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BETTER HEALTH WITH PLANT OLIGOSACCHARIDES: TRENDS AND FUTURE

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Abstract. Oligosaccharides are a group of sugar polymers with degree of polymerisation of 2 to 10 monosaccharides linked by glycosidic bonds. Oligosaccharides are grouped according to their monomer components and linkages; fructooligosaccharides, maltooligosaccharides, xylooligosaccharides, galactooligosaccharides and etc. Plant oligosaccharides are found naturally in some fruits and vegetables but certain oligosaccharides such as xylooligosaccharides can be industrially manufactured from agricultural byproducts. Oligosaccharides that cannot be digested by human digestive system but selectively fermented in the colon had been proven to be a prebiotic ingredient. The addition of prebiotic oligosaccharides to food enhances functional properties beneficial for the body including bowel function, calcium absorption and lipid metabolism, prevention of dental caries, protection against cardiovascular disease and decrease in the risk of colon cancer due to the formation of short-chain fatty acids. The global xylooligosaccharides market is valued at 88.09 million USD in 2016 and is expected to reach 119.62 million USD by the end of 2022. Due to global demand of xylooligosaccharides and availability of agricultural byproducts from oil palm plantation and palm oil industry, Malaysia and Indonesia should play important role as manufacturers of xylooligosaccharides.

1. Introduction

"We are what we eat - Anthelme Brillat-Savarin, 1826"

The phrase is literally true because what we eat daily very much affects our health and health is precious to every one of us. There are five basics nutrient groups; carbohydrate, protein, fats, minerals and vitamins that we consume every day and oligosaccharides belong to the carbohydrate group. Dietary nondigestible oligosaccharides modulate the composition and activities of intestinal microbiota that are beneficial to the host health. This paper explains the different types of oligosaccharides, production of oligosaccharides from agricultural plant byproduct, functional properties of oligosaccharides, application of oligosaccharides in food industry, and trend and future industrial demand of oligosaccharides.

2. Oligosaccharides

Oligosaccharides are a group of sugar polymers with degree of polymerisation of 2 to 10 monosaccharides linked by glycosidic bonds that are readily hydrolysed to their constituent monosaccharides either by acids or by specific enzymes. Oligosaccharides could be grouped into xylooligosaccharides (XOS), galactooligosaccharides (GOS), fructooligosaccharides (FOS), isomaltooligosaccharides (IMO), maltooligosaccharides (MOS), and soy meal oligosaccharides (SMO).

Plant oligosaccharides such as FOS can be naturally found in asparagus, sugar beet, garlic, chicory, Jurusalem artichoke, onion, leek, wheat, rye, banana, tomato and honey (Ziemer and Gibson, 1998;

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Sangeetha et al., 2005). ISO is naturally occurs in honey, sugarcane juice and products derived from molasses (Lina et al., 2002). XOS is found in bamboo shoots, fruits, vegetables, milk and honey (Vazquez et al., 2000). Seeds of legumes, lentils, peas, beans, chickpeas and mustard are rich in raffinose oligosaccharides (Johansen et al., 1996; Sanchez-Mata et al., 1998). Table 1 shows the main monomer components and linkages in different types of oligosaccharides (Patel and Goyal, 2011).

Table 1. Monomer composition and osidic bonds of common oligosaccharides.

Oligosaccharides	Monomer composition	Linkage
Xylooligosaccharides (XOS)	$(\text{Xylose})_n$	β(1-4) linked
Galactooligosaccharides (GOS)	$(\text{Galactose})_n$-glucose	α(1-4) and β(1-6) linked
Fructooligosaccharides (FOS)	$(\text{Fructose})_n$-glucose	β(2-1) and α(1-2) linked
Isomaltooligosaccharides (IMO)	$(\text{Glucose})_n$	α(1-4), α(1-6) linked
Maltooligosaccharides (MOS)	$(\text{Glucose})_n$	α(1-4) linked
Soy meal oligosaccharides (SMO) (Stachyose and Raffinose)	$(\text{Galactose})_n$-glucose-fructose	α(1-6)-α(1-2) β-fructose linked

In most of these sources, concentration of oligosaccharides range between 0.3% and 6% of fresh weight (Musatto and Mancilha, 2007) and the most frequently consumed foods only provide about 1-3 g of natural oligosaccharides per day as opposed to daily fibre requirement of 25 g for a 2000 calorie diet. Therefore, large quantity of such foods needs to be consumed to meet the requirement. Consequently, there is necessity to provide oligosaccharides fibre as supplement or food ingredient to meet the required intake.

3. Production of oligosaccharides

Generally, oligosaccharides can be extracted directly from natural sources (fruits, vegetables, roots, cereals) or by enzymatic hydrolysis from a variety of plant biomass sources or synthesized from simple monosaccharides by enzymatic transfer reactions. Three main types of commercial oligosaccharides are GOS, FOS and XOS. GOS which is mainly produced by Japanese companies is manufactured from enzymatic conversion of lactose whereas FOS is produced mainly in the Europe and the United States of America from the hydrolysis of inulin or by transfructosylation processes. Meanwhile, XOS is commercially manufactured from lignocellulosic materials (xylans) of corn cobs in the Republic of China. China produces 224.9 million metric tons corn annually and is the world second largest corn producing country whilst Indonesia placed at number 8 of largest corn producing country with an annual production of 19 million metric tons corn (Sen Nag, 2017).

Agricultural byproducts such as corn cobs are rich in lignocellulosic materials which consist of lignin, cellulose and hemicellulose. Hemicellulose is the precursor for XOS manufacturing from agricultural byproducts. Major component of hemicellulose is xylan and corn cobs contain about 35.7% xylan (Teng et al., 2010).

Several approaches for XOS manufacturing from agricultural byproducts include non-isothermal autohydrolysis treatment at high temperatures between 150°C and 220°C, chemical hydrolysis, combination of chemical-enzymatic treatment or combination of autohydrolysis-enzymatic treatment. Generally, manufacturing of XOS from agricultural byproducts follows the following steps: identification of raw materials, extraction of precursors for XOS, breaking down of precursors into XOS by autohydrolysis, chemical or enzymatic hydrolysis followed by purification to obtain XOS of higher quality (Aachary and Prapulla, 2011). Depending of the raw materials and manufacturing steps, yield of XOS over xylan feedstock range from 15.4% to 66% (Parajo et al., 2004; Ho et al., 2014). Figure 1 shows the general manufacturing of XOS from corn cobs by a combination of autohydrolysis and enzymatic treatment. Downstream processes involving isolation and purification of XOS are needed because the reaction liquor usually contains monosaccharides, acetic acid, furfural, hydroxymethylfurfural, formic acid and phenolic compounds. Non-isothermal autohydrolysis of corn cob at 202°C yielded 65.6% XOS from the xylan (Garrote et al., 2002).

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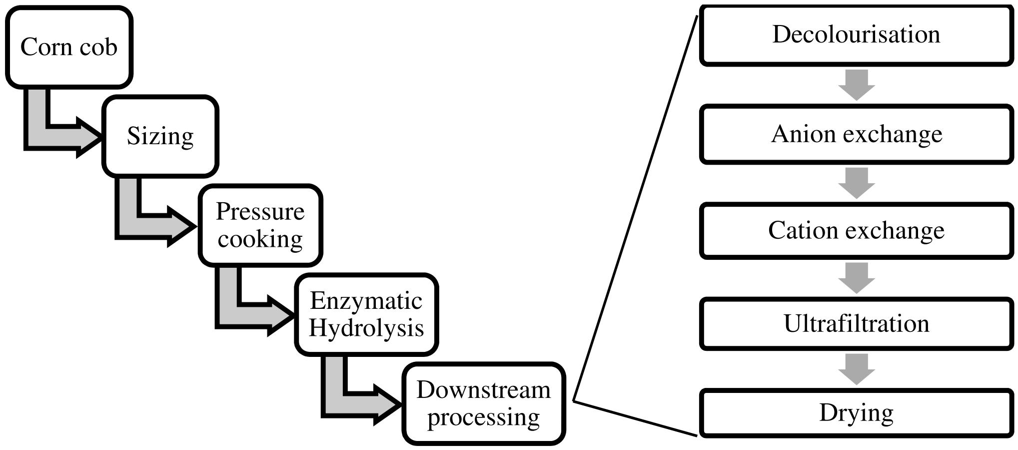

Figure 1. General manufacturing steps of XOS from corn cob.

Autohydrolysis of oil palm fronds at 121°C for 60 min was able to fractionate 49.2% hemicellulose from initial hemicellulose content (Sabiha-Hanim et al., 2011). However, by applying non-isothermal autohydrolysis at 210°C for 4 min had increased the fractionation efficiency between 77.3 and 83.3% hemicellulose from oil palm fronds (Sabiha-Hanim et al., 2015). On the other hand, non-isothermal autohydrolysis of oil palm empty fruit bunch at a temperature of 210°C generated XOS of 17.6 g/L from solubilisation of 63% xylan (precursor of XOS). The subsequent purification procedure resulted in 74-78% purity of XOS with 83-85% recovery (Ho et al 2014).

4. Functional properties of oligosaccharides

Nowadays consumer is becoming more and more health conscious. The uses of foods that promote a state of wellbeing, better health and reduction of the risk of diseases have become popular. Non-digestible oligosaccharides (NDOs) have attracted a lot of attention with its use as functional food ingredients to manipulate the composition of gut microecology in order to improve host health. The NDOs are known to have bifidogenic effect in the colon and recognized as prebiotics (Mussatto and Mancilha, 2007).

The inclusion of prebiotic NDOs in human diets has the objective to maintain intestinal microbiota by health-promoting bacteria such as bifidobacteria and lactobacilli, and to directly inhibit the growth of pathogenic bacteria such as certain species of clostridia (eg., *Clostridium difficile* and *Clostridium perfringens*) and pathogenic Enterobacteriaceae through the production of short chain fatty acids, lowering of colonic pH, production of antimicrobial compounds and competition for growth substrates and adhesion sites (Mikkelsen and Jensen, 2004).

Oligosaccharides are functional food ingredients that have a great potential to improve quality of many foods. Besides providing useful modifications to physicochemical properties of foods, these oligosaccharides have various physiological functions such as the improvement of intestinal microflora based on the selective proliferation of bifidobacteria, stimulation of mineral absorption, non or anticariogenicity, and the improvement of both plasma cholesterol and blood glucose levels (Nakakuki, 2005). Other potential health benefits associated with prebiotic oligosaccharides consumption are regulation of bowel habits, metabolic health, reduction of incidence of infections and nonfermentation-mediated effects (Pandey et al., 2015). Davani-Davari et al. (2019) had intensively reviewed the mechanisms for health maintenance and protection against disorders by prebiotic oligosaccharides.

Table 2 summarizes the physiological function of different oligosaccharides from various plant sources (Patel and Goyal, 2011).

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Table 2. Sources and application of various plant oligosaccharides.

Oligosaccharides	Sources	Functional benefits
Soybean meal oligosaccharides	Soybean	Promote competitive exclusion of potential pathogens, reduce oxidative stress, reverse cardio-cerebrovascular disease
Fructooligosaccharides	Chicory root	Improve gut absorption of Ca and Mg, prevent urogenital infections, sweetener in beverages, anticariogenic quality, effect on lipid metabolism, reduce risk of colon cancer
Maltooligosaccharides	Digestion of starch	Increase bifidobacteria population Reduce the levels of *Clostridium perfringens* and *Enterbobacteriaceae* family
Xylooligosaccharides	Wheat bran and straw, aspen wood, barley hulls, brewery spent grains, almond shells, bamboo, corn cob	Prebiotic, cosmetics, plant growth regulator, antioxidant, gelling agent, treatment of diabetes, arteriosclerosis and colon cancer
Glucan oligosaccharides	Oat	Exert better lactobacillogenic effect
Gentiooligosaccharides	Digestion of starch	Improve prebiotic profile

5. Trends

Oligosaccharides are about 0.3-0.6 times as sweet as sucrose. This low sweetness attribute is exploited in food formulations as a replacement of sucrose. The low caloric densities make the oligosaccharides useful as bulking agents in food formulations. They are used as humectants because of their high moisture-retaining capacity without increasing water activity. Based on their physiological properties, these carbohydrates are grouped as digestible or non-digestible. Among non-digestible carbohydrate, the functional oligosaccharides present important physiochemical and physiological properties beneficial to the health of consumers. Functional oligosaccharides of various origins (plants, bacteria, fungi, viruses) have been used extensively as food ingredients, beverages, confectionery processing, prebiotic supplements, drug delivery, cosmetics and including in animal feed and agrochemicals (Qiang et al., 2009).

Table 3 listed the applications of oligosaccharides in different food products (Roberfroid, 2008). Basically, oligosaccharides are added in selected foods as sugar replacer, fibre and prebiotic.

Table 3. Applications of prebiotics in food products.

Application	Functionality
Dairy products (yogurts, cheeses, desserts, drinks)	Fat or sugar replacement, body and mouthfeel, foam stabilization, fibre and prebiotic
Frozen desserts	Fat or sugar replacement, texture and mouthfeel, melting behavior
Fruit preparations	Sugar replacement, synergy with intense sweeteners, body and mouthfeel, fibre and prebiotic
Breakfast cereals and extruded snacks	Sugar replacement, crispiness and expansion, fibre and prebiotic
Baked goods and breads	Sugar replacement, moisture retention, fibre and prebiotic
Fillings	Sugar replacement, texture and mouthfeel
Tablets and confectionary	Sugar replacement, fibre and prebiotic
Chocolate	Sugar replacement, heat resistance and fibre
Dietetic products and meal replacers	Fat or sugar replacement, synergy with intense sweeteners, body and mouthfeel, fibre and prebiotic
Beverages and drinks	Sugar replacement, mouthfeel, foam

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Some of properties for an ideal prebiotic as food ingredient are listed in Table 4 (Swennen et al. 2006).

Table 4. Properties of an ideal prebiotic.

Desirable attributes	Properties of oligosaccharides
Active at low dosage	Selectively and efficiently metabolized by *Bifidobacterium* and / or *Lactobacillus* sp.
Lack of side effects	Selectively and efficiently metabolized by beneficial bacteria without producing gas.
Persistence through the colon	Preferably high molecular weight
Varying viscosity	Available in different molecular weights and linkages
Acceptable storage and processing stability	Possess 1–6 linkages and pyranosyl sugar rings
Ability to control microflora modulation	Selectively metabolized by restricted microbial species
Varying sweetness	Varying monosaccharide composition

Feed industry demanded 49.61% of global production market share of xylooligosaccharides in 2017, followed by medicine and health products (25.39%) and, food and drinks (23.18%). Figure 2 shows the global production market of xylooligosaccharides by applications in 2017 (QYResearchGlobal, 2019).

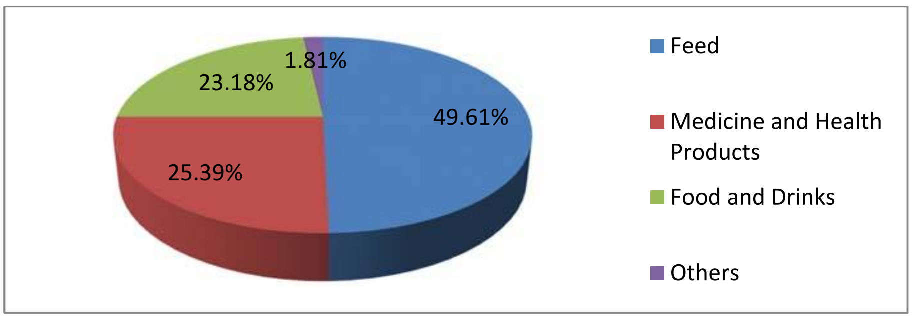

Figure 2. Global production market of xylooligosaccharides by applications in 2017.

6. Future

Due to the functionalities of oligosaccharides in medicinal and health products, and feed/food formulations, production of oligosaccharides will be expanded. The global XOS market was valued at USD88.09 million in 2016 and is expected to reach USD119.62 million by the end of 2022, growing at a compound annual growth rate (CAGR) of 5.23% between 2016 and 2022. The major players in global XOS market are from China which includes Longlive, Kangwei, AHFsugar, Henan Shengtai, YIBIN, YATAI, HBTX, YuHua and ShunTian (QYResearchGlobal, 2019).

Palm oil production is vital to the economy of Malaysia, which is the world's second largest producer after Indonesia. Malaysia has 5.8 million hectares of oil palm plantation area which produces nearly 20 million metric tons of crude palm oil (Malaysian Department of Agriculture, 2018) whereas Indonesia has nearly 13 million hectares of plantation area. Thus, there is abundant palm oil related lignocellulosic biomass waste that could be used as the raw materials for XOS production. Table 5 shows the hemicellulose content in various parts of oil palm tree that can be used as the precursor for XOS manufacturing.

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Table 5. Hemicelluloses content in different parts of oil palm tree.

Part	Hemicellulose (%)	Reference
Trunk	34.4	Kelly-Yong et al., 2007
Frond	30.4	Sabiha-Hanim et al., 2015
Empty fruit bunches	28.2	Ho et al., 2014

Besides these, mill-based palm oil industry generates byproducts such as palm pressed fibre, oil palm mesocarp fibre, palm kernel shells, and palm kernel and decanter cakes which could also be served as the raw materials for XOS manufacturing.

7. Conclusions

Plant oligosaccharides such as FOS, XOS, MOS and ISO have shown to have functional properties that are beneficial to a consumer's health. Food formulation containing oligosaccharides are becoming a trend. Abundant availability of raw materials for XOS production from palm oil plantation and oil palm industry provides potential future economic endeavours for Malaysia and Indonesia.

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