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

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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 в-(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 - $1{,}4\cdot10^{10}$ CFU/cm^3 of *L. acidophilus* and $9{,}2\cdot10^{10}$ 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, corncobs, 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 alkali 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

КСИЛООЛІГОСАХАРИДИ З СІЛЬСЬКОГОСПОДАРСЬКОЇ СИРОВИНИ: ХАРАКТЕРИСТИКА, ОТРИМАННЯ ТА ФІЗІОЛОГІЧНІ ЕФЕКТИ

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Анотація. Ця стаття є критичним оглядом ксилоолігосахаридів (КОС), їхньої характеристики, виробництва, фізіологічних властивостей і застосування. Ксилан важливий для клітинних стінок рослин і поширений в сільськогосподарській сировині. КОС - це продукти гідролітичної деградації ксилана, володіють високим пребіотичним потенціалом. Відмінності в розгалуженні молекул КОС пояснюють широкий спектр їхніх фізіологічних властивостей: антиоксидантні, імуномодулювальні, протимікробні, протизапальні, антиканцерогені та інші. Застосування КОС, розглянуте в цій статті, відкриває нові перспективи їхнього потенційного використання. Багатими джерелами ксилана є пшеничні, житні і ячмінні висівки, рисове лушпиння, пшенична солома, кукурудзяні качани, стебла бавовни. Промисловий спосіб виробництва КОС включає хімічний або ферментативний гідроліз із подальшим очищенням. Хімічні методи, засновані на гідротермічній попередній обробці і кислотній або лужній екстракції. Отримані олігосахариди мають широкий діапазон ступеня полімеризації (СП). Ферментативні методи включають обробку ксиланазою, що дозволяє контролювати накопичення КОС певного СП. Крім того отримання КОС ферментативними методами дає можливість використовувати їх в їжу, оскільки такі препарати не містять наступні домішки: моносахариди і фурфурол. КОС стабільні в широкому діапазоні температур і pH, що обгрунтовує розвиток нового покоління синбіотиків. Найбільш широко КОС використовуються у виробництві функціональних продуктів і фармацевтичних препаратів, але вони також застосовуються в косметичній, сільськогосподарській та комбікормовій промисловості.

Ключові слова: ксилоолігосахариди, ксилан, пребіотики, ферментативний гидроліз

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Introduction. Formulation of the problem

Today the food industry is targeted on new products possessing special functional properties directed at the solving of national healthcare problems. Moreover, in the light of current health diet trends, the customers prefer natural biological active supplements (BAS) as therapeutic preparations for their immune system reinforcement and well-being. As is has already been known, BAS have a purposeful effect 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 β-(1→4)-glycoside bonds. XOS are obtained from xylans by way of hydrolysis. Fig. 1 shows the molecular structure of xylose 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 б-D-xylopyranosyluronic 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].

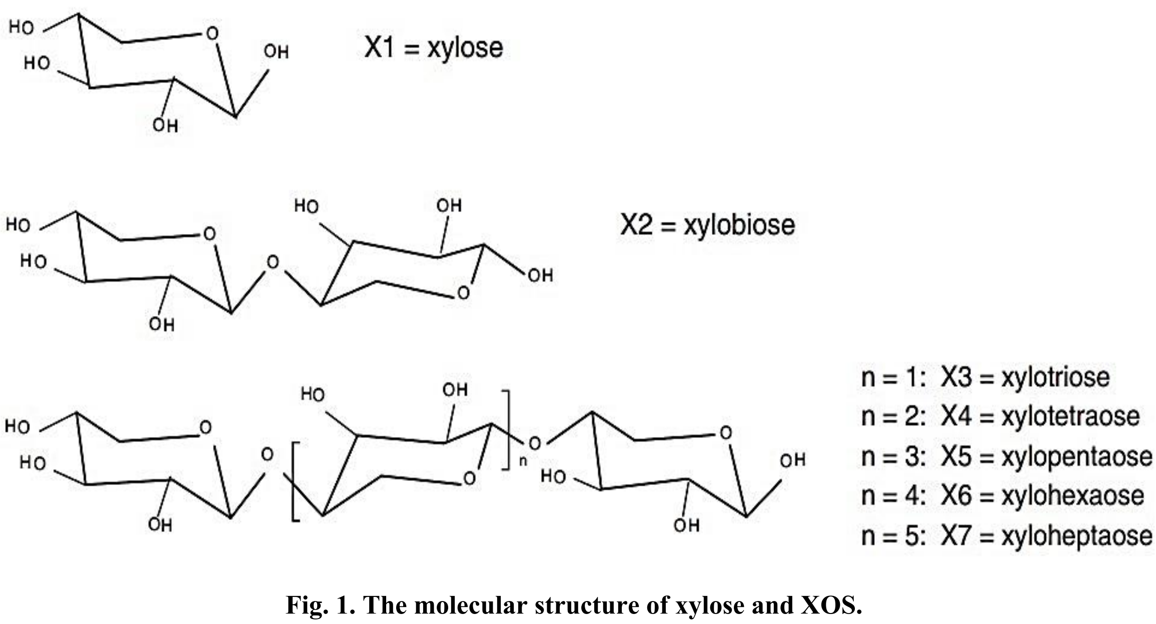

Fig. 1. The molecular structure of xylose and XOS.

Table 1 – The chemical and biological properties of XOS.

Property	Value/nature
Common name	Xylooligosaccharides
Synonym	D-xylose-hexulose
Molecular formula	C_{5n} H_{8n+2} O_{4n+1}; n=2 to 6
Chemical family	Carbohydrate; xylobiose (DP 2), xylotriose (DP 3), xylotetrose (DP 4), xylopentose (DP 5) and xylohexose (DP 6)
Molecular weight	282 to 810 (X_2 to X_6)
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.
- Glucuronoxylans 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.
- (Glucurono) 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 arabinoxylan 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 endosperm – 20 %, maize internodes – 46 %, *Brachypodium* whole grain – 4.7, rice endosperm – 32 %. Xyloglucan 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 ºC 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) xylans 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 ºC) for about 12 h, followed by authohydrolysis at high temperature (temperature 100 ºC for 1 h). Such preparation could be used as prebiotic on commertial 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-glucurono) of xylan. The 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, $Ca(OH)_2$, NH_4OH 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 % $NaHBH_4$ at 20 ºC) gives a yield – 54 % [24], from wheat straw (0.5 M NaOH at 55 ºC) gives a yield of 49.3 % [25], from wheat straw (24 % KOH and 1 % $NaHBH_4$) 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 в-xylosidase, which allows xylobiose 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 authohydrolysis (180 ºC 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 Pentopane Mono 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-в-xylosides by using reactions of transglycosylation of в-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-в-xylanase from *Cellulomonos fimi* was successfully converted into the corresponding glycosynthase by catalytic nucleophile mutating into the glycine residue. The obtained enzyme is capable to catalyze the transfer of xylobiose residues from б-xylobiosyl fluoride to ether n-nitrophenyl-в-xylobiose or benzylthio-в-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.

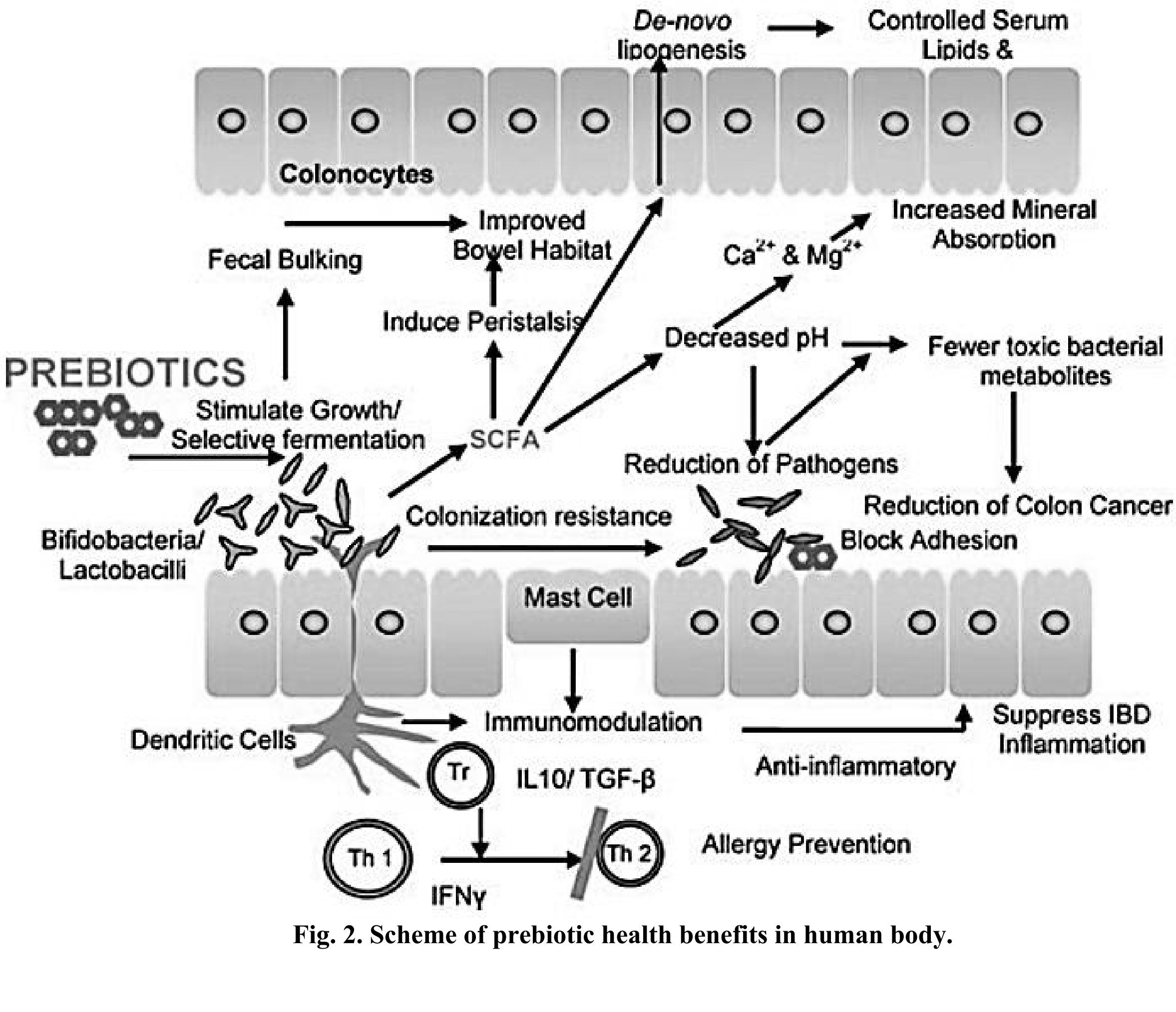

Fig. 2. Scheme of prebiotic health benefits in human body.

Physiological effects of xylooligosaccharides

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 stimulated the cells accumulation - $1,4 \cdot 10^{10}$ CFU/cm^3 of *L. acidophilus* and $9,2 \cdot 10^{10}$ CFU/cm^3 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 в-glyco-oligosaccharides. Only *L. rlantarum* 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, alduronic 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].

Application of xylooligosaccharides

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 synbiotic foods. The non-digestible oligosaccharides is the matrix for the probiotic bacteria immobilization. The obtained synbiotic 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].

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. This approach makes possible to produce low-calorie food, which reduces the risk of cardiovascular and gastrointestinal diseases, cancer and diabetes. XOS may be applied as individual functional supplements – prebiotics. XOS stimulate the growth of colon probiotic microorganisms, the same to classical prebiotic preparations. XOS are stable in a wide range of temperature and pH, the fact that justifies the development of new synbiotic generation.

It is equally important that XOS is obtained from the agricultural by-products. Analysis of xylan sources proved a high potential of using the cereal by-products for XOS production. It is a low cost raw material solving the problem of agricultural by-products recycling. Studies of XOS manufacturing demonstrated the efficiency of xylan enzymatic hydrolysis compared to chemical methods. Combination of chemical pretreatment and the raw materials bioconversion allows obtaining a high XOS yield within a short time.

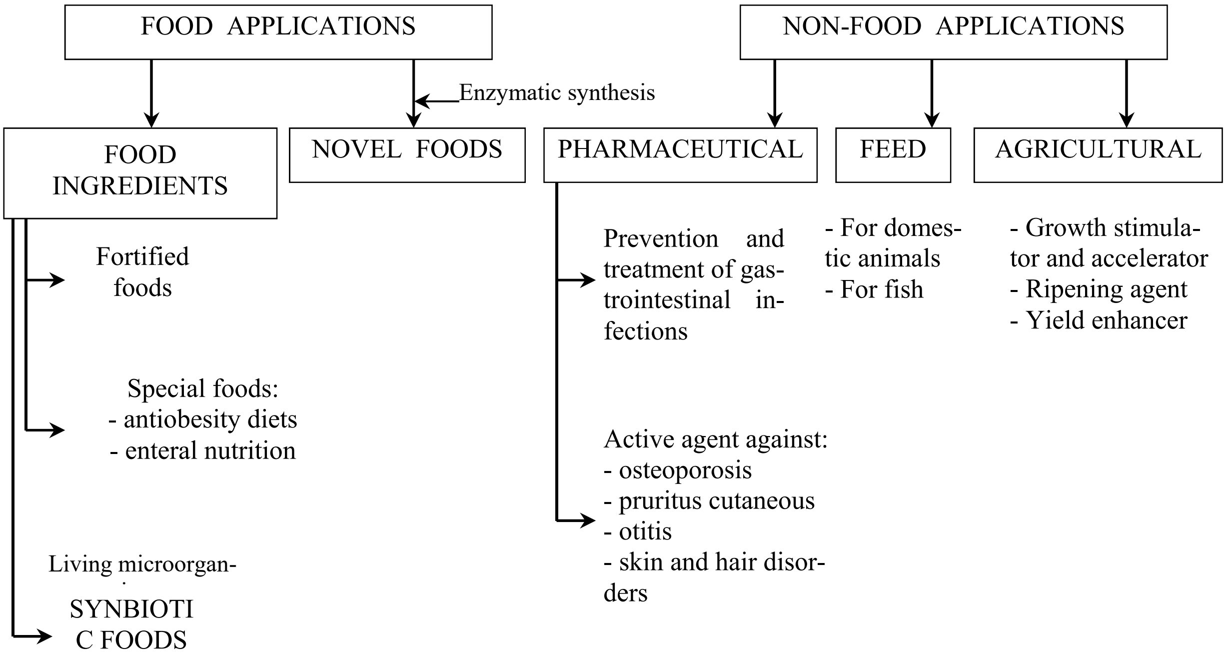

Fig. 3. Applications of xylooligosaccharides

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КСИЛООЛИГОСАХАРИДЫ ИЗ СЕЛЬСКОХОЗЯЙСТВЕННОГО СЫРЬЯ: ХАРАКТЕРИСТИКА, ПОЛУЧЕНИЕ И ФИЗИОЛОГИСЕСКИЕ ЭФФЕКТЫ

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Аннотация. Данная статья - это критический обзор ксилоолигосахаридов (КОС), их характеристики, производства, физиологических свойств и применения. Ксилан важен для растительных клеточных стенок и широко распространен в сельскохозяйственном сырье. КОС – это продукты гидролитической деградации ксилана, обладают высоким пребиотическим потенциалом. Отличия 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. Богатыми источниками ксилана являются пшеничные, ржаные и ячменные отруби, рисовая шелуха, пшеничная солома, кукурузные початки, стебли хлопка. Промышленный способ производства КОС включает химический или ферментативный гидролиз с последующей очисткой. Химические методы, основанные на гидротермической предварительной обработке и кислотной или щелочной экстракции. Полученные олигосахариды имеют широкий диапазон степени полимеризации (СП). Ферментативные методы включают обработку ксиланазой, позволяющую контролировать накопление КОС определенной СП. Кроме того, получение КОС ферментативными методами позволяет использовать их в пищу, поскольку такие препараты не содержат такие примеси как моносахариды и фурфурол. КОС стабильны в широком диапазоне температур и pH, что обосновывает развитие нового поколения синбиотиков. Наиболее широко КОС используются в производстве функциональных продуктов и фармацевтических препаратов. Но они также применяются в косметической, сельскохозяйственной и комбикормовой промышленности.

Ключевые слова: ксилоолигосахариды, ксилан, пребиотики, ферментативный гидролиз

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