Review Article

Egypt. J. Food. Sci. **Vol. 52,** No.1, pp. 107-122 (2024)

Egyptian Journal of Food Science
http://ejfs.journals.ekb.eg/

Natural Plant-Based Sugar Syrups as Potential Functional Food Ingredients

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NATURAL sugar alternatives have received much consumer interest as a result of concerns about the possible negative effects of high sugar intake on human health. Consuming sugar increases caloric intake and increases the risk of obesity, which is considered a risk indicatorfor a number of chronic illnesses. The utilization of low calorie natural plant syrups as sugar substitute is a good approach for producing value-added functional nutritional products that are safe and have positive health benefits. Natural plant-based syrups, like those made from fructan and saccharides, contain bioactive compounds and nutrients that are metabolized by the body. On the other hand, novel glycosidic syrups extracted from stevia and monk fruit have a sweet taste with very few calories. This review focuses on some natural plant syrups that can be used as substitutes for sugar. In addition, the article offers information on the process, the physicochemical characteristics, nutritional and functional compounds ofnatural plant syrups, as well as their applications in food and pharmaceutical industries.

Keywords: Natural plant syrups, Fructan, Glycosidic syrups, Stevia and Monk fruit

Introduction

The modern lifestyle and shifting eating habits of consumers have made natural plant syrups more appealing to food manufacturers, who recognize natural products as safe and healthy products. Current food industry market trends indicate that consumers prefer natural food products over those containing artificial ingredients (Saraiva et al., 2020). In recent years, there has been significant interest in using healthy foods and medicinal plants rather than artificial sweeteners from a health perspective. Furthermore, consumers are becoming more interested in natural sweetening options as a result of concerns about the possible negative effects of high sugar intake on health. Sugar (sucrose) has been associated with a number of health issues, including diabetes, high blood pressure, obesity, metabolic syndrome, dental caries, elevated cholesterol, and possibly even cancer (Deliza et al., 2021). Conversely, sugar, which is obtained industrially from sugarcane or sugar beet, is the most widely used sweetener in food products. Many studies have highlighted the technologically positive impact of sugar in the food process; it contributes to flavor, sweetening qualities, and food preservation (Lee et al., 2018). According to the Food and Agriculture Organization (FAO), sugar consumption is expected to rise rapidly in developing nations, where its usage has multiplied over the past few decades. It is predicted to rise by 32 MT by 2028 (OECD/FAO, 2019). The disadvantage of sugar is the absence of healthy nutritional components that are lost during the refining process of sugarcane juice (Cervera-Chiner et al., 2021). Furthermore, previous studies have shown 30% higher risk of type 2 diabetes development related to the increasing of sugar-sweetened beverages consumption (Wang et al., 2015). Therefore,

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Received :1/6/2024; Accepted :8/9/2024
DOI : 10.21608/EJFS.2024.294504.1186

more researchers are becoming interested in the study of natural sweeteners as potential nutrient replacements for sugar with positive effects on consumer health. Naturally occurring sources of sweeteners include plant and tree sap (such as sorghum, maple, and agave syrups), fruits (like date syrup and carob syrup), roots (like yacon syrup), herb leaves (like stevia), and bees (honey) (Edwards et al., 2016). In general, these sweeteners containdietary fibers (<3%), proteins (<1.4%), lipids (<0.5%), and phytochemicals like polyphenolsat least 3% (Ozcan et al., 2007). In certain countries, these sweeteners have been used in food processing as nutritional substitutes because of their highcontent ofantioxidants, phytochemicals, and phytohormones. Also, they contain minerals (calcium, potassium, magnesium, manganese, and phosphorous) and trace amounts of vitamins (A, B, C, E, and K) and other healthy ingredients. For example, Middle Eastern date syrup, Mexican agave syrup, Canadian maple syrup, and fig syrup, were common sweetener used by the Assyrians in antiquity (Castro-Muñoz et al., 2022). Natural sweeteners help meet daily nutritional needs and may help to support general health, reduce inflammation and maintain immune responses, especially against viral infections such as COVID-19 (Lahaye, et al., 2023). Owing to these characteristics, natural sweeteners are typically marketed as healthier alternatives and are helpful in both nutritional and medicinal applications (Edwards et al., 2016 and Valle et al., 2020). Therefore, the physicochemical characteristics, extraction techniques, manufacturing procedures, current uses and applications of some natural sweet syrup in the food industry are the main focus of this review.

Natural sources and processing of some sweet syrups

Naturally occurring sources of syrup production are plants (trees, stalks, fruits, seeds, roots), and bees. The origin of the plant, growth environment, and processing conditions influence the composition and sensory characteristics of these syrups, which also contribute to their nutritional value, sweet flavor, and medicinal qualities. The extraction, purification, and concentration of the juice during the production process of the syrups have an impact on the bioactive components and characteristics of the final syrup product.Consequently, the natural syrups can be classified based on their chemical structure: simple saccharides, fructan and glycosidic-based syrups (Fig. 1).

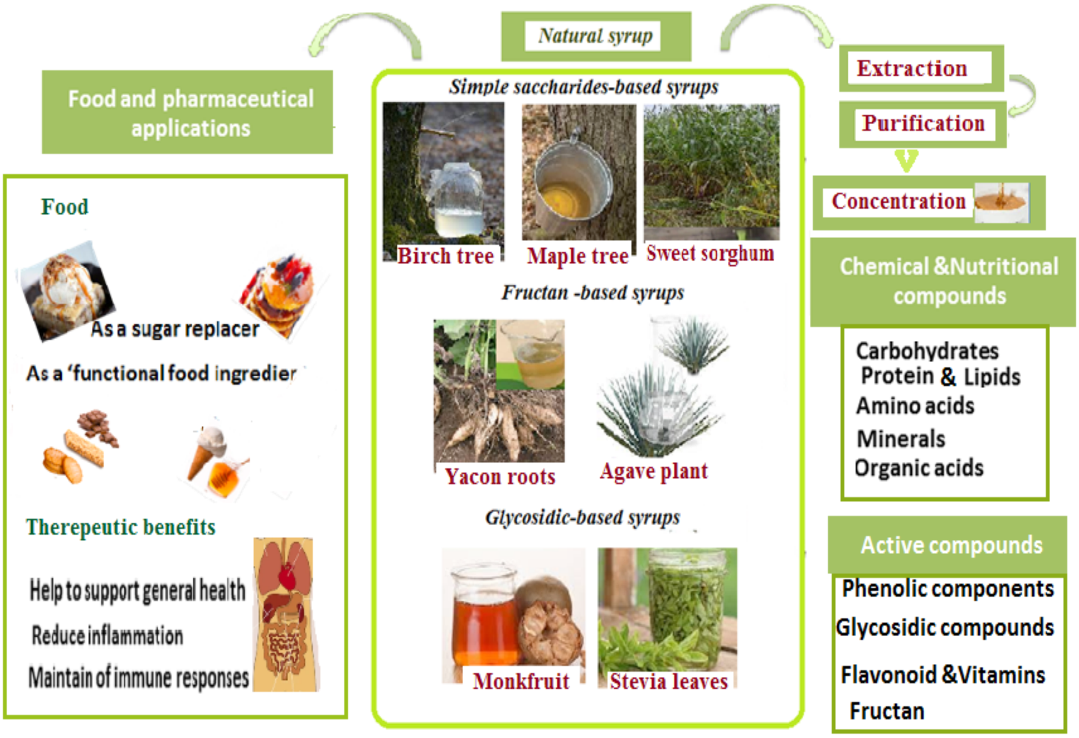

Fig. 1. Natural plants based-syrups and their application.

Simple saccharides - based syrups

Sweet Sorghum syrup

The sweet stems of sweetsorghum (*Sorghum bicolor* L.) are used for sorghum syrup production. Sweet sorghum is the fifth most important cereal crop in the world (Paterson, 2008). It contains four major types of groups: forage, grain, biomass and sweet (Roa et al., 2013), grown primarily in the Southern United States. Sweet sorghum was introduced into the USA probably from China in the 1850s. Therefore, USA became the pioneer in producing syrup from sweet sorghum, and for three decades sweet sorghum was extensively cultivated for syrup production. It is also an essential food source in many Asian and African nations (Mathur et al., 2017). Sorghum syrup is made by milling the stalks to extract the juice, after the stalks were stripped of their leaves and washed. The extracted juice is collected and then filtered through a fine plastic screen. Then, clarification process using liming with $Ca(OH_2)$ solution as stated by Takahashi et al., (2016). The review article by Harlen & Ristiarini (2023) also focused on syrup clarified with 5% bentonite and calcium hydroxide, which produce the sweet taste and caramel aroma of sorghum syrup. The clarified juice was pumped to the evaporator. The scum was continuously removed during the concentration process, which occurs as a result of the coagulation of the remaining suspended particles. The concentrated juice (syrup) which reached 72° to 76° Brix, was cooled to 80°C for 10–15 minutes, and was stored in PET (polyethylene terephthalate) bottles under ambient conditions. Chibrikov et al. (2023) mentioned that the rate of heat exchange should be as high as boiling at 105–108 °C to reduce the deterioration of carbohydrates. Sweet sorghum syrup can be stable and can keep well for up to oneyear at room temperature if stored in a cool, dry, dark place.

Maple syrup

Maple syrup is made from the boiled tree sap of sugar maple *(Acer saccharum*), black maple (*Acer nigrum*), and red maple (*Acer rubrum*). It's commonly found in the Upper Midwest US, Southeast Canada, and the Northeastern United States. (Ball, 2007;Farrel, 2013). Most previous studies focused on sap yield to ensure the sustainability of maple sugaring operations in a changing environment, climate and biodiversity crisis. It was found thatthe flow of maple sap is influenced by osmosis and gravity. The natural cycles of freeze-thaw of the tree encourage the processing of converting starch into sugar and transfer the sugar from the living cells into the vessels that allow sap to flow (Rechlin, 2015). The steps of maple syrup processing were illustrated according to Mellado-Mojica et al. (2016) and Mohammed et al. (2022). The maple sap was run through filters,then concentrated using thermal evaporation. The concentration process ends at 105°C where the sugar content reached 66-67 °Brix, and the foam that forms during the evaporation was discarded. Some large evaporators have automated defoamers. The finished syrup is filtered using a pressure or gravity filter after it comes out of the evaporator to remove any remaining nitrogen or sugar sand suspended in the syrup (Sun et al., 2016). Maple syrup quality can be categorized as grade A or more based on its physico-chemical characteristics, which are defined by the product specification. Other factors that determine quality include color, sediment-free, turbidity-free, lack of uncharacteristic odors or flavours, density, and taste. Maple syrup is high in macronutrients and micronutrients with a range of differing aromatic components, including flavors such as vanilla, hazelnut, floral, and spicy aromas (Mohammed et al., 2023).Also, it contains inulin, the prebiotic carbohydrate, which was detected for the first time by Sun et al.(2016).

Birch syrup

Birch syrup is made from the sap of the birch tree (*Betula* sp.), which is produced without the use of additives or preservatives (Kallio et al., 1989). The *betula* tree is a perennial plant that is cultivated throughout most of Europe, central Siberia, the Iberian Peninsula, southern Italy, and Greece. Also, it is also grown in Asia's northern regions (Beck et al., 2016). The main sources of tree birch sap were silver birch (*Betula pendula* Roth.) and downy birch (*Betula pubescens* Ehrh) (Svanberg et al., 2012). The type of birch, the location, and the season affect the quantity and quality of the sap produced (Kuka et al., 2013; Grabek-Lejko et al., 2017). The best time for harvesting birch sap is affected by geographical location and climate. It is late March and early April in central Europe, while, start later toward the north. The yield of the excreted sap depends on the birch tree species (Peev et al., 2010). Whereas the solute concentration in birch sap is low, syrup is made from it by boiling, reverse osmosis with a semi-permeable membrane, and vacuum evaporation to the desired concentration. Reverse osmosis is the first step in the concentration process which raises the concentration of the sap to about 10–20%. Following that, pressure evaporation will keep going until the syrup contains 70% of the total sugar. (Kallio, 2013; Wawer et al., 2018).

Fructan -based syrups

Agave syrup

Agave syrup is produced by concentrating the sap of agave plant (core or/and leaves), especially those native to Mexico (*Agave tequilana* and *Agave salmiana*). The southwest part of the United States, Central America, and the Canary Islands are the best places for this plant to grow. This plant can thrive in dry and semi-arid environments (Gonz´alez-Montemayor et al., 2019;and Castro-Muñoz et al., 2022). There is a wide range of products sold as agave syrups owing to the changeability of the type of agave, the agave growing region, and the plant parts employed in the production processes (leaves, pinas sap) (Saraiva et al., 2022). The mature blue agave plants gave the highest yield of syrup production at certain ages which are between five and seven years old (Castro-Muñoz et al., 2022). Mexican standard regulations, established by the government of Mexico and agave producers, prohibit the use of any food additives, ingredients, or sugars derived from non-agave plants in the production of commercial agave syrups. The process of producing agave syrup was stated by Montañez-Soto et al. (2013) and Gonz´alez-Montemayor et al. (2019) and can be described as follow: The mature blue agave plants were stripped of their leaves, and their piñas were cleaned to remove any remaining dirt or other impurities. Plant piñas were sliced and milled. Juicy fibers are macerated with hot water in a diffuser, then, filtrated and discard the fibers. Filtered juice is heated to 80°C for eight to twelve hours for thermal hydrolysis and vacuum evaporation at 90°C, then re-filtered to produce high fructose syrup. According to a recent study on the synthesis of novel bioactive compounds, there is increased potential for the production of agave fructans through acid hydrolysis, thermal hydrolysis, or glycosidic enzymes from agave syrups (Martínez-Herrera et al., 2021). The thermal hydrolysis of fructans in these conditions is not suitable due to undesired degradations (Maillard reaction) and the formation of by-products such as phenolic compounds from lignin, which may have a significant impact on the flavor and color of these products. Hence, enzymatic hydrolysis based on the use of inulinases considered as a promising alternative approach for the production of fructose syrup from agaves(Mancilla-Margalli &Lopez, 2002; Avila-Fernandez et al., 2009). Fructans make up more than 60% of all soluble carbohydrates in agave species (Escamilla-Treviño, 2012). The fructan syrups that have gained popularity recently are the sweeteners most in demand by the food and pharmaceutical industries worldwide due to their advantages over sucrose in terms of functionality and technology as well as their positive health effects (Mellado-Mojica & López, 2015).Fructans can be defined as fructose-based polymers that have a wide degree of polymerization (DP) ranging from DP3 to DP60. There are different types of fructans depending on their molecular arrangement. Fructans are classified as linear inulins and levans, neoseries of inulin and levan, branched graminans, and highly branched neofructans, so called agavins. Agavins are the most recently described type of fructans and they are also the most complex ones (Lopez &Salomé-Abarca, 2024).

Yacon syrup

Yacon syrup is made from *Smallanthus sonchifolius* root juice. *S. sonchifolius* (yacon) plant is grown in a number of locations, including the US, Brazil, China, Korea, Japan, New Zealand, Russia, and Taiwan (De Almeida et al., 2015 and Caetano et al. 2016). The following is a description of the yacon syrup production process as reported by Manrique et al. (2005): The first step of yacon syrup production involved peeling the root completely to preserve the flavor and quality of the syrup. The root isthen minced, and the juice isextracted immediately in a thermal receptor to maintain the extract above 60^{o}C. Antioxidants are added to the juice (4 ml of citrus juice / liter of juice or 0.15 g of ascorbic acid /kg of root) to prevent enzymatic oxidation, preserve syrup color, inhibit the growth of microorganisms, and reduce acidity, which will help in conversion of fructo-oligosaccharides into simple sugars. The juice is slowly filtered through a porous membrane. In a special evaporator, the juice is gradually concentrated to the pre-syrup stage (50°–60° Brix) until it forms the final syrup (68–70° Brix). This type of evaporator concentrates liquids in a continuous process, reducing the flavor of the burnt syrup when exposed to high temperatures. The final syrup was transferred into the flasks after passing through a 100 µm fine mesh filter. The syrup can be stored for several months, with or without refrigeration (L'homme et al., 2003). Yacon syrup is a product rich in fructooligosaccharides (40–70%) and recognized as a functional food (Ojansivu et al., 2011 &Jazmín 2020). According to Genta et al. (2009), 0.14 g fructo-oligosaccharides/kg/day is the recommended daily consumption of yacon syrup that has no adverse effects on the gastrointestinal tract. Therefore, forty grams of yacon syrup is the recommended daily intake without risk of adverse effects.

Glycosidic -based syrups

Stevia syrup

Stevia syrups were made from the *Stevia rebaudiana* plant, which is native to Argentina, Brazil, and Paraguay. The stevia leaves have ent-kaurene diterpenoid glycoside components (7–20% of the leaf dry weight) that have 200–300 times the sweetness power of sucrose (Wèilwer-Rieck, 2012). Bursać Kovačević et al. (2018) focused on the techniques for diterpenoid glycosides components extraction from stevia leaves. These techniques depends on the use of aqueous or solvent extraction using energy sources like liquid pressurization, microwaves, ultrasonic waves, distillation, and pressing. Currently, most sweet components recovery and purification techniques depend on membrane-based technologies, which are suitable for application in food industry. The steps involved in producing syrup are as follows: The stevia leaves were dried at 50°C and ground into a powder with a mesh size of 20–30 mm. The powdered leaves were soaked in hot water (78 °C) for four hours or autoclaved for 20 minutes at 121°C and 2.01 bar of pressure (Németh &Jánosi 2019). The resulting aqueous extract was filtered under vacuum (600–620 mm Hg) and prepared for electrocoagulation by passing direct current (15 V, 0.8–1.2 A) through two pairs of aluminum plates acting as electrodes for one hour. The resulting mixture was purified by passing it through activated charcoal and an ion exchanger. Vacuum evaporation was then used to determine the syrup's saturation level (Joshi et al., 2022). The ADI(accepted daily intake) for rebaudioside A is 0–12 mg/kg body weight/day, according to the Joint Expert Committee of the FAO/WHO on Food Additives (JECFA). Japan was the first country to use stevia syrups as a good substitute for sucrose in food and beverages, starting in 1970. Nowadays, stevia syrup or sweeteners are used in many countries to replace sugar in food, beverages, and pharmaceutical products (Siso´et al., 2022).

Monk fruit syrup

The Chinese *Siraitia grosvenorii* fruit, known as monk fruit or Luo Han Guo, is used to make syrup. Monk fruit is native to the southern parts of China and planted in abundance in Southeast Asia (Pandey & Chauhan,2019 ; Manhas et al., 2021). The round green fruit has a sweetening components named mogrosides that is about 250 times sweeter than sucrose. They are about 2.5 percent of the dried fruit and are classified as triterpenoid compounds. To make monk fruit syrup, fruit is cleaned, then extracted, processed, purified, and concentrated. The fruit is cleaned by the force of the water's flow in a moving water bath with an air agitator. The fruit shells are cracked by a mashing tool without crushing the seeds to preserve the flavor of the final product (Younes et al., 2019). The cracked fruits are soaked in water for one to two hours at 37–50° C (pH 4-5). The extracted liquid mixture is combined with pectinase and continuously stirred for five minutes, followed by boiling for thirty to sixty minutes to inhibit both active pectinase enzymes and bacteria. The liquid extract is separated from the solid components using high-speed centrifugation. To obtain the final syrup, the extracted liquid is combined and purified by running it through multiple mesh filters to reduce particle concentration. The mogroside V content of the monk fruit extract varies from 25% to 45% to 55%, depending on the purification process. The concentrated liquid is passed through an additional resin adsorption process which lowers the saccharides to less than 1% and raises the mogroside V content in the syrup (Chen et al., 2024). Mogrosides have a sweetness rating 200–300 times higher than sucrose. Monk fruit syrup was approved by the Food and Drug Administration (FDA) as safe and the no observed adverse effect level (NOAEL) of mogrosides in the diet for male and female rats was 7.07 and 7.48 g/kg bw/day, respectively (Marone et al., 2008). The European Food Safety Authority (EFSA) has also recognised it as safe and believes it to be a safe substitute for artificial sweeteners (Chen et al., 2024).

Composition and characteristics of natural syrups

Physicochemical properties

The physicochemical properties of natural sweet syrups are given in Table 1, which are influenced by various factors: natural syrup source, plant variety, plant portion utilized, cultivation condition, harvest season, and processing conditions. These natural syrups have high viscosities and total soluble solids values that range from 63°Brix for sorghum syrup to 83.9°Brix for agave syrup. Rajvanshi et al.(2020) reported that Brix value determines according to the required degree of concentration and reflects the moisture content of the syrup. The syrups have a wide values of pH values, ranging from 3.7 for yacon syrup to 7.1 for maple syrup. Several authors have found that some syrups tend to be slightly acidic while others tend to be neutral and these characteristics' are due to the composition of a complex mixture of sugars, organic acids, and minerals (Mellado-Mojica &Lopez, 2015). Sucrose is the main carbohydrate found in sorghum (52.1%) and maple syrup (61.2 to 65.8%), while, birch syrup contains significant amounts of fructose (37-45%) and glucose (45-50%). According to Mellado-Mojica et al. (2016), the ratio of fructose to glucose (F/G) is an important factor in establishing the degree of sweetness. Fructan-based syrups have a higher F/G rate than other syrups because they contain high levels of fructo-oligosaccharides (FOS). Yacon contains up to 50% FOS, 27.8-36.5% fructose, and 9-10% sucrose, whereas agave syrup has high soluble solids (>70° Brix) and is mostly composed of fructose and small amounts of sucrose (Manrique et al., 2005). Fructo-ogosaccharides represented 35–70% of the total soluble carbohydrates in yacon and agave plants (Muñiz-Márquez et al., 2015). Furthermore, numerous authors reported that fructan syrups have low calorie contents (1.0–1.7 kcal/g) and their physical and sensory properties are similar to thoseof honey or sugar cane syrup (Eggleston et al., 2022). Glycosidic syrups have the advantage of high-intensity sweet, and low-calorie. Sensory attributes of glycosidic syrupsare influenced by some factors, such as the variety, glycoside type, and extraction and purification techniques. According to Abou-Arab et al. (2010), the average content of stevioside was 60.51%, with 86.32% purity related to TSS, while the average value of total sugars and sucrose have the lowest amounts (4.91 and 1.72%, respectively). Monkfruit syrup is made up of polysaccharides and sugars such as glucose, mannose, galacturonic acid, fructose and arabinose (Xu &Meng, 1986; Gong et al., 2021). The primary monk fruit syrup glycoside is mogroside V at a level of 25, 40, 45, 50, or55%, which can be used as a food additive, according to Younes et al. (2019).

Nutritional compounds

The natural sweet syrups mentioned in this review article can be considered as source of nutrients that provide the body with some minerals such as sodium, zinc, potassium, chloride, calcium, phosphorus, and seleniumas well as vitaminssuch as vitamins A, B(B6, B9, B12), D, E, and K (Hernández-Ramos et al., 2020). These supplements may have a positive impact on human healthbyincreasing immune responses, especially against viral infections such as COVID-19 (Lahaye et al., 2023). Additionally, they also improve metabolic health, promote intestinal health, prevent weight gain, and have low glycemic potency. A review article by Eggleston et al. (2022) have focused on the nutritional and dietary fiber content of sweet sorghum syrups compared to maple and agave, syrups as a natural and nutritious sweetener, and functional food. Natural syrups are good dietary mineral sources, there ash content variesfrom <0.1 to 4.4% is a reflection of the total minerals. Sweetsorghum contained over half (52.7%) of the daily recommended value (13 mg) from iron as well as it was rich dietary sources of magnesium, potassium, calcium as compared to all the other syrups. Mohammed et al. (2022) summarized that the mineral content of natural syrups varies based on environmental factors, soil composition of the cultivation regions, and contamination from processes during the preparation. In the same review, the authors emphasized that the organic compounds, micronutrients, and phytochemicals in maple syrup contribute to their health benefits. Birch syrup contains seventeen amino acids, including glutamic acid, and minerals such as calcium, magnesium, manganese, potassium, phosphorus, and zinc, with small amounts of iron, copper, chromium, and selenium. It is also rich in betulinic acid, vitamins (B groups), and organic acids such as oxalic acid, succinic acid, formic acid, acetic acid, and propionic acid. Vitamin B has a role in cellular functions and is related to central metabolism and neurological function (Kennedy, 2016). However, vitamins E and C can protect against a host of degenerative diseases associated with oxidative stress and aging, such as cancer, multiple sclerosis, Alzheimer's, and heart attack (Brambilla et al., 2008). There are differences in the amounts of B vitamins found in agave syrup and maple syrup, according to Edwards et al. (2016). Agave syrup contains vitamin A (8 RAE µg/100 g), vitamin C (17 mg/100 g), vitamin K (22 µg/100 g), and vitamin E (0.98 mg/100 g). Moreover, Pandey &Chauhan (2019) and Khalid et al. (2021) illustrated that the glycosidic extracts are highly nutritious, having amino acids, vitamins, and minerals. These nutritional compounds are responsible for the specific taste and flavor of natural syrups, as stated by Asikin et al. (2018).

Functional components

A recent comprehensive review article (Khoo et al., 2023) highlighted the phytochemicals and polyphenolic compounds in natural sweet syrups that reflected their antibacterial, antioxidant properties and their health benefits.St-Pierre et al. (2014) reported that the concentration of phenolic compounds in fruit syrups were higher than in grain, stem, leaf, and tuber syrups. The total phenolic and flavonoid content of sweet sorghum syrup (2.61 mg GAE / g and 1.98 mg QAE / g syrup, respectively) are higher than that of sugarcane syrup (2.16 mg GAE / g and 1.15 mg QAE / g syrup, respectively) with greater antioxidant capability (Willis et al., 2013; Asikin et al., 2018). Also, Eggleston et al. (2021) stated that the predominant phenolic components in sweet sorghum syrups were ellagic, sinapic, and protocatechuic acids, which can help in inhibiting the oxidation of lipids and rancidity in food. Many studies have highlighted the potential benefits of flavonoids in sorghum, which influence the carbohydrate metabolism, enhance the function of pancreatic b-cells, thus improving insulin-stimulated glucose and lower the risk of several cancers, decrease the availability of calories, and reduce weight gain, preventing obesity and cardiovascular diseases (Awika &Rooney, 2004).

Maple syrup and agave syrup have the highest polyphenol content (12.92 mg/g and 14.94 mg GAE/g, respectively) (Li & Seeram, 2010). It is well known that a significant portion of all phenolic compounds are phenolic acids. They are in charge of the sensory qualities that syrup acquires during processing. Phenolic acids include p-coumaric, hydroxybenzoic, ellagic, ferulic, gallic, protocatechuic, syringic, and vanillic acids. Moreover, St-Pierre et al. (2014) found that maple syrup contain a significant amount of the phytohormone abscisic acid among some other natural sweeteners (brown rice syrup , blue agave syrup, corn syrup and natural honey), which has anti-diabetic effects as mentioned by Edwards et al.(2016). Bioactive substances found in maple syrup include phenolics, pyrazines, vitamins, minerals, organic acids, and phytohormones (Saraiva et al., 2022). Fructan in agave and yocan syrups helps the host by promoting the growth of beneficial bacteria, synthesizing short-chain fatty acids (SCFAs), improving immune function, preventing weight gain, and providing calcium absorption (Mohanty et al., 2018).

The phenolic compounds present in stevia and monk fruit syrups are a polyphenol family of esters, hydroxycinnamic acid esters with chlorogenic acids, possessing excellent hydrophilic antioxidant and therapeutic activity (Myint et al.,2020).Stevia syrup also contains a complex mixture of compounds with biological and anti-inflammatory properties, such as amino acids, fatty acids, minerals, pigments, volatile oils, some vitamins, stigmasterol, and flavonoids (Putnik et al., 2020). Many studies indicate that it may be especially beneficial for the prevention of dental caries, diabetes, heart disease, hypertension, obesity, and heart problems (Onakpoya & Heneghan, 2015).

The main flavonoids found in monk fruit syrup are flavones and flavonols, which have sugar groups bonded to the skeleton of quercetin or kaempferol. These compounds exhibit several biological effects, including scavenging free radicals, preventing lipid peroxidation, increasing insulin secretion to trigger a hypoglycemic response, and inducing apoptosis and cell cycle arrest in pancreatic tumor cells (Liu et al., 2018; Gong et al., 2021). In addition, these syrups have anti-inflammatory, antimicrobial, and antioxidant qualities because they contain other bioactive substances like quercetin, kaempferol, and rutin (Świąder et al., 2019). It is well known that phenolic acids, sterols, flavonoids, and other substances improve pharmacological activities (Simlat et al., 2023)

Food and pharmaceutical applications

Natural sweet low calorie liquid syrups are used as natural substitutes for sugar in functional nutraceutical foods and beverages, as well as pharmaceutical industries. In the field of food utilization, natural syrups in the functional food industry would provide several advantages. Simple saccharides -based syrups can be used as liquid sweeteners in food products and pharmaceutical industries and have an excellent special taste similar to sugar cane syrup (Mazumdar et al., 2012). Utilizing simple saccharides-based syrups would modify and improve the nutritional and sensory properties of some foods, such as bakery products, pastries, breakfast bars, jam, and sweet snacks.

Sweet sorghum syrup can be fortified with other fruit concentrates or protein concentrates in the development of neutraceutical beverages (Mazumdar et al.,2012), baked (Willis et al., 2013), pastries spreading or crisp biscuits and bakery beans products (Asikin et al., 2018).In terms of benefits, sweet sorghum syrup has healthy nutritional properties. It has a high magnesium content, which reduces the symptoms of tension, migraines, asthma, and sore muscles. Moreover, its low sodium content helps to maintain blood pressure. Also, it has a high manganese content and a moderate amount of pyridoxine and riboflavin, which are essential for the body's metabolism.Maple syrup can be utilized as an excellent alternative to sucrose because of its high content of sucrose, unique flavor, high nutrient content, and richness in bioactive compounds (Mellado-Mojica et al., 2016; Saraiva et al., 2022). Maple syrup is used in some products, such as carbonated beverages and condiments such as barbecuesauces, mustards, and dressings (Ramadan et al., 2021).

Also, it can replace sucrose up to 100% in producing healthy functional yogurts, low fat ice creams (Saadi et al., 2022), and whey sherbet ice (Mohammed & Mahmood, 2022). Mora et al. (2023) stated that the combination of maple syrup with honey or agave syrup used as natural sweeteners in a low-sugar diet can be used for solving the problem of excessive consumption of refined sugar. Maple syrup lowers blood glucose levels because it contains the phytohormone abscisic acid and derivatives that may act directly on muscle and adipose cells to promote the transfer of glucose transporters to the cell surface and increase these cells' insulin-independent glucose uptake (Zhang et al., 2014). Moreover , maple syrup contains biologically active compounds that have a positive impact beneficial to human health, such as anti-oxidants, antimicrobial, , antiaging, anti-inflammatory, antidiabetic,anti-proliferative, anti-mutagenics and anticancer (Rose et al., 2019; Saraiva et al, 2022). Although the cost of the production of birch syrup is very expensive, reaching 5 times the cost of maple syrup, but it has its own market because of its special taste (Helfferich, 2003). Birch syrup is used in desserts, salads, and meats without any additives, as well as being used as a sweetener in coffee, vegetables, pancakes, bread, and desserts (Kallio, 2013). Many European countries use birch syrup as a folk medicine due to its beneficial effects. It is used to treat lung diseases and gout in Belgium, while it is used to promote infertility, healthy living, and attractive appearance in the Czech Republic. It is also used as a tonic in Hungary, a revitalizer in Lithuania, a preventative measure against kidney stones in Poland, a treatment for jaundice in Romania, a preventative measure against cholera in Sweden, and a tonic and newborn food in England (Svanberg et al., 2012), It has been found that the application of fructan syrups as prebiotic, texturizers, viscosity modifiers, increasing dietary fiber, fat replacements, and low-calorie sweeteners would have a positive effect on the sensory properties of food and beverages. This would encourage the use of agave and yacon syrup as texturizers to enhance the viscosity and mouthfeel of juices, hot beverages, and desert products (Espinosa-Andrews et al., 2021). Agave syrup can be used to make gel formulations and candies as a healthier alternative to glucose and sucrose. Also, agave syrup was produced for direct use or obtaining fermented products and spirits drinks (Liliana et al., 2012). Many researchers have mentioned that agave syrup can be used as a substitute for sucrose in many products, including baked goods, ice cream, yogurt, cheese, cookies and gummy bears (Morales-Hernándezet al, 2019; Yargatti &Muley,2022). Moreover, agave syrup was utilized to produce chocolates with 20% fewer calories,improved organoleptic qualities, and increased prebiotic activity (Belščak-Cvitanović et al., 2015). In addition, Mata-Ramírez et al., (2018) succeeded in producing white bread using a combination of 53% agave syrup as a sweetener and 9% roselle flour (*Hibiscus sabdariffa*). Ozuna et al. (2020) found that agave syrup can replace up to 75% of the sucrose in muffins without affecting the physical and sensory properties of the initial product. Studies in food science have focused on the biologically active fructans or fructo-oligosaccharides that promote health benefits for consumers. Fructan syrup could also be considered as a nutraceutical product, which can reduce disease risk, improve the growth of good beneficial bacteria in the colon, enhance gastrointestinal health, and help in the absorption of calcium, folic acid, and B vitamins, as well as reduce triglyceride and cholesterol levels, reduce the risk of colon cancer, and boost the immune system (Verma et al., 2021).

In addition, glycoside syrups are currently in use as a low-calorie sweetener in soft drinks or fruit drinks, soju, sauce, pickles, chewing gum, cookies, desserts, sauces, and bakers where they are non-calorific and stable at 100 °C (Massoud & Amin,2005; Khattab et al., 2017). Monk fruit syrup can be used alone or in a blend with rebaudioside A in sweetening Arabian desserts and in the production of functional low-calorie foods and drinks (Massoud &Hashem, 2023). The use of glycoside syrups is safe. Natural glycosidic syrups provide advantageous biological properties, especially glycosidic syrups that have shown antidiabetic, anti-obesity, anti-cancer, antibacterial, and antineoplastic effects (Myint et al., 2023). According to Atteh et al. (2008), these glycosidic compounds strengthen blood vessels, promote blood coagulation and cell regeneration, prevent the growth of cancerous cells, and decrease blood levels of cholesterol. Naturally low-calorie syrups might be considered suitable for diabetics, as they do not affect blood sugar levels, and overweight or obese individuals. Biochemical characteristics of terpenoid pharmacological activity in syrups include expectorant, antioxidant, hypoglycemic, immune system, anti-inflammatory, and liver protective effects.

TABLE 1. Physicochemical properties of some natural syrup from different sources.

Physicochemical property	Natural sources of syrup						
	Simple saccharides -based syrups			Fructan-basedsyrup		Glycosidic -based syrups	
	Sorghum *Sorghum bicolor* L	**Maple** *Acer saccharum*	**Birch** *Btula pendula*	**Agave** *Agave tequilana*	**Yacon** *Smallanthus sonchifolius*	**Stevia** *Stevia rebaudiana*	***Monk fruit*** *Siraitia grosvenorii*
	Stalk	Tree trunk	Tree trunk	Core and Leaves	Roots	Leaves	Fruit
Brix^{o}	63.33- 80.39 ^{R7}	65.8-66.00^{R7}	66.4-75^{R11}	65^{R8}-83.88^{R9}	71.03$^{\circ R4}$	69.70-70.50^{R1}	60-76^{R21}
pH	3.88-5.06^{R7}	6.44-7.09^{R7}	5.6–6.4^{R11}	3.97^{R7}-5.78^{R9}	3.71^{R4}	5.50- 5.96^{R1}	4.1^{R21}
Protein%	1.81^{R7}-5.61^{R15}	0.0 ^{R6}- 0.33^{R7}	ND	0.1^{R6}-8.5^{R8}	4.74-6.63^{R3}	ND	5-2.95^{R21}
Total lipids%	0.91^{R7}	0.1^{R6}- 0.67^{R7}	ND	0.5^{R6} - 2.1^{R7}	0.07^{R4}	ND	0.22- 0.92^{R21}
Ash %	2.92^{R7}-4.17^{R15}	0.53^{R7}	2.7 - 3.0^{R11}	0.17^{R7}-8.20^{R8}	2.64-3.36^{R3}	ND	< 5^{R21}
	---	-	-	35^{R13}–85.6^{R17}	17.6 - 52.7 ^{R3}	ND	ND
Total sugar%	68.6^{R2}-72.5^{R15}	71.1 $^{R10\ 0}$	30.2 ^{R10}	68.0 ^{R3}	25.65^{R14}	4.13 -5.68^{R1}	ND
Sucrose%	52.1^{R2}	61.2-65.8^{R18}	0.52 - 0.69^{R11}	< 0.06^{R16}	9.02-10.33^{R3}	1.16-2.28 ^{R1}	2.08–3.61^{R21}
Fructose%	5.56^{R2}	0.09-0.52^{R18}	37 -45^{R11}	70–90 ^{R5}	27.78-36.46^{R3}	2.9-3.43 ^{R1}	-
Glucose%	10.88^{R2}	0.16-0.71^{R18}	45- 50^{R11}	3.99^{R17}	8.05-8.58^{R3}	-	0.51–0.61^{R21}
Manitol%	-	-	-	0.70 ^{R20}	-	-	-
Inulin %	-		-	48-60^{R12}	--		-
Steviosides%	-	-	-	-	-	56.34 -64.67^{R1}	-
Mogosides%	-	-	-	-	-	-	36.80-73.09^{R21}

ND: not determined Abou-Arab et al. (2010) (R1)- Asikin et al. (2018) (R2)- Chessum et al. (2023) (R3)- Da Silva et al. (2023) (R4)- DeChristopher &Tucker (2020) (R5)- Edwards et al. (2016) (R6) -Eggleston,et al.(2022) (R7)- Gonz´alez-Montemayor et al. (2019) (R8)- Hernandes-Ramos et al. (2020) (R9) -Jones &Ali (1987) (R10)- Kallio et al. (1989) (R11)- Liliana et al. (2012) (R12)-Mancilla-Margalli and Lopez. (2006) (R13)- Manrique et al. (2005) (R14)- Mazumdar et al. (2012) (R15)- Mellado-Mojica et al. (2016) (R16)- Michel-Cuello et al. (2012) (R17)- Nimalaratne et al. (2020) (R18)- Sun et al. (2016). (R19)- Willems & Low (2012) (R20)- Xu &Meng (1986) (R21).

Conclusion

Natural plant low calorie syrups contain several phytochemical compounds that reflect their antibacterial, antioxidant properties and health benefits. Therefore natural plant based low-calorie syrups could have great potential in the food and pharmaceutical industries by producing high value functional nutritional and safe novel, low calorie, cost-effective food and pharmaceutical products. These substances can act as sucrose replacements, which helps prevent obesity and other disorders linked to the consumption of sucrose.Further scientific study into plant-based syrups and biological studies investigating their therapeutic benefits are needed to satisfy consumer demand for reduced-calorie products and to maximize these sweeteners' advantages.

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