USE OF D-TAGATOSE AND D-ALLULOSE (PSICHOSE) AS SWEETENER SUBSTITUTES IN SUGARY PRODUCTS

Abstract

This chapter examines the potential use of the rare sugars, called as D-tagatose and D-allulose (psichose), as sweetener substitutes in sugary products. D-tagatose and D-psicose are known as low-calorie sugar alternatives naturally found in some foods. The use of these rare sugars may offer a solution to reduce the consumption of high-calorie foods and obesity-related health problems. The sweetness profiles, physical, chemical and technological properties of D-tagatose and D-psicose and how they affect product quality when used as sweetener substitutes were evaluated. The digestion, absorption and metabolism of these rare sugars were also discussed. Additionally, their applications in sugary products industry were also described. The findings in literature show that D-tagatose and D- psicose may have a potential as low-calorie sweeteners and give positive results in terms of taste and texture when used in sugary products. However, further research is needed, especially more information is needed on their long-term effects and consumption limitations. In conclusion, D-tagatose and D-psicose can be considered as promising alternatives to sweeteners used in sugary products. With the widespread adoption of commercial use, the accessibility of low-calorie products can increase, potentially yielding positive effects on public health. However, it is crucial to support their use and consumption through legal regulations and careful monitoring.

Keywords: D-tagatose; D-psychose; sugary products; substitution.

Authors

Ali Goncu
Department of Food Processing
Aydın Adnan Menderes University
Çine Vocational School
Çine, Aydın, Turkey.
ali.goncu@adu.edu.tr

Aslı Yildirim Vardin
Engineering Faculty
Department of Food Engineering,
Aydın Adnan Menderes University
Efeler, Aydın, Turkey.
asli.yildirim@adu.edu.tr

I. INTRODUCTION

Products generally produced in the confectionery industry include soft or hard candies, filled and unfilled candies, various gums, different chocolate and derivative products, coated products and dragees [1, 2]. Despite all these product differences, there are various carbohydrates as the main component in the structure of the products produced. Sucrose (sucrose, tea sugar), glucose (corn) syrup, invert sugar, dextrose or high fructose syrup are the most commonly used sweeteners in confectionery production [3]. Sugar alcohols such as sorbitol, mannitol, xylitol, xylitol, isomalt and maltitol or high intensity artificial sweeteners such as sucralose, aspartame, acesulfame potassium (K) are also used in the production of diabetic products, where there has been a significant trend recently [4]. On the other hand, there is a significant consumer demand for functional confectionery products rather than the conventional confectionery available in the food market [5]. In this section, sugary products and foods with added sugar that are not in the sugary products industry are examined. Before examining the sweeteners used in the sugary products industry, it would be more useful to address the relationship between confectionery and health.

II. THE RELATIONSHIP BETWEEN SWEETENERS AND HEALTH

The increase in the incidence of diet-related diseases, especially cardiovascular diseases and obesity, has steadily increased consumer interest in functional foods fortified with various bioactive ingredients. Therefore, in ready-to-eat foods with acceptable quality and level of sensory properties, healthier produced ones are more in demand [6]. Confectionery products are high in calories [7]. In addition, confectionery is positively associated with overweight [8]. The foods which are high in sugar and fat are generally much preferred than healthy foods such as fruits and vegetables. Consumption of these foods also increases the risk of chronic diseases. Precautions should be taken to reduce these risks for public health [9].

Obesity is one of the most serious health problems of our age. Obesity, which is a serious problem on its own, triggers many diseases. Especially psychologically, obesity has been found to cause inability to establish social relationships and lack of self-confidence [10]. According to the latest findings of the World Health Organization (WHO), the prevalence of obesity has tripled worldwide from 1975 to 2016. According to WHO, in 2016, 1.9 billion people aged 18 and over were overweight and 650 million of them were obese. According to the findings, the prevalence of obesity was estimated to be 13% (11% in men and 15% in women) in the adult population worldwide in 2016 [11]. When the body mass index is analyzed; the proportion of obese individuals aged 15 years and over was 19.6% in 2016 and 21.1% in 2019. In 2019, 24.8% of women were obese and 30.4% were pre-obese, while 17.3% of men were obese and 39.7% were pre-obese [12].

Diabetes is a chronic disease that occurs when the pancreas does not produce enough insulin hormones or the insulin hormone produced cannot be used effectively and continues throughout life [13]. According to 7. Diabetes Atlas estimates, in 2015, 1 in 11 adults had diabetes (415 million), 1 in 2 adults with diabetes (46.5%) were undiagnosed, meaning they did not know they had diabetes. 12% of global health expenditure was spent on diabetes (US$ 673 billion). 1 in 7 births affected by gestational diabetes. 542,000 children had type 1 diabetes. 1 person dies from diabetes every 6 seconds (5 million deaths). The International

Diabetes Federation (IDF) estimates that in 2040, 1 in 10 adults will have diabetes (642 million). Health expenditures for diabetes-related diseases will exceed US$ 802 million and Europe will have the highest prevalence of children living with type 1 diabetes [14].

One of the most important factors in regulating high blood glucose, a complication of type 2 diabetes, is undoubtedly the addition of foods with low glycemic index (GI) values to the diet. Foods with low GI values increase blood glucose at a moderate rate. Thus, foods with a low GI also improve glycemia control and insulin sensitivity, reducing the risk of type 2 diabetes. The most important nutrient that affects the glycemic index is carbohydrates. Simple carbohydrate foods are foods containing monosaccharides and disaccharides, which are rapidly hydrolyzed in the digestive system and rapidly increase blood glucose. On the other hand, complex carbohydrate foods are carbohydrate foods that contain pulp, have slower digestion and absorption, prevent sudden increase in blood glucose, and contain more polysaccharides [15].

III. NATURAL AND ARTIFICIAL SWEETENERS AND RARE SUGARS

The most widely used natural sweetener in the world is sucrose. In addition, sucrose has a high GI value with very rapid absorption, which can cause problems for diabetic patients and is dangerous to consume [16].

Artificial sweeteners are food additives that are used in low amounts, have negligible caloric value and high sweetness [16]. The most commonly used artificial sweeteners are acesulfame K, aspartame, saccharin and sucralose [17, 18]. They do not increase GI. For these reasons, they are commonly used in diets for diabetics and low-calorie diets. Although they seem to be an excellent sugar substitute, new research has shown that they can lead to an altered glucose metabolism. Artificial sweetener consumption has been associated with weight gain, obesity and increased risk of type II diabetes [16]. Recent studies show that non-nutritive sweeteners may be surprisingly associated with type II diabetes risk and weight gain [17, 18, and 19].

For the reasons mentioned above, it would be better to replace artificial sweeteners and sucrose with alternative sugars. One of the alternatives that can be used for this purpose is rare sugars. In recent years, many studies have been carried out on rare sugars, which are defined by the International Institute of Rare Sugar as "monosaccharides and derivatives that are rare in nature". There are more than 50 rare sugars in nature [20]. D-tagatose and D-allulose (psichose) are two of them.

D-tagatose, the D-galactose isomer and D-fructose stereoisomer, is a naturally occurring simple sugar that has been recognized as GRAS (Generally Recognized as Safe) for use in foods and beverages by FAO/WHO since 2001 [21]. D-tagatose has high solubility. It can be used in browning reactions during cooking or heating because it is a reducing sugar [22]. D-tagatose is almost odorless and white. Its melting point is 133-137 °C. The descriptive characteristics of D-tagatose were summarized in Table 1.

Table 1: Descriptive characteristics of D-tagatose [23].

Category	Characteristic properties
Synonyms	1.D-tagatopyranose, D-tagatopyranoside, D-lyxo-hexulose
Common name	D-tagatose
Empirical formula	C6H12O6
Solubility in water	160 g/100 mL at 20°C
Molecular weight	180.16
Calorie	1.5 kcal/g
pH stability	2-7
Melting temperature	133–137°C
Regulatory status	Generally recognized as safe (GRAS)
Physical form	White crystalline solid

It is used in foods as a sweetener, texture regulator, stabilizer and moisture retainer. Its sweetness level is 92% of sucrose. In addition to being a palatable and low calorie (1.5 kcal/g) sweetener, it does not have the gastrointestinal side effects commonly associated with other low energy artificial sweeteners due to gastrointestinal absorption [24]. It can also be used in dietetic foods due to its low glycemic index. With all these properties, it can be said that it is a highly suitable additive for increasing the functionality of foods [25]. Figure 1 shows the chemical structure of D-tagatose.

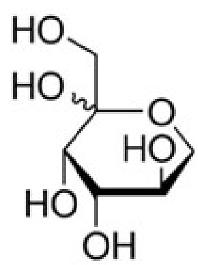

Figure 1: Chemical structure of D-tagatose [26]

Despite its use as a sweetener, D-tagatose has been found in animal and human studies to lower postprandial blood glucose and insulin response and stimulate weight loss. The mode of action was reported to be inhibition of the digestion of sucrose and maltose, possibly by inhibiting sucrase and maltase and/or interfering with glucose transport, respectively [21]. In addition to offering an effect on the reduction of total cholesterol, VLDL and LDL compared to sucrose, it similarly contributed to an increase in HDL cholesterol levels [27, 28]. D-tagatose is poorly absorbed in the small intestine [29, 30]. Only 20% of orally ingested D-tagatose is completely and mainly metabolized in the liver [31]. The unabsorbed portion of D-tagatose is then fermented by microflora in the large intestine [32]. The European Union (EU) has introduced D-tagatose as a "new food ingredient" with no restrictions on the amount to be used. Currently, D-tagatose is used as a sweetener in beverages, yogurt, creams and dietary sugars [33].

D-allulose is another rare sugar, which is also called as D-psicose [20]. After the discovery of D-tagatose 3-epimerase, the key enzyme that converts D-fructose to D-psicose, it is commercially produced [34]. D-psicose is also produced and used by chemical synthesis at a much lower cost [35].

D-allulose, an odorless, white powder, is easily soluble in water and after dissolution, a solution of 74 wt% is obtained [36]. It has a ketone group in its structure and acts as a reducing agent. The sweetness of D-psicose is about 70% of sucrose and melts at 96°C to form caramel (browning reaction) [35]. The descriptive characteristics of D-allulose were summarized in Table 2.

Table 2: Descriptive characteristics of D-allulose [37, 38]

Category	Characteristic properties
Synonyms	D-psicose, D-ribo-2-hexulose
Common name	D-allulose
Empirical formula	C6H12O6
Melting temperature	96°C
Molecular weight	180.16 g/mol
Calorie	0.4 kcal/g
Odor	None
CAS	No. 551-68-8
Regulatory status	Generally recognized as safe (GRAS)
Physical form	Solid white crystalline powder

Studies have shown that D-psicose, which has a caloric value of 0.39 kcal/g, has an effect on reducing body fat accumulation and blood glucose levels, and that the components formed as a result of heat treatment show antioxidative effects. The U.S. Food and Drug Administration (FDA) recognized D-psicose as GRAS in 2012, which facilitates the usage of this sugar as a substitute for sucrose. Research on the absorption metabolism, health effects and use of D-psicose in food industry is still ongoing at Kagawa University. It has been understood that compounds with antioxidant properties are formed as a result of Maillard Reactions in systems containing D- psicose and that these substances provide antioxidative properties to food [7]. The chemical structure of D-psichose is shown in Figure 2.

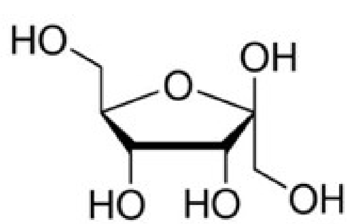

Figure 2: Chemical structure of D-psichose [39]

When the studies investigating the effect of sweeteners on food intake were examined, it was found that different amounts of sweeteners given to healthy and diabetic experimental animals significantly reduced their feed intake [40]. Lida et al. [41] obtained new sugar syrup containing rare sugars (D-psicose, Dallose, D-sorbose and D-mannose) by isomerizing high fructose corn syrup (HFCS) and added this sweetener to the diet of rats and examined its effect on body weight, abdominal fat and biochemical parameters. Statistically more significant results were obtained in terms of weight gain and abdominal adiposity in the group consuming starch and HFCS compared to the group consuming rare sugar syrup. Nagata et al. [42] reported that gene expression of liver proteins related to cholesterol metabolism decreased with D-psicose and D-sorbose, but no such effect was observed with D-tagatose. In the study of Chen et al. [43], Spaque dawlwy rats were divided into five groups and fed with diets containing 5% of different carbohydrates such as glucose, fructose, cellulose, D-psicose for 4 weeks. The results showed that compared to other carbohydrates, D-psicose supplementation led to minimal fat accumulation in rats. Favorable effects were also detected in the blood lipid profile and antioxidative activity of the rat.

D-psychose offers clean label options, synergy with other sweeteners, no unpleasant aftertaste, high solubility and participation in the Maillard reaction. It is therefore ideal for a variety of products such as beverages, baked foods, dairy products, flavorings, salad dressings, jellies, gums, confectionery, puddings, medical food fillers and coffee blends. It is also popular in ready-to-eat snack foods and convenience foods [37]. In conclusion, D-tagatose and D-psicose can be considered as healthy alternatives to traditional sweeteners. The potential usage of D-tagatose and D-psicose in various food products were summarized in Table 3.

Table 3: The usage of D-tagatose and D-psicose in various food products

Rare sugar	Food product	Intended use	Reference
D-tagatose	Strawberry-flavored yogurt	Sucrose substitute	[44]
D-tagatose and D-allulose (D-psicose)	Gluten-free muffins	Sucrose substitute	[45]
D-tagatose	Cookies	Sugar replacer	[46]
D-tagatose	Dark chocolate	Sugar substitute	[47]
D-allulose	Pound cakes	Sucrose substitute	[48]
D-allulose	Chicken breast sausage	The effect on rheological properties	[49]
D-allulose	Cupcakes	The effect on physical properties	[50]
D-allulose	Bread	The effect on fermentation ability	[51]

IV. APPLICATIONS OF D-TAGATOSE AND D-PSICOSE IN THE CONFECTIONERY INDUSTRY

1. **Confectionery and Chocolate:** In terms of functionality, various sweeteners have been tested to replace sucrose, which continues to be used in chocolate production, especially prebiotics and probiotics and the addition of different plant materials or bioactive ingredients. The production of high quality sugar-free chocolate requires the use of the

most suitable sweeteners that can substitute sucrose without adversely affecting the rheological, physical and sensory properties of the product. These include substances with an intense sweet taste such as D-tagatose [52]. D-psicose can be combined with alcohol or high-intensity sweeteners to alter the taste and quantity of the mixture used in food and beverages. At the same time, D-psicose can also improve the gel formation behavior of food, and the gel strength and water retention capacity of D-psicose are significantly higher than sucrose and sorbitol. It slows down retrogradation in starch-based confectionery, resulting in a better gel network [53]. Confectionery gels are considered to be compound gel systems consisting of high amounts of sugar in combination with gel-forming agents such as gelatin or starch. In the study of Pocan et al. [54], gelatin-based soft candies were formulated and the effect of D-psychosis on the quality of the products was investigated. Moisture content, water activity, color, hardness and glass transition temperature of the samples were studied for the characterization of soft confectionery. X-ray diffraction analysis was also performed to explain the crystallization tendency of the jelly candies. The results showed that the sample containing the highest amount of D-psicose was the softest sample, had the highest moisture content and the lowest crystallization tendency [54].

D-tagatose and inulin were substituted with sucrose as sugar substitutes and their effects on the physical, chemical, rheological and sensory properties of dark chocolate were investigated. Inulin:D-tagatose ratios of 100:0, 75:25, 50:50, 25:75 and 0:100 were used in the study. The physical, chemical, rheological and sensory properties of the chocolate samples prepared with the mixtures were analyzed. According to the results, the moisture content of the chocolate samples decreased and a_W values increased with decreasing inulin content and increasing D-tagatose content. Increasing D-tagatose increased the hardness of the samples and the sample containing 100% D-tagatose was the hardest sample comparable to the control (sucrose). In terms of color indices, the lowest values of *L, a, b*, C and hue° were observed in chocolate samples containing 100% inulin. Increases in color indices were observed with increasing D- tagatose. The lowest apparent viscosity and the lowest plastic viscosity were observed in samples containing 25% inulin-75% D-tagatose and 100% D-tagatose, respectively, and were similar to the control value. The overall acceptability of the chocolate samples increased with increasing D-tagatose level. It was concluded that the best sucrose substitutes in chocolate samples were the samples containing inulin-D-tagatose ratio of 25%-75% and 100% D-tagatose [47]. Son et al. [55] analyzed the blooming characteristics of chocolates used as alternative sweeteners containing maltitol and D-tagatose in terms of physical and sensory properties and to determine the blooming progression and typical characteristics of each chocolate. When the surface properties of the chocolates were analyzed, the number of white fat crystals, Hunter scale values and whiteness index increased as the blooming progressed. Considering sensory evaluation results, inflorescence area, inflorescence color, brittleness, granularity, bitterness and mouthfeel increased, while hardness, chewiness, taste sweetness, overall aroma intensity and cocoa aroma decreased as the blooming progressed. Overall, D-tagatose added chocolate showed the lowest blooming progression. These results encourage making chocolate with non-diabetic sweeteners with good stability.

2. **Desserts and Bakery Products:** Sun et al. [56] produced traditional pudding made from eggs, sugar and milk by using D-psicose, fructose and sucrose separately. They found that the antioxidant content of traditional pudding prepared with D-psicose was the highest and stated that pudding prepared with D-psicose can be considered as functional dessert. In another study [57], it was showed that the antioxidant activity of cookies prepared with D-psicose was high and D-psicose increased browning reactions.

The effect of D-psicose on the physical and chemical properties of beze was investigated. Beze was produced by mixing egg whites and sucrose (1:1 weight ratio) and then baking at 93°C for 2 hours. The 30% of sucrose was substituted with D-ketohexoses such as D-psicose, D-fructose, D-tagatose and D-sorbose. The bezecontaining D-psicose (P30) had the highest fracture strength and fracture deformation, resulting in the most brittle texture. Furthermore, P30 also had the highest antioxidant activity and the brownest color due to the Maillard reaction that occurs during cooking. Replacing sucrose with D-psicose improved the properties of the beze [58]. Cocoa husk, a by-product of the cocoa industry, is reported to be rich in fiber and polyphenols, which contribute to reducing sugar metabolism and glucose absorption. The production of cocoa husk-based biscuits using D-tagatose, a low glycemic index sugar with prebiotic properties that benefit consumers with diabetes, is proposed. Six prototype biscuits were produced using 0%, 10% and 20% D-tagatose instead of sugar and cocoa shell powder instead of wheat flour. The biscuits were evaluated by consumer acceptance assessment and their perceptible sensory differences were investigated by Napping® sensory characterization. Cocoa bark-based biscuits were found suitable for cocoa by-product reuse, but an optimized recipe is recommended, especially when D-tagatose is used [59].

In another study examining the sugar substitutability of tagatose, a prebiotic monosaccharide, in cookies, a sugar-containing cookie recipe was prepared as a control. Sucrose was replaced with D-tagatose in proportions ranging from 25% to 100%. Due to the structural similarities between D-tagatose and fructose, cookies containing fructose were also prepared for comparison. The rheological properties of the dough were measured using texture profile analysis. It was reported that when D-tagatose was replaced with sucrose, doughs with rheological properties similar to the control were obtained. Cookies containing D-tagatose were harder and darker in color and had a lower spreading area than the control. Sensory data indicated that the panelists liked the brown color of the cookies with 100% D-tagatose more than the control group, but they did not like the taste. The overall liking score of the cookies made by replacing half of the sucrose with D-tagatose was the same as the control group. Based on similar dough properties, cookie properties and liking scores, it appears that D-tagatose may be a partial substitute for sucrose in cookies. The physical properties of the dough prepared with D-tagatose were also very similar to the sucrose-containing control group. Therefore, engineering problems related to the production of cookie dough containing D-tagatose can be easily solved. In addition, D-tagatose cookies require a shorter baking time, which translates into a cost saving due to lower energy consumption [60].

Consumer acceptance tests have shown that wheat flour alternatives can be combined with rare sugars to create acceptable low-sugar, gluten-free muffins. In a research, vanilla muffins were formulated with monosaccharides (D-psicose or D-tagatose) or sucrose (as a control) and enhanced with stevia to bring sweetness levels to theoretically equivalent levels. The muffins containing D- psicose or D-tagatose differed from those containing sucrose in water activity and crust color (L). In the consumer panel, sugar substitutes was similar to control muffins [45]. In a study in which pound cakes were obtained with four different D-psicose ratios (25%, 50%, 75% and 100%) and their rising, textural and sensory properties were evaluated. The crust browning index increased with the addition of D-psicose. Cakes other than the control had higher appearance and flavor scores and no significant difference was found in textural scores. These results suggest that adding up to 25% of D-psicose to pound cake can be considered as pleasant low-calorie, low- sugar cakes [48]. However, in a similar study, the addition of D-psicose instead of sucrose in pound cakes increased the crust browning index. Sensory evaluation analysis showed that D-psicose added cakes had high appearance and taste scores [37].

On the other hand, in another study, the physical, chemical and sensory properties of breads in which 25%, 50%, 75% and 100% of sucrose was replaced with D-psicose were evaluated. Replacing up to 75% of sucrose with D-psicose did not affect the appearance of the bread and had similar hardness values to the control. Hedonic sensory results showed that breads modified with 100% D-psicose scored lower in the preference test, whereas breads modified with up to 75% D-psicose were equivalent in preference to breads using sucrose [51]. It has been stated that D-psicose delays retrogradation and promotes gel formation in the food to which it is added. When D-psicose is added to gel foods such as pudding, it improves the viscoelastic structure and fracture resistance of the food and promotes crosslinking of proteins in the gel [61].

3. **Yogurt and Jams:** Health-beneficial vegetable yogurt or beverages with low fat, low calorie and low sugar content are popular around the world. In a study it was aimed to develop a low-calorie soy yogurt containing D-psicose. In the study, when 50% of sucrose was replaced with D-psicose in soy yogurt fermentation, the yogurt had better overall taste with the highest lactic acid bacteria content, acceptable pH and titratable acidity. At the same time, as D-psicose increased, 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity also increased [53]. In another study investigating the effects of D-tagatose as a sugar substitute on physico-chemical properties and sensory acceptability of strawberry-flavored yogurts, six yogurt samples containing decreasing concentrations of sucrose (8.50-1.70 g/100 g) and increasing concentrations of D-tagatose (0.00-9.24 g/100 g) were evaluated. An acceptability test was carried out for the evaluation of sensory properties. It was found that up to 80% D-tagatose replacement with sucrose had limited effects on physico-chemical properties; however, the increase in redness discoloration (a) and yellowness (b) in D-tagatose replaced samples was significant. Strawberry yogurts with D-tagatose had similar acceptability scores for all attributes. Sucrose reduction showed a positive effect on purchase intention of strawberry yogurts [44].

   Rubio-Arraez et al. [62] produced lemon jams with sweeteners such as D-tagatose and isomaltulose at 10-30% as sucrose substitutes. All jams were microbiologically stable and the jams made with healthy sweeteners had better sensory scores than those made with sucrose.

4. **Beverages:** In the study of Patel et al. [63] the potential use of D-tagatose as a sweetener in Lassi was evaluated. It was shown that Lassi prepared with a mixture of sucrose with D-tagatose or D-tagatose with fructose was highly acceptable in sensory evaluation. D-tagatose could be used in Lassi as a substitute for sucrose and did not change any process parameters, and the approximate composition, physicochemical properties. Microbial counts of Lassi were very similar to the corresponding products prepared using sucrose as sweetener. The shelf-life of the Lassi prepared using sucrose substitute was also found to be similar to that of Lassi prepared with sucrose.

    The thermal stability of D-tagatose in different concentrations such as milk and lemonade was evaluated and it was concluded that this monosaccharide can be used in beverage formulation for people with diabetes with minimal degradation and very low loss of prebiotic activity [33].

    The effects of sucrose/D-tagatose ratios (100:0, 0:100 or 50:50) and commercial probiotic strains (*Lactobacillus acidophilus* LAFTI L10, *Lactobacillus casei* LAFTI L26, *Lactobacillus rhamnosus* HN001 and *Bifidobacterium animalis subsp. lactis* LAFTI B94) on some properties of probiotic chocolate milk were studied during storage. D-tagatose can be successfully used in probiotic chocolate milks as a natural sugar substitute with functional properties that enhance health benefits, but it is recommended that the sucrose/D- tagatose ratio and the strain of the probiotic strain be appropriately selected [64].

V. CONCLUSION

Sugar consumption around the world has increased in recent years, especially with added sugars found in foods and beverages. As a result, added sugar consumption has increased. Thus, total energy intake and excessive consumption of high-energy foods lead to increased body fat accumulation. For this reason, low-energy or non-energy sweeteners are considered as alternatives to sugars because they offer an energy-free taste and are now accepted and consumed as a method to reduce the energy from sugars. Finding sweeteners that can replace sucrose has emerged as an important research topic. The rare sugars D-tagatose and D-psicose are emerging as very promising alternatives to sucrose for use as sweeteners. As summarized above, studies, although they are still insufficient, support this. Better results are obtained than sucrose as they form a strong gel structure in confectionery. They are sweeteners that can be preferred in soft confectionery. The use of rare sugars in the chocolate industry is also promising. Especially in sensory analyzes, it is understood that the use of rare sugars has a positive effect on general appreciation scores. It has been determined that blooming, which is one of the most important problems in chocolates, can be prevented by the use of rare sugars. It is important to investigate traditional
And hard candies and different chocolate varieties using rare sugars. Studies in this field are limited.

It has been reported that a functional product can be produced by using rare sugar in desserts. An increase in the antioxidant capacity and browning ability of the products was observed. In beze production, it has been suggested that maximum fragility can be achieved with rare sugars. In these aspects, its use in both desserts and other bakery products will add a positive value to the products. The use of D-tagatose is recommended in biscuit production.

It is stated that partial use is more preferred in cookies and energy savings can be made by shortening the cooking time of the products. At the same time, it was emphasized that cookies containing rare sugars were similar to control cookies in terms of rheological properties. It is seen that partial use of rare sugars in cakes and breads is more preferred and recommended. Research needs to be intensified in these areas. It is especially important to use desserts and bakery products with high sugar content by functionalizing them with rare sugars and to determine their quality characteristics.

It was observed that the rare sugars used in yogurts caused an increase in the number of lactic acid bacteria, increased antioxidant capacity, had acceptable acidity and color values and scored similar to sucrose samples in all sensory criteria. In addition, when consumer behavior was examined, it was stated that products with reduced sucrose were much preferred. In jams, samples with similar acceptability levels to sucrose samples were obtained. The use of rare sugars in the yogurt and jam industry has been limited, but more research needs to be done in this area in fruit yogurts and in the jam industry where sugar use is intense. It is considered to be a good raw material for the diabetic jam industry.
Rare sugars have been studied as sucrose substitutes in milk, lemonade, chocolate milk and traditional beverages. The results are promising, because rare sugars were liked in terms of flavor and had less loss of prebiotic activity. It is understood that beverages produced with rare sugars have the same shelf life as those produced with sucrose. It has been reported in studies that more favorable results have been detected in terms of health. However, the number of studies in this field is quite limited. It should be tried as a sweetener substitute, especially in cold teas, fruit juices, fruit milks and carbonated or still drinks with added sugar.

It is recommended to investigate the effects of rare sugars on physicochemical, textural, rheological, microstructural and sensory properties of foods other than the sectors examined above. It is important to investigate the positive and negative effects of rare sugars used in the food industry on health by testing the products in which they are included in the formulation with in-vitro and in- vivo studies.

REFERENCES

[1] K. Manjula, C. Suneetha, “Formulation and development of functional confectionery by incorporating pumpkin juice,” Int. J. Food Agri .Vet. Sci, 2014, pp. 47-52.
[2] J. Li, Q. Dai, Y. Zhu, W. Xu, W. Zhang, Y. Chen and W. Mu, “Low-calorie bulk sweeteners: Recent advances in physical benefits, applications, and bioproduction,” Crit. Rev. Food Sci, 2023, pp. 1-15.
[3] R.W. Hartel, H. Joachim and R. Hofberger, “Confectionery science and technology,” Berlin/Heidelberg, Germany: Springer, 2018, Vol. 536.
[4] M. Grembecka, “Sugar alcohols-their role in the modern world of sweeteners: a review,” Eur. Food Res. Technol., 2015, pp. 1-14.
[5] V.T. Kharat and H.W. Deshpande, “Studies on proximate analysis and microbial analysis of probiotic chocolate,” J. Pharmacogn. Phytochem., 2017, pp. 407-411.
[6] R. Güneş, İ. Palabıyık and Ş. Kurultay, “Şekerleme teknolojisinde fonksiyonel ürün üretimi,” Gıda, 43(6), 984-1001. (2018).
[7] H.M. Öztop, S. G. Şumnu, G.B. Mazı and U.B. Söyler, “Düşük Rezolüsyonlu NMR Relaksometre ve Manyetik Rezonans Görüntüleme (MRG) Teknikleri Kullanarak D-Psikoz (Nadir Şeker) içeren Glike Protein ve Şekerleme Ürünleri Tasarımı ve Bu Ürünlerin Fiziksel ve Kimyasal Karakterizasyonu,” TÜBİTAK TOVAG Projesi, Proje No: 116O759, Proje Bitiş Tarihi: 15.06.2019.
[8] T.A. Nicklas, S.J. Yang, T. Baranowski, I. Zakeri and G. Berenson, “Eating patterns and obesity in children: The Bogalusa Heart Study,” Am. J. Prev. Med., 2003, pp. 9-16.
[9] D.A. Cohen and S.H. Babey, “Candy at the cash register—a risk factor for obesity and chronic disease,”

New Engl. J. Med., 2012, pp. 1381-1383.
[10] S. Karaçor, T. Tuncer, Y. Bulduklu, "Çocuklarda obezite artışı ile yiyecek ve içecek reklamları arasındaki ilişki," Pesa Uluslararası Sosyal Araştırmalar Dergisi, 2018, pp. 134-141.
[11] W.H.O. World Health Organization, "Facts about overweight and obesity," accessed on: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight Access date 23.06.2021.
[12] TÜİK, "Türkiye Sağlık Araştırmaları-2019," https://data.tuik.gov.tr/Bulten/Index?p=Turkiye-Saglik-Arastirmasi-2019-33661, 2020, Accessed on: 04.04.2021.
[13] B.M. Kösedağ and N. Hamzaoğlu "Diyabet Tedavisinde Kullanılan Pulsatil İntravenöz İnsülin İnfüzyon Yönteminde Verimin İncelenmesi," Journal of Medical Sciences, 2021, pp. 41-56.
[14] IDF, "Uluslararası Diyabet Federasyonu," (IDF) 7. Diyabet Atlası, http://www.diabetcemiyeti.org/c/diyabet-istatistikleri, 2015, Accessed on:04.04.2021
[15] F. Gürdöl, "Beslenme Biyokimyası," (F. Gürdöl, Ed.). İstanbul: Nobel Tıp Kitapevleri, 2018.
[16] G. Budak and Tezcan, E. "Gıdalarda Sıklıkla Kullanılan Doğal ve Yapay Tatlandırıcıların Sağlık Üzerine Etkileri," Journal of Health and Sport Sciences, 2019, pp. 74-78.
[17] S. Murray, A. Tulloch, K. Criscitelli and N.M. Avena, "Recent studies of the effects of sugars on brain systems involved in energy balance and reward: relevance to low calorie sweeteners," Phys. Behav. 2016, pp. 504-508.
[18] M.Y. Pepino, "Metabolic effects on non-nutritive sweeteners," Physiol. Behav., 2015, pp. 450-455.
[19] F. Gültekin, M.E. Öner, H.B. Savaş and B. Doğan, "Tatlandırıcılar, Glikoz İntoleransı ve Mikrobiyota," Journal of Biotechnology And Strategic Health Research, 2017, pp. 34-38.
[20] M. Özgür and A. Uçar, "Karbonhidrat ve Yağ Metabolizmasında D-alluloz (D-psikoz)," Düzce Üniversitesi Sağlık Bilimleri Enstitüsü Dergisi, 2019, pp. 188-195.
[21] I. Espinosa and L. Fogelfeld, "Tagatose: from a sweetener to a new diabetic medication?," Expert opinion on investigational drugs, 2010, pp. 285-294.
[22] G.V. Levin, "Tagatose, the new GRAS sweetener and health product," J Med Food., 2002, pp. 23-36.
[23] S. Roy, J. Chikkerur, S.C. Roy, A. Dhali, A.P. Kolte, M. Sridhar and A.K. Samanta, "Tagatose as a potential nutraceutical: Production, properties, biological roles, and applications," J. Food Sci., 2018, pp. 2699-2709.
[24] G.V. Levin, L.R. Zehner and J.P. Saunders, "Sugar substitutes: their energy values, bulk characteristics and potential health benefits," Am. J. Nutr. 1995, pp. 1161S- 8S
[25] M. Açu, "Fonksiyonel Özellikleri Geliştirilmiş Dondurma Üretimi," Ege Üniversitesi, Fen Bilimleri Enstitüsü, MSc Thesis, 2014. [26]Anonymous, "D-tagatoz'un kimyasal formülü," https://www.sigmaaldrich.com/deepweb/content/dam/sigmaaldrich/structure3/159/mfcd00134449.eps/_jcr_content/renditions/mfcd00134449-medium.png, 2023a, (Accessed on: 19.06.2023).
[27] S.B. Police, J.C. Harris, R.A. Lodder and L.A. Cassis, "Efect of diets containing sucrose vs. D-tagatose in hypercholesterolemic mice," Obesity, 2009, pp. 269–275. 2009.
[28] T.W. Donner, L.S. Magder and K. Zarbalian, "Dietary supplementation with d-tagatose in subjects with type 2 diabetes leads to weight loss and raises high-density lipoprotein cholesterol," Nutrition Research, 2010, pp. 801–806.
[29] B. Buemann, S. Toubro, A. Astrup, "Human gastrointestinal tolerance to D-tagatose," Regul. Toxicol, 1999, Pharmacol. 2pp. S71-7.
[30] H.N. Laerke, B.B. Jensen, "D-Tagatose has a low small intestine digestibility but high large intestinal fermentability in pigs," J. Nutr., 1999, pp. 1002-9.
[31] Y. Lu, G. V. Levin and T.W. Donner, "Tagatose, a new antidiabetic and obesity control drug," Diabetes, Obesity and Metabolism, 2008, pp. 109–134.
[32] H. Bertelsen, H. Andersen, M. Tvede, "Fermentation of D-tagatose by human intestinal bacteria and dairy lactic acid bacteria," Microb. Ecol. Health Dis., 2001, pp. 87-95. 2001.
[33] M. Guerrero-Wyss, S. Durán Agüero and L. Angarita Dávila, "D-Tagatose is a promising sweetener to control glycaemia: A new functional food. BioMed research international," 2018.
[34] K., Izumori, "Izumoring: A strategy for bioproduction of all hexoses," J. Biotechnol., 2006, 717-22.
[35] W. Mu, W. Zhang, Y. Feng, B. Jiang, L. Zhou, "Recent advances on applications and biotechnological production of D-psicose," Applied Microbiology and Biotechnology, 2012, pp. 1461-7.
[36] K. Fukada, T. Ishii, K. Tanaka, M. Yamaji, Y. Yamaoka, K.I. Kobashi, K. Izumori, "Crystal structure, solubility, and mutarotation of the rare monosaccharide D- psicose," Bulletin of the Chemical Society of Japan, 2010, pp. 1193-7.
[37] M. Hu, M. Li, B. Jiang and T. Zhang, "Bioproduction of D-allulose: Properties, applications, purification, and future perspectives," Compr. Rev. Food Sci. F., 2021, pp. 6012-6026.
[38] W. Zhang, S. Yu, T. Zhang, B. Jiang and W. Mu, "Recent advances in D-allulose: physiological

functionalities, applications, and biological production," Trends Food Sci. Tech., 2016, pp. 127-137.
[39] Anonymous, "D-psikoz'un kimyasal formülü," https://www.sigmaaldrich.com/deepweb/content/dam/sigmaaldrich/structure8/189/mfcd00083478.eps/_jcr_content/renditions/mfcd00083478-medium.png, 2023[b], (Access date: 19.06.2023).
[40] A.Y. Onaolapo, O.J., Onaolapo, and P.U. Nwoha, "Alterations in behaviour, cerebral cortical morphology and cerebral oxidative stress markers following aspartame ingestion," J. Chem. Neuroanat., 2016, pp. 42-56.
[41] T. Lida, T. Yamada, N. Hayashi, K. Okuma, K. Izumori, R. Ishii, T. Matsuo, "Reduction of abdominal fat accumulation in rats by 8-week ingestion of a newly developed sweetener made from high fructose corn syrup," Food Chem. 138: 781–78. 2013.
[42] Y. Nagata, N. Mizuta, A. Kanasaki and K. Tanaka, "Rare sugars, D-allulose, D-tagatose and D-sorbose, differently modulate lipid metabolism in rats," J. Sci. Food Agric., 2018, pp. 2020–2026.
[43] J. Chen, W. Huang, T. Zhang, M. Lu, B. Jiang, "Anti-obesity potential of rare sugar D-psicose by regulating lipid metabolism in rats," Food Funct., 2019,10, pp. 2417-2425.
[44] D.D. Torrico, J. Tam, S. Fuentes, C. Gonzalez Viejo and F.R. Dunshea, "D-tagatose as a sucrose substitute and its effect on the physico-chemical properties and acceptability of strawberry-flavored yogurt," Foods, 2019, pp. 256.
[45] M.M. Moss, E.N. Caswell, A.W. Yeargin, N.A. Volz, J.C. Woodland, L.C. Guthrie, G.C. Ahlborn, D.L. Eggett and B.J. Taylor "Optimization of flour-replacing ingredients for low-carbohydrate, gluten-free muffins via a mixture design with complete sucrose substitution by d-allulose or d-tagatose," LWT, 2022, pp. 113779.
[46] T. Taylor, "Evaluation of the bulk sweetener D-tagatose and the high intensity sweetener Splenda as sugar replacers in cookies," 2006, Auburn University.
[47] M. Shourideh, A. Taslimi, M.H. Azizi, M.A. Mohammadifar and M. Mashayekh, "Effects of D-Tagatose, inulin and stevia as sugar substitutes on the physical, chemical, rheological and sensory properties of dark chocolate," Iranian Journal of Nutrition Sciences & Food Technology, 2010, 29-38.
[48] P. Lee, H. Oh, S.Y. Kim and Y.S. Kim, "Effects of d‐allulose as a sucrose substitute on the physicochemical, textural, and sensorial properties of pound cakes," J. Food Process. Pres., 2020, pp. 14472.
[49] M. Hadipernata, M. Ogawa and S. Hayakawa, "Effect of D-allulose on rheological properties of chicken breast sausage," Poultry Science, 95(9), 2120-2128. (2016).
[50] A.M. Bolger, R.A. Rastall, M.J Oruna-Concha and J. Rodriguez-Garcia, "Effect of D-allulose, in comparison to sucrose and D-fructose, on the physical properties of cupcakes," LWT, 2021, pp. 111989.
[51] S. Sawettanun and M. Ogawa, "Physicochemical parameters, volatile compounds and organoleptic properties of bread prepared with substituted sucrose with rare sugar D‐allulose," Int. J. Food Sci. Tech., 2022, pp. 5931-5942. (2022).
[52] R.P. Aidoo, F. Depypere, E.O. Afoakwa, K. Dewettinck, "Industrial manufacture of sugarfree chocolates-applicability of alternative sweeteners and carbohydrate polymers as raw materials in product development," Trends Food Sci .Technol., 2013, pp. 84-96.
[53] H.J. Kim and M.J. Han, "The fermentation characteristics of soy yogurt with different content of d-allulose and sucrose fermented by lactic acid bacteria from Kimchi," Food Sci. Biotechnol., 2019, 1155-1161.
[54] P. Pocan, E. Ilhan, and M.H. Oztop, "Effect of D‐psicose substitution on gelatin based soft candies: A TD‐NMR study," Magn. Reson. Chem., 2019, pp. 661-673.
[55] Y.J. Son, S.Y. Choi, K.M. Yoo, K.W. Lee, S.M. Lee, I.K. Hwang and S. Kim, "Anti-blooming effect of maltitol and tagatose as sugar substitutes for chocolate making," LWT, 2018, pp. 87-94.
[56] Y. Sun, S. Hayakawa, M. Ogawa and K. Izumori, "Antioxidant properties of custard pudding dessert containing rare hexose, D-psicose," Food Control, 2007, pp. 220-227.
[57] Y. Sun, S. Hayakawa, M. Ogawa, K. Fukada and K. Izumori, "Influence of a rare sugar, D-Psikoz, on the physicochemical and functional properties of an aerated food system containing egg albumen," J. of Agric. Food Chem., 2008, pp. 4789–4796.
[58] S. O'Charoen, S. Hayakawa, Y. Matsumoto and M. Ogawa, "Effect of d‐psicose used as sucrose replacer on the characteristics of meringue," J. Food Sci., 2014, pp. E2463-E2469.
[59] O. Rojo-Poveda, L. Barbosa-Pereira, D. Orden, C. Stévigny, G. Zeppa and M. Bertolino, "Physical properties and consumer evaluation of cocoa bean shell- functionalized biscuits adapted for diabetic consumers by the replacement of sucrose with tagatose," Foods, 2020, pp. 814.
[60] T.P. Taylor, O. Fasina and L.N. Bell, "Physical properties and consumer liking of cookies prepared by replacing sucrose with tagatose," J. Food Sci., 2008, pp. S145-S151.

[61] H. Özhanlı, D.G. Bilgin, C. Mutlu, M. Erbaş, "Nadir bir şeker olan D-allülozun beslenmede kullanım imkanları ve üretim yöntemleri," GIDA, 2021, pp. 925-938
[62] S. Rubio‐Arraez, C. Ferrer, J.V. Capella, M.D. Ortolá and M. L. Castelló, "Development of lemon marmalade formulated with new sweeteners (isomaltulose and tagatose): Effect on antioxidant, rheological and optical properties," J. Food Process Eng., 2017, pp. e12371.
[63] A.M. Patel, S. Hati, B.M. Mehta and K.D. Aparnathi, "Substitution of Sucrose in Lassi by Tagatose as a Sweetener," Intl. J. Ferment. Food., 2021, pp. 25-34 (2021).
[64] M. Rouhi, R. Mohammadi, A.M. Mortazavian, Z. Sarlak, "Combined effects of replacement of sucrose with D-tagatose and addition of different probiotic strains on quality characteristics of chocolate milk," Dairy Sci. & Technol., 2015, 115–133.

