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Effect of the Sweeteners on the Qualities of Vanilla-Flavored and Yoghurt-Flavored Ice Cream

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ABSTRACT

The objectives of this research were: 1) to study the effect of sucrose replacement with alternative sweeteners on the qualities of vanilla-flavored ice cream, freezing points and raw material cost; and 2) to produce a low sugar, yoghurt-flavored ice cream containing sucralose and inulin. The outcome of this research provided broader information for ice cream manufacturers that intend to apply a sweetener and inulin to their ice cream production lines. For vanilla-flavored ice cream, five ice cream formulas were produced in this work comprised of the control sample using sucrose and the other four samples applying erythritol, maltitol, sucralose and xylitol as the sweeteners, respectively. In order to achieve the equivalent sweetness value to sucrose, the applied weights of erythritol, maltitol, xylitol and sucralose were 125, 111, 100 and 0.17% compared with sucrose. It appeared that the viscosity of samples after the mixing step was higher than after the other steps for all recipes except for the samples using xylitol. The addition of xylitol increased the overrun value and lightness whereas maltitol resulted in the reverse effects. Rapid melting was found in the sample substituted with xylitol. The freezing temperatures of all samples were higher than that of the control. The sensorial characteristics of samples with sucralose were not significantly different from the control while the mouthfeel and smoothness of the maltitol and xylitol recipes significantly differed from the control. The sucrose replacement sucralose led to the lowest cost as it was the least applied. Four yoghurt-flavored ice cream formulas were prepared made from whey protein powder or buffalo milk with or without sucralose replacement and added inulin. The results showed that the overrun of buffalo yoghurt ice cream was lower than for the whey protein powder formulas by an estimated 1.5 times. All sensorial scores of both types of yoghurt ice cream with sucralose substitution and added inulin were similar to samples without sweetener and inulin.

Keywords: ice cream, yoghurt, buffalo milk, inulin, sweetener

INTRODUCTION

Ice cream is a popular frozen dessert and is consumed by people of all ages. Plain dairy ice cream is composed of milk, sweeteners, stabilizers, emulsifiers and flavoring agents (Marshall *et al.*, 2003). Ice cream may be flavored by artificial or natural flavoring. In North America and Europe, vanilla flavoring is the most common used in ice cream (Berger, 2007). Yoghurt is another fermented dairy product also gaining popularity with consumers (Kailasapathy and Sultana, 2003) because it has potential for improving the health and nutrition of the consumer (Gilliland, 2003).

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Therefore vanilla-flavored and yoghurt-flavored ice cream were produced and developed in this study.

Table sugar or sucrose is used as a primary sweetener in ice cream because it is cheap and has no aftertaste (Salama, 2004). Many different types of sugar can also be used in ice cream such as glucose, fructose, glucose syrups and corn syrups (Ozdemir *et al.*, 2008). Sugar is added to adjust the solids content in the ice cream and to give it sweetness according to consumer preference as well lowering the freezing point of the ice cream mix and having an effect on the texture and sensorial characteristics (Kilara and Chandan, 2006).

Sugar also provides a good source of calories; however, it should not be consumed in excess since over consumption can cause several diseases such as obesity, diabetes and high blood pressure (Ozdemir *et al.*, 2008; Song *et al.*, 2012).

Sugar substitutes are substances with a sweet taste that can be used to replace sugar (sucrose) as a sweetener in the product and based on their relative sweetness compared to sucrose, sweeteners are divided into two classes: intense sweeteners and bulk sweeteners (Mortensen, 2006). Intense sweeteners are used in very tiny amounts so that their contribution to the energy content of foods is negligible (Grabitske and Slavin, 2008). Sucralose is an intense sweetener that is approximately 600 times sweeter than sugar and is safe, hardly absorbed and can be used in a wide range of products; for instance, soft drinks, desserts, ice cream and confectionery (Quinlan, 2007; Dabbas *et al.*, 2012). Another class of sweetener is bulk sweeteners which are substances with sweetness less than or comparable to that of sucrose (Mortensen, 2006). Their sweetness values vary from 40% to 100% that of sucrose (Nabors, 2007; Grabitske and Slavin, 2008). In contrast to intense sweeteners, bulk sweeteners tend to have fewer calories than regular sugar (Nabors, 2007; Shankar *et al.*, 2013). Polyols or sugar alcohols are known as bulk sweeteners and are commonly used in food products for example candy, gum, bakery and ice cream products (Nabors, 2007). Maltitol and maltitol syrups have been used in sugar-free ice cream and maltitol syrup has 75–90% of the sweetness of sucrose resulting in a taste, sweetness, hardness and melting resistance that were comparable to those of the standard (Lawson, 2007b). Xylitol has a sweetness intensity equal to sucrose. (Hyvoenen *et al.*, 1977) This polyol can be used in the manufacture of many dairy products and frozen desserts, including yoghurt and ice cream (Bond, 2007). Erythritol is non-caloric sweetener with a maximum energy value of 0.2 kcal.g^{-1}. Its sweetness is approximately 60–80% compared to sucrose. Sugar alcohols are not absorbed in the small intestine but are fermented by bacteria in the large intestine (Grabitske and Slavin, 2008); therefore, they do not cause an increase in the blood sugar level; however, sugar alcohols can cause gas, bloating, diarrhea and headaches when consumed in large amounts (Schardt, 2004).

Apart from cow's milk, milk from other species such as buffalo, sheep, goat and camel is consumed in various parts of the world (Ménard *et al.*, 2010). Buffalo milk provided higher fat and protein content than cow's milk (Sindhu and Arora, 2011). Mangsi *et al.* (2011) reported that buffalo milk can be utilized to produce yoghurt ice cream with an attractive appearance, acceptable flavor and better texture.

Dietary fiber diets have been associated with weight maintenance, weight loss and may reduce the risk of developing cardiovascular disease and diabetes (Mann and Cummings, 2009; Elleuch *et al.*, 2011). Inulin is a nondigestible, carbohydrate-occurring, soluble fiber that is added to a variety of processed foods to increase the dietary fiber, replace fat, add mild sweetness (especially in combination with high intensity sweetener) and modify texture (Meyer *et al.*, 2011).

Due to the potential benefits of applying sweeteners to the ice cream formula, the purposes of this study were: 1) to study the effect of sucrose replacement with alternative sweeteners on the qualities of vanilla-flavored ice cream, freezing points and raw material cost; and 2) to produce a low sugar yoghurt-flavored ice cream by adding sucralose and inulin. In this study, the application of these particular sweeteners in ice cream production will supplement the information for ice cream producers who plan to adjust the product formulation with sweeteners and dietary fiber.

MATERIALS AND METHODS

Raw materials

Vanilla-flavored ice cream

Whole ingredients (whey protein powder, shortening, emulsifier, stabilizer, vanilla flavor and food grade color) except sweeteners were supplied from Jittanit Padrew Co., Ltd.; Chachoengsao, Thailand. Commercial sugar (Mitr phol; Mitr Phol Sugar Corp. Ltd.; Bangkok, Thailand) was used for the control sample. Three sugar alcohols and one intense sweetener were used as sugar replacers. They consisted of erythritol (Erylite, Brentag Ingredients Public Co. Ltd.; Bangkok, Thailand), maltitol syrup (Kontrol; Siam Sorbitol Co. Ltd.; Bangkok, Thailand), xylitol (Lab Valley LP; Bangkok, Thailand) and sucralose (Chemipan Corporation Co. Ltd.; Bangkok, Thailand).

Yoghurt-flavored ice cream

There were two types of raw materials used for yoghurt ice cream production. The first type was whey protein powder and a yoghurt recipe using cow's milk. The main ingredients (whey protein powder, shortening, emulsifier and stabilizer) were supplied by Jittanit Padrew Co. Ltd.; Chachoengsao, Thailand. Commercial sugar and sucralose were used as sweeteners. Cow's milk yoghurt was purchased from the Dairy Center, Kasetsart University, Bangkok, Thailand. Inulin powder (Orafti®HSI; inulin/oligofructose 86% glucose/fructose/sucrose 14%) was acquired from BENEO-Orafti (DPO (Thailand) Ltd.; Bangkok, Thailand). The second type was a buffalo yoghurt ice cream formula. Buffalo milk and yoghurt were purchased from Murrah Café and Birtro (Bangkok, Thailand). Shortening, emulsifier, stabilizer, sweeteners and inulin were obtained from the same suppliers mentioned above.

Ice cream production

Vanilla-flavored ice cream

Five ice cream formulas were produced —the control using sucrose and the other four samples applying erythritol, maltitol, xylitol and sucralose as the sweeteners, respectively. The applied weights of erythritol, maltitol, xylitol and sucralose were 125, 111, 100 and 0.17%, respectively, relative to sucrose.

The flow chart for the production of vanilla-flavored ice cream is shown in Figure 1. All dry ingredients (whey protein powder, emulsifier and stabilizer) were blended together. Then these mixed dry ingredients and either sucrose or sweeteners were put into warm water (60 °C) and shortening was added into the mixture. A blender (Model AY46; Moulinex; Shanghai, China) was used to obtain a smooth mixture. The resultant mixture was homogenized in a two-stage homogenizer at 20 and 4.8 MPa (Model 15MR-8TBA; APV Gaulin, Inc.; Everett, MA, USA) and then pasteurized at 80 ^{o}C for 2 min. After pasteurization, the ice cream mix was cooled down and allowed to age at 4 °C for 24 hr. After the addition of vanilla flavor and food grade color, the aged ice cream mixtures were frozen using a freezing machine (Model TS2; Frigomat; Guardamiglio, Italy). The frozen mix was packaged in 50 mL plastic cups with covers and then stored at -18 °C for hardening.

Yoghurt-flavored ice cream

The production lines for yoghurt ice cream were similar to that for the vanilla-flavored ice cream except for the addition of yoghurt and no added vanilla-flavoring and no food color. The four samples consisted of two formulas which were produced from whey protein powder and cow's milk yoghurt with or without added sucralose and inulin. The other two recipes were made from buffalo milk and yoghurt with or without added sucralose and inulin. Yoghurt was an additional 32% of the total component content. Inulin was added at 3% of the total ingredient weight including yoghurt. Sucrose was used as the control in the two types of yoghurt-flavored ice cream. The amount of sucrose was reduced by half and replaced with sucralose. The applied weight of sucralose was calculated by comparison with the equivalent sweetness of sucrose.

The process of yoghurt-flavored ice cream is shown in Figure 2. In brief, there were two production lines—whey protein powder and cow's milk yoghurt ice cream recipes— which started with warming water to 60 °C and the process of buffalo yoghurt ice cream began with warming buffalo milk to 60 °C. All dry ingredients were blended together and put into the warm water or buffalo milk. Then, shortening and yoghurt were added into the mixture and blended. After that, the mixes were processed using homogenization, pasteurization, cooling, aging, freezing, packing and hardening as mentioned previously.

Quality measurements

Vanilla-flavored ice cream

The mixtures and ice cream samples were examined after four steps comprising (1)

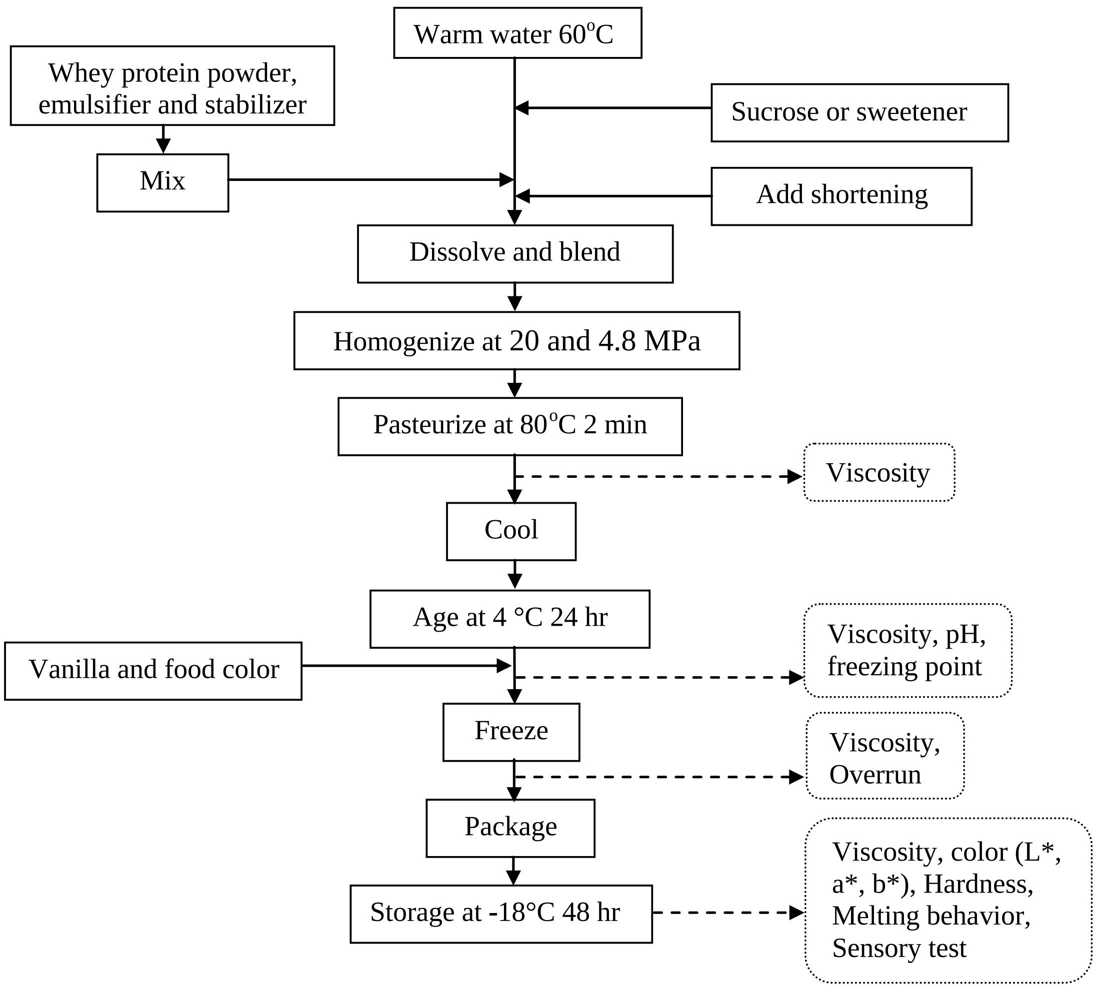


Figure 1 Flow chart for production of vanilla-flavored ice cream and quality measurement.

mixing, (2) aging, (3) freezing using an ice cream freezing machine and (4) hardening in a frozen storage room at -18 °C for 48 hr. In the first step, the mixtures were determined for viscosity (Model HB DVII+; Brookfield; Middleboro, MA, USA) using spindle number 0 with the data recorded after the spindle had swirled for 30 s). For the second stage, the aged mixtures were measured for their viscosity, pH (Model PH-207; Lutron; Taipei, Taiwan) and freezing temperature. The frozen ice cream samples from the third step were determined for their viscosity and overrun. The viscosity of the mixture and ice cream were assessed when the temperature of the samples reached 20 °C. The overrun of the ice cream samples was determined using Equation 1 (Akin *et al.*, 2007):

Overrun % = 100 × (weight of unit mix – weight of ice cream) / weight of ice cream (1)

The ice cream products from the final step were measured for their viscosity and color (L*, a* and b*) using a colorimeter (Model Miniscan XE; HunterLab; Reston, VA, USA) based on Hunter and Harold (1987).

The hardness of vanilla-flavored ice cream was measured in triplicate using a texture analyzer (model TA.XT plus; Stable Micro Systems Ltd.; Surrey, UK). The ice cream products from the final step were promptly transported to

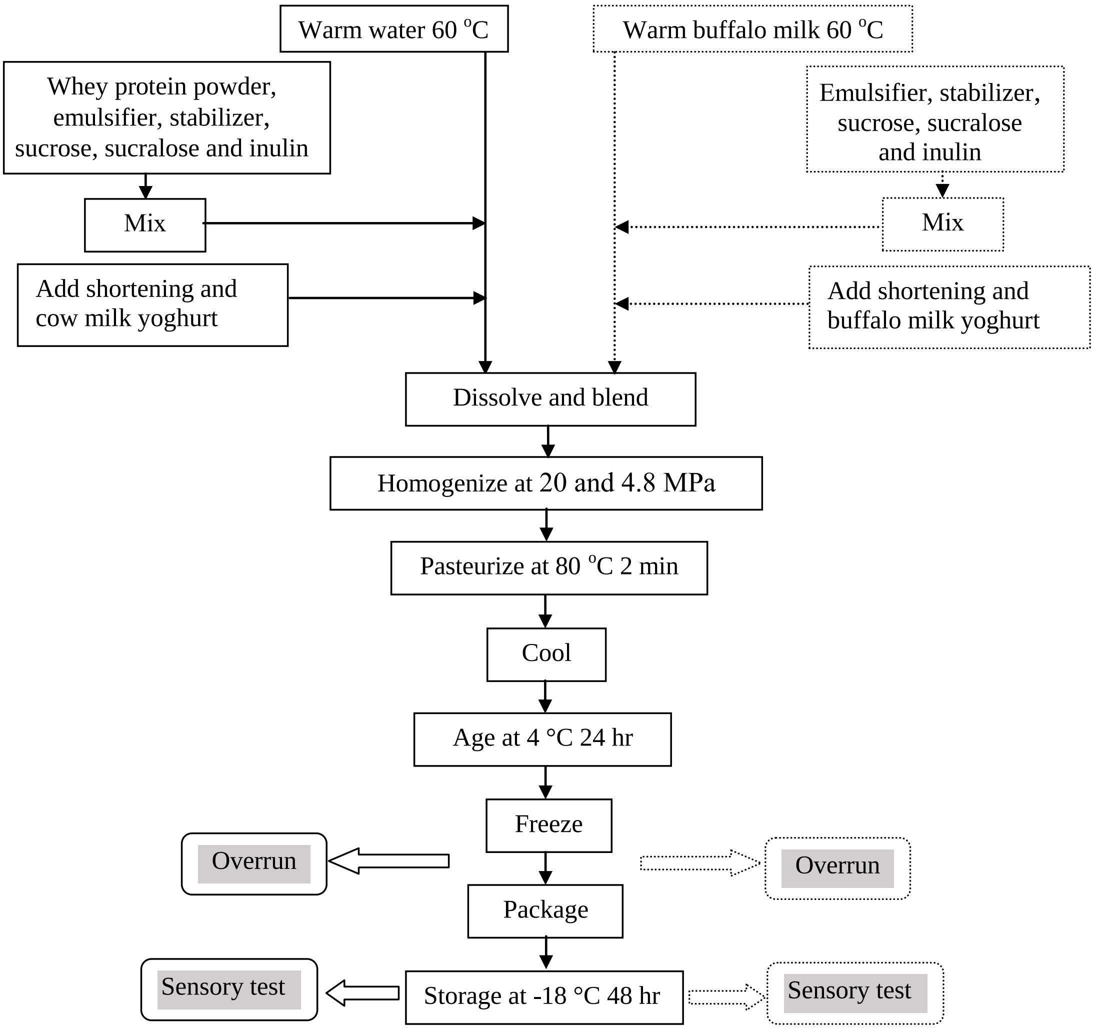


Figure 2 Flow chart for production of yoghurt-flavored ice cream and quality measurement.

the texture analyzer and held at room temperature (25 °C). The analysis started when the temperature at 1 cm depth was -10 °C. The cone probe (P/45C) was used to penetrate the sample to a depth of 15 mm at a speed of 1 mm.s^{-1} (modified from Supavititpatana and Kongbangkerd, 2011). Hardness (N) of the samples was determined as the peak compression force during penetration.

Melting behavior was determined by the method modified from Akin *et al*. (2007), whereby 45 ± 5 g of ice cream was left to melt at room temperature (25 °C) on a 0.2 cm wire mesh screen above a beaker. The dripped weight was recorded at 10, 20 and 30 min and calculated as a percent (%) of meltdown. All quality measurements were done in triplicate.

The sensorial qualities of ice cream specimens were evaluated for smoothness, color, odor, sweetness, viscosity, mouthfeel and overall characteristic by 30 panelists who were students in the Faculty of Agro-Industry, Kasetsart University, Bangkok, Thailand using a seven-point hedonic scale (1=dislike very much, 2 = dislike moderately, 3 = dislike slightly, 4 = neither like nor dislike, 5= like slightly, 6 = like moderately and 7 = like very much).

Yoghurt-flavored ice cream

Four formulas of yoghurt-flavored ice cream were evaluated to determine their qualities with to be the overrun while sensory tests were performed using 15 panelists who were students in the Faculty of Agro-Industry, Kasetsart University, Bangkok, Thailand using a seven-point hedonic scale.

Determination of freezing point

The freezing point was measured only for vanilla-flavored ice cream samples. Each formula of aged ice cream mixture was poured into plastic 50 mL cups. Before covering, a hole was punched in each lid in order to insert a type–T thermocouple and then the hole was sealed with silicone. During the process of freezing, a thermocouple together with a data logger (model DX 1012; Yokogawa Electric Corporation, Tokyo, Japan) were used for measuring and recording the temperature profiles of the ice cream samples that had been frozen in a chest freezer. The freezing point determinations were conducted in duplicate.

Raw material cost estimation

The amounts of all ingredients in the five ice cream formulations (vanilla-flavored ice cream) were identical excepting for the sweetener. Therefore, in this study only the cost of sweetener for each formula was calculated and compared.

Statistical analysis

Data analysis was performed using the SPSS statistical software package (version 17; SPSS Inc.; Chicago, IL, USA). All data from quality determinations were analyzed using analysis of variance whereas mean comparisons were carried out using Duncan's multiple range test.

RESULTS AND DISCUSSION

Table 1 illustrates the viscosity of the samples of mixture and ice cream which was to study the effect of the sugar replacer. It was found that after aging at 4 °C for 24 hr, every mixture formula had a significantly (P < 0.05) lower viscosity. During the aging process, the fat crystals that melted during pasteurization recrystallized. Moreover, the stabilizers also completed their hydration process and the proteins completed their adsorption at the fat/water interface (Kilara and Chandan, 2006). The fat recrystallization and the changes in the stabilizers and proteins during aging led to the low viscosity structure. Sucrose replacement with erythritol and maltitol clearly increased the sample viscosity. According to Lawson (2007a) erythirol provides lower water activity in solution. Therefore, the addition of erythritol in a mix increased the viscosity compared to the control due to there being less free water in the sample. Due to the fact that moltitol has the highest solubility among all the disaccharide polyols, it provided the most viscous solution (Lawson, 2007a). Thus, the addition of maltitol in the ice cream mix resulted in an apparently viscous mixture. In this work, sucrose replacement by either xylitol or sucralose provided a low viscosity mixture. This result was in agreement with Bond (2007) who pointed out that xylitol solutions are less viscous than a sucrose solution at any given temperature or concentration. According to the report of Jenner and Smithson (1989), the viscosities of sucralose solutions are similar to those of a sugar solution if the same concentration is applied. Furthermore, Dabbas *et al*. (2012) stated that the replacement of a large proportion of sucrose with a low amount of sucralose produced a decrease in the viscosity of nectars. Thus, it is not surprising that the sucrose replacement using sucralose provided a low viscosity ice cream mixture. The decrease in the sample viscosity occurred after freezing and then enlargement occurred again after storage at -18 °C for 48 hr excluding the maltitol sample where the viscosity decreased continuously after the aging, freezing and storage steps. The amount of air consolidated into the product during the freezing process by the ice cream freezer caused a reduction in the sample viscosity. During hardening and storage in a chest freezer, the ice crystals of the ice cream would be enlarged and become firmer leading to a microstructural change in the ice cream and an increase in the sample viscosity when melted.

The overrun and hardness values of vanilla-flavored ice cream are shown in Table 2. The freezing process usually helps by incorporating air into the ice cream leading to volume expansion that produces the so-called “overrun”. The range of overrun values found in this study varied from 17.50 to 41.07%. The overrun value of the xylitol sample was similar to the control. In contrast, sucralose and maltitol decreased overrun to 28.99 and 17.50%, respectively. Overrun normally affects both the appearance and taste of ice cream; a higher overrun raises the creaminess of the ice cream (Kilara and Chandan, 2006). The viscosity values in Table 1 show that the maltitol and sucralose specimens had high viscosity which might have been a consequence of their low overrun values. Another direct effect of a low

Table 1 Mean (± SD) viscosity of mixtures and ice cream.

Sweetener	Viscosity (cP)			
	Mixing	Aging	Freezing	Storage -18 °C
Control	$129.43^{f} \pm 3.38$	$103.49^{i} \pm 4.35$	$17.47^{n} \pm 4.00$	$95.26^{j} \pm 2.55$
Erythritol	$260.73^{a} \pm 0.49$	$226.67^{b} \pm 0.38$	$143.90^{e} \pm 2.51$	–
Maltitol	$259.80^{a} \pm 0.26$	$202.40^{c} \pm 3.60$	$175.53^{d} \pm 0.06$	$143.53^{e} \pm 2.77$
Xylitol	$122.27^{g} \pm 0.26$	$93.87^{k} \pm 3.60$	$109.13^{h} \pm 0.59$	$141.10^{e} \pm 1.15$
Sucralose	$112.33^{h} \pm 1.59$	$89.85^{k} \pm 3.86$	$39.73^{m} \pm 0.29$	$66.06^{l} \pm 6.18$

$^{a-n}$ = Different lowercase superscripts in all rows and columns indicate significant differences ($P < 0.05$) and the erythritol sample was inadequate for viscous determination.

Table 2 Mean (± SD) overrun and hardness values of vanilla-flavored ice cream samples.

Sweetener used in ice cream	Overrun (%)	Hardness (N)
Sucrose (control)	$40.25^{a} \pm 3.00$	$307.22^{c} \pm 69.61$
Maltitol	$17.50^{c} \pm 0.76$	$4,645.88^{b} \pm 752.45$
Xylitol	$41.07^{a} \pm 1.91$	$155.44^{c} \pm 12.06$
Sucralose	$28.99^{b} \pm 1.07$	$10,894.36^{a} \pm 1,836.39$

$^{a-c}$ = Means in the same column having different lowercase superscripts differ significantly ($P < 0.05$).

overrun value is a high hardness value.

The meltdown percentage of vanilla-flavored ice cream with different sweeteners, in ascending order, was sucralose < erythritol < maltitol < sucrose (control) < xylitol. The physical structure of the ice cream does affect its melting rate and hardness (Muse and Hartel, 2004). The sucralose recipe had low overrun and high hardness resulting in the lowest meltdown as shown in Figure 3. On the other hand, the hardness of the xylitol formula sample was the lowest whereas the overrun was the highest; as a result, of its melting rate being the maximum.

The color and pH of vanilla-flavored ice cream products are shown in Table 3. It was found that the colors of the erythritol and maltitol formulas were more intense than that of the control. Similarly, the application of sucralose that required only a small amount resulted in extreme color. The xylitol recipe had color most similar to the control. These results occurred because the xylitol was added in the same amount as sucrose but erythritol and maltitol were added at 125 and 111% of the sucrose weight resulting in lower lightness and higher redness and yellowness than in the control recipe. The pH of ice cream was observed in the range 6.09–6.23. In general, the pH of sugar and sweeteners is in the range 5–7; therefore, the pH levels of the ice cream samples were in the normal range.

The freezing point of ice cream mixture is considered to be another important factor for the manufacturer as it affects the texture, mouthfeel and the efficiency of freezing machine (Baer and

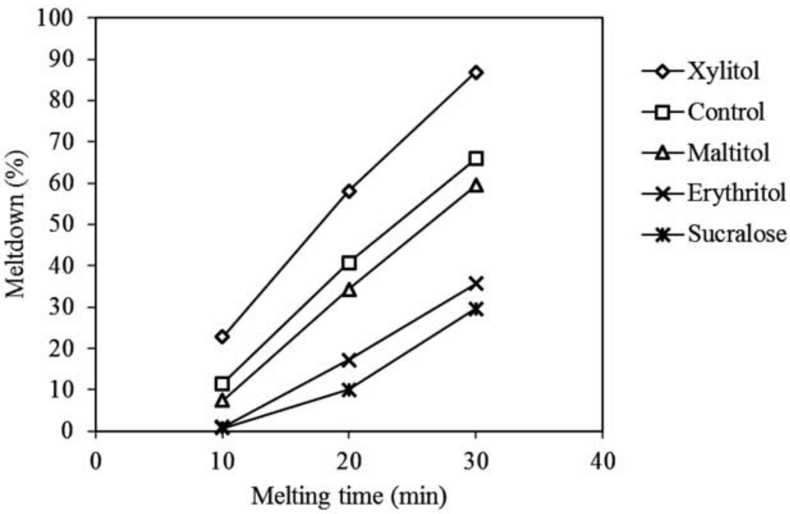


Figure 3 Meltdown percentage over time for vanilla-flavored ice cream with different sweeteners.

Table 3 Mean (± SD) color and pH of vanilla-flavored ice cream with different sweeteners.

Sweetener	Color			pH
	L*	a*	b*	
Control	$85.31^{b} \pm 0.88$	$-1.47^{e} \pm 0.22$	$23.65^{c} \pm 0.48$	$6.09^{e} \pm 0.00$
Erythritol	$69.45^{d} \pm 0.98$	$6.83^{a} \pm 0.32$	$43.35^{a} \pm 1.02$	$6.20^{b} \pm 0.01$
Maltitol	$78.67^{c} \pm 0.26$	$5.08^{b} \pm 0.30$	$37.21^{b} \pm 0.54$	$6.23^{c} \pm 0.00$
Xylitol	$86.88^{a} \pm 0.08$	$-0.77^{d} \pm 0.51$	$23.03^{c} \pm 1.74$	$6.15^{a} \pm 0.01$
Sucralose	$85.12^{b} \pm 0.42$	$1.99^{c} \pm 0.47$	$36.00^{b} \pm 1.17$	$6.11^{d} \pm 0.01$

a-e = Means in the same column having different lowercase superscripts differ significantly ($P < 0.05$). Color system based on Hunter and Harold (1987).

Keating, 1987; Muse and Hartel, 2004). Table 4 and Figure 4 show the freezing points of the ice cream mixtures with the different sweeteners. It was found that the sucrose-added sample had the lowest freezing point (-8.3 °C) whereas the freezing points of the other samples were significantly (P < 0.05) higher than that of the control. The freezing point of ice cream mixes depends upon the soluble ingredients in the mixture and the freezing point of ice cream mix is depressed mainly by the sugar (Baer and Keating, 1987; Kilara and Chandan, 2006) while fat and protein are not soluble; therefore, they have an indirect effect on the freezing point. The information obtained in the current work is useful for the development of ice cream formulation and production lines.

The sensory scores of the vanilla-flavored ice cream samples are shown in Figure 5. All the sensory parameters were significantly (P < 0.05) affected by the addition of different sweeteners. All sensorial attributes of products were scored between 4 and 5 (neither like nor dislike = 4 and like slightly = 5). The xylitol formula got a higher sensorial score compared to the control recipe. The sensorial characteristics of the samples with sucralose were not significantly (P > 0.05) different from the control in all aspects while the mouthfeel and smoothness of maltitol and xylitol recipes were significantly (P < 0.05) different from the control.

The estimated sweetener costs for producing 1.5 L of vanilla-flavored ice cream are presented in Table 5. Due to the small amount of sucralose applied to reach the equivalent sweetness as sucrose, the sucralose formula was the least expensive. Though the unit prices of sugar alcohols were reasonable, the bulk addition caused the formula to be more expensive than the original formula and the intense sweetener substitution.

It can be seen that the development of sugar-free ice cream, made with only one type of bulk or intense sweetener might not offer all

Table 4 Mean (± SD) freezing points of vanilla-flavored ice cream with different sweeteners

Vanilla-flavored ice cream formula	Freezing point (°C)
Control (sucrose)	$-8.3^{d} \pm 0.06$
Maltitol	$-2.7^{b} \pm 0.20$
Xylitol	$-5.7^{c} \pm 0.10$
Sucralose	$-1.7^{a} \pm 0.30$

$^{a-d}$ = Means in the same column having different lowercase superscripts differ significantly (P < 0.05) and the erythritol sample was inadequate for freezing point determination.

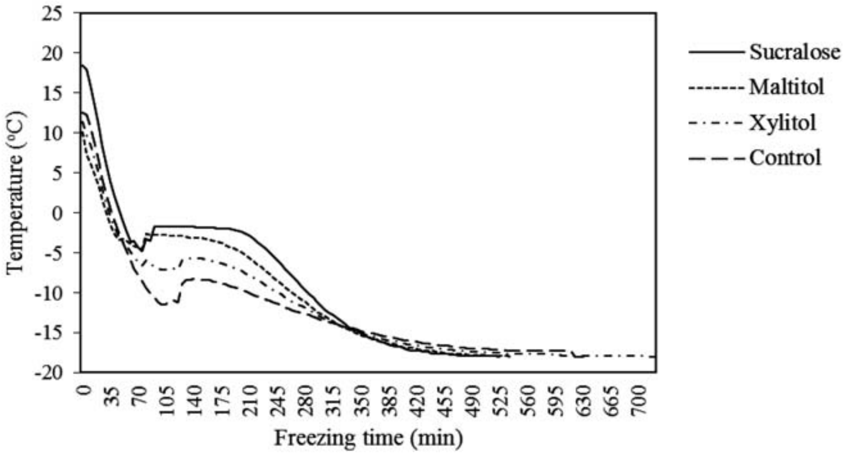


Figure 4 Freezing curves of vanilla-flavored ice cream with different formulas.

good physical and sensorial qualities. As a result, a half reduction in the amount of sugar and its replacement with sucralose in yoghurt-flavored ice cream was examined. Yoghurt ice cream in this study was produced from: 1) whey protein powder and cow's milk yoghurt with or without added sucralose and inulin; and 2) buffalo milk and yoghurt with or without added sucralose and inulin.

Overrun values of yoghurt-flavored ice cream samples are shown in Figure 6. The range of the overrun values of cow milk yoghurt ice cream and buffalo milk yoghurt ice cream was 43.05–45.83% and 26.12–28.74%, respectively. The overrun of buffalo yoghurt ice cream was significantly ($P < 0.05$) lower than for the cow yoghurt formulas by an estimated 1.5 times, which indicated that the overrun values of the ice cream decreased with the type of milk used. When comparing the influence of sucralose and inulin addition on the overrun of samples of each type of milk, it was observed that the overrun values of ice cream with sucralose replacement and added inulin were slightly lower than samples without the addition.

The sensorial scores of the yoghurt ice cream samples are presented in Figure 7. The results showed that all sensory properties of the four yoghurt-flavored ice cream formulas were not significantly ($P > 0.05$) different. The acceptance scores of the yoghurt flavor and sourness attributes of the buffalo formulas were low due to buffalo

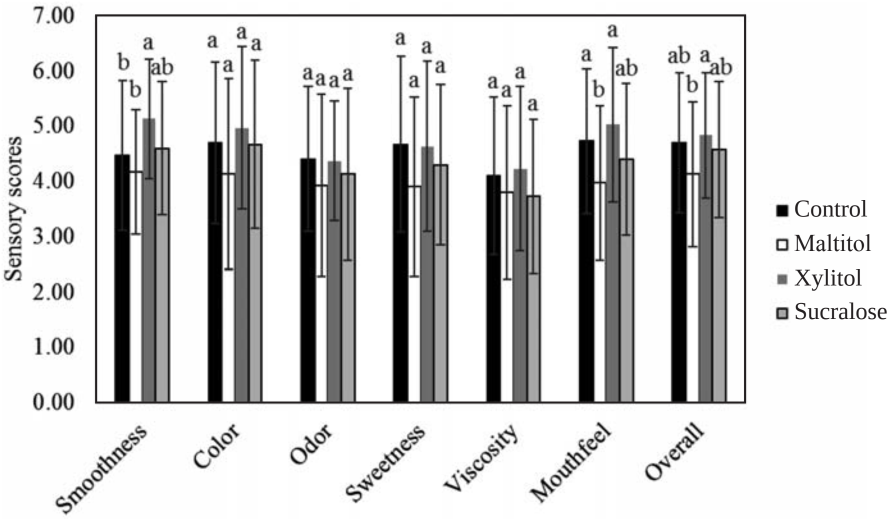


Figure 5 Mean sensory scores of vanilla-flavored ice cream made using different sweeteners. Means with different lowercase letters above each column for the same sensory attribute differ significantly ($P < 0.05$). The erythritol sample was inadequate for sensory testing. Vertical error bars show ± SD.

Table 5 Weight and cost of sucrose and sugar replacers in 1.5 L of vanilla-flavored ice cream.

Description	Sweetener				
	Sucrose	Erythritol	Maltitol	Xylitol	Sucralose
Added amount (g)	333.00	416.00	396.63	333.00	0.55
Price per kg (THB)	23.50	237.85	44.00	338.00	9,120.00
Cost of added sweetener (THB)	7.83	98.95	17.45	112.55	5.02

1 USD ≈ 33 THB.

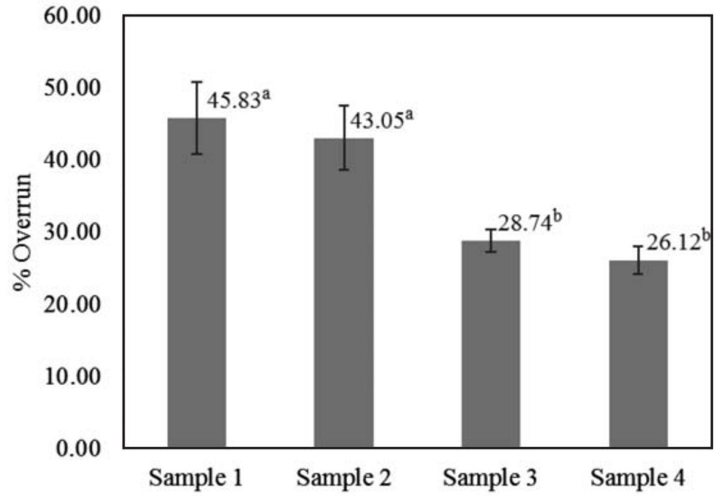
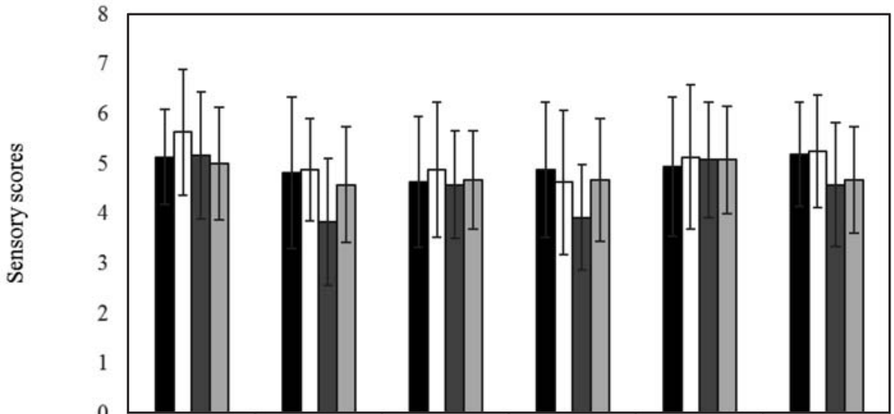


Figure 6 Overrun values of yoghurt-flavored ice cream samples. Sample 1 = Yoghurt ice cream; Sample 2 = Yoghurt ice cream added with sucralose and inulin; Sample 3 = Buffalo yoghurt ice cream; Sample 4 = Buffalo yoghurt ice cream added with sucralose and inulin. Means having different lowercase superscripts differ significantly ($P < 0.05$). Vertical error bars show ± SD.



	Smoothness	Yoghurt flavor	Sweetness	Sourness	Mouthfeel	Overall
■ Sample 1	5.13	4.81	4.63	4.88	4.94	5.19
□ Sample 2	5.63	4.88	4.88	4.63	5.13	5.25
■ Sample 3	5.17	3.83	4.58	3.92	5.08	4.58
■ Sample 4	5.00	4.58	4.67	4.67	5.08	4.67

Figure 7 Mean sensory scores of yoghurt-flavored ice cream. Sample 1 = Yoghurt ice cream; Sample 2 = Yoghurt ice cream with added sucralose and inulin; Sample 3 = Buffalo yoghurt ice cream; Sample 4 = Buffalo yoghurt ice cream with added sucralose and inulin. Sensorial attribute values of four ice cream formulas were not significantly different ($P > 0.05$). Vertical error bars show ± SD.

yoghurt having a specific flavor and less acidity. However, the overall acceptance scores of cow milk yoghurt ice cream (sample numbers 1 and 2) were slightly liked (the sensorial scores were 5.19–5.25) and higher than the sensory scores for the buffalo milk recipes (sample numbers 3 and 4) as shown in Figure 7. When low concentrations of inulin were added into the product, the sensory quality and the rheological properties of the product were not intensely affected because of the neutral or mild sweet taste and the limited effect on viscosity of this ingredient (Franck, 2002; Kalyani Nair *et al*., 2010; Meyer *et al.*, 2011).

CONCLUSION

This research showed the potential of applying sugar replacer in vanilla-flavored ice cream production. The results indicated that sugar alcohols led to higher viscosity whereas sucralose resulted in the converse effect. The addition of xylitol increased the overrun value, lightness and melting rate. The freezing temperatures of all ice cream formulas containing sugar replacer were higher than that of the control. The samples with xylitol obtained high sensorial scores and were not significantly different from the control. The applied amount of sucralose in a recipe was minimal resulting in a low sweetener cost. The yoghurt-flavor ice cream formulas, with both cow and buffalo recipes with or without sucralose replacement and added inulin, provided similar sensorial acceptance; nevertheless, the buffalo yoghurt ice cream had a lower overrun. The overall results showed that it is possible to produce sugar-free, vanilla-flavored ice cream and yoghurt-flavored ice cream with reduced sugar by half replacing the sugar with sucralose and the incorporation of inulin.

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