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Textural and rheological properties of stevia ice cream

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Abstract

Ice cream contains high sugar content and therefore it is in contradiction with the concept of healthy diet. The objective of this study is to determine the suitability of using stevia as an alternative natural sweetener in making ice cream. In- house ice cream formulation (as the control) and three different concentrations of stevia ice cream formulations of (A, B and C) were used. Physical properties of the ice cream such as the overrun, total soluble solid, meltdown rate, rheology, and textural properties were evaluated. All ice cream samples exhibited a non-Newtonian flow with pseudoplastic behavior. Stevia ice cream has a lower melting rate and has a higher sustainability. The power law also showed that apparent viscosities of stevia ice cream were higher. Therefore, stevia can be used as a natural sugar substitute in ice cream production.

Introduction

Due to the high prevalence of obesity and Type 2 diabetes among children and adolescents, people are now more aware of their health status and hence conscious of their diet. This health-conscious decision poses a formidable challenge to the ice cream industry. As a result, the ice cream market trend is moving towards a low calorie, low sugar ice cream formulation and with excellent texture and sensory properties to gain the consumers' satisfaction.

Consequently, a number of studies had been carried out in developing new functional ice creams with ingredients such as dietary fibers (Soukoulis *et al.*, 2009), probiotics (Akin *et al.*, 2007), low glycemic index sweeteners (Whelan *et al.*, 2008), and alternative sweeteners such as xylitiol, sorbitol, and maltitol (Soukoulis *et al.*, 2010). Mainly, these innovative ice creams are produced using artificial sweeteners. There are few studies done using natural sweeteners in ice cream production.

Stevia, a natural sweetener (Ozdemir *et al.*, 2008), has been used by many food and beverage companies in Japan, Korea, and South America (Panpatil and Polasa, 2008; Goyal *et al.*, 2010; Hossain *et al.*, 2010). Stevia is used to replace sucrose in yogurt, soy sauce (Hossain *et al.*, 2010), and candies (Goyal *et al.*, 2010). It is also known to be the best alternative natural sweetener. It is ideal for diabetics and obese people due to its 100% natural composition (Lemus-Mondaca *et al.*, 2012). Most importantly, it contains little or no calories and has been proven that it does not contain glucose, sucrose, maltose, or fructose level per se. It can produce foods that are healthy and nutritious. Stevioside and rebaudioside A are believed to be the main compounds providing the sweetening properties in stevia (Lemus-Mondaca *et al.*, 2012). These compounds give the taste of sweetness without any side effects for diabetics and certainly can help people who have obesity, diabetes, and dental caries in meeting their sweet cravings (Ghanta *et al.*, 2007). Besides as a sweetener, a number of studies have reported stevia for its therapeutic benefits of having anti-hyperglycemic, anti-hypertensive, anti-inflammatory, anti-tumor, anti-diarrhea, and diuretic effects (Chatsudthipong and Muanprasat, 2009). Therefore, this study aimed at evaluating the effect of replacing sugar with different concentration of stevia on the physical properties of ice cream namely overrun, total soluble solid, meltdown rate, rheology, and textural properties.

Materials and Methods

Materials

The ingredients used in this study were full cream milk (Malaysia Milk Sdn. Bhd., Selangor, Malaysia), non-fat milk solid (Nestle Philippines Inc., Laguna, Philippines), butter (Lam Soon Edible Oil Sdn. Bhd., Selangor, Malaysia), caster sugar (Malayan Sugar Mfg. Co. Bhd., Penang, Malaysia), Stevia extract

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powder- rebaudioside –A (98%) (Botanical Essence Marketing Sdn. Bhd., Selangor, Malaysia), lecithin (Super 88, Selangor, Malaysia), and vanilla extract (FFM Marketing, Selangor, Malaysia).

Preparation of ice cream

Control ice creams were prepared by using the In-house formulation developed by Faculty of Food Science and Technology, University Putra Malaysia. Ice cream formulation of A, B, and C equivalent to sugar of 0.5: 1.0; and 1.5, respectively, were used since 1 g stevia powder is equivalent to sweetness provided by 14 g sugar. All ice creams were prepared in duplicate. The ice cream formulations are as in Table 1. Milk and water were heated using a jacketed kettle (TDB/6, Groen, USA) to 65 ± 1°C. Non-fat milk powder, sugar, and lecithin were weighed and mixed before pouring into the heated milk. The mixtures were stirred, and melted butter was added. The mixtures were pasteurized at 65 ± 1°C, held for 30 minutes and then homogenized at 210- 240 psi for 5 minutes using a high speed homogenizer (L2R, Silverson Machines Ltd, England). The ice cream mixes were aged for 24 hours at 4 ± 1°C in a stainless steel container. They were then transferred into a hard ice cream maker (C119, The Taylor Company, USA) and were whipped until cool. When the ice creams' temperature reached 5.5°C, they were drawn out from the machine to be filled into 220 ml polypropylene cups (6.0 cm in diameter, 3.5 cm in height) and were carefully leveled to avoid compaction (Prindiville *et al*., 2000) in order to prevent the air from being displaced from the pores and the ice cream becomes hard as this will affect the texture profile analysis. The ice creams were transferred to the blast freezer (WBCF 40, Williams, UK) to be hardened at -18°C. Ice creams were stored for five days in a cabinet freezer (-18°C) before being analyzed.

Overrun

Overrun was measured by comparing the weight of mix and ice cream in a fixed volume container (Özdemir *et al*., 2003) by using a 250 ml beaker. The overrun percentage was determined according to the following equation

$$O_n \%= 100 \quad (W_m - W_{ic})/W_{ic}$$

where O_n (%) is the overrun percentage, W_m (g) is the weight of a given volume of mix and W_{ic} (g) is the weight of same volume of ice cream.

Total soluble solid

Ice creams were allowed to melt at room temperature at 25°C before they were subjected to total soluble solid analysis. Total soluble solid was determined using a Palatte-style digital refractometer and ranged from 0% to 45% Brix (Model PR-101, Atago, Japan).

Table 1. The ice cream formulation for control and different stevia concentration

Ingredients (%)	Formulation			
	Control	A	B	C
Full Cream Milk	72.0	83.2	82.8	82.3
Non-fat Milk Solid	4.8	5.6	5.5	5.5
Butter	8.2	9.4	9.4	9.3
Caster Sugar	14.0	0.0	0.0	0.0
Stevia Powder	0.0	0.6	1.1	1.7
Lecithin	0.4	0.5	0.5	0.5
Water	0.6	0.7	0.7	0.7

Meltdown

To determine the meltdown of ice cream, 80.0 ± 2 g of sample was put on a wire mesh attached to a graduated cylinder and maintained under a controlled temperature chamber at 25ºC and environment of constant relative humidity (50 ± 1%). The dripped volume was measured at a 10 minute intervals for a total of 45 minutes (Lee and White, 1991). The first drop time was measured as the volume drip per minute. The data recorded was used to determine the melting rate (ml/minute).

Rheological properties

The analysis was conducted using rheometer (RheoStress600, HAAKE, Germany) coupled with a cone and plate system (d: 35 mm, α: 2°). The melted ice cream was rested for 5 minutes before measurement. The flow curves were obtained by registering shear stress from 0.5 to 200 s^{-1} in 120 s at 20°C (Karaca *et al*., 2009). Power law model was used to determine the non-Newtonian properties of the ice cream,

$$\sigma = K\dot{\gamma}^n$$

where σ is the shear stress, *K* is the consistency index, $\dot{\gamma}$ is the shear rate, and *n* is the dimensionless number that indicates the closeness to Newtonian flow. The value of *K* and n were determined using the non-linear regression method available in Microsoft Excel, version 2010.

Texture profile analysis (TPA)

A texture analyzer (TA-XT2i, Stable Micro System, UK) was used to determine the hardness, adhesiveness, cohesiveness, gumminess, and

Table 2. Percentage of overrun, total soluble solid, consistency index, flow behavior and the texture profile analysis of ice cream with different stevia concentration

Formulation	Overrun (%)	Total Soluble Solid (%)	Consistency index, K (Pa s^n)	Flow behavior index, n	RMSE	Hardness	Adhesiveness	Cohesiveness	Gumminess	Springiness
Control	63.81 ± 1.66^{bc}	33.10 ± 0.06^a	0.20 ± 0.02^a	0.58 ± 0.03^a	0.13	1139.26 ± 83.98^b	-207.11 ± 12.71^{ab}	0.04 ± 0.01^a	46.62± 9.81^a	0.89 ± 0.05^a
A	62.90 ± 1.56^c	20.10 ± 0.06^b	0.30 ± 0.03^b	0.43 ± 0.02^b	0.08	687.77 ± 23.51^a	-129.22 ± 20.90^b	0.09 ± 0.00^b	64.81 ± 2.41^b	0.98 ± 0.03^a
B	65.46 ± 0.51^b	21.30 ± 0.10^c	0.31 ± 0.03^b	0.43 ± 0.03^b	0.07	779.93 ± 43.73^a	-301.28 ± 30.53^a	0.15 ± 0.01^c	113.37 ± 8.21^c	0.96 ± 0.04^a
C	68.31 0.51^a	22.40± 0.06^d	0.34 ± 0.04^b	0.42 ± 0.02^b	0.06	2245.97 ± 87.50^c	-305.05 ± 94.86^a	0.06 ± 0.03^a	134.52 ± 6.13^d	0.98 ± 0.04^a

$^{a-d}$ Mean ± SD with different letters indicates significant difference ($p<0.05$)

springiness of the ice cream samples. The analysis was carried out at 25°C. For each sample, three measurements were carried out using a 2 mm stainless steel cylindrical probe (P2) attached to a 5 g load cell. The penetration depth at the geometrical center of the samples was 20 mm and the penetration speed was set at 3.3 mm/s.

Statistical analysis

Statistical analysis for all the data were performed using the MINITAB Statistic Software for Windows, Version 16.2.1 (Minitab Inc., United State). One-way analysis of variance (ANOVA) was performed and the statistical significance was given in terms of p-values, with differences at the 95% confidence level ($p<0.05$) being considered statistically significant for the result of all analysis using different ice cream formulations. The final results obtained were expressed as the mean values ± standard deviation.

Results and Discussion

Overrun

It was found that the average overrun of ice cream, based on different formulations, was 65.12%. This value is lower than the general literature value of 80 -100% (Ozdemir *et al.*, 2008). A possible reason for getting a lower overrun value is due to the inconsistency during the whipping process (Chang and Hartel, 2002) which is caused by the limitation of equipment. Reports also commented that it is difficult to get an overrun value in ice cream produced by a batch-type freezer (Guven *et al.*, 2003; Özdemir *et al.*, 2003; Dervisoglu *et al.*, 2005). Nevertheless, the result of this study show that the increment in the concentration of stevia had significantly ($p<0.05$) increased the overrun percentage of the ice creams. This trend is in agreement with previous reports that sugar concentration increased the overrun significantly (Güven and Karaca, 2002; Akin *et al.*, 2007).

Total soluble solids

The increasing concentration of stevia significantly ($p<0.05$) increased the total soluble solid of ice cream. However, the solidity was still less than that of the control (Table 2). Total soluble solids of the ice cream are contributed by the addition of sweetener into ice cream, besides that, sweetener also gives essential bulk, texture, and body to ice cream (International Dairy Federation, 1998). Several studies found that ice cream with lower total soluble solids may have proportionately more water to freeze, thus contributing to more ice crystal formation (Flores and Goff, 1999; Tharp and Young, 2008), influencing the texture and body of ice cream. Thus, these texture differences will directly influence the consumers' judgment on the ice creams' quality. Other soluble solids should be added when stevia is used as a sweetener in the production of ice cream.

Meltdown

Figure 1 shows the melting kinetics of ice cream over a span of 45 minutes. The existence of stevia had linearized the behavior of ice melting, especially at a high concentration of stevia. This can be seen clearly in Figure 2, where the melting rates were more stable with stevia and increments of stevia concentration. As an average, melting rates were 1.50 ± 0.01, 1.32 ± 0.01, 1.19 ± 0.01, and 1.09 ± 0.02 ml/minute for control, formulations of A, B, and C, respectively. This is an enhancement because lower melting rate relates to the sustainability of the ice cream's shape, which is typically evaluated as a good quality ice cream (Tharp *et al.*, 1998). Type and amount of sweetener affects the melting rate of ice cream (Muse and Hartel, 2004). This observation is related to the overrun of the ice cream that was discussed earlier. This is because the overrun and the nature of air-cell distribution in ice cream influences the rate of heat

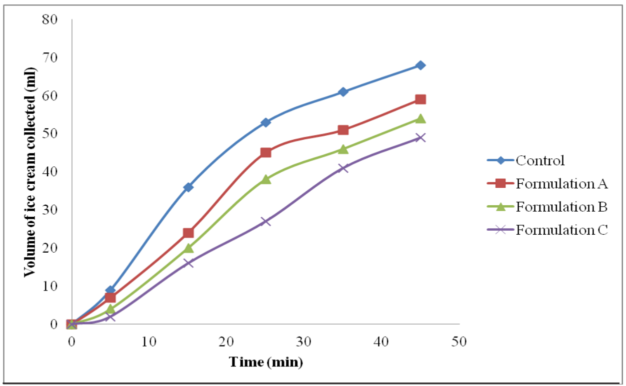

Figure 1. The melting kinetics of ice cream with different stevia concentration at 25ºC

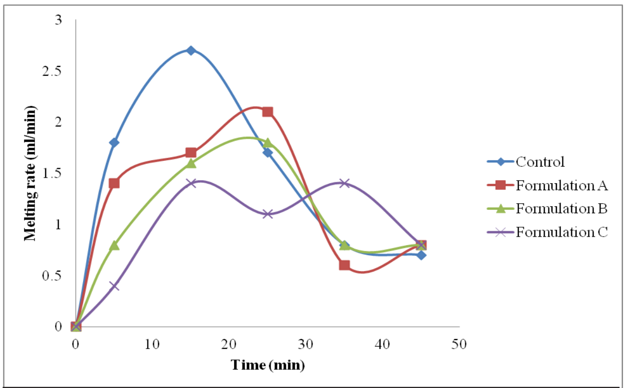

Figure 2. The melting rate of ice cream with different stevia concentration over 45 minutes

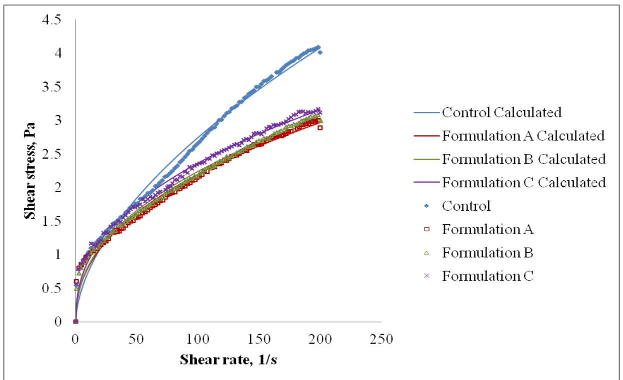

Figure 3. The shear stress and shear rate curve of ice cream with different stevia concentration

penetration into the ice cream, affecting the melting stability (Muse and Hartel, 2004). Several studies have reported that ice cream with a low overrun melted quicker than those with higher overrun (Sakurai *et al.*, 1996; Alamprese *et al.*, 2002; Hartel *et al.*, 2003). This may be due to a higher amount of air cells that decelerate of heat transfer across the ice cream, thus slowing the meltdown (Flores and Goff, 1999).

Rheological properties

The shear stress and shear rate of the different ice cream formulations are shown in Figure 3. All curves showed shear thinning behavior with the control being the same as most of the mix ice cream (Goff *et al.*, 1994; Karaca *et al.*, 2009). The model of power law was used to determine the consistency index, *K*, and flow behavior index, *n* (Table 2). This model adequately describes the shear stress-shear rate behaviors for all samples, with root-mean-square error (RMSE) of 0.06 - 0.13. The replacement of stevia produces viscous (increment of consistency indexes) ice cream. This is due to the difference in molecular size between the sweeteners used in this study, which affected the water holding capacity, degree of polymerization, and degree of branching (Soukoulis *et al.*, 2010). Samples containing larger molecules tend to have higher viscosity. The large molecules have stronger intermolecular forces attracting them to one another and there is a greater strength that hinders molecular flow, hence more viscous. However, in the range of stevia concentration covered in this study, the ice cream's consistency indexes increases but were not significantly different. This finding was contradictory with findings of Akin *et al*. (2007), where they found the viscosity of ice cream to have increased when sugar concentration increased. It can be suggested that the total replacement of sugar with stevia and the increment of stevia percentage in each formulation is too little to have significant effect on the viscosity. The n-value indicates the degree of pseudoplasticity of a fluid. In this study, all *n*-values obtained from different formulations were less than 1 (0.42 - 0.58), which is a characteristic as a pseudoplastic material. This finding corroborated previous studies in which the n-values for ice cream mix ranged from 0.48 to 0.94 (Cottrell *et al.*, 1980; Karaca *et al.*, 2009). However, the shear thinning behavior increased with the replacement of sugar with stevia.

Texture profile analysis

The replacement of sugar with stevia in different concentration affected the hardness of the ice cream (Table 2). This may be due to the micro-structure change, namely phase volume, ice crystal size, and fat stability in the ice cream (Muse and Hartel, 2004). This finding was in line with the previous discussion that the replacement and the concentration of stevia affect the total soluble solid, determining amount of ice formation. With high water content, ice crystal is packed closer to each other (Muse, 2003). A larger force is required to be applied to the surface of the ice cream that is being categorized as hard. Besides hardness, replacement of sugar with stevia and in different concentration also significantly increased the adhesiveness and the cohesiveness of ice cream. Both of these terms refer to the texture and stickiness of food (Dunnewind *et al*., 2004), which can be interpreted as a characteristic that stevia ice cream can provide. Stevia ice cream is described as having more chewy (at least the first and second chew) and sustainability of texture, as well as more sticky in the mouth. This is because the higher value of adhesiveness represents more energy that is required to overcome the attractive forces between the ice cream and mouth when they come into contact (Radoĉaja *et al*., 2011). Higher cohesiveness represents an improvement in sustainability of the ice cream as it is compressed in the mouth before it breaks (Radoĉaja *et al*., 2011). The sustainability of stevia ice cream in the mouth was also supported by the increment of gumminess. As a secondary texture profile, gumminess is defined as the product of hardness and cohesiveness. It refers to the energy required in disintegrating the ice cream before swallowing. However, there was no significant difference in springiness for all the ice cream samples; similar amounts of force were required for the ice cream from the end of the first bite to the start of the second bite.

Conclusion

The replacement of stevia as sweetener with different concentrations has significantly affected the physical properties of ice cream. The results reveal that stevia ice cream has a lower melting rate and higher sustainability in the mouth. The power law shows stevia ice cream to be a pseudoplastic material and more viscous than the control recipe containing sugar. The usage of stevia in ice cream affected the hardness and also increased the adhesiveness and the cohesiveness of ice cream. Therefore, stevia can be used as a sugar substitute in formulating ice cream for the health conscious market due to the benefits stevia provides.

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