*Dr inż. Katarzyna ŚWIĄDER
Inż. Aleksandra LIPSKA
**Prof. Nadiya BOYKO
*Institute of Human Nutrition Sciences, Warsaw University of Life Sciences – SGGW Warsaw, Poland; Polish Society of Nutritional Sciences, Warsaw, Poland
** Department of Molecular Microbiology and Mucosal Immunology
Uzhhorod National University, Uzhhorod, Ukraine
*Instytut Nauk o Żywieniu Człowieka, Szkoła Główna Gospodarstwa Wiejskiego SGGW Warszawa, Polska; Polskie Towarzystwo Nauk Żywieniowych, Warszawa, Polska
** Katedra Mikrobiologii Molekularnej i Immunologii Śluzówkowej, Użhorodzki Uniwersytet Narodowy, Użhorod, Ukraina

NOVEL SWEETENERS: ISOMALTULOSE, D-TAGATOSE, TREHALOSE AND SUCROMALT – THEIR DESCRIPTION AND PROPERTIES®

Nowe substancje słodzące: izomaltuloza, D-tagatoza, trehaloza i sukromalt – ich opis i właściwości®

Key words: novel food, novel sweeteners, isomaltulose, D-tagatose, trehalose, sucromalt.

The food and pharmaceutical industries are still looking for sweeteners that could be suitable alternatives to sucrose. Substances that will impart a sweet taste but at the same time have a sufficiently low Glycemic Index so that they can be used in products aimed at diabetics, among others. Noteworthy are the new sweeteners classified as novel foods under the Regulation (EU) 2015/2283 of the European Parliament and of the Council on novel foods. These substances include isomaltulose, D-tagatose, trehalose and sucromalt. The objectives of this study were to characterize these substances and discuss their physical and chemical, nutritional and health properties, safety of use, and applicability in products. The discussed new sweeteners are characterized by a lower sweetness in comparison to sucrose, therefore, in order to obtain the same sweetness in products, they should be used in appropriately larger concentrations. However, the new sweeteners do not raise blood glucose levels quickly and cause less insulin secretion than glucose, so they are recommended for use in products aimed at diabetics.

Słowa kluczowe: nowa żywność, nowe substancje słodzące, izomaltuloza, D-tagatoza, trehaloza, sukromalt.

Przemysł spożywczy i farmaceutyczny nadal poszukuje substancji słodzących, które mogłyby być odpowiednią alternatywą dla sacharozy. Substancji, które będą nadawały słodki smak, ale jednocześnie będą miały odpowiednio niski indeks glikemiczny, tak aby mogły znaleźć zastosowanie w produktach skierowanych między innymi do diabetyków. Na uwagę zasługują nowe substancje słodzące, zaliczane do nowej żywności zgodnie z rozporządzeniem Parlamentu Europejskiego i Rady (EU) 2015/2283 w sprawie nowej żywności. Do substancji tych zaliczamy izomaltulozę, D-tagatozę, trehalozę i sukromalt. Celem pracy było dokonanie charakterystyki tych substancji oraz omówienie ich właściwości fizycznych i chemicznych, odżywczych i zdrowotnych, bezpieczeństwa stosowania oraz możliwości aplikacyjnych w produktach. Omówione nowe substancje słodzące charakteryzują się niższą słodyczą w porównaniu do sacharozy, dlatego aby uzyskać w produktach identyczną słodycz należy je zastosować w odpowiednio większych stężeniach. Nowe substancje słodzące nie podnoszą szybko poziomu glukozy we krwi i powodują mniejsze wydzielanie insuliny w porównaniu z glukozą, dlatego rekomendowane jest stosowanie ich w produktach skierowanych dla diabetyków.

INTRODUCTION

Novel food is food or a food ingredient which, until May 1997, was rarely or not at all consumed in the European Union. 1997 was the year in which the first rules on novel foods in the EU came into force in the form of Regulation (EC) No 258/97 [28, 29].

Novel foods are new food sources or foods that are newly developed, innovative, produced with new technologies and production processes and traditionally consumed outside the EU but not within it [12].

Examples of food ingredients or foods categorized as novel foods are agricultural products from third countries, e.g.

Corresponding author- Adres do korespondencji: Katarzyna Świąder, Institute of Human Nutrition Sciences, Warsaw University of Life Sciences – SGGW, Nowoursynowska Sreet 159C, 02-776, Warsaw, Poland, e-mail: katarzyna_swiader@sggw.edu.pl

chia seeds; plant extracts, e.g. rapeseed protein; a new food production process, e.g. subjecting bread, mushrooms or milk to UV light to increase their vitamin D content; new sources of nutrients, e.g.: microalgae oil rich in docosahexaenoic acid (DHA).

On 30 December 2017, Commission Implementing Regulation (EU) 2017/2470 of 20 December 2017 establishing an EU list of novel foods in accordance with Regulation (EU) 2015/2283 of the European Parliament and of the Council on novel foods [5] was published. The list lists all novel ingredients and novel foods authorised for use in the European Union. The type of ingredient is indicated, together with an indication of which products it may be added to and in what quantities. It also lists contra-indications to their use and the information that the manufacturer using them should indicate on the packaging label.

Noteworthy among them are the new sweeteners such as isomaltulose, D-tagatose, trehalose and sucromalt. The aim of the study was to characterize these substances and discuss their physical and chemical properties, nutritional and health properties, safety of use and possible applications in products.

NOVEL SWEETENERS: DESCRIPTION AND PROPERTIES

ISOMALTULOSE (PALATINOSE)

Definition

Isomaltulose, also known as palatinose (6-O-α-D-glucopyranosyl-D-fructofuranose), is an isomer of sucrose that may be a valuable alternative to it (Table 1.) [5]. It is a reducing disaccharide composed of glucose and fructose linked by an α-1,6 glycosidic bond [22]. It occurs naturally in small amounts in honey and sugarcane juice [33]. The Table 1 shows chemical name and formula, as well as formula weight of isomaltulose but also the other new sweeteners.

Physical and chemical properties

Palatinose is a white fine crystalline powder, looks and tastes like sucrose but is half as sweet as it [15]. Sawale and colleagues [31] report that the sweetness intensity of this sugar is in the range of 0.3–0.4 with respect to sucrose considered as 1, while McNutt and Sentko [25] describe that, in a 10% solution, its sweetening power is 50–60% of sucrose. According to Sentko and Willibald-Ettle [32], its sweetening power relative to sucrose is 0.48. In addition, it has no foreign aftertaste, imparts a slight cooling effect and masks the unpleasant odours of intense sweeteners [32] (Table 2). The Table 2 shows calorie value, GI and sweetness of isomaltulose but also all descripted novel sweeteners [26].

Isomaltulose melts at a lower temperature (123-124° C) compared to sucrose (160-185 °C) and is more stable under acidic conditions [22]. It is soluble in water, although its solubility is lower than that of sucrose and increases with increasing temperature, reaching 85% of the yield of sucrose at around 80°C [10].

Manufacturing

Isomaltulose can be obtained from sucrose by enzymatic bioconversion. For industrial purposes, it is produced with the help of bacteria: *Klebsiella singaporensis, Serratia plymuthica* [31], *Erwinia rhapontici, Klebsiella planticola, Pseudomonas mesoacidophila, Protaminobacter rubrum* and *Enterobacter sp.* [42].

Metabolism and absorption

Isomaltulose is metabolized completely in the human body. The digestion process proceeds much slower than that of sucrose, and this is due to the greater durability of the α-1,6 glycosidic bond than that present in sucrose [14, 18, 22]. After ingestion, it is slowly broken down by enzymes (saccharidases), the rate of hydrolysis being 26-45%, compared to sucrose. The hydrolysis products formed, i.e. glucose and fructose, are

Table 1. Description of novel sweeteners

Tabela 1. Opis nowych substancji słodzących

	Isomaltulose	D-Tagatose	Trehalose	Sucromalt
Chemical name	6-O-α-D-glucopyranosyl-D-fructofuranose, monohydrate	D-tagatose	α-D-glucopyranosyl-α-D-glucopyranoside, dihydrate	n.a.
Chemical formula	$C_{12}H_{22}O_{11} \cdot H_2O$	$C_6H_{12}O_6$	$C_{12}H_{22}O_{11} \cdot 2H_2O$ (dihydrate)	n.a.
Formula weight	360,3 (monohydrate)	180,16 (g/mol)	378,33 (dihydrate)	n.a.

Source: Own elaboration based on [5]

Źródło: Opracowanie własne na podstawie [5]

Table 2. Calory value, GI and sweetness of novel sweeteners

Tabela 2. Wartość kaloryczna, indeks glikemiczny i słodycz nowych substancji słodzących

	Isomaltulose	D-Tagatose	Trehalose	Sucromalt
Calory value (kcal/g)	4	3	4	4
GI	32	3	72	53
Sweetness	0.48	0.92	0.48	0.7

Source: Own elaboration based on [3, 5, 8, 11, 13, 14, 17, 21, 31, 32, 37, 39]

Źródło: Opracowanie własne na podstawie [3, 5, 8, 11, 13, 14, 17, 21, 31, 32, 37, 39]

Table 3. The designation of the novel food (sweetener) on the labelling of the foodstuffs containing it

Tabela 3. Oznaczenie nowej żywności (substancji słodzącej) na etykietach zawierających ją środków spożywczych

Isomaltulose*	D-Tagatose*	Trehalose*	Sucromalt*
The designation of the novel food on the labelling of the foodstuffs containing it shall be:			
'Isomaltulose'	'D-Tagatose'	'Trehalose' and shall be displayed on the labelling of the product as such or in the list of ingredients of foodstuffs containing it.	'Sucromalt'
The designation of the novel food on the labelling shall be accompanied by indication that the:			
'Isomaltulose is a source of glucose and fructose'.	D-Tagatose exceeds 15 g per serving and all beverages containing greater than 1 % D-Tagatose 'excessive consumption may produce laxative effects'	'Trehalose is a source of glucose'	product is a source of glucose and fructose
*Specified food category and Maximum levels are not specified			

Source: Own elaboration based on [5]

Źródło: Opracowanie własne na podstawie [5]

absorbed and metabolized identically to those after ingestion of normal sugar. However, due to the slow hydrolysis of palatinose and the slow absorption of glucose into the blood, insulin levels also rise slowly and do not reach the same high levels as after consuming sucrose. The slow carbohydrate absorption is determined by isomaltulose's low glycemic index of 32 [11, 14]. Its caloric value is 4 kcal/g [31] (Table 2).

Nutritional and health value

The European Food Safety Authority (EFSA) considers it as a food ingredient that can regulate postprandial glycaemia. It does not cause aggressive increases in blood sugar and does not contribute to tooth decay [7].

Safety of use and application

Isomaltulose has been used in Japan since 1985 [15]. In the US, it has been recognized as GRAS (Generally Recognized as Safe) by the Food and Drug Administration (FDA) [31]. All claims for isomaltulose were positively reviewed by EFSA in a fourth series of opinions published in April 2011. These claims, address two issues: dental health concerns and glycaemic-reducing effects. Isomaltulose was placed on the market in the European Union in 2005 and was granted the status of Novel Food [4]. It has also been approved as a food in Australia and New Zealand [33]. Currently, isomaltulose is used as a substitute for other sugars and maltodextrins in foods and beverages, including sports drinks, energy drinks, breakfast cereals, cereal bars, dairy products, cakes, toppings, chocolates, jelly beans and chewing gum [31]. Isomaltulose is successfully added to sports drinks up to 7% and in energy and nutritional bars up to 15%. The addition of isomaltulose in chocolates is about 25%, similarly in breakfast cereals (30%), and in energy tablets up to 97% [37]. In Table 3 the designation of the novel sweetener on the labelling of the foodstuffs containing it is presented.

D-TAGATOSE

Definition

D-tagatose is a ketohexose with a similar chemical structure to fructose [6] (Table 1). The only structural difference between tagatose and fructose is the reverse orientation of the hydroxyl group on the fourth carbon [20].

D-tagatose is a simple sugar naturally found in trace amounts in dairy products (sterilised UHT milk, yoghurt and some cheeses) [19, 27, 39] and some fruits [6, 20].

Physical and chemical properties

D-tagatose is a white, odourless, anhydrous crystalline solid [6] with a melting point of 134°C [20]. It is a compound that is well soluble in water, stable at pH 2-7 and exhibits a sweet taste. The sweetness of tagatose is equal to 92% of that of sucrose with a simultaneously lower caloric content. The high sweetness and low calorific value make tagatose attractive as a substitute for sucrose and sugar alcohols used in the food industry as low-calorie sweeteners. In addition, this sugar has a synergistic effect with synthetic sweeteners such as aspartame or acesulfame K, enhancing their sweetness while reducing their bitterness. It enhances mint, lemon, cream and toffee flavours [39] (Table 2).

Manufacturing

Production of tagatose on an industrial scale can be carried out by chemical or enzymatic methods. The chemical method consists in the isomerization of D-galactose to D-tagatose under strongly alkaline conditions by the addition of calcium hydroxide and in the presence of a catalyst. The precipitating complex is neutralized with acid, liberating the tagatose. The insoluble calcium salt formed is removed by filtration and the D-tagatose remaining in solution is concentrated and crystallized. The enzymatic method is carried out by isomerization of D-galactose to D-tagatose using arabinose isomerase, an enzyme found in mesophilic (e.g. *Escherichia coli, Bacillus halodurans*), thermophilic bacteria (e.g. *Geobacillus, Thermoanaerobacter, Thermotoga, Thermus*). The isomerisation reaction requires considerable energy to heat the reaction mixture and the enzymes require the presence of heavy metal ions to maintain high activity and stability [39].

Metabolism and absorption

Tagatose is poorly absorbed in the small intestine. Approximately 75% of this sugar enters the cecum and colon, where it is completely fermented to short-chain fatty acids (SCFAs), which are then absorbed and metabolized [23, 40].

EFSA [8] based on human data showing that the average absorption of D-tagatose is 80% and excretion in urine is 1% or 5%, and that the remaining 20% of D-tagatose that is not absorbed in the small intestine is fermented in the colon, estimated the energy conversion factor for D-tagatose at 3 kcal/g (12,5 kJ/g) (Table 2).

D-tagatose has a very low glycemic index of 3, and many studies in healthy subjects have shown a positive effect after consumption of tagatose compared to glucose [11] (Table 2).

Nutritional and health value

D-tagatose has a low caloric value due to poor absorption in the human small intestine. The advantages of consuming tagatose include the intensification of the development of normal intestinal microflora and safety for diabetics, as it does not cause a sharp rise in blood sugar levels. Additionally, it does not cause diarrhoea, as is the case with excessive consumption of sugar alcohols [39].

Safety of use and application

The labels of products with levels of D-tagatose greater than 15 g per serving and all beverages containing more than 1 % D-tagatose (as consumed) contain the phrase „excessive consumption may have a laxative effect" [5] (Table 3).

In the United States, tagatose has GRAS status under Food and Drug Administration (FDA) regulations, thus allowing its use, as a sweetener in foods and beverages, health foods and dietary supplements [24]. It is approved for use in food in the European Union, Australia, New Zealand, South Africa, Korea and Brazil [1, 36].

The main aim of developing D-tagatose was to use it as a sugar substitute that could be used in products for energy and weight control [8]. D-tagatose is currently used as a low-energy sweetener in soft drinks and yoghurt [8], as well as in the production of low-calorie sweets, beverages, breakfast cereals and jams. Due to its resistance to high temperatures, it can be used for baking, cooking and for sweetening tea or coffee [39].

D-tagatose can be used without any restrictions on the amount [5] (Table 3) but their use is limited by its high production cost [11].

TREHALOSE

Definition

Naturally occurring trehalose consists of two glucose molecules linked by an α-1,1'-O-glycosidic bond [2]. Their chemical name is α-D-glucopyranosyl-α-D-glucopyranoside, dihydrate [5] (Table 1).

Trehalose is widely distributed in nature. It is present in bacteria, fungi, plants and in many invertebrates such as nematodes, crustaceans and insects. Although its biosynthesis in mammals is unknown, significant amounts of trehalase, an enzyme that cleaves trehalose has two glucose molecules, have been found in the human small intestine [2].

Physical and chemical properties

Trehalose is a non-reducing sugar. It occurs as a white odourless, hygroscopic powder. Its sweetness equals 45% of that of sucrose [21]. Korzeniowska-Ginter [17] reports that the sweetness of trehalose is equivalent to 45–50% of that of sucrose while having an identical caloric value 4 kcal/g, and the sweet taste profile shows a rapid onset of sweetness sensation with longer persistence than sucrose. Characteristic features are the clean and balanced sweet taste time profile and the absence of extraneous aftertaste. From the point of view of food technology, it has many advantageous characteristics: it has no reducing properties, is chemically and thermally stable, has good solubility, reduces water activity and lowers the freezing point shows high hydrophilicity and a high glass transition temperature [38] (Table 2). It does not undergo caramelization or non-enzymatic browning. It protects protein and starch substances from retrogradation during drying and freezing – trehalose reduces or even eliminates changes in the hydration layer of proteins, stabilizing them in the case of significant dehydration or increase in product temperature or freezing [34].

Manufacturing

The industrial production of trehalose is carried out by an enzymatic method, where the substrate is inexpensive and easily available maltose syrups. Synthesis Trehalose synthase (maltose α-D-glucosyltransferase – EC 5.4.99.16) is an enzyme that catalyses the isomerization of the α-1,4-glycosidic bond found in maltose to the α-1,1-glycosidic bond characteristic of trehalose. This enzyme is found in some bacteria of the genus *Thermus, Pimelobacter* sp. R48 and *Pseudomonas* sp. F1 [16].

Metabolism and absorption

The metabolism of trehalose is comparable to that of other disaccharides [26]. In the human body, trehalose is digested in the small intestine by the enzyme trehalase, resulting in the formation of two α-D-glucose molecules. Trehalase is an enzyme synthesized in the renal tubular epithelial brush cuticle of the intestine, where it hydrolyses trehalose to two glucose molecules [35].

Nutritional and health value

Trehalose reduces the pH value of dental plaque to a lesser extent than sucrose, which reduces the risk of dental caries. Due to its weaker insulin response, it allows for a longer time of energy availability, resulting in better so-called mental awareness. The aforementioned properties predispose to the use of trehalose in the production of products alleviating stress and fatigue [17]. GI of trehalose is 72 [37] whereas ingestion of trehalose, compared to ingestion of glucose, did not cause a sharp rise in blood glucose levels, and insulin secretion [41] (Table 2).

Safety of use and application

Trehalose was first produced in Japan in 1994 and was approved as a food additive a year later. Since then, it has been used without restriction in hundreds of Japanese products such as confectionery, beverages, processed fruits and vegetables, bakery products and frozen foods. In Japan, Europe and the United States, trehalose is used in the cosmetics industry and in personal care products. In 1991 in the UK trehalose was approved for industrial use as a protectant in freeze-dried foods at concentrations of no more than 5% of the product. As a food ingredient, it was approved for unrestricted use in Korea and Taiwan in 1998 [9]. In the USA, it was Generally Recognized as safe as a food ingredient (GRAS) in 2000,

and in 2001 it achieved the same status in European Union countries. Currently the use of trehalose in the food industry is limited only by Good Manufacturing Practice (GMP). Current global regulations allow the addition of trehalose to food and its daily intake is not restricted to date [30] (Table 3).

SUCROMALT

Definition

Sucromalt is a concentrated aqueous solution of saccharides of different chain lengths obtained by an enzymatic reaction between sucrose and maltose. The final product contains fructose (35–45%), leucrose (7–15%), other mono and disaccharides (<5%) and 40 to 60% oligosaccharides [13].

Physical and chemical properties

The sweetness of sucromalt corresponds to 70% of that of sucrose (Table 2). It is soluble in water, has a clean sweet taste, low hygroscopicity, and is resistant to heat and acidic environments. Sucromalt is a reducing sugar and is involved in Maillard browning reactions [3].

Manufacturing

Suromalt is produced from sucrose and maltose (or high maltose corn syrup). These substrates are treated with an enzyme produced by a strain of *Leuconostoc citreum* bacteria or a recombinant strain of *Bacillus licheniformis* [13]. The resulting oligosaccharides are characterized by the presence of α- (1, 6) and α- (l, 3) glycosidic compounds. The overall product is a syrup, in addition to oligosaccharides, containing mainly fructose, but also the disaccharide leucose and other disaccharides [5].

Metabolism and absorption

When digested, sucromalt breaks down into its primary components, glucose and fructose. Its glycemic index is 53 and its caloric value is equal to 4.0 kcal /g [13] (Table 2).

Safety and use

There are no risks associated with the consumption of sucromalt in humans, and it is well digested by both children and adults. When comparing sports drinks sweetened with sucromalt and those sweetened with sucrose, there were no differences in gastrointestinal discomfort, aftertaste, sweetness, acidity or bitterness. It can be used as a food ingredient in a wide range of foods according to current good manufacturing practices (GMP). This includes: bakery products, beverages, cereal products, dairy products and substitutes, desserts, dessert toppings and fillings, fats and oils, foods for special dietary purposes, fruit juices, jams, jellies and marmalades, miscellaneous, sauces, dips, dressings and condiments, snacks, sugars and confectionery [13] (Table 3).

CONCLUSIONS

Novel sweeteners can provide an alternative to sucrose. Apart from giving a sweet taste to products, they can also have positive effects on human health. The novel sweeteners do not rapidly raise blood glucose levels and cause less insulin secretion than glucose They can be used in a variety of foods, especially those dedicated to diabetics. However, their specific properties must always be taken into account.

WNIOSKI

Nowe substancje słodzące mogą stanowić alternatywę dla sacharozy. Oprócz nadawania słodkiego smaku produktom, mogą one mieć również pozytywny wpływ na zdrowie człowieka. Nowe substancje słodzące nie podnoszą gwałtownie poziomu glukozy we krwi i powodują mniejsze wydzielanie insuliny niż glukoza. Mogą być stosowane w różnych produktach spożywczych, zwłaszcza tych przeznaczonych dla diabetyków. Należy jednak zawsze brać pod uwagę ich specyficzne właściwości.

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