, 2012. – Mode of access: WWW: URL: http://stud.epsilon.slu.se/4771/10.1016/j.biortech.2011.02.059.

14. Burton R. A. Evolution and development of cell walls in cereal grains [Text] / R. A. Burton, G. B. Fincher // Front Plant Sci. – 2014. – No 5. – P. 1-15. doi: 10.3389/fpls.2014.00456

15. Gullon P. Manufacture and prebiotic potential of xylooligosaccharides derived from industrial solid wastes [Text] / P. Gullon, M. J. González-Mucoz, J. C. Paraj // Bioresearch. – 2011. – Vol. 102, No 10. – P. 6112-9. doi: 10.1016/j.biore.2011.02.059.

16. Gullon P. Assesment on the fermentability of xylooligosaccharides from rice husks [Text] / P. Gullon, N. Salazar, M. J. Gonzalez-Mucoz, M. Gueimonde, P. Ruas-Madiedo, C. G. de los Reyes-Gavilan, J. C. Paraj // BioResources. – 2011. – Vol. 6, No 3. – P. 3096-3114.

17. McDougall JM, Boernier KN. Poultry feedstuffs. Supply, composition and nutritive value [Text] Poultry Science Symposium Series. England: Carfax Publishing Company, 2002. – P. 427

18. Garrote G. Autodysholysis of corncob: study of non-isothermal operation for xylo-oligosaccharide production wood [Text] / G. Garrote, H. Domingu, J. C. Paraj // Journal of Food Engineering. – 2002. – Vol. 52, No 3. – P. 211-218.

19. Telemann A. Characterization of acetylated 4-O-methylglucuronoxyylan isolated from aspen employing 1H and 13C NMR spectroscopy [Text] / A. Telemann, J. Lundqvist, F. Tjerneld, H. Stalbrand, O. Dahlqvist // Carbohydr. Res. – 2000. – No 394, No 4. - P. 807-815.

20. Otko D. O. A thermochemical pretreatment process to produce xyloooligosaccharides (XOS), arabinooligosaccharides (AOS) and mannoooligosaccharides (MOS) from lignocellulosic biomasses [Text] / D. O. Otko, B. A. Ahir // Bioresearch. – 2012. – No 112. – P. 285-292. doi:10.1016/j.biortech.2012.01.162.

21. Nabarlina D. Purification of xylooligosaccharides from almond shells by ultrafiltration [Text] / D. Nabarlina, C. Torres, R. Garcia-Valls, D. Montane // Separat. Purificat. Technol. – 2007. – Vol. 3, No 3. – P. 235-243. doi:10.1016/j.seppur.2006.07.006

22. Nabarlina D. Autodysholysis of almond shells for the production of xyloooligosaccharides: product characteristics and reaction kinetics [Text] / D. Nabarlina, X. Fariol, D. Montane // Indus. Engineer. Chem. Res. – 2005. – Vol. 44, No 20. – P. 7746-7755. doi: 10.1021/ie050664n

23. Капрельянц Л. В. Пребиотики: химия, технология, применение [Текст] / Л. В. Капрельянц. - К: EnterPrint, 2015. – 252 с.

24. Ergues I. Effect of alkaline and autohydrolysis processes on the purity of obtained hemicellulose from corn stalks [Text] / I. Ergues, C. Carrast, J. Mondragon, J. Labidi // Bioresearch Technology. – 2012. – Vol. 103, No 1. – P. 239-248. doi: 10.1016/j.biortech.2011.09.139.

25. Ruzene D. S. An alternative application to the Portuguese agro-industrial residue: Wheat straw [Text] / D. S. Ruzene, P. D. Silva, A. A. Vicente, A. R. Goncalves, J. A. Teixeira // Applied Biochemistry and Biotechnology. – 2008. – Vol. 147, No 1-3. – P. 85-96. doi:10.1007/s12010-007-0866-2.

26. Akpinar O. Enzymatic production of xylooligosaccharide from selected agricultural wastes [Text] / O. Akpinar, K. Erdogan, S. Bostanci // Food Bioprocess and Processing. – 2009. – Vol. 87, No 2. – P. 145–151. doi: 10.1016/j.fbp.2008.09.002
27. Samanta A. K. Enzymatic production of xylo-oligosaccharides from alkali solubilized xylan of natural grass (Schima nervosum) [Text] / A. K. Samanta, N. Jayapal, A. P. Kolte, S. Senani, M. Sridhar, K. P. Suresh, K. T. Sampath // Bioresource Technology. – 2012. – Vol. 112. – P. 199–205. doi:10.1016/j.biortech.2012.02.036.

28. Sun J. Y. Expression of recombinant Thermomonospora fusca xylanase A in Pichia pastoris and xylo-oligosaccharides released from xylans by it [Text] / J. Y. Sun, M. Q. Liu, X. Y. Weng, L. C. Qian, S. H. Gu // Food Chem. – 2007. – Vol. 104, No 3. – P. 1055–1064.

29. Yuan, X. Antioxidant activity of feruloylated oligosaccharides from wheat bran [Text] / X. Yuan, J. Wang, H. Yao // Food Chem. – 2004. – Vol. 90. – P. 759–764. doi:10.1016/j.foodchem.2003.01.018.

30. Lin Y. S. Production of xylo-oligosaccharides using immobilized endo-xylanase of Bacillus halodurans [Text] / Y. S. Lin, M. J Tseng, W. C. // Lee Process Biochemistry. – 2011. – Vol. 46. – P. 2117–2121.

31. Shinozama H. Superiority of alcohols [Text] / H. Shinozama, T. Yasui // Agric. Biol. Chem. – 1988. – Vol. 52. – P. 2197-2202.

32. Swennen K. Ultrafiltration and ethanol precipitation for isolation of arabinoxylooligosaccharides with different structures [Text] / K. Swennen, C. M. Courtin, B. Van der Bruggen, C. Vandecasteele, J. A. Delcour // Carbohydr. Polym. – 2005. – Vol. 62, No 3. – P. 283–292. doi:10.1016/j.carbpol.2005.08.001.

33. Montane D. Removal of lignin and associated impurities from xylo-oligosaccharides by activated carbon adsorption. [Text] / D. Nabarlatz, A. Martorell, V. Torne-Fernandez, V. Ferrero // Indused Engineer Chem Res. – 2006. – Vol. 45, No 7. – P. 2294-302. doi: 10.1021/ie051051d

34. Nabarlatz D. Autohydrolysis of agricultural by-products for the production of xylo-oligosaccharides [Text] / D. Nabarlazt, A. Ebringerovб, D. Montani // Carbohydrate Polymers. – 2007. – No 69. – P. 20–28. doi:10.1016/j.carbpol.2006.08.020.

35. Wang J. On-line separation and structural characterization of feruloylated oligosaccharide from wheat bran using HPLC-ESI-MS [Text] / J. Wang, X. Yuan, B. Sun, Y. Cao, Y. Tian, C. Wang // Food Chemistry. – 2009. – Vol. 115, No 4. – P. 1529–1541. doi: 10.1016/j.foodchem.2009.01.058.

36. Mussatto S. I. Non-digestible oligosaccharides: A review [Text] / S. I. Mussatto, I. M. // Mancilha Carbohydrate Polymers. – 2007. – Vol. 68, No 3. – P. 587–597. doi:10.1016/j.carbpol.2006.12.011.

37. Tugland B. C. Non-digestible oligo- polysaccharides (dietary fiber): their physiology and role in human health and food [Text] / B. C. Tugland, D. Meyer // Compr. Rev. Food Sci. Food Safety. – 2002. – Vol. 1, No 3. – P. 73–92. doi:10.1111/j.1541-4337.2002.tb00090.x.

38. Rycroft C. E. A comparative in vitro evaluation of the fermentation properties of prebiotic oligosaccharides [Text] / C. E. Rycroft, M. R. Jones, G. R. Gibson, R. A. Rastall // Journal of Applied Microbiology. – 2001. – Vol. 91, No 5. – P. 878–887.

39. Aachary A. A. Bioactive xylo-oligosaccharides from corncob: enzymatic production and applications (Thesis) [Text]: thesis Ph. D.: 2009 Apr. / Aachary A. A. - Mysore, India, 2009.

40. Kaprielian L. B. Получение природных ксилоолигосахаридов-пребиотиков из вторичных продуктов переработки зерна [Text] / L. B. Kaprielian, Е. Д. Журлова // Сборник тезисов третей конференции молодых учёных “Биология растений и биотехнологии”. – 2017. – К: НАУ. – С. 79.

41. Kontula P. Oat bran α-glucos- and xylo-oligosaccharides as fermentative substrates for lactic acid bacteria [Text] / P. Kontula, A. Von Wright, T. Mattilla-Sandholm // Int. J. Food Microbiol. – 1998. – No 45. – P. 163–169.

42. Fooks L. J. J. In vitro investigations of the effect of probiotics and prebiotics on selected human intestinal pathogens. [Text] / L. J. Fooks, G. R. Gibson // FEMS. Microbiol. Ecol. – 2002. – Vol. 39, No 1. – P. 67–75. doi:10.1111/j.1574-6941.2002.tb00907.x.

43. Christakopoulos P. Antimicrobial activity of acidic xylo-oligosaccharides produced by family 10 and 11 endoxylanases [Text] / P. Christakopoulos, P. Katopoulos, E. Kalogeris, D. Kekos, B. J. Macris, H. Stamatileris, H. Skaltsa // Int. J. Biol. Macromol. – 2003. Vol. 31, No 4-5. – P. 171–175.

44. Singh R. D. Prebiotic potential of oligosaccharides: a focus on xylan derived oligosascharides [Text] / R. D. Singh, J. Banerjee, A. Arora // Bioactive carbohydrates and dietary fiber. - 2015. – Vol. 5, No 1. – P. 19-30. doi:10.1016/j.bcf.2014.11.003.

45. Vazquez M. J. Xylo-oligosaccharides: manufacture and applications [Text] / M. J. Vazquez, J. L. Alonso, H. Domnguez, J. C. Parajo // Trends in Food Science & Technology. – 2000. – Vol. 11, No 11. – P. 387–393. doi:10.1016/S0924-2244(01)00031-0.

46. Gibson G. R. Prebiotics: Development and Application Gibson [Text] // G. R. Gibson, R. A. Rastall. - England: John Wiley & Sons, 2006. – P. 264.

47. Gupta P. K. A Review on Xylooligosaccharides [Text] / P. K. Gupta, P. Agrawal, P. Hegde // International Research Journal of Pharmacy. – 2012. – Vol. 3, No 8. – P. 71–74.

48. Gupta P. K. Xylooligosaccharide - a valuable material from waste to taste: a review [Text] / P. K. Gupta, P. Agrawal, P. Hegde, N. Shankarnarayan, S. Vidyashree, S. A. Singh, S. Ahuja // Journal of Environmental Research And Development. – 2016. – Vol. 10, No 3. – P. 555-563.