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Recent Application and Future Perspective of Sugar Substitutes in Food Products

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A B S T R A C T

Sucrose is the most common sweetener used in food products. Nowadays, sugar consumption in all daily food items increases the incidence of various diseases such as type 2 diabetes and cardiovascular disease. Due to its harmful effects on human health, the desire to reduce it in food products has increased. One of the ways to reduce sugar in food products is the use of sweeteners instead of sugar. There are different types of sugar substitutes, which are divided into natural and artificial groups. The main purpose of this review was to provide an overview of the application of various sugar substitutes in food products with a focus on recent advances and outputs. Sweeteners used as sugar substitutes in food products may cause changes in the technological, organoleptic, or physicochemical properties of the new product. It may also cause nutritional challenges in the produced product. Therefore, challenges and future trends of sugar substitutes in food products are investigated in more detail.

1. Introduction

In recent years, the tendency to maintain and improve health and consume safe food has increased. Sugar is an integral part of people's diet, but the high consumption of sugar plays an important role in many diseases including tooth decay, obesity, glucose intolerance, increased blood pressure and arterial fat, heart diseases, and increased mortality. Sugar is a strong sweetener and flavor, besides, it plays an essential role in creating the texture and structure of the product. According to WHO guidelines, the daily calorie intake from sugar should not exceed 10 percent. As a result of the obesity epidemic, diets containing high sugar and calories are a major concern for consumers and the demand for low-calorie or no-calorie foods is increasing. Due to the low calories compared to sugar, sugar substitutes are used in the food and beverage industries (1).

Reducing sugar consumption is a major challenge for the food industry. 90 percent of the average sugar consumption is related to processed foods such as drinks and bakery products which often have high sucrose indices. Studies show that consumption of these products increases the incidence of various diseases such as type 2 diabetes and cardiovascular disease. For this reason, researchers are looking to discover natural and artificial sweeteners as a substitute for sucrose (2).

Each of the natural or artificial sweeteners as food additives has unique properties. A classification for sweeteners is as follows, Non-nutritive sweeteners (NNS) (intense, artificial, and no-calorie or low-calorie sweeteners) with a sweetening power higher than sucrose are used in canned and baked products and sugar-free drinks, Nutritious sweeteners (caloric and bulky sweeteners) with a sweetening power similar to or less than sucrose are used to create texture and bulk in baked products, cakes, ice cream, and jams.

Non-nutritive sweeteners include aspartame, saccharin, sucralose, stevia, and acesulfame K. Nutritive sweeteners are sugar alcohols such as maltitol, sorbitol, lactitol, xylitol, erythritol, mannitol, isomalt, hydrogenated starch hydrolysates, hydrogenated glucose syrups, trehalose, and tagatose (3). Among the 30 types of artificial sweeteners available in the market sodium saccharin and acesulfame potassium are the most important sweeteners. Considering that excessive consumption of artificial sweeteners endangers human health as a result, their concentration should be controlled (3). Many food manufacturers use a combination of

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artificial sweeteners and sugar. It is expected that diet and non-alcoholic beverages have the maximum consumption of artificial sweeteners. In the world, consumers are extremely health-conscious and follow the consumption of natural foods. In the meantime, the consumption of natural sweeteners has been taken into consideration and the claims and discussions that they are carcinogenic have been rejected by many studies (4).

The change in people's lifestyles, the importance of a balanced diet in people's health, and the desire to lose weight have increased the demand for sugar-free foods and drinks all over the world. This study aims to introduce and present the details of all types of sugar substitutes in food products and to examine the applications and challenges of using sugar substitutes.

2. The function of sugar in food products

2.1. Type of sugar substitutes

Sugar is an integral part of many foods such as fruit juice, cake, cookies, and chocolate and it is used in the food industry because it creates a pleasant taste. Sugar consumption is very high in the world (500 calories per day). Department of Agriculture (USDA) recommends reducing sugar consumption (%6-10). Therefore, attention to sucrose and refined sugar substitutes has increased (5, 6).

2.2. Natural substitute

The results of surveys in different countries showed that attention to natural and low-calorie foods has increased because the consequences of artificial ingredients for health are unknown (7). All kinds of fruits, vegetables, and milk have different percentages of natural sugar and contain fiber, antioxidants, bioactive compounds, and minerals. According to the definition of the World Health Organization (WHO), natural sugar is obtained from the plant wall. Natural sweeteners include sugars, sugar alcohol, glycosidic, terpenoid, and phenolic compounds, and those with desirable characteristics (solubility and stability and good taste) are used in industry (5, 8). Natural sugars include the following..

2.2.1. Fruits and vegetables

Dates are sources of natural sugar (glucose and fructose) that have been used since the past and it is rich in nutrients (60-75% sugar, 5-8% fiber, 1% fat, and 2% protein). Dates are the primary food ingredients in many countries and are used as sweeteners (9). Grapes are known in the world as a substance rich in sugar (150-250 grams per liter), organic acids, phenolic and mineral compounds. Ripe grapes have high fructose and are sweeter than sucrose, so a small amount produces a lot of sweetness and it can be used as a substitute for refined sugar. Another source of natural sugar is beetroot, which is cultivated due to the high presence of sucrose in it. Also, one of the new natural sweeteners is stevia, which creates a sweet taste than sucrose due to the presence of steviol glycoside. Consuming this glycoside within the permissible limit (4 mg/kg) does not cause any problems. It has anti-inflammatory and anti-diabetic properties and is used in the preparation of chocolate, ice cream, and candy (10, 11). Natural sugars that are produced and used in smaller amounts are licorice and proteins found in other fruits, which taste thousands of times sweeter than sucrose. For example, thaumatin has low calories, so it reduces the bitterness and creates an umami flavor. This protein sweetener is obtained from an African fruit (Thaumatococcus daniellii). Its sweetness is higher than sucrose (1600-3000) and it is produced through transgenic plants and microorganisms. Thaumatin is resistant to pH and temperature and is used in preparing soup sauce and cooked chicken. However, its high consumption is not recommended because cases of allergic reactions have been reported (12, 13).

2.2.2. Other natural sweeteners

Honey is the sweetest natural sugar (rich in fructose) and can be consumed instead of sucrose (14). Trehalose and tagatose (prebiotics in dairy products) create a good taste and texture in food and are used in sports drinks (12). 5-Keto-D-fructose is also a natural sugar present in honey, white wine, and vinegar and its sweetness is similar to D-fructose. It is produced from D-fructose by acetic acid bacteria and during enzymatic oxidation (15).

2.3. Artificial sweeteners

In addition to synthetic and natural compounds, some sweeteners have been introduced as Artificial (neohesperidin dihydrochalcone, neotame, and alcoholic sugars), because they are plant extracted, but, they can be used as sweeteners after microbial fermentation and artificial chemical process. Neohesperidin dihydrochalcone does not cause tooth decay like other sweeteners and can be used in the production of ice cream, yogurt, and desserts. Alcoholic sugars are produced during hydrogenation from aldose and can be present in fruits (plum, pear, peach, olive, and strawberry). They do not cause overweight problems, have few calories (2.4 kcal/g), and are a suitable alternative for diabetic patients. Xylitol is a sugar alcohol that has antioxidant properties and causes loss of weight and appetite. Xylitol inhibits carbohydrate digestion enzymes, absorbs muscle glucose, and inhibits obesity by reducing intestinal hormone secretion (16). Polyols do not pose a health risk even if consumed in large amounts. So far, no specific dose has been considered for xylitol. Xylitol is a prebiotic that has fewer calories than sucrose (40%) and is absorbed slowly. In addition to sweetening, it also has other uses (emulsifier, stabilizer, moisturizer, and thickener). In the industry, xylitol is mostly used in the production of chewing gum and is effective in cooling and refreshing the mouth. Lactic acid bacteria, some fungi, and yeasts such as Aspergillus, Penicillium, Trichoderma, and Hansenula can naturally produce polyols. Other sugar alcohols are mannitol, sorbitol, and erythritol. Fermentation of glucose and fructose by lactic acid bacteria and yeasts can lead to the production of mannitol (six-carbon alcohol). Mannitol has food, pharmaceutical, medical and industrial uses. Some important characteristics of sorbitol, such as low sweetness and high dissolution rate, have made it widely used in the industry (50% of the polyol market). The production strategy of sorbitol and mannitol by Lactobacillus plantarum and Lactobacillus casei is similar. Unlike sorbitol and mannitol (six carbons), erythritol has four carbons and is present in nature (fruits and seaweed). Also, osmophilic yeasts (Torula sp., C. magnoliae, and Yarrowia lipolytica), Lactic acid bacteria (L. oenos), and other microorganisms (Trichospor-onoides megachiliensis and Pseudozyma tsukubaensis) are used in the commercial production of erythritol. Production of this sweetener depends on the growth conditions and the amount of initial glucose. Recently, there have been reports of mutant strains that produce more erythritol and fewer byproducts. UV rays can also be effective in increasing the production of erythritol, but the production of sugar alcohols by microorganisms has a high cost and it has not been well received in industrial and commercial terms. Another type of artificial sweeteners have low calories and high sweetness and have been used since 120 years ago, including aspartame, acesulfame potassium, neotame, sucralose, and saccharin. Among artificial sweeteners, aspartame is produced and consumed more (18.5 thousand metric tons). Saccharin, acesulfame, and sucralose are in the next rank, and their annual production is 9.7, 6.8, and 3.3 thousand metric tons, respectively. Recently, acesulfame, sucralose, alitame, and neotame have been used more than saccharin in sugar-free products (soft drinks, jam, medicine, and toothpaste) (17). According to studies conducted by Alsunni (2020), artificial sweetener consumption was high among children (25.1%) and adults (41.4%), and sucralose was ranked first (18). The sweetest artificial sugar is Lugduname (200,000-300,000 times the sweetness of sucrose) (19). In 2002, the Food and Drug Administration (FDA) recognized acesulfame (Brand Name: Sunett and Sweet One brand name) as a safe sweetener and it was used in various industries (sweets, puddings, chewing gum). Some artificial sweeteners such as aspartame (BN: NutraSweet/ Equal/ Spoonful and Equal-Measure) are used in the production of diet sodas and the use of 50 mg/kg is approved by the FDA, but its use is not recommended for phenylketonuria patients. Sucralose (BN: Splenda/ Sukrana/ SucraPlus/ Candys/ Cukren and Nevella) is sweeter than white sugar (600 times) and consists of several sugars (dextrose, sucralose, and maltodextrin). Sucralose is used in milk powder products, frozen foods, and baking. Saccharin (B N: Sweet'N Low/ Sweet Twin/ Necta Sweet and Equal) is used in combination with other sweeteners due to its bitter taste. The sweetness of saccharin is 300 times that of sugar, and the low pH of the stomach makes it better absorbed. The sweetness of cyclamate (BN: Sucaryl and Sugar Twin) is 30 to 50 times that of sucrose, and usually the combination of cyclamate and saccharin (1 to 10) creates a desirable sweetness (19).

3. Application of sugar substitute in food products

3.1. Dairy products

Table 1 provides a brief comprehensive overview of the effects of sugar substitutes on the technological, nutritional, textural, and physicochemical characteristics of different products. Almost all dairy products have some amount of sugar in their formulation. Flavored milk, ice cream, flavored yogurt, dairy-based desserts, and cottage cheese are examples of these products. Considering that dairy products play a major role in daily consumption, the reduction of sugar in them will have a major contribution to the health of society. Stevia is one of the compounds used as a sugar substitute, and due to its effects on health, it has received special attention in the dairy industry. For example, it was used to reduce sucrose in a yogurt study done by Rupa and Vijay (2022). For this purpose, 25, 50, 75, and 100% stevia was used as a sugar substitute, and the physicochemical properties of the produced yogurt were investigated. According to the aforementioned study, using stevia leaves instead of sugar not only produces low-calorie yogurt but also preserves and improves the texture and organoleptic properties (20). In another study done by Jouki et al., (2021), cinnamon extract (CE) was used as a substitute for sugar in dairy desserts and sweetened condensed milk (SCM). The cinnamon with its antioxidant properties was introduced as a suitable substitute for sugar in dairy products according to sensory evaluations and physicochemical tests (21). In a similar study of Furlán and Campderrós, (2017), the replacement of sucralose and stevia in the dairy dessert was investigated. The results showed that replacing part of the sugar with sucralose and stevia leads to the production of a product with improved properties. The best sample produced using 50% sucralose and 50% stevia was the most similar to the control sample and had no significant difference from the control sample (22). In a study conducted by Yazdanpanah, (2020), maple syrup was used at levels of 0, 25, 50, and 75% as a substitute for sugar in ice cream. The physicochemical, rheological, microbial, and sensory tests were then performed. With the increase in replacement percentage, the amount of viscosity and hardness of the treatments increased significantly. The amount of dry matter, increase in volume, specific weight, and melting speed decreased significantly. The results of sensory tests showed that replacement up to the level of 50 and 75% had an effect on overall acceptance compared to the control, and replacement at the level of 50% was chosen as the most suitable level for replacement (23). In Ozdemir and Ozcan, (2020) study, steviol glycosides were used as a sugar substitute in milk gels. The fermented product produced from stevia had organoleptic and technological properties close to the control sample. It is also considered as a beneficial and suitable fermented product for diabetics (24). Seyed Mahmoodzade and Ahmadi, (2021)'s research aims to reduce the amount of fat and sucrose in chocolate milk desserts using inulin and stevia used as a substitute for fat and sugar, respectively. Investigating the effect of inulin and stevia on the chemical, antioxidant, and sensory properties of dairy desserts showed that by increasing the amount of inulin and decreasing the fat, the amount of energy per serving of the dessert decreased. By increasing the amount of stevia, the regeneration power of low-calorie chocolate milk dessert increased. Also, by increasing the amount of inulin up to 4% and stevia up to 0.03%, general acceptance increased, and using more than these amounts caused it to decrease. In general, the highest overall acceptance score for dessert chocolate milk was related to a sample containing 4% of inulin and 0.03% of stevia (25). The replacement of sugar with date syrup and powder in a dairy dessert was also studied. This compound increased dry matter, lipid, protein, total phenolic content, and antioxidant activity. Furthermore, the produced product was similar in texture to date juice syrup and control dairy dessert. The product produced from date syrup had pseudoplastic properties and high microbial quality. Date syrup was introduced as a suitable substitute for sugar to produce low-calorie and functional products (26).

Table 1. Summary of sugar substitute effect on characteristics of several products.

Foods	Type of sugar substitute	Substitution rate/ or concentration	Textural properties	Sensorial aspects and overall-acceptability	Rheological aspects	Physicochemical properties	Nutritional effects	Author's claims	Reference
Tomato ketchup	High fructose corn syrup (HFCS)	0, 25, 50, 75, and 100 %	NA	Improved features Sensory ketchup such as color, consistency, taste, and overall acceptance	Storage Modulus ↑ Loss Modulus ↑	a*/b*↑ pH↑ acidity ↓ aw ↔ energy ↔	Lycopene ↑	Replacing sugar with HFCS up to 75% can increase the stability of bioactive compounds, and the sensory and rheological characteristics of the sauce. Improve ketchup	(40)
Peach beverage	Stevia	20, 25, 30 and 35 mg/100 mL	NA	Overall acceptability ↔ Sweetness↔ Taste↓ Flavor↓	NA	pH ↔ acidity ↓ a* ↓ b*↓	Antioxidant activity ↑	low-calorie peach ready-to-serve beverages could be safe and promising nutraceutical drinks for the management of obesity, diabetes, and its associated complications	(41)
Sponge cakes	mesquite flour and coconut sugar	0, 100 %	NA	NA	NA	Volume ↔ Porosity ↓ Baking loss ↓ Water-absorbing capacity ↓ Density ↑ a* ↓ b*↓ Energy ↓	Protein ↑ Fat↓ Carbohydrate↓ Total dietary fiber ↑	The results confirm the adaptability of mesquite flour to be incorporated in different cakes formulations rendering healthier distinctive products.	(42)
Crust pastry	stevia	0, 100 %	hardness↑	occurrence of a little bitterness which is attributed to the inherent bitterness of steviol glycosides	NA	Energy ↓ aw↓ bake loss ↑ a* ↓ b*↔	Protein↔ Carbohydrate↓ Fat↔ fiber ↔	NA	(43)
Crust pastry	xylitol	0, 100 %	hardness↓	acceptable by the panelist	NA	Energy ↓ aw↓ bake loss ↑ a* ↔ b*↑	Protein↔ Carbohydrate↓ Fat↔ fiber ↔	NA	(43)

Crust pastry	Dried bannana	0, 100 %	hardness↓	acceptable by the panelist	NA	Energy ↓ aw↓ bake loss ↑ a* ↓ b*↔	Protein↑ Carbohydrate↑ Fat↔ fibre↑	NA	(43)
Crust pastry	Coconut sugar	0, 100 %	hardness↑	acceptable by the panelist	NA	Energy ↓ aw↓ bake loss ↑ a* ↔ b*↓	Protein↔ Carbohydrate↓ Fat↔ fibre↔	NA	(43)
Ice cream	Date syrup (dibis)	20, 40, 60 and 100%	Texture↔	Flavor ↓	NA	Color ↓ Melting rate (min) ↓ Texture↔	protein↑	the dibis can be used as a replacement of sugar up to 60% to give good quality ice cream with enhancing the nutritive value of the products.	(44)
Confectionery	stevia	10, 30, and 50%	Layer thickness↔	the amount of 10 % and 30 % has not significantly affected the organoleptic indicators of the finished product. However, at 50 % substitution, a weakly pronounced bitter taste and herbal odor has been observed, which is inherent in this sweetener at high concentrations.	NA	Moisture↔ Mass fraction of sucrose ↓ Dry matter content↔	Nutritional value ↔	it is recommended to substitute sugar with sweetener "Stevioside" in the amount of 30 % when producing the "Spring" roll, as this allows to increase the amount of the product produced by reducing the technological process and will increase the level of profitability.	(45)
Ice cream	maple syrup	0, 20, 50, and 75 %	Cohesiveness↑ Hardness↓ Gumminess↑ Chewiness↑	Taste↔ General Acceptance↑	Dynamic viscosity↑	pH↔ Melting speed↓ Dry matter↓ Acidity↔ overrun↓	NA	Maple syrup can be used alone or in combination with other sweeteners Production of nutritional and dietary products suitable for all ages.	(23)
Chocolate	mulberry molasses microcapsules	0, 5, 7, 10, 15, 20, and 25 gr	Hardness↓ Particle size parameters↑	acceptable	Casson yield stress↑ Casson viscosity↑	Moisture↓ pH↓	Total phenolic content↑ Antioxidant activity↑	the addition of mulberry molasses microcapsules offer functional properties to white chocolate as well as good acceptance of the resulting white chocolate.	(35)

Abbreviation: (↑); increase, (↓); decrease, (↔); no significant change. NA; not analyzed.

3.2. Bakery products

Sugar is an essential ingredient in the formulation of virtually all bakery products. These include a wide range of delectable products such as biscuits, breakfast cereals, cookies, baby foods, and cakes. By reducing sugar by using its substitutes in products that are at the base of the food pyramid, it is possible to help to reduce sugar consumption in society. In the following, the investigations of sugar substitutes in bakery products for the production of ultra-profitable products are mentioned. The production of biscuits with the use of papaya pulp was examined. This compound was used as a substitute for sugar and to increase antioxidant properties. Various formulations containing 0, 25, 30, and 35% papaya pulp were produced. The production of biscuits with papaya pulp improved the physicochemical properties and also the formulated product had favorable organoleptic properties. The addition of papaya pulp also improved the antioxidant properties of the biscuit samples (27). Sanggramasari (2019) used honey and stevia as a complete sugar substitute in chiffon cake. The taste of the stevia cake was similar to the sweet control sample and the vanilla-lemon flavor was retained. It also had a slightly bitter taste and sweet aftertaste (28). Also, in the study done by Stavale et al., (2019), sugar was replaced with apple puree. The produced cake had less fat and carbohydrates. Also, the amount of fiber increased and differences in taste, color and texture were observed, but despite this, the sensory evaluation showed that the consumer liked this cake. It was also observed that the cake made with apple puree had a favorable glycemic index (29). Also, a type of sugar-free muffin cake with a combination of stevia, inulin, and bovine plasma proteins was produced. The sample containing 12.5% of these compounds was the most similar to the control sample (30). In a study conducted by Esaulko et al., (2019), it was shown that the use of 10% and 30% stevioside as a sugar substitute in biscuit samples did not significantly change the organoleptic characteristics of the manufactured product compared to the control sample. However, at concentrations of 50% or more, stevioside biscuits have a slightly bitter taste and less strength. The best sample was produced using 30% stevioside as a sugar substitute (31). In a study conducted by Conde Molina et al. (2020), the objective was to create a low-calorie bread using granofiber (GC) sweetener as a substitute for sugar (32). The bread produced in this research was examined in terms of textural characteristics. It was shown that the bread using GC had the same texture as the control sample.

3.3. Snacks

A snack is a small portion of food that is usually eaten between meals. Commercial snacks include convenience food, sweets, chocolate, candy, and chips. In the study carried out by dos Santos Filho et al. (2019), sucralose was used in probiotic cocoa juice. No adverse effects were observed with the addition of this sugar substitute for the performance of the probiotic bacteria used in the product (33). The tagatose and maltitol were used as sugar substitutes in chocolate. One of the problems in the chocolate industry is blooming. The FE-SEM pictures showed the effect of anti-bloom in the produced chocolates (Fig 1). The tagatose and maltitol-based product exhibited reduced hardness, chewiness, sweetness, overall flavor intensity, and cocoa flavor compared to other variants, although it also had a lower level of bloom (34). In another study on chocolate, it was proven that the use of mulberry molasses microcapsules as a substitute for sugar, in addition to the positive effect it had on the physicochemical characteristics of the manufactured chocolates, also increased the antioxidant activity as a result of the phenolic content of chocolates. White chocolate produced from mulberry molasses microcapsules had less hardness than the control sample, and lower pH, moisture content, and sugar content. These chocolate samples produced with mulberry molasses microcapsules were acceptable to consumers (35). In the study conducted by Loqmani et al. (2022), the combination of inulin, isomalt and sorbitol was used as a sugar substitute in the production of molten dark chocolate. The fabricated product had reduced G′ and G″ values. The sugar substitutes used in this study had more liquid-like behavior than gel-like behavior, which was obtained by examining the rheological parameters. In general, the produced product was accepted by the consumer (36). According to the investigations conducted in recent studies, it is possible to reduce the amount of sugar in various food products by using sugar substitute compounds. Also, by using the optimal percentage of sugar substitute compounds, the technological characteristics of the manufactured product are maintained at the optimal level, and on the other hand, a functional product can be produced that fits the needs of society. These products can be introduced to society as products with innovation and different formulations from similar traditional examples. As mentioned earlier, Table 1 shows a summary of the effect of sugar substitutes in different products on technological, nutritional, textural, and physicochemical properties.

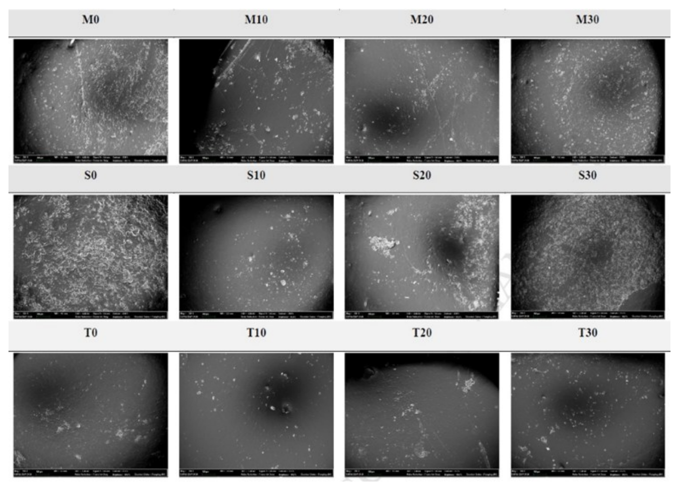

Figure.1. Images of the surfaces of blooming induced chocolates with different sweeteners by FE-SEM (Magnification ratio: ×250) M, maltitol; S, sugar; T, tagatose added chocolates. The last numbers mean blooming cycles (day), Adapted from ref. (34) with permission.

4. Safety of sweeteners

In some cases, it has been reported that the consumption of sugar causes dependence and habit in the consumers and acts like caffeine, alcohol, tobacco, and cocaine. People of all ages (children to adults) have decayed teeth (80%) and the sugar in the diet is an important factor in it. Studies have shown that people with decayed teeth consume more sugar. Although various natural and artificial alternatives to refined sugar have been proposed, their use is controversial because of their harmful health consequences. On the other hand, a safe dose has been considered for them. Artificial sweeteners do not pose a health risk if they are consumed according to the standard and in the permitted amount. Refined sugar causes noncommunicable diseases such as diabetes, cardiovascular diseases, obesity, and hypertension, and is related to cancer and metabolic syndrome. Tagatose is a sweetener that causes diarrhea and abdominal bloating. The use of licorice in the United States and Europe is recognized as an illegal sweetener because it has a bad effect on blood pressure despite its beneficial effect on the intestine. High consumption of fructose as a natural sweetener (high fructose syrup from corn starch) is not recommended because it causes resistance to insulin production (37). Some artificial sweeteners have been approved by the European Union (EU), while their use is not recommended in America and are illegal, such as cyclamate. Cyclamate and saccharin create a bitter and metallic taste, are laxatives, and cause flatulence in the digestive system. 5-Keto-D-fructose, which was explained, is not used in food due to its effect on cellular processes and cytotoxic symptoms (38). In addition to health effects, emerging sweeteners have a detrimental effect on the environment because they have a long half-life and persist in the environment. Due to the conflicting information regarding the consumption of sweeteners, more studies on humans and animals are needed. Sugarcane has a positive effect on some diseases such as influenza, cough, constipation, weakness, anemia, and liver damage, despite its sweet taste, it has antioxidant, phenolic, flavonoid, and anti-radical compounds, and improves bowel function (39). Honey is a rich source of B vitamins and promotes the growth of beneficial intestinal bacteria such as Lactobacillus and Bifidobacterium. Also, stevia with high sweetness and almost zero calories has an effective role in reducing obesity and it can replace high-calorie sugars. This plant reduces appetite and glucose levels in diabetes (1 and 2). Some side effects of sweetener consumption are shown in Fig 2.

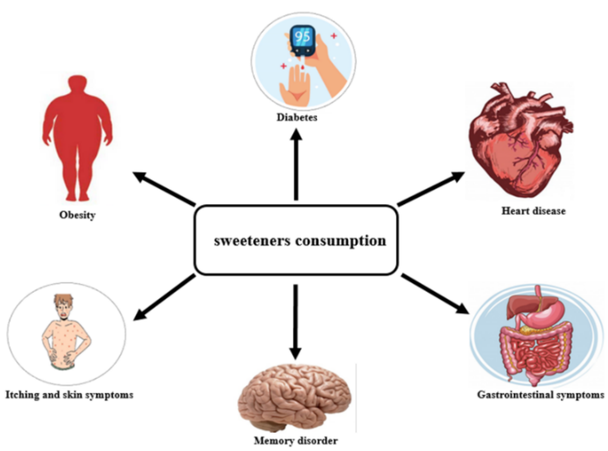

Figure.2. Side effects of using different sweeteners and the organs that are affected.

5. Challenges and future trends

The utilization of sugar substitutes in food products presents several challenges, including taste and flavor replication, functionality and texture, stability and shelf life, and regulatory considerations. Replicating the taste and flavor profile of sugar is a major concern, as many substitutes have a different taste and it can be difficult to achieve the same level of sweetness without the aftertaste. The sensory properties of sugar substitutes need to be understood to ensure consumer acceptance. sugar plays a crucial role in food products, contributing to texture, browning, and moisture retention. Replacing sugar with substitutes can impact the functional properties of the final product, which requires attention to texture and mouthfeel during formulation. In addition, sugar substitutes may exhibit different stability characteristics that affect the shelf life of food products. Some substitutes are prone to degradation, leading to changes in flavor, color, and overall quality, necessitating stability studies. Regulatory considerations pose another challenge, as sugar substitutes are subject to approval and regulation in different countries. Compliance with guidelines and maximum daily intake levels can be complex and requires extensive testing and documentation. Addressing these regulatory challenges is crucial for food manufacturers. Looking to the future, natural and plant-based sweeteners are gaining popularity due to the increased consumer demand for natural ingredients. Stevia, monk fruit, and erythritol are being investigated as alternatives to traditional sugar in food products. Sweetener blends that are a combination of different substitutes offer a solution to taste and functionality challenges. Blending sweeteners with complementary characteristics can create a balanced sweetness profile while addressing texture and stability concerns. Advancements in food processing technologies present opportunities for improving the performance of sugar substitutes. Techniques such as microencapsulation can enhance stability, mask off-flavors, and control release, improve functionality and overall quality. Consumer education and acceptance play a vital role in the success of sugar-reduced products. Educating consumers about the benefits and appropriate use of sugar substitutes will help increase awareness and address misconceptions. In conclusion, challenges in incorporating sugar substitutes in food products include taste and flavor replication, functionality and texture, stability and shelf life, and regulatory considerations. Future trends focus on natural sweeteners, innovative blends, and improved processing techniques. By addressing these challenges and capitalizing on emerging trends, the food industry can successfully develop and market sugar-reduced products that meet consumer demands for healthier options without compromising taste and quality.

6. Conclusions

In conclusion, the use of sugar substitutes in food products has gained significant attention due to the increasing concern about the harmful effects of excessive sugar consumption on human health. Sucrose, the most commonly used sweetener, has been associated with various health issues such as tooth decay, obesity, diabetes, and cardiovascular diseases. As a result, there is a growing demand for reduced-sugar or sugar-free food options. Sugar substitutes offer an alternative to traditional sugar, providing sweetness without the same caloric content and potential health risks. However, the use of sugar substitutes in food products is not without its challenges. The incorporation of sweeteners can lead to changes in the technological, organoleptic, and physicochemical properties of the final product. It may also pose nutritional challenges, as some substitutes may lack the same functional properties and nutritional benefits as sugar. Therefore, it is crucial to carefully consider the appropriate amounts and combinations of sugar substitutes to ensure the production of high-quality and nutritionally balanced food products. Despite these challenges, the demand for low-calorie or no-calorie food options has driven the food industry to explore and develop innovative formulations using sugar substitutes. The application of sugar substitutes in food products presents both opportunities and challenges. Further research and development are needed to optimize the use of sugar substitutes, ensuring that they provide a viable and safe alternative to traditional sugar while meeting consumer expectations for taste and quality. Overall, the exploration of sugar substitutes in food products opens up new possibilities for the food industry to address health concerns and consumer preferences. By using suitable amounts of sugar substitutes and maintaining a balanced approach, it is possible to produce innovative and healthier food options without compromising on taste and quality.

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9. Author Contributions

Leila Zare; investigation, writing original draft, and contribution to the preparation of tables, Mahya Soltani; investigation, writing original draft, and contribution to the preparation of figures, Hadiseh Ebdali; investigation, writing original draft, and contribution to the preparation of figures, Zohre Mansourinia; writing original draft, Khadije Abdolmaleki; conceptualized, reviewed, and corrected the framework and contents of the text as well as finalized the manuscript.

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