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A REVIEW: ALTERNATIVES TO SUBSTITUTE FRUCTOSE IN FOOD PRODUCTS FOR PATIENTS WITH DIABETES

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Abstract
Diabetes is a metabolic disease whose prevalence in the world is increasing every year. To improve the life quality of diabetes patients and achieve better treatment results, adjusted food products with lower carbohydrate quantities are necessary. Primarily fructose is used in products for diabetes patients, but fructose increases obesity risk. The aim of the study is to evaluate available scientific articles on potential natural sweeteners for the substitution of fructose in food products for people with diabetes. Natural sweeteners could be a good alternative to fructose, they decrease product glycemic index and positively influence the health of diabetes patients. Stevia is a plant used in food production for obtaining sweet taste. Glycosides extracted from stevia are food additives, i.e. sweeteners. Stevia decreases sugar levels and improves insulin secretion, it has antibacterial and antioxidative features. The use of stevia in food production causes a bitter aftertaste of products. To disguise the bitter aftertaste, other natural sweeteners are added to stevia. Thaumatin is a sweet protein used in food production. To improve product taste, polyols and other natural sweeteners are added. Polyols are a good alternative for fructose substitution because they slightly influence sugar levels in the blood and they have high chemical thermal stability. Products containing different combinations of several natural sweeteners possess the best sensory features. The research results show that stevioside, rebaudioside, thaumatin, and polyols are good alternatives for fructose substitution in products. To clarify how sweeteners, influence food product features additional researches are necessary.
Key words: stevia, steviol glycosides, thaumatin, polyols, diabetes.

Introduction

Diabetes is a metabolic disease that, if not treated, is characterised by increased sugar levels in the blood. The disease is also characterised by insulin secretion or insulin activity distortion resulting in carbohydrate, fat, and protein metabolism dysfunction (Adler *et al*., 2021). Diabetes prevalence in the world is growing every year. In 2021 in the age group from 20 up to 79 years, 537 million people were suffering from diabetes which constitutes 10.5% of the total adult population in this age group (*IDF Diabetes Atlas 10th Edition*, n.d.). For diabetes patients having obesity, increased blood pressure, continuously increased sugar level in the blood, and increased cholesterol level, the risk of heart and blood vessel diseases is considerably higher (Elek & Bíró, 2021). The development of obesity is influenced by genetic factors, age, physical activities, and eating habits (Ling & Rönn, 2019).

In food production, glucose and sucrose are substituted by fructose to decrease the glycemic index. Fructose is a natural sugar found in many fruits. An equal quantity of fructose is sweeter than one of glucose and sucrose *(Taskinen et al*., 2019). Fructose metabolism takes a longer time and only part of fructose is turned to glucose. Fructose does not increase the sugar level in the blood as much as the same quantity of glucose does (Teff *et al*., 2004). Diet enriched with fructose facilitates fat acid synthesis in livers and fosters accumulation of triglycerides. (Muriel *et al*., 2021). In the Netherlands, in 2016 the systematic report stated that the substitution of carbohydrates needed for energy does not affect insulin concentration in the system measured on empty stomach. Keeping the same consumed fructose quantity, the tendency to increase insulin concentration measured on empty stomach has been observed for people with excessive weight or obesity (Ter Horst *et al*., 2016). Increased fructose consumption has negative side effects. The main fructose metabolism routes are the ones that provide turning to glucose and lipids. Therefore, exorbitant fructose intake increases fructose concentration in the port that stimulates endogenous glucose production and lipid synthesis in the liver which is connected with metabolic syndrome, alcohol-free fatty liver disease, obesity, and type 2 diabetes (Merino *et al*., 2020). In the major fructose metabolic processes, different cardio- and metabolic risk factors can be caused in the tissues, including the small intestine, liver, and kidneys. They are steatosis, hypertriglyceridemia, increased obesity, and increased blood pressure (Hannou *et al*., 2018). Fructose sweetening effect is two times higher than that of glucose. For people, it can be the reason for higher craving for fructose-containing alcohol-free drinks (Mai & Yan, 2019).

Taking into account the aforementioned, the aim of the study is to evaluate available scientific articles on potential natural sweeteners and their technological properties for substitution of fructose in food products for people with diabetes.

Materials and Methods

The research was performed using the monographic method to review the most suitable alternatives of sweeteners aimed at the substitution of fructose. The information was searched in *Science*

Direct, *Scopus,* and *Google Scholar* for original studies and reviews published in English for the period from 2004 to 2022. Full-text papers were included in this study. A wide range of keywords such as stevia, steviol glycosides thaumatin, polyols, diabetes, obesity, sweeteners, fructose, food production and glycemic index was used to find relevant literature. The articles in any way unrelated to sugar diabetes (slimming, glycemic index, glucose control, medical treatment, prophylaxis) were excluded. The pool review collected 44 full-text articles.

Results and Discussion

To improve life quality and treatment results for diabetes patients, sweeteners causing no or minimal influence on glucose levels in the blood are used in food production. Sweeteners can be distinguished into low-calorie sweeteners and no-calorie sweeteners. No-calorie sweeteners are further divided into artificial and natural ones. Summarising information on suitable natural sweeteners three sweeteners were selected: steviol glycosides, thaumatin, and polyols.

Stevia and Steviol glycosides

Development and risk factors of diet-dependent diseases can be decreased and eliminated by observing a healthy lifestyle introducing a balanced diet as well as changing eating habits. Stevia has several fatty acid and minerals constituents that are essentially meaningful in pharmacy and food production (Singh *et al*., 2019). Stevia contains glycosides which belong to the secondary metabolites of the plant diterpenoid group. Its chemical structure base has steviol (Libik-Konieczny *et al*., 2021). In the composition of stevia there are the following components: stevioside (5–10%), rebaudioside A (2–5%), rebaudioside C (1%), ducloside A (0.5%), rebaudioside D, E, F (0.2%) and steviolbioside (0.1%) (Wojewoda *et al*., 2018). Stevioside and rebaudioside A have the best sweetening effect (Wang *et al*., 2020). Besides having additional glycosides stevia is a good source of vitamins and minerals. In stevia composition, there are irreplaceable amino acids, fatty acids and other favourable bioactive combinations including flavonoids, phenolic compounds, phytosterols, chlorogenic acids, and hydrocarbons (Wölwer-Rieck, 2012). Stevia is 200–400 times sweeter than fructose (Hameed *et al*., 2020). Recommended daily intake for steviol glycosides that is allowed to consume is 4 mg kg^{-1} of body mass (Swiader *et al*., 2019). The use of steviol glycosides in drinks is wider than that in food products (Table 1). Steviol glycosides is used in dairies such as ice cream, yoghurts, and flavoured milk. It is also used in the production of breakfast cereals, cereal bars, certain confectionary, and sweet bread (Ahmed *et al*., 2011). Partial substitution of fructose with steviol glycosides gives a total carbohydrate quantity decrease in confectionary as well as product colour and consistency improvement (Yildiz & Gocmen, 2021). Stevioside and glycosides is widely researched from the point of view of both chemical characteristics and its influence on human and animal systems. Using stevioside and glycosides in the diet leads to a decrease of glucose levels in the blood (Ahmad & Ahmad, 2018). Steviosides improve pancreas beta cell function for diabetes patients (Philippaert *et al*., 2017). Rats studying research have proven that adding stevia extract to their diet and substituting fructose with it lead to the fact that the researched animals developed better metabolic, oxidative, and histopathological indicators (Ranjbar *et al*., 2020). Clinical researches prove that stevia and its separate combinations have therapeutic and pharmacological effects and do not harm human health. Stevia leaf extract and individual Stevia glycosides stimulate insulin production for diabetes patients, improve the condition of polycystic kidney disease, they have a strong antibacterial and antioxidative effect (Peteliuk *et al*., 2021). The negative aspect of using steviol glycosides in food products is the bitter aftertaste disliked by consumers. Therefore, interest in steviol glycoside taste profile improvement is growing. The use of taste enhancers is the approach to improve the steviol glycoside taste profile. To disguise bitter aftertaste maltodextrin (powder from rice, corn, wheat or potato starch), erythritol, xylitol, maltitol, sorbitol, vegetable glycerin, fructooligosaccharides, inulin, dextrose or sucrose are added in commercially available stevia extract products (Gerwig *et al*., 2016).

Table 1

Concentrations of steviol glycosides in various products (European Parliament and Council, 2011)

Products	Maximum level (mg kg^{-1} or mg L^{-1})
Carbonated soft drinks	80
Flavoured fermented milk products	100
Edible ices	200
Jam, jellies, and marmalades	200
Cocoa and Chocolate products	270
Chewing gum	3300
Breakfast cereals and bakery wares	330

Thaumatin

Thaumatin is a sweet protein derived product from *Thaumatococcus daniellii* tropical fruit (Kant, 2005). In its composition, thaumatin has 207 amino acids. Commercially thaumatin is extracted from fruit seeds, and it exists in five isoforms. They are thaumatin I, II, III, A, and B. The basic forms are thaumatin I and II (Fry, 2012). Thaumatin keeps stability up to 120 °C and endures pasteurisation and high-temperature sterilisation processes (Joseph *et al*., 2019). Thaumatin is used in the production of chewing gums, dairy, ice cream, sweets and flavoured drinks (European Parliament and Council, 2011). Thaumatin is often used in combination with other sugar substitutes. Low-concentration thaumatin is a flavor enhancer, thus it is suitable for mixing up with other intensive sweeteners and polyols (Mora & Dando, 2021). Thaumatin does not cause tooth damage, it is not toxic, and does not cause allergy (Joseph *et al*., 2019). Thaumatin is a confirmed food additive and its highest possible dosage in products is from 0.5 up to 400 mg kg^{-1} (Table 2).

Table 2

Highest possible thaumatin quantity in food products (European Parliament and Council, 2011)

Food category name	Restrictions/exception	Maximum level (mg L^{-1} or mg kg^{-1} as appropriate)
Flavoured fermented milk products including heat-treated products	Flavour enhancer	5
Edible ices	Only energy-reduced or with no added sugar	50
Other confectionery including breath freshening micro sweets	Only cocoa or dried fruit based, energy-reduced or with no added sugar	50
Chewing gum	Only with added sugar or polyols, as a flavour enhancer	10
Flavoured drinks	Only water-based flavoured non-alcoholic drinks, as flavour enhancers only	0.5
Cocoa and Chocolate products	Only energy-reduced or with no added sugar	50
Desserts	Flavour enhancer	5
Food supplements supplied in a solid form, excluding food supplements for infants and young children	Only food supplements in chewable form	400

Polyols

Polyols are low-calorie sweeteners that are naturally found in fruit, vegetables, mushrooms, and seaweed, or chemically synthesized. Polyols have been acknowledged to be safe food additives (Grembecka, 2015). Polyols are allowed to be used in food production. They are maltitol, mannitol, sorbitol, xylitol, erythritol, isomalt, and lactitol. Polyols energy value is from 0.2 to 2.6 kcal g^{-1} (Table 3). Polyols are characterised by high chemical thermal stability up to 180 °C (Shah & de Jager, 2016).

Maltitol is hygroscopic non-reductive sugar and disaccharide polyol. Small quantities of maltitol are naturally found in seeded malt and chicory leaves. It is commercially produced from crop starch such as corn, wheat, and potatoes. Producers use D-maltose catalytic hydrogenation to create hydrogenated disaccharides consisting of interconnected glucose and sorbitol molecules (Rozzi, 2007). *Maltitol* is used in the production of bread, dairy, chocolate, chewing gums, and sweets. Products have a pleasant taste, and no unpleasant aftertaste is felt in the mouth. Usage of increased doses can lead to diarrhea, bloating and flatulence in the digestive tract. (Awuchi, 2017). *Maltitol* has a low glycemic reaction, few calories, and low glycemic index (Saraiva *et al*., 2020). In food products and drinks, *maltitol* is used as a volume magnifier, emulsifier, sweetener, stabiliser, thickener, or humidifier (Grembecka, 2015).

Mannitol is a 6-carbon polyol that is naturally found in big quantities in olives, carrots, figs, pineapples, and sweet potatoes. *Mannitol* industrial production is the catalytic hydrogenation of a glucose/fructose mixture. The process is performed under high temperature and pressure (Ghoreishi & Shahrestani, 2009). *Mannitol* improves the taste, texture, and storage features of food products. *Mannitol* is used in the production of chocolate, ice cream, confectionery, chewing gums, and sugar-free products (Grembecka, 2015). In food products, it is used as an anti-sticking agent, volume

Table 3
Sugar alcohols' relative sweetness (Awuchi, 2017)

Name	Sweetnes relative to sucrose	Food energy (kcal g^{-1})
Erythritol	0.7	0.2
Isomalt	0.8	2.21
Lactitol	0.4	2.0
Maltitol	0.9	2.1
Mannitol	0.5	1.6
Sorbitol	0.6	2.6
Xilitol	1.0	2.4

magnifier, moisture maintainer, stabiliser, sweetener, and thickener (Grembecka, 2018).

Sorbitol is mannitol isomer. In nature, it is found in different fresh and dried fruit as well as in different vegetables. In industrial production catalytic hydrogenation is used. For this process, glucose or sucrose substrates are necessary. They are hydrogenated under high temperatures by applying nickel catalysts (Grembecka, 2015). *Sorbitol* is important in C vitamin production. In the human system, it is not absorbed in the metabolic process, it produces fewer calories. In the food industry, it is used for the production of drinks, ice cream, sweets, and chewing gums (Marques *et al*., 2016).

Xylitol possesses high chemical and biological stability. It is widely used separately as well as in combination with other sweeteners for product taste improvement (Mohamad *et al*., 2015). Products give a refreshing sensation in the mouth; therefore, they can be used for enhancement of peppermint taste or for ensuring product refreshing aftertaste. It does not foster insulin secretion in diabetes patients (Chattopadhyay *et al*., 2014). *Xylitol* helps in the bone mineralisation process stimulating calcium absorption as well as increasing the biostability of minerals (Xiao *et al*., 2015). In products, it is used as an emulsifier, humidifier, stabiliser, sweetener, and thickener (Grembecka, 2015).

Naturally, *erythritol* is found in fruit and vegetables, for example, in grapes and mushrooms, as well as in fermented food products. It is widely used as a sweetener for low-calorie food products, as well as in sweets and confectionaries (Regnat *et al*., 2018).

Naturally, *isomalt* is not available and it is produced industrially. In food production, it is used as a sweetener, thickener, stabiliser and volume magnifier (Grembecka, 2018).

Naturally, *lactitol* is not available, and it was first synthesised in 1920 from lactose. In products, it can be used as a sweetener, emulsifier or thickener (Grembecka, 2015).

Conclusions

For patients with diabetes, it is essential to decrease the quantity of consumed simple sugars to improve their treatment results, decrease complication risk factors and improve life quality. Steviol glycosides, thaumatin, sorbitol, maltitol, isomalt and erythritol are good alternatives for fructose substitution, as this is the way to decrease the number of calories in food products and reduce the risk of obesity. Additional research is necessary aiming at the development of new food products with alternative sweeteners for people with diabetes.

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