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REVIEW ARTICLE

NATURAL SWEETENERS IN A HUMAN DIET

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ABSTRACT

Sweeteners, both natural and artificial, play an important role in a human diet as well as are of great importance to the food industry and dieticians. Many people associate sweet taste with sucrose, which is commonly known as table sugar. However, there are many sweet substances that food manufacturers add to food products because none of them is ideal for all applications. Besides sucrose there are also other sugars such as glucose and fructose that originate both from natural sources such as fruits and honey or from added sugars. Among sweeteners there are also compounds which have a sweet taste and contain no calories or those which sweetness is so intense so can be used at very low concentrations, thus, their impact on the total caloric value of the product is negligible. They can be classified due to their origin (natural or synthetic agents), the technological function (sweeteners and fillers), texture (powders and syrups), and nutritional value (caloric and non-caloric). Natural sweetening substances include carbohydrates, sugar alcohols, thaumatin and stevia. Besides providing well tasting foods, they might have an impact on products' texture, color, preservation and caloric value. Sugar alcohols, which belong to carbohydrates, are both natural sugar substitutes and food additives. They are becoming more and more popular among consumers mainly due to their lower caloric values and glycemic indexes as well as anticariogenic effects. Sugar alcohols are often combined with other sweeteners to enhance food products' sweetness. Stevia, which is 200 times sweeter than sucrose, is a non caloric substance whereas thaumatin, a sweet protein, provides 4 kcal/g but characterizes with sweetness about 2000 times higher than sucrose (on a weight basis).

Key words*: sweeteners, added sugars, sugar alcohols, stevia, thaumatin*

STRESZCZENIE

Substancje słodzące, zarówno pochodzenia naturalnego jak i syntetycznego odgrywają niezwykle istotną rolę w diecie człowieka, jak również mają duże znaczenie dla przemysłu spożywczego i dietetyków. Wiele osób kojarzy słodki smak z sacharozą, która jest powszechnie znana jako cukier. Jednakże jest wiele róznych substancji słodzących, które producenci dodają do żywnosci gdyż żadna z nich nie jest idealna do wszystkich zastosowań. Do cukrów oprócz sacharozy zaliczamy również glukozę i fruktozę, które pochodzą zarówno z naturalnych źródeł, takich jak owoce czy miód czy też z cukrów dodanych w czasie przetwarzania technologicznego. Wśród substancji słodzących można wyróżnić związki, które mają słodki smak i nie zawierają żadnych kalorii oraz te, których słodycz jest tak intensywna, że mogą być używane w bardzo małych ilościach, a zatem ich udział w całkowitej wartości kalorycznej produktu jest niewielki. Można je również sklasyfikować ze względu na pochodzenie (naturalne lub syntetyczne), funkcję technologiczną (substancje słodzące oraz wypełniacze), postać (proszki i syropy) i wartości odżywcze (kaloryczne i niekaloryczne). Naturalne substancje słodzące obejmują węglowodany, alkohole cukrowe, stewię i taumatynę. Oprócz nadania odpowiednio słodkiego smaku, substancje słodzące mogą wpływać na teksturę, barwę, trwałość i wartość kaloryczną produktów. Alkohole cukrowe, które należą do węglowodanów, są zarówno naturalnymi zamiennikami cukru jak również dodatkami do żywności. Stają sie one coraz bardziej popularne wśród konsumentów, głównie ze względu na ich niższą kaloryczność, indeks glikemiczny oraz korzystne działanie przeciwpróchnicze. Alkohole cukrowe są często stosowane w połączeniu z innymi substancjami słodzącymi celem zwiększenia efektu słodzącego produktów spożywczych. Stevia, która jest 200 razy słodsza od sacharozy, nie dostarcza żadnej energii, podczas gdy taumatyna, słodkie białko, dostarcza 4 kcal/g, ale charakteryzuje się słodkością około 2000 razy wyższą niż sacharoza (w przeliczenie na masę).

Słowa kluczowe*: substancje słodzące, cukry dodane, alkohole cukrowe, stewia, taumatyna*

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INTRODUCTION

The most desirable of all flavors is a sweet taste which affects our senses and often determines the acceptance or rejection of the food product. People are used to associating sweetness with something safe, energizing and strength. Sweeteners are chemical compounds, found in nature and chemically synthesized, which have a sweet taste that determines their usage as sweetening agents. Since thousands of years human diet has included a variety of natural sugars from fruits, berries and honey. However, in the beginning of 20th century sucrose became the main sweetener used by consumers and food industry. Currently, table sugar is produced in almost 120 countries with its global production exceeding 165 million tons a year (80% from sugar cane, the rest from sugar beets) [49]. The biggest sugar cane producer in 2013 was Brazil followed by India and China [18].

However, sweeteners may be used not only to impart the proper taste, but also to influence on consumers' health. Therefore, sweetening agents naturally present or added to food products, are extremely important compounds in the human diet. They can be classified due to their origin (natural or synthetic agents), the technological function (sweeteners and fillers), texture (powders and syrups), and nutritional value (caloric and non-caloric).

One of the major challenges facing humanity is the change in dietary patterns. Nowadays, nearly a billion people suffer from inadequate diet, which is usually high in processed foods, rich in added sugars and solid fats. Such situation contributes to people becoming overweight or obese and is associated with development of non-communicable diseases such as diabetes and coronary heart disease [58]. According to the World Health Organization (WHO), around 12% of adults aged 20 and over were obese in 2008. In Poland, 55.7% of adults were overweight, with an average body mass index (BMI) amounting to 26.7 (males) and 25.9 (females) [20].

Epidemic obesity and diabetes prompted the change in the population lifestyle and increase of consumer awareness of foods they should eat. Thus, they are looking for sugar alternatives that would be a healthy option. Natural sweeteners are generally recognized as safe, yet concern exists about increasing sweetener intakes relative to optimal nutrition and health. Besides sweetening, these substances may influence product color, flavor, texture and preservation.

CARBOHYDRATES

Carbohydrates are the most important and widely recognizable natural sweeteners, which are also a source of simple and quickly digestible energy (nutritive sweeteners). Carbohydrates can be divided into digestible, which are a source of energy, and undigested in the gastrointestinal tract, i.e. some components of dietary fiber. Among the digestible carbohydrates, there can be found complex compounds such as starch and glycogen, and sugars, namely mono- and disaccharides [26, 40]. Carbohydrates also include polyhydric alcohols, also known as polyols or sugar alcohols [26].

Carbohydrates are usually ranked according to their glycemic index, which is simply a number (typically between 1 and 100) that gives a good indication of the speed in which body digests, absorbs and metabolizes foods containing carbohydrates (Table 1).

Carbohydrates can also be classified due to their origin, namely the compounds naturally occurring in foods and those added during the process, which are called added sugars. They are both mono- and disaccharides (sucrose, fructose, glucose, starch hydrolysates, glucose syrup, and high fructose syrup) used as such or added to food during its preparation or processing [26]. However, this term does not include naturally occurring sugars, such as lactose in milk or fructose in fruits. Added sugars are used mainly to ameliorate the sensory characteristics of the product, i.e. to give a sweet taste, or to improve the taste itself or form suitable texture and viscosity of products. Moreover, due to their ability to increase the osmolarity, they may exhibit antibacterial activity [12]. However, despite the fact that added sugars perform functions similar to food additives, they are not classified as them in view of food regulations [45].

SUGARS

Sucrose, glucose and fructose are sugars in the diet that originate both from natural sources such as fruits and honey or from added sugars, mainly sucrose and high fructose corn syrup (HFCS). The sweetness of sucrose, and more specifically its 10% aqueous solution, is taken as equal to one, and this is a reference value used for measuring the sweetening power of alternative sweeteners (Table 1). Fructose has replaced sucrose in many foods and beverages because of its sweetening power, low cost, low glycemic index and ability to enhance the functional properties of a product, i.e. taste, color, and stability.

The common mark for all sugars is not only their caloric values, on average 4 kcal/g on a dry solid basis, but also they share the same intestinal sites for absorption. Disaccharides such as sucrose and lactose require hydrolysis before absorption. The major absorbed end products of food digestion of carbohydrates are monosaccharides, mainly glucose, but also fructose or galactose, and they reach the small intestines predominantly.

Table 1. Characteristics of natural sweeteners [14, 23, 36, 45]

Substance	Chemical formula	E index	Sweetness	Caloric value kcal/g	Glycemic index[b]
Sugars					
Glucose	$C_6H_{12}O_6$	-	0.75		100
Fructose	$C_6H_{12}O_6$	-	1.7		23
Sucrose	$C_{12}H_{22}O_{11}$	-	1	4	65
Maltose	$C_{12}H_{22}O_{11}$	-	0.3		105
Lactose	$C_{12}H_{22}O_{11}$	-	0.15		45
Sugar alcohols					
Erythritol	$C_4H_{10}O_4$	E968	0.6-0.8		0
Isomalt	$C_{12}H_{24}O_{11}$	E953	0.45-0.65		9
Lactitol	$C_{12}H_{24}O_{11}$	E966	0.3-0.4		6
Maltitol	$C_{12}H_{24}O_{11}$	E965	0.9	2.4	35
Mannitol	$C_6H_{14}O_6$	E421	0.5-0.7		0
Sorbitol	$C_6H_{14}O_6$	E420	0.5-0.7		9
Xylitol	$C_5H_{12}O_5$	E967	1.0		13
Other natural sweeteners					
Stevia (Steviol glycoside)	$C_{38}H_{60}O_{18}$ [a] $C_{44}H_{70}O_{23}$ [b]	E960	200	0	0
Thaumatin	Polypeptide (207 amino acids)	E957	2000	4	0

[a] stevioside
[b] rebaudioside A

However, their metabolism differs. The absorption of glucose and galactose is through an active, energy--requiring mechanism mediated by sodium-dependent hexose transporter, known more formally as SGLUT-1. Fructose is not co-transported with sodium but enters the enterocyte by GLUT5 transporter [53]. What is more, fructose metabolism differs significantly from that of glucose as its effect on serum insulin concentration is negligible; therefore, leptin (the satiety hormone) is not activated as well as ghrelin (the hunger-promoting hormone) suppressed [62]. In liver cells, fructose is phosphorylated to fructose-1-phosphate, which can be directly used in lipogenesis. Fructose absorption is limited and with high intakes, there can be malabsorption observed, which can result in abdominal discomfort and diarrhea [52]. There are certain researches which implied that a high-fructose intake can result in adverse metabolic alterations such as an increase in plasma triglycerides, hepatic insulin resistance and hepatic steatosis [3, 29, 35, 52, 53].

SUGARS' CONSUMPTION

Over the past few years there has been a significant increase in sugar consumption, especially sucrose and fructose [32, 46, 57]. Today, a world population consumes approximately 8 million tons of sugar, i.e. 5.1 kg per capital [49]. In 2012, the total sugar consumption in Poland amounted to 42.5 kg per person (GUS), which was significantly higher than the previous year (39.4 kg) [7]. According to *Ostrowska* et al. [39], who researched dietary patterns of students of Medical University in Bialystok between 1997 and 1999, 3.14% of female students and 23.5% of male students were overweight. *Terlikowska* et al. [54] analyzed Polish women diets and stated that they consume daily too much sucrose, i.e. 32 g/day. Similar trends were observed in the United States as well as other European countries where added sugars consumption exceeds the level recommended by the WHO, i.e. 10% of the diet total energy value. On average, Americans consume daily 16 teaspoons of sugar, which is 256 kcal per day in the form of added sugars [12, 16]. *Ervin* and *Ogden* [16], based on studies conducted in the United States in 2005-2010, found that 16% of the children's total energy comes from added sugars. It has been also shown that the consumption of sugar was higher among men (335 kcal/day) than women (239 kcal/day), and accounted for about 13% of the total energy [16]. Furthermore, it was also noted that the number of calories consumed in the form of sugars decreased with the consumer's age [16]. According to *Brisbois* et al. [4] and *Willett* and *Ludwig* [63] adults in Canada, the USA and the UK consume 13-15% of dietary energy in the form of added sugars. Similar dietary patterns were observed among children in Belgium, Cyprus, Estonia, Germany, Ireland, Hungary, Italy, Spain, Sweden and the USA [43, 50, 61]. *Kwasek* [31] stated that only in three countries, i.e. Romania (7.8%), Italy (8.9%) and Greece (9.4%), sugar intake is within proper nutrition recommendations. According to *Bronkowska* et al. [5], who compared diet of Greeks and Polish living in Athens, the latter diets characterized with high amounts of animal fats and proteins, saturated fatty acids and were poor in carbohydrates and fiber.

Moreover, nutrients intake in both populations did not meet the proper nutritional recommendations [5].

According to American data [12] the largest source of added sugars in the diet constitute drinks, i.e. sweetened sodas, sports and energizing drinks (35.7%), followed by grains desserts (13%), sweetened fruit drinks (10%) and dairy desserts (6%). Also different kinds of sweets, bakery products, dairy products and other food products are sources of added sugars in the diet. Therefore, the product's label should have complete nutritional value in order to allow consumers make reasonable food choices. Information concerning sugar content should be a combination of naturally occurring ingredients in the product and those optionally added. Differences in values declared by producers and actually determined in products can lead to overconsumption of sugars what might result in people and especially children addiction to sweet taste which would be difficult to change [57]. *Grembecka* et al. [22] analyzed energy drinks and found discrepancies concerning the total sugar content ranging from 12% to 48% of the value indicated on the package. What is more, they calculated that one glass of an energy drink supplies the body with 7.09% of the total daily energy (2000 kcal), mostly in the form of added sugars such as sucrose or HFCS. Misleading information might also concern the type of sugar used for sweetening purposes, i.e. HFCS instead of sucrose or *vice versa* [22, 60].

NUTRITIONAL RECOMMENDATIONS WITH REGARD TO CARBOHYDRATES

The nutritional requirements for carbohydrates are based on the average minimum amount of glucose that is utilized by the brain [26, 40]. Recommended Dietary Allowance (RDA), which is the average daily dietary intake level sufficient to meet the nutrient requirements of nearly all (97–98 percent) healthy individuals in a group, for dietary digestible carbohydrates amounts up to 130 g/day [13, 26].

Excessive intake of sugar that is being added to an increasing number of food products may result in a much higher caloric diet. American studies show that the energy of a daily diet containing added sugars can increase by an average 35%, which constitutes almost 800 kcal [12]. However, this additional amount of calories does not result in increase of the diet nutritional value, as foods rich in added sugars, are usually low in fiber, minerals and vitamins. Furthermore, digestible carbohydrates, in particular added sugars, are often indirectly related to non-communicable disorders such as overweight and obesity, metabolic syndrome, cardiovascular disease or diabetes [25, 30]. Therefore, it has become important to develop standards regarding the consumption of added sugars. The first recommendation concerned the general restriction of added sugars in the diet. Then, the WHO issued a recommendation that the consumption of added sugars should not exceed 10% of the diet total energy in order to prevent non-communicable diseases, obesity and tooth decay. A similar recommendation was adopted in the United States, the European Union and Poland [26, 38]. In 2009 the American Heart Association, in order to prevent the development of coronary heart disease, recommended that no more than 100 calories a day for women and 150 calories for men can be consumed in the form of added sugars, which is 5% of the total energy [30]. In 2014, the WHO has announced a public consultation on dietary recommendations for added sugars, which supports earlier findings and considers reduction of dietary energy intake by 5% [57].

POLYHYDRIC ALCOHOLS

Polyhydric sugar alcohols (sugar alcohols, polyols) are low digestible carbohydrates which occur naturally in fruits, vegetables, mushrooms and human organism [23, 36, 47]. The most important and most commonly used polyols in food products are sorbitol, xylitol, maltitol, mannitol, erythritol, isomalt and lactitol [23]. They are mainly produced from corresponding sugars by catalytic hydrogenation; however, mannitol can be extracted from seaweed while erythritol is obtained in fermentative processes led by osmophilic yeasts such as *Moniliella pollinis* or *Trichosporonoides megachiliensis* [2, 8, 9, 11, 17, 34]. Polyols' sweetness varies from 25% to 100% as compared with table sugar, thus, they are often used in combination with other sweeteners to achieve the desired flavor and level of sweetness (Table 1). They are used volume-for-volume like sugar and are called bulk sweeteners. Similarly to carbohydrates, they also play role in retaining moisture and texture as well as product preservation. However, contrary to sugars, they prevent browning when heated and add a cooling sensation to products [23].

These compounds have lower nutritional value than the sugars, and supply only 2 kcal/g, due to incomplete digestion in the human organism, usually through fermentative degradation which results in short-chain fatty acids and gases [21].

Sugar alcohols glycemic index is much smaller than sugars (Table 1), thus, they are frequently used to sweeten food products for diabetics. In addition, they can be used as probiotics and anti-caries agents. Anti-caries action results from the fact that sugar alcohols are not fermented by bacteria appearing in the mouth, so that the teeth are not exposed to acid damaging the enamel. Furthermore, maltitol and lactitol were found

to increase mineral bioavailability in human and rats [37, 65].

Unlike sugars, polyols are recognized as food additives which may be used in accordance with good manufacturing practice (GMP) as acceptable daily intake (ADI) was not specified for them. According to the European food regulations, all food additives are identified by an E number (Table 1). In addition, the product label containing such compound should indicate a possible laxative effect due to polyol slower and incomplete metabolism [15, 21, 36].

STEVIA

Stevia rebaudiana Bertoni, which is a shrub of the Asteraceae family originating from the northeast part of Paraguay, is the source of noncaloric sweetening compounds, i.e. steviol glycosides. There are known over 30 different steviol glycosides, but the most commonly known are stevioside and rebaudioside A, which are commercially produced by chemical and physical processes [19, 64]. The latter characterizes with the greatest taste with no bitterness [6]. Stevioside and rebaudioside A constitute about 90% of all sweet glycosides in the leaves of stevia. Steviol glycosides are stable in high temperature, up to 200 °C, thus they can be used in products which are baked or heated. Moreover, they are suitable to sweeten sour food as are stable in acidic and alkaline medium (pH 3-9). Stevia sweetener can be stored for long periods, is not fermentable and does not undergo browning reaction [19]. Parpinello et al. [42] compared stevioside and sucrose as juice sweeteners and found that 34 g/l of the latter can be successfully replaced by stevioside. According to *Palazzo* et al. [41]. Stevia is 200 times sweeter than sucrose. Besides sweetening function, it has been also found that stevioside expresses antimicrobial activity but further research is needed [27, 44, 51]. In clinical studies, stevia glycosides expressed antihyperglycemic, insulinotropic, glucagonostatic and antihypertensive effects [1, 24, 28, 33, 47].

The steviol glycosides are used as intense sweeteners in teas, medicines, food and beverages in many countries such as Japan, China, Russia, Korea, Paraguay, Argentina, Indonesia, Malaysia, Australia, New Zealand and South America [19].

According to JECFA (Food and Agriculture Organization/World Health Organization's Joint Expert Committee on Food Additives) steviol glycosides are safe for human consumption as a non-medical ingredient up to 4 mg/kg b.w./day [48]. They also have been approved by the European Commission in 2011 for use in food and beverages in European countries [10]. Highly purified steviol glycosides were also classified as GRAS (Generally Recognized as Safe) in the USA [59]. Up to date, there is scarce information on stevia extracts allergenicity, and during regulatory reviews the population potential hypersensitivity towards these compounds was dismissed or minimized [59].

THAUMATIN

Thaumatin is a mixture of two proteins (thaumatin I and thaumatin II) that is extracted from the arils of the fruit of *Thaumatococcus daniellii* (Benth). It enhances and modifies flavors, improves mouth feel and also provides natural sweetness. It is soluble in water and heat-stable. Thaumatin has a shelf life of at least 36 months when stored at cool temperature [14].

It characterizes with sweetness about 2000 times higher than sucrose (on a weight basis) and a licorice after-taste. As it is protein, it undergoes the same digestion in the human organism and supplies 4 kcal/g, but due to such high sweetness it is used in extremely small amounts, thus, their caloric values in food is negligible [14, 56].

According to JECFA and EFSA thaumatin is safe for use as a sweetener with no ADI specified, which means it can be used according to GMP. However, in the USA it has not been approved as a sweetener but has a GRAS status as a flavor enhancer [14, 56]. There is no data of thaumatin mutagenic, allergenic or teratogenic effects [56].

SUMMARY

Due to the fact that obesity and diet-related chronic diseases are international health problem, it is recommended to consume small amounts of sugars especially those added during technological processing. Qualitative composition of carbohydrates in the diet is of paramount importance considering differences in fructose and glucose metabolism in the human body. Thus, consumers should pay attention to the label and analyze the composition of food products. However, nutrition surveys show that most adults and children eat more sugars both of natural origin and added than is recommended as part of a healthy balanced diet. This can be changed as sugars can be replaced by other natural sweeteners such as polyols, stevia or thaumatin that provide the taste wanted by many people without adding unnecessary calories. A large amount of added sugars also increases the likelihood of developing tooth decay, whereas sugar alcohols can be used as anticarcinogenic agents which might also help to reduce sugar cravings.

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