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REVIEW

ALTERNATIVE NATURAL SWEETENERS AS SUGAR SUBSTITUTES USED IN MAKING ICE CREAM

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Abstract: Ice cream is a frozen dessert highly appreciated by all categories of consumers. Lately, consumers' attention is focused on healthy products, with as few ingredients as possible or with natural ingredients. By definition, ice cream is a sweet product. As a rule, sugar is used to obtain ice cream for its characteristics (sweet taste, creaminess, texture, melting time), but the new requirements require the addition or substitution of sugar with other sweeteners. Consumers still prefer the sweet taste of artificial sweeteners, but they are cultivating their taste and increasingly choosing natural nutritious or non-nutritive sweeteners as consumer awareness of healthy foods has increased. This manuscript was based on the study of the literature regarding the use of natural sweeteners in ice cream formulations.

Keywords: *functional product, health benefits, innovation, low glycemic index, special categories of consumers*

INTRODUCTION

Ice cream is the most popular frozen dessert and one of the most consumed desserts in the world [1]. Ice cream includes all whipped dairy products, products containing dairy or non-dairy fats, water ice and fruit ice. The ingredients used in ice cream formulations are represented by milk or milk substitutes of non-animal origin, sugar or sweeteners, stabilizers, dyes, flavors, inclusions specific to the assortment [2]. The ice cream mixture has its basic structure in the form of an emulsion, with a phase of partially crystalline fat globules, surrounded by an interfacial layer containing proteins and surfactants [3]. The finished product is represented by a complex colloidal system, in which fat plays an important role, and the ice crystals and dispersed air cells are in a continuous viscous serum phase [2]. Historically, milk, cream, and sugar have been the fundamental ingredients of ice cream in its most rudimentary form. The flavored blend, frozen and homogenized, did not need improvement because it had a successful formulation. However, market pressures and economic opportunities have emerged, ice cream needing a change, including in terms of stability, long-term frozen storage, but also the response of a more diverse population interested in more diversified assortments. The demands of the market have generated research focused on the stability of ice cream, probably one of the most complex foods manufactured [4]. Advances in understanding the science of ice cream manufacturing, especially related to understanding the complex structures that must be controlled to create a desirable product for them, have also improved the quality and stability of the finished product. While significant progress has been made, there remain numerous niches for further advancements both scientifically and technologically [5].

Considering the high-calorie ingredients used in traditional ice cream recipes, but also the consumer trends to lead a healthier lifestyle, functional products have been developed that bring health benefits, but also the change of their perception of ice cream consumption, from format, size to new flavors, premium products that imply innovations in the technological process, texture combinations but last but not least a competitive price in the quality-price ratio [6]. Since ice cream is a food product intended for all categories of consumers, products are continuously developed for them, but also for special categories of consumers, thus developing low-carbohydrate or low-calorie ice cream varieties [7]. In terms of flavors and taste, the ice cream trend is heading in two main directions, namely one that brings back the taste of memories of the past and the other is associated with the most daring flavors and exotic combinations. The boldness in terms of flavors also has an upward trend, noticing more and more the fact that innovative combinations are made with spices such as cinnamon (used in a percentage of 2 %), nutmeg, cloves, especially in the Middle East, as well as combinations of chilli pepper or pepper. The concept of metaverse has been used in the exploitation of flavors in ice cream, it has already been tested in several countries such as Spain, USA, where consumers propose new flavors, tastes, logs but also different improvements of their favorite ice cream brands [8].

The most common sweeteners used in the frozen products industry are the following: sugar, dextrose, invert sugar, corn syrup (liquid or dry), maple syrup, honey, brown sugar, malt syrup (liquid or dry), maltose syrup (liquid or dry), lactose, fructose, aspartame, sucralose, glucose syrup. The sensory attribute of sweeteners influences a wide variety of other characteristics, such as freezing point depression, osmotic power,

ice crystal growth, reactivity with primary amines for example, rheology or product malleability [9]. Studies have been conducted, led primarily by economic interests that have explored the substitution of sucrose using ingredients such as invert sugar and cornstarch-based sweeteners [6]. The discovery of sweeteners and interest in carbohydrates sparked an interest in including low-calorie sweeteners such as aspartame and sucralose [1, 8, 10].

ICE CREAM FOR THE USE OF PARTICULAR NUTRITION

Standard ice cream consists on average of 50 % air, 30 % ice, 15 % non-non-greasy dry matter and 5 % fat, other ingredients and food additives, especially stabilizers [11]. Figure 1 present an ice cream classification and an approximate composition (adaptation after Douglas Goff, 2023).

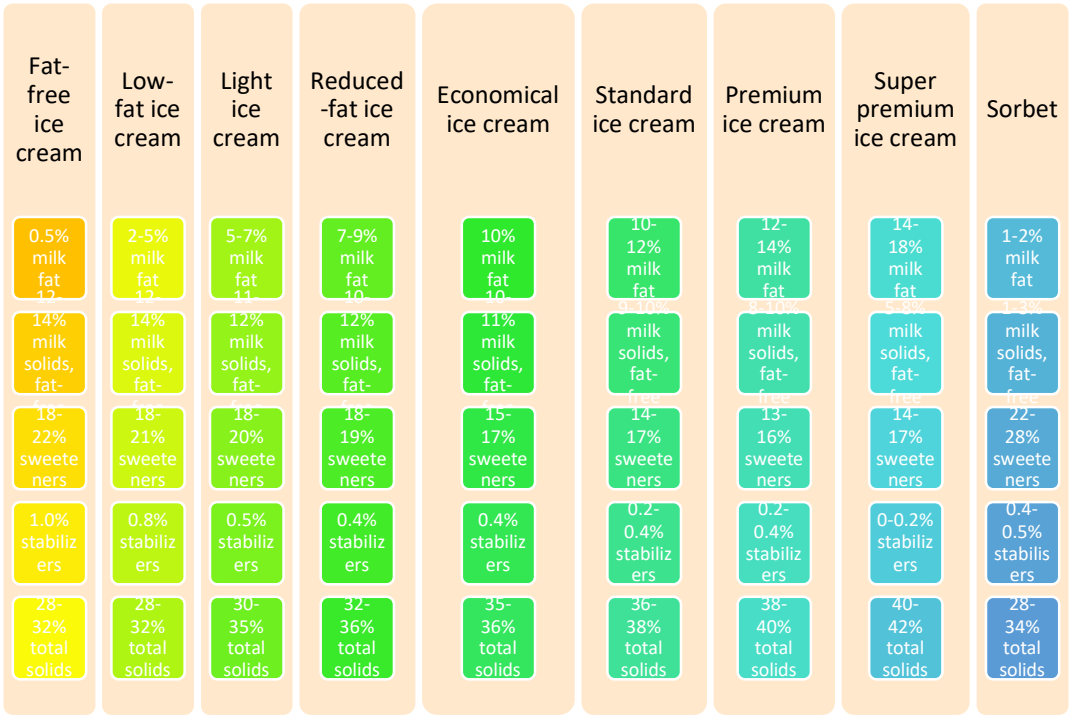

Figure 1. *Ice cream classification (adaptation after Douglas Goff, 2023)*

Because ice cream is the most popular frozen dairy product, it has a high potential to help people improve their diet by reducing their intake of certain nutrients associated with an increased risk of obesity and other associated diseases. In addition, it provides beneficial and essential components for health. However, reducing or removing the usual ingredients in the ice cream or adding unusual ingredients to the standard recipe should not alter the sensory characteristics and storage stability of the ice cream. Therefore, in order to keep the attractiveness of ice cream high, the food industry is subject to constant challenges, as functional ice cream must be tasty and beneficial (Figure 2). Recipe review focuses on maintaining or improving appearance, health benefits, but also maintaining sensory characteristics within high parameters [13].

The advantage of developing a functional ice cream is that it can benefit people of all ages and from all social classes by replacing fats, sugars, but also by using innovative ingredients [13].

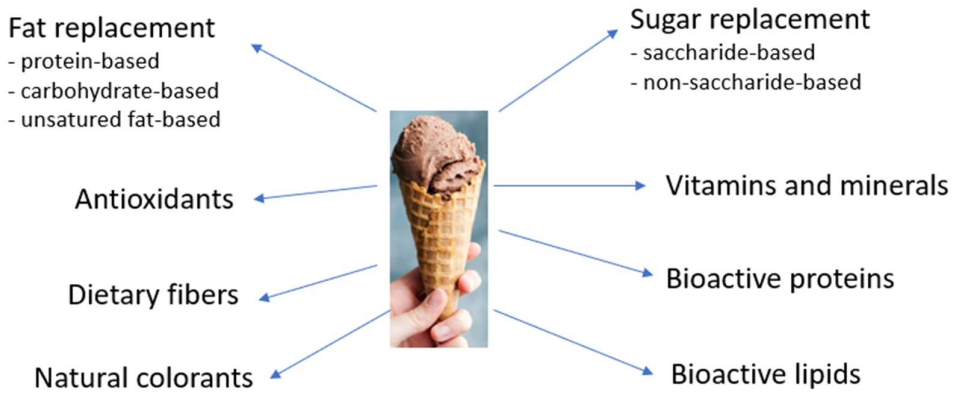

Figure 2. *Functional ice cream*

Hypoglycemic and hypocaloric ice cream

Although functional ice cream can be rich in proteins, fibers, antioxidants, probiotics, etc., its consumption should not replace the basic diet, but should be consumed occasionally as part of a balanced diet [11, 14, 15]. Consumers are increasingly interested in the foods they eat having the same organoleptic characteristics as traditional foods, but with a low-calorie content [13]. The same thing happens with ice cream, which is why researchers have started using various sweeteners both to reduce its caloric value and to improve its functional properties [12, 16, 17]. The sweeteners used in the production of ice cream are: sucrose, glucose, fructose, maltose, lactose, invert sugar, high-fructose corn syrup, high-maltose corn syrup, brown sugar, honey, sugar alcohols (such as sorbitol, maltitol, mannitol, lactitol, and xylitol), and high-intensity sweeteners (aspartame, acesulfame K, saccharin, and stevia) [1, 4, 8, 9, 18, 19]. A sugar alcohol often used as a substitute for sugar in ice cream is erythritol and lactitol, as it provides volume and texture and represents only a fraction of the calories of sucrose (0.2 kcal·g^{-1}) [20]. Cadena and Bolini (2011) found that calorie-reduced ice creams sweetened with sorbitol and sucralose were most accepted compared with other "light" vanilla ice creams or ice cream [21]. Obtaining low-fat and low-sugar ice cream varieties without affecting texture, melting temperature or viscosity is a major challenge worth exploring.

Sugar consumption is known to be associated with a whole range of adverse health effects, including overweight and type II diabetes [20]. In 2015, the World Health Organization issued a guideline recommending reducing sugar intake [22]. In this context, alternative sweeteners have gained interest as sugar substitutes to achieve this goal without losing their sweet taste. Alternative sweeteners such as polyols constitute a diverse group and each substance exhibits one or more metabolic effects [12, 16, 19, 23]. Therefore, no sweetener can be considered inert. In addition, xylitol, erythritol, and D-allulose show promise as alternative sweeteners due to favorable metabolic results. These alternative sweeteners can replicate the benefits of sugars (e.g. sweetness and

release of gastrointestinal hormones), while circumventing the harmful effects of these substances on human health [13].

The structure and sensory properties of ice cream are enriched by the addition of sugar by increasing the taste of sweetness, ice crystals, melt rate and hardness. [5, 14, 24]. On the other hand, sugar is associated with an increased incidence of metabolic disorders such as obesity, diabetes, and cardiovascular disease [13, 19]. Figure 3 exemplifies the main natural sweeteners that can be used in ice cream technology.

Figure 3. *Ice cream with added natural sweeteners*

NATURAL SWEETENERS USED IN ICE CREAM

Fruit (pulp or syrup)

Partially replacing granulated sugar with fruit (pulp/syrup) could help improve the antioxidant activity of ice cream without significantly affecting sensory acceptability. Among the fruits that could be used as substitutes for sucrose, grape pulp has been used to improve the content of phenolic compounds. In particular, different percentages (25 % to 100 %) of Muscat de Hamburg grape pulp and bulking agent enriched with leather matter were used. Enriched ice creams showed higher values with an increase in thixotropicity and orally macro-viscosity, glucose and fructose having a better plasticizing role than sucrose. However, a substitution with sucrose greater than 50 %

negatively affected the sensory characteristics in terms of grainy texture, bitterness and astringency [13].

Concentrated apple syrup

Concentrated apple juice can be used as a sweetener in the production of ice cream due to its high content of vitamins and minerals [25], in order to obtain low-calorie ice cream varieties. Another alternative to replace sugar in ice cream is to use ripe apples or apple peels [26, 27] to obtain a low-calorie ice cream and better nutritional value [25].

Stevia

Among the intensive natural sweeteners, stevia has been considered to replace sucrose to produce an ice cream suitable for diabetics as well. Stevia allows the production of ice cream with a reduced calorie content and a lower glycemic index [4, 7, 10, 13, 28, 29]. Due to the stability of stevia in a wide range of temperatures, it is suitable for use in the process of obtaining ice cream.

Stevia rebaudiana has gained scientific and industrial attention for its wide applications as a natural sweetener in commercial foods, for its nutritional value, and as a potential alternative to sucrose. *Stevia rebaudiana* is a perennial herbaceous plant native to South America, notable for its intensely sweet taste and potential pharmaceutical and medicinal applications. Diterpene glycoside compounds, especially stevioside and rebaudioside, are responsible for the sweetness of stevia. Of the 230 species of stevia plants, *Stevia rebaudiana* and *Stevia phlebophylla* exhibit a sweet taste, to which a high concentration of steviol glycosides (SG) contributes, accounting for 4 - 20 % of the weight of dried stevia leaves. SGs exhibit sweet taste intensity 40 to 450 times higher than sucrose. The amount of SG in the plant varies depending on climatic, environmental, and growing conditions [4, 28]. As previously mentioned, sucrose consumption is controversial due to health concerns related to long-term weight gain, metabolic syndrome induction, and, in the case of saccharin, glucose intolerance and dysbiosis. Therefore, the intensity of SG jam, low calorie content, cardiotonic, anticancer and anti-inflammatory properties of stevia increase its commercial value in the food market. Currently, SG extraction methodologies need to be revised to improve the extraction yields of these biologically active compounds [23, 28]. Ice creams containing stevia and cocoa showed the best of technological performance. In fact, samples with the addition of stevia and cocoa showed the highest overrun and viscosity index. Replacing sucrose with stevia resulted in significantly lower viscosity with higher overshot and melting speed in a dose-dependent manner. Partial, rather than total, replacement of sucrose with stevia improved sensory acceptability. Intensive sweeteners can reduce the calorific value of ice cream by damaging the thermal properties[16, 30]. Adding up to 10 % stevia extract to low-sugar ice cream increased the melting rate. In addition, ice creams with the highest concentration of stevia had the lowest sensory scores in terms of color and appearance, taste and aroma, and overall acceptability descriptors. Stevia has been associated with a bitter taste. Due to their high sweetening power, these types of sweeteners intensively they are added to ice cream in very small quantities [13].

According to the study by Ahmed *et al*., 2023 the addition of stevia to ice cream has a significant impact on its chemical composition, especially on total solids, protein, fat, ash and titratable acidity values, which is in agreement with the study undertaken by

Alizadeh *et al.*, 2014 and Deshmukhan *et al*., 2014 [1, 30, 31]. The presence of stevia reduces total solids value, ash and fat, but increases the protein content, having a positive impact on ice cream by developing the ice cream structure and stabilizing the air interface in ice cream [30]. The positive effects were noticed when stevia was used as a natural sweetener [1, 29, 30]. The addition of stevia does not influence the color of the products, but a high amount leads to bitter aftertastes more persistent than in the case of other natural sweeteners [31]. Stevia acts as a good antioxidant due to its high phenolic and flavonoid contents [28]. The addition of stevia leads to an increase in the viscosity of ice cream as a result of a higher proportion of stevia leaf powder, according to Mayangsari *et al*., 2019 [4].

Date syrup

Dates are rich in essential nutrients (carbohydrates, fiber, proteins, amino acids, fatty acids, vitamins and minerals) [32]. Date pulp and date syrup can be easily incorporated into ice cream mix, making it a potential sugar substitute [29, 33], resulting in an acceptable product in terms of texture, taste, smell, and color [34].

Tammam *et al*., 2014 evaluated the effect of adding date syrup on ice cream characteristics [9]. The titratable acidity increased significantly with the addition of date syrup, while the specific gravity decreased. Also, the viscosity increases proportionally to the addition of date syrup, while the melting speed decreased significantly compared to the control sample. The authors concluded that up to 60 % substitution with date syrup provides a good quality ice cream in terms of sensory and nutritional composition [9]. Arifan *et al*., 2021 showed in their study on replacing sugar with date puree that the overrun value decreases with the increase in the percentage of substitution [35]. A low overrun value indicates a higher content of total solids, which leads to a higher viscosity value, a value that influences the air trapping process in ice cream. Also, a low overrun value limits the mobility of water molecules due to the limited space between particles, which prevents air from entering the ice cream composition during the stirring process. On the other hand, replacing sugar with date puree leads to an increase in melting rates. The high content of total solids leads to a low content of water content, so the ice crystals formed are smaller, which translates into more resistant to melting. The final quality of ice cream is measured by its viscosity, as this value can influence the smoothness, consistency, and final texture. The addition of date puree leads to an increase in the value of viscosity [35]. Mansour *et al*., 2021 founded that the addition of date to ice cream formulations led to an increase in the viscosity and melting resistance due to the high- fiber content in date and a decrease of overrun, date fiber powder can replace the fat in ice cream to achieve characteristics relatively similar to those in full-fat ice cream [32]. Hamad *et al*., 2017 used in their study a date substitution between 0 - 25 %, with an optimal 15 % substitution, which led to the best results for appearance, color, smell and texture [36]. The addition of date fibers has an effect on the mineral content of ice cream, so K, Mg and Zn recorded higher values, while Ca and P recorded lower values in ice cream samples [37, 38]. The total substitution of sugar with date syrup leads to a decrease in the *p*H and an increase in the acidity of the ice cream [39]. In the study undertaken by Salem, 2017 it was concluded that the substitution of 5 % dates molasses is the best option in terms of public acceptance for camel milk ice cream [40].

Maple syrup

Maple syrup is comparable to sucrose in terms of health and nutritional benefits, each sweetener used in ice cream contributes to a different intensity of sweet taste [41, 42]. The addition of maple syrup had the following effects on the ice cream: the sweet taste desired by consumers was preserved, a creamy ice cream was obtained, very smooth in texture, but the total solid mass increased. Another consequence of substituting sugar with maple syrup is a decrease in the freezing point [43]. Studies have shown that maple syrup consumption produced significantly lower peak and global responses of glucose, insulin, amylin and gastric inhibitory polypeptide (GIP) as compared to brown rice syrup, corn syrup and pure dextrose. Maple syrup is a healthy alternative to refined sugar due to its composition and metabolic response to insulin. [44].

Agave syrup

In order to obtain agave syrups (agave syrup, agave honey or agave nectar) [45], agave plants that have grown for at least 6 years before harvesting are used, has 90 % fructose content and lower glucose levels [44]. The sweetening power is relatively more than honey, corn syrup or sugarcane syrup, it has a low glycemic index (13 - 27) [45], but also antioxidant and antibacterial properties, and contains slow-release carbohydrates with a high prebiotic capacity [23, 45]. Agave syrup is sweeter than sucrose and darker than honey [46], agave fructans may be used to replace fat. The use of agave syrup in low-fat ice cream improves sensory and textural properties. In the study undertaken by Jardines *et al*., 2020 low concentrations of agave added to ice cream led to the growth of ice crystals, with unwanted hardness and texture. Higher concentrations of agave in ice cream helped achieve ice cream with longer melting time, creamy with a greasy feel [47]. Pintor-Jardines *et al*., 2018 revealed that the addition of agave improved the melting properties of the ice cream, reducing the number of ice crystals and free water in the ice cream compared to the control samples [48]. Agave syrup is worth paying attention to in terms of its use in ice cream for its status as a vegan product, a quality that cannot be attributed to honey [19].

Yacon syrup

Yacon syrup is mainly composed of fructooligosaccharides and inulin (about 60 % of the dry mass), coming from the processing of the perennial plant of the species *Smallanthus sanchifolius*. Yacon syrup contains phenolic acids known for their human health benefits. Due to its low calorie content, this natural sweetener can be used for diabetic nutrition [23].

Brown rice syrup

Brown rice syrup is used as the healthier version of high-fructose corn syrup [49], is rich in complex carbohydrates (22 % polysaccharides and 21 % oligosaccharides [44] and it is a cheaper sweetener [50].

Acacia and linden honey

Honey can be used in ice cream recipes as a sugar substitute, flavoring, and supplement [16, 51, 52]. Honey-containing ice cream mix revealed a significantly lower value of soluble solids (30.4 °Bx vs. 34.5 °Bx) and apparent viscosity (36.5 mPa·s vs. 47.6 mPa·s) and a significantly higher extrusion time (8.18 min vs. 7.04 min). The

firmness of honey ice cream decreases proportionally with the honey addition [53]. Rahim & Sarbon, 2019 used in their study a concentration between 0 - 15 % honey used as a natural sweetener, resulting in products with an improved texture, but also with positively influenced sweetness and sourness. Compared to the addition of stevia, the addition of honey does not influence the overrun, and the value for hardness is lower. Also, the values for *p*H and moisture decrease with the increase of the addition of honey [51].

Coconut sugar

Coconut sugar is a product derived from coconut, with a low glycemic index (35 ± 4), which makes it suitable for incorporation into ice cream intended for diabetics or people who want to be careful with their weight [54]. The speed at which carbohydrates are converted into glucose is the glycemic index, for a speed below 55 it is considered a low glycemic index, a speed between 56 and 69 is considered a medium glycemic index, and a speed above 70 indicates a high glycemic index [45]. Coconut sugar is a healthy alternative because it has a low glycemic index, contains iron, magnesium, zinc, vitamins B1, B2, B3 and B6, is gluten-free, has a caramel smell and a light brown color. The addition of coconut sugar in ice cream can disrupt the foaming capacity and lead to a slight reduction in overrun compared to the control sample. Products derived from coconut can lead to a premium category ice cream, both in the case of dairy based ice cream and in the case of milk-free ice cream. The improved aspects were appearance, taste, aroma, phenolic compound content and mineral element content. The negative aspects were related to the overrun and the total amount of solids [55].

Palm sugar

Palm sugar is a natural sweetener obtained from the sap of flowers of different species, used mainly due to the fact that it can be stored for a longer period of time, the content of potassium, sodium and iron, the vitamins C, D and E contained, but also due to the total polyphenolic content [23].

Mesquite powder

Mesquite powder is a sweetener that can replace sugar, resulting in products with good seasonal qualities [56], mesquite (*Prosopis* spp.) is a legume plant that grows in Asia, Africa, and Latin America [57, 58]. The softer flavor of cinnamon mesquite powder, but also the high sucrose content make it suitable for use in ice cream recipes [59]. Guilherme *et al*., 2009 used in their study a honey-like syrup from mesquite pods (*Prosopis juliflora*) and cashew (*Anacardium occidentale*) apple juice with superior nutritional quality than honeys regarding their mineral contents [56].

Egyptian Jallab

Egyptian Jallab is considered an unrefined sugar or a non-centrifugal form of sugar, obtained from sugar cane juice with a high sugar content, dietary fibers, antioxidant and minerals. Jallab is used both as a functional food or food ingredient and as a natural sweetener, increasing the nutritional value of the finished products. The addition of jallab in ice cream recipes significantly increased the total solids content and protein content, which influences emulsification, whipping and water-holding capacity. On the other hand, the addition of jallab improves the melting quality of ice cream and

increases viscosity, the total solid content and the polyphenol content [60]. It can also be found under the generic name of jaggery, meaning syrup obtained by concentrating juice (sugar cane, sweet sorghum, date or coconut-palm). It is considered one of the traditional sweeteners, being an alternative to refined sugar and is found in solid or semi-liquid form [61].

Monk fruit extract

Monk fruit, commonly called as Luo Han Guo [62] or "Lo Han Kuo" [63] is a fruit of a perennial vine (*Siraitia grosvenorii*) with mogrosides as major sweetening compound (which is a terpene glycosides) [64], 250 - 400 times sweeter than sucrose and low calorific value than sucrose. Mogroside V is the major component of monk fruit, is more sweeter than sucrose, so many compounds of this fruit are much sweeter than sugar, but contain no calories [63]. Due to its low glycemic index, monk fruit extract can be safely used in the diet of people suffering from diabetes [6], being declared a low-calorie sweetener [62, 65]. Monk fruit extract can be used as a supplement for functional food development due to mogrosides and polysaccharides that have been shown to have hypoglycemic effects on fasting and postprandial blood glucose in diabetes [65]. It is considered a non-nutritive sweetening and flavor enhancing purpose and has been approved in the USA 20 year 2010 as a safe natural sweetening agent [62] according to the Food and Drug Administration (FDA). The taste of sweetness was felt when the use of monk fruits was limited to 25 %, values above this percentage highlight bitter and metallic aftertastes [19].

CONCLUSION

The amount of sugar can be increased or decreased depending on the destination of the products (ice cream for diabetics or other special categories of consumers). The choice of sweeteners used must be made carefully because their impact on consumer acceptance is high, influencing texture, viscosity and freezing point. This addition of natural sweeteners must preserve the quality characteristics of the ice cream or improve them, too high quantities can alter the taste or remain unpleasant residual tastes, while a low amount of sweeteners can affect the melting speed or rheological properties of the finished products.

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