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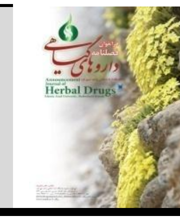

Effect of Sucrose Replacement by Stevia as a Non-Nutritive Sweetener and Bulking Compounds on Physiochemical Properties of Foodstuffs

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ABSTRACT

Background & Aim: Changes in lifestyle, decrease in physical exercise along with incidence of obesity, hypertension and cardiovascular diseases indicate a need for low calorie formulations. The sweetness of Stevia, a natural sweetener, is estimated to be 300 times as much as that of sugar. Extraction of stevia leaves is considered a promoter of calorie balance and a beneficial part of a healthy diet. Stevia is also used to treat diabetes, obesity, tooth decay, hypertension, exhaustion and depression.

Experimental: Regarding the aforementioned applications and critical role of sucrose in the creation of texture, color and taste, the replacement of sucrose is an important issue. Most researches indicate the fact that sugar-free products are not pleasant and acceptable; thus, the presence of sugar is inevitable i.e. in case of complete substitution, concurrent consumption of both sugar and stevia (different combinations) seemingly gives it more flavors and makes it the most demanded product. This article reviews effective parameters in sucrose substitution with stevia and the results obtained from it.

Industrial and practical recommendations: Its bitter aftertaste can diminish its consumption in food formulation; however, other flavoring agents and fillers can modify this problem. With regard to its high sweetness (300 times as much as sucrose), its consumption is low and thus it is economically justifiable. Using this sweetener in daily industries, fruit juices and confectioneries as a sucrose substitute is possible with respect to the research findings.

1. Introduction

Nowadays, changes in lifestyle, reduction of physical education and exercise, and incidence of diseases such as obesity and cardiovascular problems are all factors in obligation of production low calorie foods and decrease of sucrose consumption due to incidence of diabetes and its undesirable effects on the body (Glicksman and Farkas, 1966). Since obesity is a complicated disorder with both environmental and genetic reasons, its incidence due to quick changes in lifestyle and increase of fatty foods consumption has increasingly grown in the Middle Eastern countries, and recently, it is considered a prevalent reason for mortality. In Iran, incidence of obesity in children and teenagers is 8.8% and 4.5%, respectively (Farokhzad and Bagheri, 2004). Overall, using nonnutritive sweeteners as a possible solution to the prohibition of obesity has widely been taken into consideration by researchers.

1.1. Stevia

Stevia, which refers to all products from *Stevia rebaudiana* (Carakostas *et al*., 2008), is a natural sweetener practically used in pharmaceutical industries (Mogra and Dashora, 2009; Ahmed *et al*., 2011). Stevioside was first extracted by Bertoni, and after that by a French chemist (Ahmed *et al*., 2011; Jaroslov *et al*., 2007). Stevia sweetness is estimated to be 300 times as much as that of sugar cane (Ghosh *et al*., 2008; Koyama *et al*., 2003; Laribi *et al*., 2012). Stevia is native to Brazil and Paraguay (named Paraguay sweet plant). The most abundant varieties include *Stevia eupatoria*, *Stevia ovate*, *Stevia plummerae*, *Stevia rebaudiana*, *Stevia salicifolia*, and *Stevia serrata* (Curry and Roberts, 2008). Stevia is diploid with 11 paired chromosomes (Brandle *et al*., 1998). Studies have shown that stevia can be a replacement for some/all sugar sources with acceptable physical and eventual properties but no remarkable side effects (Madan *et al*., 2012). So far, 9 diterpenic glycoside compounds have been identified in *Stevia rebaudiana* structure with a common skillet (figure 1) (Reddy *et al*., 2005). These compounds compose 5-10% of dried leaves and heat-sensitive; besides, they are 200-300 times as sweet as sugar beet (Ahmed *et al*., 2011). This partial sweetness arises from diterpen glycosides, which seem to occur due to the difference in remained carbohydrates in carbons number 13 and 19, common in hardness of aglicon steviol. A new method of extraction and refinery of these compounds and their pharmacokinetical investigation has been reported by Chatsudthipon and Muanprasate (Thomas and Glade, 2010). Most processes are accompanied by using organic solvents and coagulators, in some cases, chromatography or chelating agents along with extracting solvents have also been used. However, all previously mentioned processes have complicated processes, which need modifications in order to lessen the use of chemicals, extra steam, color and flavor. Direct effect of stevioside (low concentration) in transferring Glucose in skeletal organs was investigated and the results revealed that insulin activities improve (Ahmed *et al*., 2011) and thus it can be concluded that stevia extract is considered a beneficial part of healthy lifestyles in diet (Thomas *et al*., 2010). Stevia is used to cure diabetes, obesity, tooth decay, hypertension, exhaustion and depression (Mogra and Dashora, 2009; Ghosh *et al*., 2008; Goyal and Goyal, 2010). Stevioside and Rebadioside A, polyphenolic compounds of stevia extract, are non-decay e.g. sucrose solution causes tooth decay in rat's infants while no decay has been observed in stevioside consumption. Stevioside also has inhibited S. Mutans, the main organism of tooth decay, along with low acid secretion condition (Thomas and Glade, 2010); besides, it has been recommended as an inhibitor of microorganisms' growth in the mouth (Fatemi, 2007). Table 1 depicts researches on sucrose replaced with Stevia as a non-nutritive sweetener in various products.

1.2. Investigation of sucrose replacement with stevia on color and microstructural properties of food products

Regarding the key role of sucrose in creation of color in browning processes, three color indexes including L* ،a*, and b* were used to investigate products' color where L* is brightness ranges from 0(darkness)-100(light reflection). Positive amounts of a* refer to red and its negative amounts to green; moreover, positive amounts of b* are related to yellow and negative amounts to blue (Ghandehari Yazdi *et al*., 2013). Substitution of sucrose with Stevioside in biscuits significantly brightens treatments in two levels of %50 and %100 replacement (Vatankhah *et al*., 2014). Besides, results obtained from the presence of stevioside-maltodextrin in 4 levels of substitution including %25, %50, %75 and %100 showed that samples became brighter so that the least amount of browning index was related to treatment including %100 stevioside-maltodextrin (Omidvar *et al*., 2014). Brightness arose from substitution also have found in apple jam where Stevioside-Arabic Gum caused an increase in L* and a decrease in a* (Ghandehari yazdi *et al*., 2014a), while in mango jam, the presence of stevioside led to an increase in L*, b*, and C* with no change in a* (Basu *et al*., 2013); moreover, in another study on mango jam containing %50 sucrose, %0.27stevioside during 20 days of storing, the amount of L* and b* has been constant while a* has significantly decreased (Yoosefi Asl *et al*., 2012). Reduction of color by stevioside-sorbitol in cake and stevioside-xylitol in combined gel of rice flour and chitosan has been reported as well (Manisha *et al*., 2012; Torres *et al*., 2013). Brightening surface due to sucrose replacing by stevioside and thus increase of L* and b* and decrease of b* have been reported in Naneghandi (an Iranian bread) (Vatankhah *et al*., 2013). Unlike reviewed results from literature, increase in malt beverage color due to steviosde-CMC as a sucrose replacer has been observed (Nasiri *et al*., 2013). Reduction of L* ،a* and b* has been reported in sucrose substitution with a mixture of stevioside-bulky agents in chocolate (Shah *et al*., 2010). Sucrose replacement with stevioside-tragacanth on Ghotab caused an increase in color intensity (Ghandehari Yazdi *et al*., 2014b). Observed differences in the obtained results arose from using different bulky agents such as alcoholic sugars, digestible compounds like poly dextrose and indigestible compounds like cellulose (Bullock *et al*., 1992) in the presence of maltodextrin due to its high molecular weight with outer reducing groups, Millard, Caramelization and browning reaction occur less._Therefore, its consumption with dietary sweetener reduces color (Ghandehari Yazdi *et al*., 2013). Color intensity increased by using tragacanth associated with stevioside because of galactronic acid as its main chain and presence of some pentose like fructose, pyranose, Galactose, Xylose, L Arabinose. Former sugars participate in caramelization and Millard and increase the browning index. On the other hand, increase in tragacanth amount accelerates water binding; thus, during frying time, more water is lost, water activity is reduced; and consequently, dry solid increases leading to an increase in caramelization (Ghandehari Yazdi *et al*., 2014b). Microstructure of sucrose-replaced products has been investigated in some studies; e.g. study on microstructure of Ghotab showed an increase in roundness amount and number of holes (Ghandehari Yazdi *et al*., 2014c); however, in the same study on sucrose replaced by stevioside-tragacanth, the obtained results were the opposite. This is thought to be because of the type of filler. Microstructure study on mango jam showed that produced pectin gel from sucrose was well distributed and had a homogenous structure while substitution creates a non-homogenous with thick matrix. In fact, sucrose molecule can place among the matrix gaps i.e. sucrose itself has no role in gel production but its chemical structure affects the size of produced matrix while bigger sizes of stevioside molecules lead to a non-homogenous structure (Basu *et al*., 2013).

1.3. Investigation of sucrose replacement with stevia on physiochemical and rheological properties of food products

Due to its high amount of proteins and thus high water-holding capacity, Stevia can make soups, pastes, and bakery products swell. Oil absorption capacity is related to entrapment of oil into the matrix, and stevia leaves powder shows appropriate oil absorption (Lemus-Monadca *et al*., 2012). Stevia extracts have the capability of heat resistance more than 200°C, and high resistance in 100°C for 1 hour as well (Kroyer *et al*., 2010). Unlike alcoholic sugar, stevia's sugars are heat resistance with the capability of keeping their sweetening property; thus, stevia can be a suitable replacer for sugar in formulations (Jaroslov *et al*., 2007; Carino *et al*., 2006), and it is stable in pH=3-9 (Brandle *et al*., 1998). In substitution of sucrose with stevia-inulin in milk chocolate, viscosity decreased while increase in inulin caused an increase in viscosity so that in treatment containing %6 inulin and % 100 substitutions, no significant differences were observed in comparison to control (Rad *et al*, 2012). In another study on chocolate sucrose replaced with a mixture of stevia, maltodextrin and polydextrose, physical factors including hardness, melting point and rheological properties in prepared treatment with different inulin polymerization degree including HP (DPav ≥23, long chain inulin), HPX (DPav ≥ 23, longchain inulin with low solubility) and GR (DPav ≥10) were investigated. Obtained results revealed that hardness of HPX remarkably decreased, no significant difference was found in melting point of HP, and the amount of viscosity in HP treatment was more than others. The best model in describing data was Herschel Bulkey model (Shah *et al*., 2010). Shorideh *et al*. (2013) produced a low calorie dark chocolate with functional properties from a mixture of stevia-inulin-tagatose. In sucrose replaced with stevia milk shake (mixture of kiwi, banana and apple), there was no effect on the amount of acidity, vitamin C and pH, while it affected the amount of total soluble solid (Alizadeh *et al*., 2014a). Stevia also has no effect on the amount of ash, fat, protein, density, apparent viscosity, while it increases water activity because sucrose replacement reduces hydrogen bonds, and thus free water increases thickness, pH and moisture amount along with spread ability and diameter (Vatankhah *et al*, 2013a). Results obtained from Texture analyzer indicate an increase in flexibility and a decrease in hardness.

Table 1. Replacing of saccharose by Stevia as non-nutritive sweetener in food products.

Product	Percent replacement	Additional compound	Reference
Halva masghati lari (an Iranian confectionary)	50%	Maltodextin	(Omidvar *et al*., 2014)
Saffron beverage	25%	-	(Hashemi *et al*., 2014)
Mango jam	25%	Sucrlose	(Basu *et al*., 2013)
Ice Cream	4.65 gr Stevia, 13.95 gr Sucrose in the formulations	-	(Alizadeh *et al*., 2014b)
Apple jam	100%	Arabic gum	(Ghandehari Yazdi *et al*., 2014)
NanGhandi (an Iranian bread)	50%	-	(Vatankhah *et al*., 2013a)
Fruit based Milk shake	100%	-	(Alizadeh *et al*., 2014a)
Quince jam	50%(0.27% in the Formulations)	Pectin	(Yousefi Asl *et al*., 2012a)
Malt beverages	25-50%	CMC gum	(Nasiri *et al*., 2013)
Choclate	-	inulin or polydextrose	(Shah *et al*., 2010)
Ghotab(an Iranian confectionary)	100%	Tragacanth Gum	(Ghandehari Yazdi *et al*., 2014b)
Biscuit	50%	-	(Vatankhah et al., 2014)
Products powder	0.05% in the Formulations	Sucralose	(Shokouhi, 2013)
Orange beverage	75%	-	(Ajeli *et al*., 2014)
Cream	-	Flavors(Vanilla, Cocoa, Saffron)	(Bagheri *et al*., 2013)
Cake	0/4% weight of flour	Isomalt	(Hematian Soraki and Rahimi Ahmadabad, 2013)

Omidvar *et al*. (2014) found that in sucrose replacement with stevioside in Halva Masghati, hardness and stickiness increased while cohesiveness, gumminess and brittleness decreased. Additionally, substitution of sucrose in cream revealed that texture integrity and acidity increase but synersis decreased (Bagheri *et al*., 2013). In the case of sucrose replacing by stevia-CMC in malt beverage, it has no effect on the amount of pH despite increase in ash, BX, total solid and density and increase in viscosity (Nasiri *et al*., 2013). Replacing of sucrose with steviosided-sucralose in mango jam indicates that the amount of consistency coefficient and yield stress has decreased but flow index has increased (Basu *et al*., 2103). Consistency coefficient and decrease in yield stress was also found in sugar replaced with stevioside-Arabic Gum in apple jam; however, the amount increased when the Gum increased. Additionally, it is thought that replacement due to reduction of sugar amount and lack of free water inhibition, and obtaining a softened pectin structure led to a decrease in hardness (Ghandehari Yazdi *et al*., 2014a). Sucrose substitution in ice cream caused an increase in volume, a decrease in viscosity and BX (Alizadeh *et al*., 2014b). Reduction of hardness was also observed in replacing sucrose with stevioside-tragacanth treatment in Dietary Ghotab (Ghandehari Yazdi *et al*, 2014b). Stevioside affects chemical properties of food e.g. stevia extraction due to the presence of compounds called Rebadiana and steviolbioside (Wheeler *et al*., 2008), and flavonoids, Alcaloids, xantophyls, hydroxyl cinamic acid as well (De Oliveira *et al*., 2008; Delshadian *et al*., 2012) have antioxidant activity.

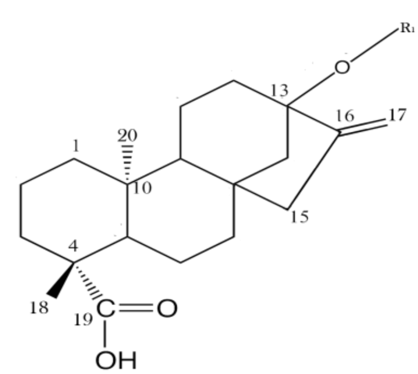

Fig. 1. Stevia structure (Reddy *et al*., 2005)

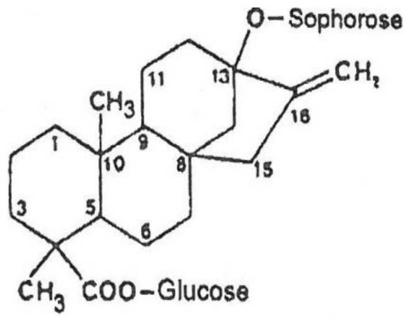

Fig. 2. Stevioside structure (Keramat, 2008)

Investigation of peroxide index in biscuit revealed an inverse relationship between peroxide index and stevia concentration (Hamzeloei *et al*., 2008). These results are in agreement with those obtained in peroxide value in stevia replaced treatments of cocoa milk (Delshadian *et al*., 2012).

1.4. Investigation of sensorial properties of food products

Due to its association with some essential oils like tanans and flavenoides, and recently considering the presence of stevioside or rebadioside A (with less effect than stevioside) (Mogra & Dashora, 2009), Stevia extract creates a bitter aftertaste (Keramat, 2008). Since flavor is a paramount issue in consumer acceptability, researches focus on investigation of substitution effects on the occurrence of possible aftertastes e.g. observation of significantly bitter taste in Halva Masghati samples containing %50 replacement (Omidvar *et al*., 2014). In addition, results obtained from substitution in Gel powers (Shokouhi Torghi, 2013), dietary cream (Bagheri *et al*, 2013), apple jam (Ghandehari Yazdi *et al*, 2013a), and cake (Hematian Soraki *et al*, 2013) were in agreement with the latter. Using flavoring agents or powdery fillers is a way of detracting or removing aftertaste (Hematian soraki *et al*, 2013; Bagheri *et al*, 2013).

1.5. Investigation of stevioside on the calorie of food products

While sucrose and other conventional sweeteners are easily absorbed, participate in metabolism, and thus increase body weight, researches have shown that stevia extract with 2.7 kcal/g, barely contributes to body metabolism, and plays a role in the reduction of intake energy (Lemus-Mondaca *et al*., 2012). In fact, this calorie reduction arises from sugar substitution with stevia e.g. calorie amount in Halva Masghati (an Iranian confectionery) sample containing %100 stevioside-maltodextrin has decreased from 4500 cal/g to 3500 cal/g (Omidvar *et al*., 2014). This calorie reduction is also found in saccharoe replaced with stevia in fruit juice in both control and free sugar treatment, which were 338.9 and 194 kcal/100g, respectively (Alizadeh *et al*., 2014a). In addition, the presence of stevia instead of sugar diminished calorie amount from 143.03 to 105.25 in ice cream (Alizadeh *et al*., 2014b).

4. Conclusion

Antioxidant properties and being secure and low calorie make stevia a nonnutritive sweetener in food products. However, its bitter aftertaste can diminish its consumption in food formulations, but other flavoring agents and fillers can modify this problem. Most researches indicate the fact that products free of sugar do not have enough desirability and acceptability; hence, the presence of sugar is inevitable i.e. in case of complete substitution, concurrent consumption of both sugar and stevia (different combinations) seemingly makes it more favorable and a must-be-purchased product.

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