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Tagatose: A Low Calorie Multifunctional Sweetener

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Abstract

A sugar called tagatose is one of the next things that will be appearing on the horizon for products labelled under the pseudo-hygienic appellations of "light", "lite", "low calorie", "sugar free", "sugarless", "low fat", "low sodium", etc. The only true hygienic starting point, in this day and age of universal deceit, if we want good foods that are optimum for our health, is: "Start with fruit, grains, nuts, and vegetables simply and wholesomely prepared FROM SCRATCH at home". This review contains a brief study on chemistry of tagatose, how it is produced, applications, limitations and legislations associated with tagatose.

Keywords: *Tagatose, pseudohygiene, sugar free, sugarless*

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INTRODUCTION

The need for low-calorie sweeteners has been evident for many years, but the emphasis has grown recently with the accelerating trend toward obesity in the developed nations. Following the lead of body stylists, consumers equate slimness with health and glamour [1]. Thus, both health and body image drive the market for low-calorie sweeteners. These reduced calorie sweeteners can be categorized into two groups.

The first group consists of noncaloric sweeteners with a very intense sweet taste that are used in small amounts to replace the sweetness of a much larger amount of sugar; for example, acesulfame-K, aspartame, neotame, saccharin, sucralose, etc. The second group comprises of low-caloric sweeteners that can substitute for both the physical bulk and sweetness of sugar including the sugar alcohols (also called "polyols") sorbitol, mannitol, xylitol, isomalt, erythritol, lactitol, maltitol, hydrogenated starch hydrolysates, and hydrogenated glucose syrups and often termed as "sugar replacers" or "bulk sweeteners".

Although two other sweeteners, namely trehalose and tagatose, are actually sugars rather than sugar alcohols yet are similar in function to the polyols. D-Tagatose is patented as a low energy sweetener and bulking agent [2]. Tagatose was originally developed by Spherix Incorporated (formerly Biospherics Inc.) as a low-calorie sugar substitute. The discovery of tagatose has its origin in the quest by its discoverer, Gilbert Levin to identify a low calorie analogue to sucrose.

Biosperics Inc., entered into understanding with Arla Foods (Denmark) to supply technology transfer for tagatose production. It was identified as a component of a gum exudate of the cacao tree (*Sterculia setigera*) and detected as a component of an oligosaccharide in lichens of the *Rocella* species [3, 4]. As a result of these properties, D-tagatose is considered to be a potential reduced-energy sweetener.

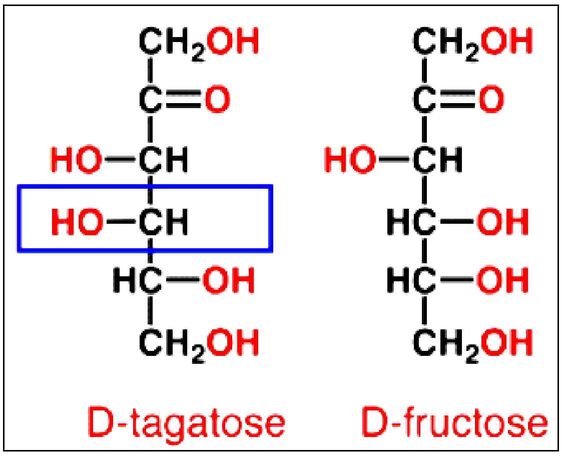

Fig. 1: *Structural Formula for D-tagatose and D-fructose.*

CHEMISTRY

D-tagatose is a ketohexose in which the fourth carbon is chiral and is a mirror image of the respective carbon atom of the common D-sugar, fructose. The CAS number for D-tagatose is 87-81-0 and the empirical formula is $C_6H_{12}O_6$. The molecular weight of D-tagatose is 180.16. The structural formula for D-tagatose is depicted in Figure 1, along with that of D-fructose.

PRODUCTION

Several methods have been studied for D-tagatose production.

Chemical Production

Tagatose can be produced from D-galactose by a chemical method using a calcium catalyst [5]. It uses lactose as the main raw material. Lactose is enzymatically split into glucose and galactose by passing the solution through an immobilized lactase column. The sugar mixture is then fractionated using chromatographic techniques. The galactose fraction is then converted into tagatose under alkaline conditions by adding a suspension of calcium hydroxide and a catalyst. The conversion is alkaline driven—the process is halted by changing to acid conditions. After a purification and crystallization step, tagatose appears as a pure crystalline white product.

Microbial Production

Biological manufactures of D-tagatose have been studied using several microorganisms. *Arthrobacter globiformis* [6], *Gluconobacter oxydans* [7, 8], *Enterobacter agglomerans* [9], and *Klebsiella pneumoniae* [10] have been reported. The responsible enzyme for the biotransformation from galactitol to D-tagatose is a sorbitol dehydrogenase [8]. Various strains of *Mucoraceae* fungi convert D-psicose to D-tagatose [11]. As the mass production of D-psicose from D-fructose has become industrially feasible in recent years [12, 13], the production of D-tagatose from D-fructose via D-psicose as an alternative method can be proposed in spite of the requirement for further intensive investigation. A new process to convert D-galactose to D-tagatose is introduced using lactic acid bacteria [14]. *Enterobacter agglomerans* also produces D-tagatose from D-galactose when grown on an L-arabinose pre-induced medium [15]. The cloned L-arabinose isomerases of *Escherichia coli*, *Bacillus subtilis*, and *Salmonella typhimurium* mediate the conversion of D-tagatose from D-galactose [16]. L-arabinose isomerase has been of interest and studied intensively in recent years due to its industrial feasibility in D-tagatose production [12].

Enzymatic Production

D-tagatose is produced through enzymatic isomerization of D-galactose. Galactose is found in the highest concentrations in lactose. During hydrolysis, equimolar amounts of D-glucose and D-galactose are formed. Lactose hydrolysis can be carried out chemically or enzymatically. The enzymatic hydrolysis can be accomplished under milder circumstances (pH 3.5–8.0 and temperature of 5–60°C). β-galactosidase catalyzes hydrolysis of β-1, 4-D-galactosidic bonds. Possible sources of the enzyme are plants, animal organs, bacteria, yeasts (intracellular enzyme), fungi or molds (extracellular enzyme). The enzymatic properties depend on the source and optimal temperature and pH differ according to the source and particular commercial preparation. A number of bacterial L-arabinose isomerases (araA) were evaluated for their ability to convert D-galactose to D-tagatose. The most efficient enzyme was produced heterologously in *E. coli* and characterized. The arabinose isomerase from *Geobacillus stearothermophilus* was selected as the most appropriate enzyme for converting D-galactose to D-tagatose [17].

PROPERTIES

Many properties of D-tagatose are closer to those of sucrose than that of the other known sugar-substitute candidates. D-tagatose has unique properties as a functional sweetener [18]. It is an isomer of D-galactose, ketohexose; its melting temperature is 134°C and it is 92% as sweet as sucrose when compared in 10% solutions. No cooling effect is found which is a unique property of polyalcohol sugar substitute candidates (i.e., xylitol). The caloric value of D-tagatose for humans is 1.5 kcal/g. Its bulk value is similar to that of sucrose and its humectant properties are similar to those of sorbitol. D-tagatose is less hygroscopic than fructose. Since tagatose is a reducing sugar, it is involved in browning reactions during heat treatment (i.e., cooking processes).

Sweetness
Based on the sweetness equivalence taste test, D-tagatose was determined to be 92% (10/10.8 × 100) as sweet as sucrose in a 10% aqueous solution. This sweetness equivalency taste test was based on difference in threshold methodology [19]. The sweetness level for D-tagatose was determined by means of a linear regression plot of the fraction of times that D-tagatose solutions were chosen as sweeter than 10% sucrose versus the percent D-tagatose concentration.

The point at which judges could not distinguish which solution was sweeter (at 50% probability) resulted in equivalent sweetness of the D-tagatose solution to the 10% sucrose solution.

Flavour Enhancer
D-tagatose shows synergistic effect with aspartame-acesulfame K combinations. Consistent changes in flavor attributes have been observed across all sweetener systems. D-tagatose speeds sweetness onset times, and reduces bitterness in blends. The mouth-feel characteristics are improved, for example, mouth drying is significantly reduced, the sweet aftertaste is significantly reduced, and the bitter aftertaste is reduced. The sensory contribution of tagatose was found to be universally beneficial [20].

Crystal Form
D-tagatose is a white crystalline powder with an appearance very similar to sucrose. The main difference is the crystal form. D-tagatose has a tetragonal bipyramid form which on crystallization from aqueous solution results in anhydrous crystals in α-pyranose form, with a melting point of 134°C–137°C.

In solution, D-tagatose mutarotates and establishes an equilibrium of 71.3% α-pyranose, 18.1% β-pyranose, 2.6% α-furanose, 7.7% β-furanose and 0.3% keto-form [21].

Hygroscopicity
D-tagatose is a nonhygroscopic product similar to sucrose. This means that D-tagatose will not absorb water from its surrounding atmosphere under normal conditions and does not require special storage [22].

Water Activity
Water activity influences product microbial stability and freshness. D-tagatose exerts a greater osmotic pressure and, hence lower water activity than sucrose at equivalent concentrations. The effect on water activity is very similar to fructose (same molecular weight) [19].

Solubility
D-tagatose is very soluble in water and similar to sucrose. This makes it suitable for use in applications where it is substituted for sucrose. The same amounts produce nearly the same sweetness. In comparison with polyols, D-tagatose is more soluble than erythritol (36.7% w/w at 20°C) and less soluble than sorbitol (70.2% w/w at 20°C) [20].

Heat of Solution
D-tagatose has a cooling effect stronger than sucrose and slightly stronger than fructose [22].

HEALTH BENEFITS
A number of health benefits have been attributed to tagatose such as promotion of weight loss [23], no glycemic effect [24, 25], antiplaque, noncarcinogenic, antihalitosis, prebiotic, and antibiofilm properties [26–29], organ transplants [30], improvement of pregnancy and fetal development [1], treatment of obesity [31], reduction in symptoms associated with type 2 diabetes, hyperglycemia, anemia, and hemophilia [1, 24]. *In vitro* studies have also indicated that D-tagatose can inhibit the activity of carbohydrases in the small intestine [24, 32] with a possible further reduction of the energy value of the diet and a depression of the glycemic response [24].

APPLICATIONS
D-tagatose can be used as a low-calorie sweetener (1.5 kcal), as an intermediate for synthesis of other optically active compounds, and as an additive in detergent and pharmaceutical formulation [33]. Besides affecting enhancement of flavor [34], it provides the natural taste and texture of sugar. Since tagatose has been approved by the Generally Recognized as Safe (GRAS) status it can be used in:

- Bakery products [35]
- Milk and diet lemonade [36]
- Toothpaste and mouthwash [37]
- Chocolate [38]
- Tea [39]
- Low fat ice cream [40]
- Carbonated beverages [41]
- Chewing gums [42]
- Ready to eat cereals [43]
- Yoghurt [44]
- Confectioneries [45]

LIMITATIONS

In sensitive individuals, tagatose, when taken in doses higher than 10–15 g per meal may cause mild digestive problems, such as nausea, flatulence and diarrhea. Doses as high as 45 g/day can be well tolerated, though. Tagatose is probably not safe to use by individuals with hereditary fructose intolerance (HFI) since it is metabolized the same way as fructose, but accidental intake of small amounts of tagatose from commercial products is not likely harmful. Tagatose does not affect the absorption of fructose in individuals with fructose malabsorption (FM), though. It slightly increases blood uric acid levels, but there is no evidence that it increases the risk of gout. Tagatose does not likely trigger allergic reaction in individuals with milk allergy [46].

STABILITY

To deliver its prebiotic effect to the consumer, tagatose should experience minimal degradation during processing and storage. Except for two studies, little research has been reported on tagatose stability. Tagatose degradation in unbuffered solutions held at 100ºC for 5 h was negligible, but was enhanced in the presence of an amino acid, presumably via a Maillard-type reaction [47]. Tagatose degradation did occur in buffer solutions stored for 9 month at 20ºC to 40ºC [48].

The rate of tagatose degradation is faster at higher temperatures, higher buffer concentrations, and higher pH values. It is also faster in phosphate buffer than in citrate buffer. Tagatose degradation is accompanied by brown pigment formation and a decrease in solution pH [49].

SAFETY

Tagatose was classified as GRAS by the U.S. Food and Drug Administration (FDA) in 2001 [50]. The FDA permitted maximum levels of tagatose in specific products; for example, 1% in carbonated beverages, 2% in bakery products, 15% in hard candies, and 60% in chewing gum [51]. The World Health Organization’s Joint Expert Committee on Food Additives (JECFA) has left acceptable daily intake for tagatose as “ADI unspecified,” which means even high intakes are not expected to have long-term toxic effects [52].

LEGISLATIONS

In USA tagatose obtained GRAS approval in October 2001. In June 2004, tagatose was approved by the JECFA also with an ADI, not specified. In September 2005, tagatose was approved in Brazil and South Africa as a food ingredient [53]. In December 2005, the energy conversion factor of tagatose was determined as 1.5 kcal/g in South Africa. Also in December 2005, tagatose was approved as a novel food ingredient in the EU [54]. In May 2010, the European parliament amended the definition of “sugars,” defining sugars as all monosaccharides and disaccharides present in food, excluding polyols, isomaltulose and D-tagatose [55].

ANALYSIS

Tagatose is analysed in food systems by a high-performance liquid chromatography (HPLC) with a refractive index detection unit. Also, sylation method for gas chromatography is used for estimating the yield of tagatose by analysing milk. Parrish *et al.* [56] used spectroscopic and HPLC method to quantitate galactose, tagatose, lactose, and lactulose from lactulose syrup.

CONCLUSION

Tagatose can be used in a wide range of product applications. It is either chosen for its health performance in functional and healthy food products or for its unique flavor enhancing effect, enabling good taste properties in diet products, in a cost-efficient way. Finally, tagatose can be used beneficially as a flavour creator in food systems where special toffee, chocolate or malty notes/ flavours are desirable.

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