International Food Research Journal 22(3): 1138-1147 (2015)
Journal homepage: *http://www.ifrj.upm.edu.my*

Qualities and sensory characteristics of coconut milk ice cream containing different low glycemic index (GI) sweetener blends

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Article history

Received: 3 August 2014
Received in revised form: 13 October 2014
Accepted: 20 October 2014

Keywords

Coconut milk ice cream
Glycemic index
Sweeteners
Physical properties
Sensory properties

Abstract

The development of a low glycemic index (GI) coconut milk ice cream by replacing 12% sucrose with different low GI sweeteners (xylitol, erythritol, inulin and fructose) was investigated. Three mixtures of sweeteners (6.2% xylitol + 7% inulin, 4% erythritol + 7% inulin + 2.15% fructose, 8.5% inulin + 5% fructose) were reformulated to obtain the similar characteristics as using 12% sucrose, including sweetness, freezing point depression (FPD) (-2.5 to -3.0) and total solid (40 ± 1%). All ice cream samples containing sweeteners had similar FPD and unfrozen water (UFW) as compared to the control (12% sucrose) ($p > 0.05$). Flow behavior of ice cream added with erythritol + inulin + fructose were pseudoplastic flow ($n < 1$) and had the highest consistency coefficient. However, the ice cream substituted sucrose with inulin + fructose possessed the lowest melting rate ($p \leq 0.05$). Sensory evaluation results showed that firmness and meltdown intensities as well as acceptance scores of all attributes of ice cream with erythritol + inulin + fructose were not different from the control ($p \leq 0.05$). In addition, GI value of ice cream containing erythritol + inulin + fructose was the lowest and approximately 64% lower than that of the control. Therefore, the mixture of erythritol, inulin and fructose might be successfully used to replace sucrose as sugar sources in low GI coconut milk ice cream production.

Introduction

Ice cream is a highly complex food matrix, containing proteins, fat, sugars, air, minerals, etc. and countless interfaces between the different constituents (Frost *et al*., 2005). Sugars or sweeteners provided as corn syrup solids or sugar alcohols are of the most importance ingredient for the structural and sensorial characteristics of ice cream as well as for its storage stability (Conforti, 1994; Stampanoni-Koeferli *et al*., 1996; Miller-Livney and Hartel, 1997; Bordi *et al*., 2004). They especially impart the sweet taste to ice cream, enhance the flavor and control its temporal release during consumption, improve the perceived creaminess, mask the sourness and astringency, and affect its body and melting behavior (Conforti 1994; Guinard *et al*., 1994; 1996; 1997; Stampanoni-Koeferli *et al*., 1996). Therefore, sweetness control in ice cream is very crucial in order to achieve maximum consumer acceptance (Wilson-Walker, 1982). However, sucrose, the most widely used sweeteners in ice cream, provides high calories and moderately high GI, leading to limitation for consumers concerning with health or suffering from diabetes and obesity.

The glycemic index (GI) is a measure of the ability of food, specifically the carbohydrate in food, to raise blood sugar (glucose) levels after consumption, compared with an equivalent dose of glucose. Low-GI foods release glucose slowly into the blood, producing a gradual and relatively low rise in blood glucose and insulin levels which play an important role in the dietary management of diabetes (Jenkins *et al*., 1981). Several studies have been reported on diabetic or low-calories ice cream. Whelan *et al*. (2008) revealed that the low GI ice cream containing tagatose (6%), polydextrose (6%) and maltitol (3%) or maltitol (15%) and trehaolse (2.5%) in a formulation with milk, cream and milk protein concentrate (MPC) showed satisfaction in both physicochemical and sensory requirements. Soukoulis *et al*. (2010) reported that partial substitution of sucrose with macromolecular sweeteners, such as corn starch hydrolysed oligosaccharides led to increase in consistency coefficient, apperance viscosity, thixotropy index and improving of creaminess, mount-coating as well as reduced icy and coarse sensation. The use of polyols (xilitol, sorbital, maltitol, etc.) had also a positive impact on the rheological properties of ice cream mixes and enhanced vanilla flavor. However, polyols addition resulted in significant decrease in the hardness and creaminess and increase in coarseness and iciness (Soukoulis *et al*., 2010). Soukoulis *et al*.

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(2010) found that maltose and maltitol functionality was very similar to that of sucrose. Ozdemir *et al.* (2003) produced diabetic ice cream using maltitol, sorbitol and high-fructose corn syrup as the sweetening agents and compared them with a sucrose-sweetened control. Sensory analysis showed that maltitol-based ice cream was more preferred than that containing sorbitol.

In Thailand, coconut ice cream is an alternative ice cream product for Thai manufacturers, since the main raw material is an economic plant. In addition, coconut ice cream provides a unique flavor and is suitable for Halal consumers. Thus, replacement of sucrose with low GI sweeteners such as maltitol, tagatose, xylitol and erythritol can be alternative way of development of coconut milk ice cream that meet consumers need.

However, no report has been published on formulation of low GI coconut milk ice cream. From our previous study showed that sucrose substitution with a single low GI sweetener (12.83% xylitol, 19.51% erythritol or 24% inulin) in coconut milk ice cream production significantly affected the physical, chemical and sensory characteristics of the coconut milk ice cream samples ($p \leq 0.05$) and led to lower acceptance scores when compared to the control (12% sucrose) ($p \leq 0.05$) (Fuangpaiboon and Kijroongrojana, 2013). Therefore, the objective of the present study was to optimize formulation of low GI sweetener blends matching sensory and physical properties as well as freezing point depression (FPD) of the control coconut milk ice cream.

Materials and Methods

Materials

The mature coconut meat (*Cocos nucitera* Linn.) used in this study was grown in Narathiwat province, Thailand. The coconut milk was prepared by pressing coconut meat using a hydraulic press (Thai Sakaya-A2, Sakaya, Thailand). The obtained coconut milk consisted of 19% fat, 2.73% protein, 57.74% moisture, 0.82% ash and 19.71% carbohydrate. Milk solid not fat (MSNF) was purchased from Fa'avae Enterprises Co., Ltd. (Woodridge Brisbane, Queensland, Australia). Mono-diglycerides, locust bean gum, xylitol and fructose were obtained from DupontTM Danisco® Co., Ltd. (Terre Haute, IN, USA). Erythritol was purchased from Zibo Green Biotech Co., Ltd. (Zibo, China). Inulin (Orafti®HP, DP 2-5) was obtained from Beneo-Orafi Co., Ltd. (Tienen, Belgium). Sucrose was purchased from Mitr Phol Co., Ltd. (Bangkok, Thailand).

Preparation of coconut milk ice cream

Formulations of coconut ice cream added with different low GI sweetener blends and the control with 12% sucrose are shown in Table 1 (Modified from Surapat and Rugthavon, 2003). Blend sweeteners prepared from various common sweeteners including xylitol (sucrose equivalent for sweetness, SE = 87-100), erythritol (SE = 53-70), inulin (SE = 40-60) and fructose (SE = 180-190) at different proportions (Whelan *et al.*, 2008) were used to replace sucrose in the formulation (Table 1). The amount of sweeteners of each blend in the formulations was calculated to obtain similar sweetness to the control (SE = 12 ± 3) with 40 ± 1% total solid and the target of freezing point depression (FPD) of -2.5 to -3.0 using equation according to Marshall *et al.* (2003) with slight modification.

$$SE_{FPD} = (MSNF \times 0.545) + S + (\text{Blend sweeteners} \times FPD_{sweetener}) + (\text{Sugars from coconut milk} \times FPD_{sugar})$$

where SE_{FPD} = Sucrose equivalent for freezing point depression (FPD); MSNF = milk solid not fat; S = sucrose or other disaccharides; Sweeteners = xylitol or erythritol or inulin or fructose; FPD of xylitol or erythritol or inulin or fructose is 2.25, 2.80, 0.74 and 1.9, respectively; Sugars from coconut milk comprised of 5.71% sucrose, 0.07% glucose and 0.73% fructose. FPD of sucrose (or other disaccharides) and fructose (or other monosaccharides) are 1 and 1.9, respectively.

To calculate the freezing point of a mix, the equivalent concentration of sucrose in water (g/100 g water) was determined by dividing the SE_{FPD} by the water content.

$$\text{g sucrose/100g water} = SE_{FPD} \times 100/W$$

where W is the water content (%).

To obtain the freezing point depression associated with this concentration of SE in water (FPD_{SE}), Table of freezing point depression (°C) below 0°C of sucrose solution (g/100g water) was used (Marshall *et al.*, 2003).

The contribution to freezing point depression from salts (FPDSA) in MSNF was calculated according to the following equation (Marshall *et al.*, 2003):

$$FPD_{SA} = (MSNF \times 2.37) / W$$

FPD_T, the two contributions are summed.

$$FPD_T = FPD_{SE} + FPD_{SA}$$

Table 1. Constituents of sweetener mixes used for production of low GI coconut ice creams

Ingredients (%)	Samples			
	Control	E + I + F	X + I	I + F
Fat (from Coconut milk)	8	8	8	8
Sucrose	12			
Inulin (I)		7	7	8.5
Erythitol (E)		4		
Xylitol (X)			6.2	
Fructose (F)		2.15		5
MSNF	10	10	10	10
Locust bean gum	0.1	0.1	0.1	0.1
Mono-diglycerides	0.1	0.1	0.1	0.1
Culculated SE	12	9.94	9.3	13.5
Calculated FPD	-2.61°C	-3.13°C	-3.00°C	-2.56°C

Example of SE calculation for ice cream containing 4% erythritol, 7% inulin and 2.15% fructose.

$$SE = \Sigma(\text{Sweeteners} \times (SE/100))$$
$$SE=(4\times(61.5/100))+(7\times(50/100))+(2.15\times(185/100)) = 9.94$$

Example of FPD calculation for ice cream mix containing 8% fat (42.1% coconut milk), 10% MSNF, 0.1% locust bean gum, 0.1% mono-diglyceride, 4% erythritol, 7% inulin, 2.15% fructose and 60.30% water content (39.70% total solids).

First, calculate the sucrose equivalents for FPD:

$$SE_{FPD} = (10\times0.545) + 0 + [(4\times2.8) + (7\times0.2) + (2.15\times1.9)] + [2.403 + (0.031\times1.9) + (1.011\times1.9)] = 26.52$$

The equivalent concentration of sucrose in water is,

$$\text{g sucrose/100 g water} = 26.52 \times 100/60.30 = 43.98$$

Now, by interpolation find the freezing point depression for this level of sucrose equivalent from Table of freezing point depression (°C) below 0°C of sucrose solution (g/100g water).

$$FPD_{SE} = 2.74°$$

For salts:

$$FPD_{SA} = (10\times2.37)/60.30 = 0.39°$$

Find the total freezing point depression of the mix:

$$FPD_{T} = 2.74° + 0.39° = 3.13°$$

Thus, the initial freezing point temperature for this ice cream mix is -3.13°C

The ice cream mix was prepared by dispersing the dry blend of stabilizer, sweeteners, emulsifier and skimmed milk into the liquid materials at 50°C using water bath (W350 Memmert, Frankfurt, Germany) for 10 min. The mixture was heated up to 60°C and homogenized using homogenizer (APV-Gaulin, Minilab 8.30H, Massachusetts, USA) for 2 min at 5,000 rpm. The mixture was pasteurized at 80°C for 2 min and rapidly cooled down using iced water. The ice cream mix was aged in a cold room at constant temperature (4 ± 0.5°C) for 24 h. Some part of the aged mix was subjected to determinations of rheological properties, overrun and thermal properties. The rest was pre-whipped using a batch freezer (Taylor, Model 104-40, Illinois, USA) at a constant whipping time of 15 min. The ice cream was then packed into 50 mL high density polyethylene (HDPE) containers, covered with plastic lid and stored at -20°C for at least 24 h before subjected to analyses.

Analyses of ice cream mixes and ice creams

Chemical Analyses

Total solids

Total solid content was determined according to AOAC (2000). One to five grams of sample was accurately weighed into a pre-weighed round flat-bottomed metal dish provided with a fitting lid (about 5 cm diameter). The uncovered dish was placed on a boiling-water bath for 30 min or until most of the moisture was driven off. The bottom of the dish was then wiped off and the dish was transferred to an oven at 105 ± 2°C. They were dried for 3 h in the oven and then cooled for 30 min in a desiccator and weighed. The dish and the lid was heated again for 30 min periods in the oven, cooled and weighed until the difference between the two successive weightings did not exceed 1 mg.

Total and reducing sugar

The total sugar and reducing sugar contents were quantified by the Lane and Eynon Volumetric method using titration with Fehling's reagents (Ranganna, 1986). The results were expressed as grams of glucose per 100 g of sample.

Glycemic index (GI)

GI value of the product was calculated based on the sum of ingredient proportional GI as described by Schakel *et al*. (2008) using the following equations:

$$\text{GI of the product} = \Sigma(\text{ingredient proportion GI}) = \Sigma((ACHOi/ACHOT) \times GI_i)$$

when $ACHO_i$ is the weight of carbohydrate of each ingredient available in food.

$ACHO_T$ is the weight of total carbohydrate in food,

GI_i is the GI value of each ingredient (obtained from International table of glycemic index (Foster-Powell *et al*., 2002)).

Physical properties

Rheological properties

Rheological measurement was conducted according to the method of Karaca *et al.* (2009) using a rheometer (Haake, RS75, Duisburg, Germany) coupled with a Peltier/Plate TCP/P temperature control unit (Haake K10, Duisburg, Germany) and a coaxial cylindrical system. The ice cream mix at 4°C was allowed to rest for 5 min after loading before measurement. The flow curve was obtained by registering shear stress *(τ)* at sweeping shear rates (γ) from 0.5 to 200/s in 120 s and down in 120 s at 20°C. The Oswalt-de-Waele power-law model was used to describe the data of shear-induced behavior of the ice cream (Karaca *et al.*, 2009):

$$\tau = K\gamma^{n}$$

where *K* is the consistency index or apparent viscosity ($Pa.s^n$); n, the flow behavior index, is dimensionless and also reflects the closeness to Newtonian flow.

Hardness

The hardness of ice cream samples was determined using a Texture Analyzer (TA.XT2i, Stable Microsystems, Surrey, England) following the method of Soukoulis *et al.* (2010) with some modifications. Prior to testing, ice cream samples that had been tempered at -20°C were transferred to room at 26 ± 2°C for 1 min. The measurement was carried out using a 6 mm stainless steel cylindrical probe (SMSP/6) attached to a 25 kg load cell. The penetration depth at the geometrical centre of the sample was 10 mm and the penetration speed was set at 2.0 mm/s. Hardness (g) of the samples was determined as the peak compression force during penetration.

Melting rate

Ice cream samples (80 g) were placed on a 12-mesh grid at room temperature (26 ± 2°C). The weight of the ice cream at time 0 and of the 'dripped portion' passing through the screen were recorded every 10 min for 120 min. Tests were done in triplicate. The time (min) was plotted against the dripped weight (as % mass loss) and the maximum meltdown rate corresponded to the highest gradient (slope) in the ascending meltdown curve (Whelan *et al*., 2008).

Overrun

Overrun was measured by comparing the weight of mix and ice cream in a fixed volume container and was calculated as follows (Whelan *et al*., 2008):

% Overrun = [(weight of mix - weight of ice cream) × 100] / (weight of ice cream)

Color

Color was measured by Hunter Lab (C04-1005-631 colorFlex, Reston,VA, USA). A colorimeter was adjusted for reflectance, illuminant D 65, and angle of 10°. A colorimeter was standardized with black glass and white tile. Instrumental color data was provided in accord with the CIE system in terms of L^* (lightness), a^* (redness and greenness) and b^* (yellowness and blueness).

Thermal behavior

Thermograms were obtained by a differential scanning calorimeter (DSC) (Q1000, TA Instruments, New Castle, DE, USA). The DSC instrument was calibrated with pure indium standard before analysis. 15 mg aliquots of each sample (ice cream mix) was sealed into aluminum pans (50 µL, Perkin–Elmer) and placed into the DSC. The implementing protocol according to Soukoulis *et al*. (2010) included the following steps: (a) cooling to -80 °C at 10 °C/min, (b) heating from -80°C to -40°C at 10 °C/min and annealing at the same temperature (-40°C) for 30 min to promote maximal ice formation, (c) cooling to -80°C at 10°C/min and isothermal holding for 5 min, (d) heating from -80 to 20°C at 5°C/min. Freezing point of the formulation was calculated from the DSC melting curves by determining the temperature at which the steepest slope will be observed.

The amount of ice formed per gram of sample (IC) was determined by integrating the melting peak and dividing the melting enthalpy with the pure ice fusion latent heat ($\Delta H = 334\ J\ g^{-1}$). The percentage of unfrozen (bound) water (UFW) was calculated using the following formula (Soukoulis *et al*., 2010):

UFW (%) = Moisture content (%) – IC (%)

Sensory Analysis

Generic Descriptive Analysis

A generic descriptive analysis (Lawless and Heymann, 2010) was used to develop the language and measurement protocols for the evaluation of all samples. The sensory characteristics of the coconut ice cream were judged by 12 trained panelists. The ice cream samples were served in the 50 g plastic container placed in a 2-L-polystylene container to ensure that all ice creams were of the same consistency. The cups were labelled with random three-digit codes. The order of presentation of the samples was randomized according to "balance order and carry-over effects design" (Macfie *et al*., 1989). Initially, judges developed a list of terms describing the attributes of ice cream using references samples. Definitions were also given for each of the four terms chosen (firmness, meltdown, mouth-coating and sweetness). Then, the judges were practiced on scaling by rating intensities of reference samples (Table 2). The final score sheet and test protocol were agreed to accurately measure the test products, then step testing panelist performance and finalise a list of the panel members to work on sample evaluation. Panelists undertook a 30-hours training programme. Table 2 displays the sensory attributes used in generic descriptive analysis as well as their definitions and references used for panelists training. A 15 cm line scale, anchored with the words 'low' and 'high' 1.5 cm from each end, was used to rate intensity of the attributes. The samples stored at −20°C, were removed from the freezer and tempered for 2 min at -2 ± 2°C prior to sensory testing. After testing the sample, the panelists were required to rinse their mouths with warm water between samples.

Acceptance Test

The acceptance of ice cream was judged by 35 panelists who commonly consume coconut milk ice cream using a 9-point Hedonic Scale for appearance, flavor, texture and overall liking. The samples were presented and served as mentioned in generic descriptive analysis part.

Statistical analysis

Experiments were run in triplicate using three different lots of samples. A completely randomized design (CRD) were used for the statistical analysis of physical and chemical analysis as well as generic descriptive analysis. A randomized complete block design (RCBD) were performed for the analysis of acceptance test. Data was subjected to analysis of variance (ANOVA). Means were compared by Duncan's multiple range test at a significant level $p<0.05$. Investigation of correlation coefficient (r) between physical properties and sensory data was also conducted. Analysis was performed using the Statistical Package for Social Science (SPSS 10.0 for windows, SPSS Inc., Chicago, IL, USA).

Table 2. Sensory descriptors for generic descriptive analysis of coconut milk ice cream

Attributes	Definitions	References	Intensity
Firmness	The force required to compress the sample between the tongue and palate.	Coconut milk ice cream added with 7% xylitol + 7% inulin, 4% erythritol + 7% inulin and 12% sucrose	7.5 9.5 3.5
Meltdown	The time required for the product to melt in the mouth when continuously pressed by the tongue against the palate. Sample size is 1/3 tsp.	Coconut milk ice cream added with 7% xylitol + 7% inulin, 4% erythritol + 7% inulin and 12% sucrose (3.5 cm)	10.5 11.5 3.5
Mouth-coating	A sensation of having a slick/fatty coating on the tongue and other mouth surfaces.	Coconut milk ice cream added with 7% xylitol + 7% inulin, 4% erythritol + 7% inulin and 12% sucrose	9.5 11.5 7.5
Sweetness	Taste on the tongue elicited by sugars or other high potency sweeteners	Coconut milk ice cream added with 8% sucrose, 10% sucrose, 12% sucrose and 14% sucrose	5.5 7.5 10 13

Results and Discussion

Chemical properties of coconut milk ice cream

Solid, reducing and total sugars

Total solids, reducing and total sugars of coconut milk ice cream with different sweetener blends are shown in Table 3. The total solid of all ice cream samples were in the range of 39.70 to 40.21. The use of different sweetener blends in the ice cream production significantly affected the sugar contents of ice cream samples ($p \leq 0.05$). Sweetness control in ice cream is very important in achievement of maximum consumer acceptance and minimum production cost (Wilson-Walker, 1982). The amount of sweeteners create desirable flavor properties, and are the major ingredients to lower the freezing point, which is one of the influential factors for quality of the ice cream mixes. Furthermore, sweetener concentration also affected viscosity of the mix and firmness of the ice cream (Baer and Baldwin, 1984). Reducing sugar of the samples was slightly different among the samples mostly due to lactose from MSNF and the blends containing fructose, a reducing hexose. MSNF is composed of approximately 55% lactose, 37% protein, 8% minerals and others including vitamins, acids and enzymes (Arbuckle, 1986). Total sugar contents of ice cream added with sweetener blends were lower than the control ($p \leq 0.05$). Most of total sugar content of sucrose-replacing ice cream samples was contributed by lactose, fructose and inulin in the formulation. A quantitative determination of

Table 3. Chemical, rheological and thermal properties of coconut milk ice cream with various sweeteners

Sweeteners	Chemical properties				Rheological properties		Thermal behavior	
	Total solid (%)	Reducing sugar (%)	Total sugar (%)	Glycemix index	Consistency coefficient, K (Pa.s^n)	Flow behavior index, n	Freezing point (°C)	Unfrozen water (%)
Sucrose	39.71 ± 0.06^b	3.95 ± 0.02^c	18.95 ± 0.18^a	51.569	0.018 ± 0.001^a	0.863 ± 0.006^b	-2.90 ± 0.25^a	22.56 ± 3.78^a
E + I + F	39.70 ± 0.10^b	4.78 ± 0.21^b	12.73 ± 0.37^c	18.474	0.015 ± 0.003^{ab}	0.863 ± 0.010^b	-2.87 ± 0.42^a	22.65 ± 3.86^a
X + I	40.20 ± 0.24^a	4.13 ± 0.19^c	10.49 ± 0.11^d	18.544	0.013 ± 0.002^b	0.986 ± 0.040^a	-2.03 ± 0.65^a	24.12 ± 1.81^a
I + F	40.21 ± 0.16^a	5.54 ± 0.28^a	18.32 ± 0.45^b	20.584	0.013 ± 0.001^b	0.991 ± 0.029^a	-2.76 ± 0.89^a	22.21 ± 1.95^a

All values are means ± standard deviation (n = 3). For each run, three determinations were conducted.
[a-c] In the same column within sweeteners or sweetener blends, mean values followed by the different superscripts are significantly different ($p \leq 0.05$)

total sugar is a measurement of aldose oxidized to aldonic acid (Bemiller and Whistler, 1996). During acid hydrolysis, inulin can be converted into D-fructose which is classified as aldose group. Nevertheless, erythritol and xylitol are polyhydric alcohols with the formular of $(CHOH)_2(CH_2OH)_2$ and $(CHOH)_3(CH_2OH)_2$, respectively (Whelan *et al.*, 2008) and do not take part of that reaction.

Glycemic index

The GI is a measure of the ability of food, specifically the carbohydrate, to raise blood sugar (glucose) levels after consumption, compared with an equivalent dose of glucose. Foods with a low GI play an important role in the dietary management of diabetes, weight reduction, peak sports performance and the reduction of risks associated with heart disease and hypertension (Jenkins *et al.*, 1981). The GI values of coconut milk ice creams added with sucrose and various sweetener blends are shown in Table 3. As expected, the control ice cream had the highest GI value (51.569) ($p \leq 0.05$). GI values of ice creams added with erythritol + inulin + fructose, xylitol + inulin and inulin + fructose were 18.474, 18.544 and 20.584, respectively, which were approximately 64% lower than that of the control. This was simply due to the fact that xylitol, erythritol and inulin have low GI with the value of 7, 0 and 0, respectively, whereas sucrose has GI value of 59 (Whelan *et al.*, 2008). Whelan *et al.* (2008) reported that the low GI ice cream containing tagatose (6%), polydextrose (6%) and maltitol (3%) or maltitol (15%) and trehaolse (2.5%) in a formulation with milk, cream and milk protein concentrate (MPC) showed satisfaction in both physicochemical and sensory requirements. The lower GI of coconut milk ice cream with sweeteners indicated release glucose slowly into the blood, producing a gradual and relatively low rise in blood glucose and insulin levels which play an important role in the dietary management of diabetes (Jenkins *et al.*, 1981).

Flow behavior of coconut milk ice cream

The effects of low GI sweeteners addition on the rheological characteristics of ice cream mixes are given in Table 3. Flow behaviors of all ice cream samples were pseudoplastic flow ($n < 1$) where the viscosity *(n)* decreased with increasing shear rate (γ). Pseudoplastic behavior ($n \approx$ 0-1) was widely observed for various milk ice cream (Soukoulis *et al.*, 2009; Soukoulis *et al.*, 2010). Different sweetener blends added affected the flow behavior of coconut milk ice cream differently, as indicated by power laws index *(n)* (Table 3). From the results, the power laws index *(n)* of all coconut milk ice cream was slightly different which was in the range of 0.860-0.991. However, the ice creams with sucrose and E+I+F had lower n value than did those with X+I and I+F ($p \leq 0.05$). This indicated that the former showed more shear thining behavior than the former. Soukoulis *et al.* (2010) reported that flow behavior of all ice cream partially substituted 7-16 % sucrose by bulk sweeteners were pseudoplastic flow ($n < 1$). However, there was no different in the behavior between coconut milk ice cream added with sucrose and E+I+F. For consistency coefficient *(K)*, the control coconut milk ice cream added with sucrose and E+I+F had the highest K ($p \leq 0.05$), following by those with X+I and I+F, respectively. Similar K value was found in ice creams containing E+I+F, X+F and I+F ($p > 0.05$). These three formulations also showed lower K value than the control ($p \leq 0.05$). Addition of E+I+F or X+I or I+F might lead to the formation of weaker interaction among the components in the ice cream mixes, resulting in less resistance to shear deformation as compared to those with sucrose. The high consistency index *(K)* indicates the more viscous mix (Karaca *et al.*, 2009). Marshall *et al.* (2003) reported that water holding capacity, degree of polymerization and branching of polysaccharide were among the most critical factors influencing viscosity development in ice cream mixes. Due to sample complexity, rheology is affected by many factors including the presence of components (e.g. fat, polysaccharides and proteins) and their concentrations, hydration phenomena occurring

Table 4. Physical properties of coconut milk ice cream with various sweeteners

Sweeteners	Hardness*** (g)	Melting rate* (g/min)	Overrun* (%)	Color**		
				L*	a*	b*
Sucrose	847.86 ± 34.74^{c}	1.51 ± 0.01^{a}	30.59 ± 3.24^{a}	90.37 ± 0.30^{b}	-0.92 ± 0.11^{ab}	14.47 ± 0.61^{a}
E + I + F	851.50 ± 26.06^{c}	1.47 ± 0.02^{b}	30.23 ± 2.87^{a}	90.49 ± 0.42^{b}	-1.06 ± 0.19^{b}	14.41 ± 0.84^{a}
X + I	1043.38 ± 55.40^{b}	1.52 ± 0.02^{a}	26.11 ± 1.42^{a}	89.16 ± 0.23^{c}	-0.86 ± 0.12^{a}	14.86 ± 0.83^{a}
I + F	1086.28 ± 44.03^{a}	1.40 ± 0.02^{c}	29.02 ± 0.86^{a}	91.05 ± 0.31^{a}	-0.83 ± 0.05^{a}	14.15 ± 0.67^{a}

All values are means ± standard deviation (n = 3). For each run, three* or five** or ten*** determinations were conducted.
[a-c] In the same column within sweeteners or sweetener blends, mean values followed by the different superscripts are significantly different (p ≤ 0.05).

during ageing, protein aggregation, fat crystallisation, fat droplets' coalescence or flocculation, etc. (Goff *et al*., 1994; Mc Clements, 1999; Nor Hayati *et al*., 2007). The increase in viscosity of the samples containing E+I+F seemed to be caused by the increase in serum concentration, due to contribution of the soluble matter to the composition of the aqueous phase (Soukoulis *et al*., 2010) and also by formation of inulin gel (Glibowski, 2009). Therefore, replacing sucrose with sweetener blends influenced the rheological properties of coconut milk ice cream.

Thermal behavior of coconut milk ice cream

The effect of different sweetener blends on the thermal properties of coconut milk ice cream mixes is shown in Table 3. The amount of sweeteners added to ice cream influence on the freezing point depression, which is one of the influential factors for quality of the ice cream mixes (Baer and Baldwin, 1984). If a mix has lower freezing point which causes less water to be frozen as the ice cream exits the freezer, the storage life of the ice cream is shortened due to being more susceptible to increases in ice crystal size during temperature fluctuations (Schaller-Povolny and Smith, 1999). From the results, all ice cream mixes had similar FP (-2.90 to -2.03°C) and UFW (22.21-24.12%) ($p > 0.05$), possibly due to reformation of sweetener mixture to meet similar freezing curve as the control. Generally, the freezing point is depressed as the serum phase concentration is increased or as the solutes molecular weight is decreased (Hartel, 2001). Moreover, total solid also leads to the lower %UFW (Soukoulis *et al*., 2009). The total solids of the samples containing sucrose (control), E+I+F, X+I and I+F were 39.71, 39.70, 40.20 and 40.21%, respectively (Table 3). It was found that this range of total solid had no effect on %UFW ($p > 0.05$). The results were in agreement with Whelan *et al*. (2008) who found that the calculated and measured freezing points and freezing curves were similar among ice cream formulations reformulated to match FPD and solid content. FPD of sucrose, erythritol, xylitol, inulin and fructose are 1.00, 2.80, 2.25, 0.74 and 1.90, respectively (Whelan *et al*., 2008). The FP of all samples was close to those obtained by calculation (Table 1).

Physical properties

Physical properties of coconut milk ice cream with various sweetener blends are shown in Table 4. Ice cream hardness is an objective measurement related to many parameters including overrun, viscoelasticity of serum phase, thermal properties, etc. (Goff *et al.*, 1995; Muse and Hartel, 2004). The coconut milk ice cream replacing sucrose with E+I+F and the control had similar hardness values ($p > 0.05$). Those added with I+F or I+X had much higher hardness than the control or that with E+I+F ($p \leq 0.05$). This was probably due to the higher total solid of the ice cream mixes. Soukoulis *et al*. (2009) reported that hardness score was minimized in moderate total solid (16%). Moreover, Soukoulis *et al*. (2010) found that the partial substitution of sucrose by inulin, fructo-oligosaccharides and maltodextrins led to increase of the instrument hardness of vanilla ice cream.

The meltdown properties of ice cream contribute to sensory properties of the product (Tharp *et al.* 1998). Inulin + fructose containing coconut milk ice cream had the lowest melting rate, whereas the ice cream with xylitol + inulin and the control possessed the highest melting rate ($p \leq 0.05$). This might be due to the higher inulin content (8.5%) of the former than the latter (7%). Inulin has been reported to form cryogel in the inulin added ice cream (Soukoulis *et al.*, 2010). Inulin would bind water and form gel-like network (Kim *et al.*, 2001). Therefore, the water molecules become immobilized and unable to move freely among other molecules of the mixes leading to retarding product melting (El-Nagar *et al.*, 2002). In addition, Whelan *et al.* (2008) reported that melting rate is mainly dependent on hardness rather than the internal structure of the ice cream. The concomitantly higher hardness and lower melting rate was concomitantly observed in ice cream added with inulin + fructose, more likely due to the higher total solid as described previously.

Table 5. Generic descriptive analysis and liking score of coconut milk ice cream with various sweeteners

Treatment	Mean scores*				Liking scores**			
	Sweetness	Firmness	Meltdown	Mouth-coating	Appearance	Taste	Texture	Overall
Sucrose	10.71 ± 0.95^a	4.55 ± 0.87^b	3.90 ± 0.75^a	7.70 ± 0.88^a	7.63 ± 1.03^a	7.40 ± 1.04^a	7.33 ± 0.88^b	7.33 ± 0.99^a
E + I + F	8.34 ± 1.15^b	5.15 ± 0.98^b	4.38 ± 0.79^a	7.14 ± 1.16^a	7.63 ± 0.81^a	7.10 ± 1.06^a	7.83 ± 0.83^a	7.37 ± 1.03^a
X + I	9.05 ± 1.09^b	7.03 ± 0.98^a	3.88 ± 0.85^a	7.21 ± 1.20^a	7.67 ± 0.66^a	7.50 ± 1.14^a	7.53 ± 0.82^{ab}	7.50 ± 0.73^a
I + F	8.15 ± 1.31^b	7.14 ± 0.82^a	4.43 ± 0.81^a	6.84 ± 0.99^a	7.60 ± 0.62^a	7.03 ± 1.16^a	7.23 ± 1.01^b	7.13 ± 0.78^a

*,** All values are means ± standard deviation from twelve and thirty five panelists, respectively.
a-b Different superscript in the same column indicate significant differences ($p \leq 0.05$)

The overrun of sample added with various sweetener blends are shown in Table 4. No significant differences of overrun were observed among all ice cream mixes ($p > 0.05$). Overrun is calculated as the percentage increase in volume that occurred as a result of the air addition (Marshall *et al*., 2003). Soukoulis *et al.* (2010) revealed that sugars and macromolecular carbohydrates might affect foam formation and stability through their impact on the viscosity increase of ice cream mix during the whipping-freezing process as well as due to their contributions to the formation of entanglements which entrap and stabilize air cells, leading to decrease in overrun. All mixes in this study were reformulated to obtain the target of freezing point depression (FPD) ranged from -2.5 to -3.0°C and 40 ± 1% total solid; therefore, the differences in viscosities among the samples were not high enough to affect overrun. Nevertheless, Soukoulis *et al.* (2010) reported that partial substitute sucrose with polyols (xylitol, sorbital, maltitol and manitol) in vanilla ice cream led to increase of overrun when compared to the control.

For color value, the mixed sweeteners had no effect on b^* values of the coconut milk ice creams ($p > 0.05$). However, the sweetener blends had slight impact on L^* and a^* values ($p \leq 0.05$). The lowest lightness (L^*) and the highest a^* values were observed in the ice cream samples added with xylitol + inulin ($p \leq 0.05$), due to the effect of xylitol color which was pale yellow ($L^* = 93.66$, $a^* = -0.41$, $b^* = 0.30$). No significant differences in L^*, a^* and b^* values were observed between the control and ice cream containing erythritol + inulin + fructose ($p > 0.05$).

Sensory characteristics of coconut milk ice cream

Generic Descriptive Analysis

The effect of various sweetener blends on the sensory characteristics of coconut milk ice cream is demonstrated in Table 5. The ice cream samples added with E+I+F and X+I had lower sweetness score than the control ($p \leq 0.05$) which was in agreement with calculated SE as shown in Table 1. It was noticed that the sample with I+F obtained lower sweetness intensity than the control, even though it had higher calculated SE compared with the control. The higher inulin content of the sample might effect on mouth-coating and led to a lower sweetness perception. In addition, this difference might be attributable to an error due to the SE calculation using SE ranges of erythritol, xylitol, inulin and fructose at 53-70, 87-100, 40-60 and 180-190, respectively. Similar observation was noticed by Whelan *et al*. (2008). However, no difference in sweetness score was found among all ice cream added with different sweetener blends ($p > 0.05$). Moreover, coconut milk ice cream added with X+I also produced a cooling feeling in the mouth reported by Burt (2006). Firmness score of ice cream substituted sucrose with xylitol + inulin and inulin + fructose was higher than that of the control ($p \leq 0.05$), mostly due to the higher total solid (Table 3) as described previously. Firmness scores were in agreement with instrument hardness (Table 4) with $r = 0.979$ ($p \leq 0.05$). The different sweetener blends added had no effect on meltdown and mouth-coating scores ($p > 0.05$). Although, melting rate of the samples were significantly different ($p \leq 0.05$) (Table 4), the differences in meltdown were not detected by the trained panelists ($p > 0.05$). The meltdown score are fairly concomitant with the melting rate (Table 4) with $r = -0.884$ ($p \leq 0.05$).

Acceptance test

Liking scores of coconut milk ice cream added with different sweetener blends are shown in Table 5. Although, the sweetener blends generally affected L* and a^* values (Table 4) and sweetness scores (Table 5) ($p \leq 0.05$), the appearance, taste and overall liking scores of all ice cream samples were not significantly different ($p > 0.05$). Although the firmness scores of samples added with X+I and E+I+F assessed by trained panelists were significantly different ($p \leq 0.05$), the difference might be not big enough to affect on texture liking score evaluated by consumer-type panelists. In addition, each consumer might judge texture liking using various texture attributes e.g. smoothness, melt-down, mouth-coating etc. However, it was noticed that the ice cream sample with erythritol + inulin + fructose had the highest liking score of texture attribute, compared to the others and the control ($p \leq 0.05$). Our previous study showed that the coconut milk ice cream substituted sucrose with erythritol alone had lower texture and overall liking scores (6.83 and 6.77, respectively) when compared to the control (7.50 and 7.50, respectively). The addition of high content of erythritol increased the hardness, mouth-coating as well as melting rate and might lead to inferior texture of the coconut milk ice cream sample as compared with the control (Fuangpaiboon and Kijroongrojana, 2013). The ice cream substituted sucrose with inulin + fructose and the control had the lowest textural acceptance score ($p \leq 0.05$). Inulin at higher content increased mouth coating and hardness as well as reduced the sweetness of ice cream (Fuangpaiboon and Kijroongrojana, 2013). These effects might have impact on acceptance.

Conclusion

The coconut milk ice cream having low GI value were produced by replacing sucrose with different low GI sweetener blends (erythritol + inulin + fructose or xylitol + inulin or inulin + fructose). These sweetener blends were reformulated to obtain the target SE (21 ± 2), FPD (-2.5 to -3.0°C) and total solid (40 ± 1%) similar to the control added with sucrose. Although, the use of different blends significantly affected physical and sensory properties of the coconut milk ice cream samples, liking scores in all attributes of these samples were not different or even higher when compared to the control. GI value of coconut milk ice cream containing those sweetener blends was approximately 64% lower than that of the control. The coconut milk ice cream containing erythritol + inulin + fructose blend exhibited the most similar physical and thermal properties and sensory characteristics to the control ($p>0.05$), but the highest acceptance scores ($p\leq 0.05$). As a consequence, mixture of 4% erythritol, 7% inulin and 2.15% fructose might be the most potential formulation used to replace 12% sucrose as sugar sources in low GI coconut milk ice cream production.

Acknowledgements

The financial support of PSU research fund (AGR 5503265) and the Grant-in-aid for dissertation from Graduate School, Prince of Songkla University, Thailand is gratefully acknowledged. Authors would also like to thank Asst. Prof. Dr. Thammanoon Prodpran and Asst. Prof. Dr. Piyarat Siriwongpaisarn for their technical assistances with rheological measurements.

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