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Full Paper

Sensorial and physical properties of coconut-milk ice cream modified with fat replacers

Nattavong Fuangpaiboon and Kongkarn Kijroongrojana *

Department of Food Technology, Faculty of Agro-Industry, Prince of Songkla University, Hat Yai, Songkhla, 90112, Thailand

* Corresponding author, e-mail: kongkarn.kij@gmail.com

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Abstract: The effects of some fat replacers (carbohydrate-based fat replacers, namely inulin, maltodextrin and modified tapioca starch, or protein-based fat replacers, namely Simplesse® 100 and Dairy Lo™) on the sensory and physical properties of reduced-fat (4%) and low-fat (2%) coconut-milk ice cream were investigated in comparison with a control containing 8% fat. All the ice cream mixes exhibited shear thinning characteristics as indicated by a flow behaviour index (n) of less than 1. The use of modified tapioca starch led to the most pronounced increase in the consistency index. All the fat replacers used tended to elevate the freezing point and glass transition temperature as well as the melting rate of the ice cream. The hardness of the low-fat ice cream was higher than that of the reduced-fat ice cream, except those with inulin and Dairy Lo™ added. The physical properties of the ice cream samples were in agreement with their generic descriptive analysis data. Regardless of which fat replacer was used, the reduced-fat ice cream exhibited higher mouth-coating and coconut flavour, but lower iciness and a less skimmed-milk-powder-like flavour than did the low-fat ice cream ($p<0.05$). The reduced-fat ice cream with Simplesse® 100 added exhibited the sensory characteristics (firmness, iciness, melt-down, mouth-coating, sweetness, coconut flavour and skimmed milk powder flavour) most similar to the control. However, acceptance test results showed that the reduced-fat ice creams with inulin, maltodextrin and Simplesse® 100 added were not significantly different from the control in any of their attributes ($p>0.05$). For the low-fat ice cream, there were no significant differences in liking scores, except in respect of odour, between that with inulin added and the control ($p>0.05$). Therefore, inulin and Simplesse® 100 can be used to replace fat in low-fat and reduced-fat coconut-milk ice cream production.

Keywords: coconut-milk ice cream, fat replacer, sensory evaluation

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INTRODUCTION

Ice cream is a highly complex food matrix, containing proteins, fats, sugars, air and minerals with countless interfaces between the different constituents [1]. Milk fat including that from non-dairy sources is an important ingredient in ice cream because it provides desirable flavour and helps to provide a good melting property as well as decrease the size of ice crystals. Moreover, fat also affects textural attributes such as viscosity, tenderness, elasticity, emulsification and ice crystallisation, and other desirable attributes such as richness and smoothness [2]. In Thailand coconut-milk ice cream is an economically viable alternative ice cream produced by Thai manufacturers since the main raw material is derived from a locally grown plant. In addition, coconut-milk ice cream has a unique flavour. In a previous study it was shown that coconut-milk ice cream containing sweeteners with a low glycemic index, viz erythritol, inulin and fructose, has a freezing point, melting rate, overrun and sensory characteristic similar to those of the control ice cream sweetened with sucrose [3]. However, coconut-milk ice cream is still not appropriate for consumers suffering from obesity, heart diseases and hypertension, as well as consumers concerned with energy balance, due to its high fat content (8-12%). The limitation on working with low-fat ice cream is related to the fact that the fat globule network may either be disrupted or be completely absent and this can adversely affect the texture of the product. A reduction in the fat content of ice cream, particularly to or below 30 g/kg, results in a loss of textural and sensory properties [4]. Thus, in selecting a fat replacer, its mimetic functions (flavour, texture, lubrication, volume/ bulk, or heat transfer) must be carefully considered in order to produce an acceptable product that meets the demand of health-conscious consumers.

A fat replacer is an ingredient that can be used to perform some or all of the functions of fat, while providing fewer calories. Fat replacers are based on carbohydrate, protein, or fat components used alone or in combination, and provide a calorie content ranging from 0 to 9 kcal/g. Carbohydrate-based fat replacers such as maltodextrin, polydextrose, fibre and modified starch can absorb water and form a gel that imparts a texture and mouthfeel similar to those generated by fat. Whey-protein-based fat replacers including microparticulated whey protein (e.g. Simplesse® 100) and heat-denatured whey protein (e.g. Dairy Lo™ and Prolo 11) can incorporate water thus preventing iciness, provide opacity, stabilise air cells, and control viscosity and emulsion. Moreover, the tiny spherical particles which make up microparticulated protein provide a creamy mouthfeel [5].

The use of both carbohydrate-based and protein-based fat replacers in ice cream containing different fat levels has been extensively reported. Danesh et al. [6] reported that the addition of whey protein with transglutaminase as a fat replacer decreased the melting rate, overrun and hardness, and influenced the flavour and odour of reduced-fat ice cream. Karaca et al. [7] found that reduced-fat (6%) and low-fat (4%) Kahramanmaraş ice creams with added Simplesse® 100, N-lite D (a waxy-maize maltodextrin) and inulin were given sensory texture scores similar to those for a full-fat (8%) ice cream used as control in a sensory test. It has been reported that the sensory attributes of a reduced-fat (5-6%) vanilla ice cream containing Simplesse® 100 [8] or modified pea starch [4] were comparable to those of the regular fat (10-12%) product. Mahdian and Karazhian [9] found that the mix viscosity and consistency coefficient of reduced-fat ice cream (5% fat) increased while the flow behaviour index decreased when compared with ice cream containing a milk protein concentrate or inulin (2 and 4%) as fat replacers. However, the hardness of the ice cream was not

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affected by the type or amount of the fat replacer, and based on a sensory evaluation, the sample with 2% inulin obtained the highest score. In addition, Akbari et al. [10] reported that a low-fat ice cream (2% fat) with 2, 3 or 4% inulin had a lower melting rate but higher hardness than the control (10% fat). Nevertheless, a sensory evaluation of the low-fat sample with 4% inulin showed no difference from the control. Ohmes et al. [11] showed that replacing 5% fat with Simplesse® 100, Dairy Lo™ or Prolo 11 in vanilla ice cream had no effect on the vanilla flavour, but increased the intensities of whey, syrup and cooked milk flavours. In addition, Prolo 11 produced a smoother and gummier product which melted in the mouth more slowly than did the others with which it was compared.

However, different fat replacers may affect the characteristics and qualities of a coconut-milk ice cream system in different ways. Thus, the aim of the present study is to investigate the impact of fat replacers of various types and concentrations on the sensorial and physical properties of coconut-milk ice cream.

MATERIALS AND METHODS

Materials

The mature coconut meat used in this study was obtained from coconuts (*Cocos nucitera* Linn.) grown in Narathiwat province, Thailand. The coconut milk was prepared by pressing the coconut meat using a hydraulic press (Thai Sakaya-A2, Sakaya, Thailand). The obtained coconut milk consisted of 19% fat, 2.7% protein, 57.7% moisture, 0.8% ash and 19.7% carbohydrate as determined by the method of AOAC [12]. Skimmed milk powder was purchased from Fa'avae Enterprises Co. (Woodridge, Australia). Mono-diglycerides and locust bean gum were obtained from Dupont™ Danisco® Co. (Terre Haute, USA). Sucrose was purchased from Mitr Phol Co. (Thailand). Inulin (Orafti®HP, DP 25) was obtained from Beneo-Orafi Co. (Tienen, Belgium). Maltodextrin (DP 10) was purchased from Nutrition Sc Co. (Thailand). Modified tapioca starch (N-creamer 180) was obtained from National Starch and Chemical Co. (Thailand). Simplesse® 100 (microparticulated whey protein) was obtained from CP Kelco US Inc. (USA). Dairy Lo™ (thermally denatured whey protein) was obtained from Cultor Food Science (USA).

Preparation of Coconut-Milk Ice Cream Samples

Coconut-milk ice creams without and with the addition of protein-based fat replacers (Simplesse® 100 (S) or Dairy Lo™ (D)) or carbohydrate-based fat replacers (inulin (I), maltodextrin (M) or modified starch (Mo)) were formulated as shown in Table 1 [3]. Their preparation is described in the following sections.

Preparation of coconut-milk ice cream

The ice-cream mix was prepared by dispersing a stabiliser (locust bean gum), sweetener, emulsifier (mono-diglycerides) and skimmed milk dry blend into a mixture of coconut milk and water at 50°C in a water bath (W350, Memmert, Germany) for 10 min. The mixture was then heated to 60°C, homogenised with a homogeniser (Minilab 8.30H, APV-Gaulin, USA) for 2 min. and pasteurised at 80°C for 2 min. The ice-cream mix was rapidly cooled to 4°C and allowed to remain at 4°C for 24 hr to age. Part of the aged mix was subjected to tests to determine its rheological properties, overrun and thermal properties. The remainder of the sample was pre-whipped using a batch freezer (Model 104-40, Taylor, USA) at a constant whipping time of 15 min. The ice cream was then packed into 50-mL high-density polyethylene containers covered with plastic lids and stored at -20°C for at least 24 hr before being subjected to analysis.

Preparation of coconut-milk ice cream with fat replacers

To study the effect of the fat replacers on the qualities of the coconut-milk ice cream, mix samples were prepared with the addition of different fat replacers. First, samples of the coconut-milk ice cream mix had their fat content adjusted to 8, 4 and 2% representing control, reduced-fat (RF) and low-fat (LF) ice creams respectively. Then a protein-based fat replacer (S or D) or a carbohydrate-based fat replacer (I, M or Mo) was blended into the RF and LF samples at different amounts to supplement the fat content of the ice cream. The resulting mixes were then used to prepare ice creams as described above, hereafter referred to as RFS, RFD, LFS, LFD (containing protein-based fat replacers) and RFI, RFM, RFMo, LFI, LFM and LFMo (containing carbohydrate-based fat replacers).

Table 1. Formulations of coconut-milk ice cream with addition of protein-based or carbohydrate-based fat replacers at different concentrations or without addition (control)

Ingredient (%)	Control	RF	LF
Fat (from coconut milk)	8	4	2
Fat replacer	-	4	6
Sucrose	12	12	12
Skimmed milk	10	10	10
Locust bean gum	0.1	0.1	0.1
Mono-diglycerides	0.1	0.1	0.1

Physical Properties

Rheological properties

Rheological measurements were conducted using a rheometer (RS75, Haake, Germany) coupled with a Peltier/Plate TCP/P temperature control unit (K10, Haake, Germany) using a coaxial cylindrical system (modified from Karaca et al. [7]). The Oswalt-de-Waele power-law model [7]: $\tau = K\dot{\gamma}^n$, where τ is the shear stress, K is the consistency index or apparent viscosity (Pa.s^n), n is the flow behaviour index and $\dot{\gamma}$ is the shear rate, was used to describe the data related to the shear-induced behaviour of the ice cream.

Hardness

Prior to analysis the samples were tempered at -20°C for at least 24 hr, then transferred to a room at 26±2°C for 1 min. The hardness was determined using a texture analyser (TA.XT2i, Stable Microsystems, England) with a 6-mm stainless steel cylindrical probe (SMSP/6) as described in Soukoulis et al. [13].

Melting rate

The melting rate of the ice cream was determined according to the method of Whelan et al. [14].

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Overrun

Overrun was measured by comparing the weight of the mix and that of the ice cream in a fixed volume container and was calculated as follows [14]:

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

Colour

Colour was measured by a Hunter Lab spectro-colorimeter (C04-1005-631, ColourFlex, USA). The colour value was obtained by reflective detection and expressed as L* (lightness), a* (redness) and b* (yellowness) values.

Thermal properties

Thermograms were obtained using a differential scanning calorimeter (Q1000, TA Instruments, USA) and Pyris software for Windows. The implementing protocol followed Soukoulis et al. [13]. The freezing point of a formulation was calculated from the differential scanning calorimetry melting curve by determining the temperature at which the steepest slope was observed.

The glass transition temperature (T_g) was determined at baseline shift prior to the melting peak and measured at the midpoint of the transition [15].

Sensory Analysis

Generic descriptive analysis

The sensory characteristics of the coconut-milk ice cream were judged by 15 trained panelists. The samples were served in 50-g plastic containers placed in a 2-L polystyrene container to ensure that all the ice creams were of the same consistency. The cups were labelled with random three-digit codes. The order of presentation of the samples was randomised according to a 'balance order and carry-over effects design' [16]. Initially, the judges developed a list of terms describing the attributes of the coconut-milk ice cream using reference samples. Definitions were also given for each of the seven terms chosen (firmness, iciness, melt-down, mouth-coating, sweetness, coconut flavour and skimmed-milk-powder-like flavour). Then the judges practiced scaling by rating the intensities of reference samples. The final score sheet and test protocol were agreed on to accurately measure the test products. The panelists' performance was then assessed and the list of the panel members to work on the sample evaluation was finalised. The panelists undertook a 30-hour training programme. A 15-cm line scale, anchored with the words 'low' and 'high' 1.5 cm from each end, was used to rate the 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 each sample, the panelists were required to rinse their mouths with warm water before evaluating the next sample. Table 2 shows the sensory attributes used in the general descriptive analysis as well as their definitions and the references used for panelists training.

Acceptance test

The acceptance of the ice cream samples was judged by 30 panelists who commonly consume coconut-milk ice cream, using a 9-point hedonic scale for appearance, flavour, texture and overall. The samples were presented and served as mentioned above under Generic descriptive analysis section.

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

Attribute	Definition	Reference
Firmness	The force required to compress the sample between the tongue and palate (using the ice cream base only, without obvious inclusions, if present)	Coconut-milk ice cream with 0%, 2%, 4% and 6% M added
Iciness	The defect is evident while compressing the sample between the tongue and palate. The ice crystals hold the incisors slightly apart leading to a crunchy and rough sensation which disappears as the crystals melt.	Coconut-milk ice cream with 0%, 2%, 4% and 6% M added
Melt-down	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 table spoon	Coconut-milk ice cream with 0%, 2%, 4% and 6% M added
Mouth-coating	A sensation of having a slick/fatty coating on the tongue and other mouth surfaces	Coconut-milk ice cream with 0%, 2%, 4% and 6% M added
Sweetness	Taste on the tongue elicited by sugars or other high potency sweeteners	Coconut-milk ice cream with 8%, 10%, 12% and 14% sucrose added
Coconut-milk flavour	The intensity of the coconut-milk flavour	Coconut-milk ice cream with 100% (control), 80%, 60%, 40%, 20% and 0.5% coconut milk
Skimmed-milk-powder-like flavour	The intensity of the skimmed milk-like flavour	Coconut-milk ice cream with 100% (control), 80%, 60%, 40%, 20% and 0.5% coconut milk

Statistical Analysis

The experiments were run in triplicate using three different lots of samples. A completely randomised design was used for the statistical analysis of the physical and chemical data as well as the generic descriptive analysis. A randomised complete block design was performed for the analysis of the acceptance test. The data was compared for significant differences by analysis of variance. Means were compared by Duncan's multiple range test at a significance level of $p<0.05$. Correlation coefficients (r) between physical properties and sensory data were also derived. The data analysis was performed using the Statistical Package for Social Science (SPSS for Windows, SPSS Inc., USA).

RESULTS AND DISCUSSION

Physical Properties

Rheological properties

The rheological properties of the control coconut-milk ice cream and the experimental mix samples containing protein-based fat replacers (S and D) or carbohydrate-based fat replacers (I, M and Mo) are shown in Table 3. The flow curves of all the ice cream mixes exhibited pseudoplastic behaviour [13, 17] and in all cases the flow behaviour index (n) of the samples was less than 1, ranging between 0.743-0.938 and 0.772-0.972 for those containing protein-based and carbohydrate-based fat replacers respectively. Ice cream mixes are generally colloids containing fat droplets coated with a protein-emulsifier layer as the dispersed phase [18]. The n value of ice cream can be as low as 0.38, but indices as high as 1.00 have been reported [13]. It has been found that the pseudoplastic characteristic of ice cream is associated with a change in the aggregation of fat globules [19]. During shearing, the aggregate structure breaks down and shear thinning behaviour is observed [7].

When compared within each treatment, the n value of the ice cream mix containing D, I and M displayed the least shear thinning behaviour (i.e. a higher n value). This may be due to a lower number of fat globules and total solids. In this study when the fat content of a sample was adjusted by reducing the amount of coconut milk, the non-fat solid content was also decreased. However, the LFS and LFM had the lowest n-values (0.743 and 0.772 respectively), suggesting that aggregates other than fat globules and the solid content might take part in shear thinning. Those fat replacers might form strong aggregates which were able to resist the shear force applied.

Table 3. Rheological and thermal properties of coconut-milk ice cream mixes containing different protein-based and carbohydrate-based fat replacers

Treatment	Rheological properties		Thermal properties	
	Consistency index, K ($Pa.s^n$)	Flow behaviour index, n	Freezing point (°C)	Glass transition temperature, T_g (°C)
Protein-based fat replacers				
Control	0.0072 ± 0.0008^d	0.890 ± 0.026^b	-2.90 ± 0.25^b	-32.97 ± 2.36^b
RFS	0.0106 ± 0.0008^b	0.847 ± 0.008^c	-1.96 ± 0.59^a	-28.80 ± 1.06^a
RFD	0.0093 ± 0.0004^c	0.903 ± 0.009^b	-1.98 ± 0.17^a	-29.94 ± 1.00^a
LFS	0.0456 ± 0.0009^a	0.743 ± 0.007^d	-1.35 ± 0.39^a	-28.56 ± 0.65^a
LFD	0.0064 ± 0.0002^d	0.938 ± 0.005^a	-1.85 ± 0.19^a	-30.43 ± 0.18^a
Carbohydrate-based fat replacers				
Control	0.0088 ± 0.0010^c	0.917 ± 0.038^b	-2.01 ± 0.56^{bc}	-31.98 ± 3.51^b
RFI	0.0075 ± 0.0008^c	0.925 ± 0.006^b	-2.29 ± 0.26^c	-31.24 ± 0.46^{ab}
RFM	0.0077 ± 0.0005^c	0.946 ± 0.020^{ab}	-1.79 ± 0.38^{abc}	-29.99 ± 0.57^{ab}
RFMo	0.0297 ± 0.0028^b	0.829 ± 0.012^c	-1.51 ± 0.34^{abc}	-29.39 ± 0.53^{ab}
LFI	0.0084 ± 0.0004^c	0.941 ± 0.008^{ab}	-1.46 ± 0.27^{ab}	-30.01 ± 1.48^{ab}
LFM	0.0054 ± 0.0001^c	0.972 ± 0.005^a	-1.78 ± 0.68^{abc}	-28.69 ± 1.25^a
LFMo	0.0667 ± 0.0056^a	0.772 ± 0.008^d	-1.09 ± 0.18^a	-28.40 ± 0.74^a

Notes: 1) All values are means ± standard deviation (n = 3). For each run, three determinations were conducted.
2) Mean values in the same column for the same type of fat replacer followed by different superscripts ($^{a-d}$) are significantly different ($p<0.05$).

A high consistency index (K) indicates a more viscous mix [7]. Due to sample complexity, rheology is affected by many factors including the components (e.g. fat, polysaccharides and proteins) and their concentrations, hydration phenomena occurring during ageing, protein aggregation, fat crystallisation, and coalescence or flocculation of fat droplets [20]. The addition of S or D resulted in a significantly increased viscosity of the ice cream mixes compared to the control ($p<0.05$). This might be associated with the liquid binding or water holding ability of both protein-based fat replacers [8, 21]. The results are in agreement with those by Ohmes et al. [11] who found that substituting 5% fat with D, S or Prolo 11 increased the viscosity of a vanilla ice cream mix. In addition, it has been reported that microparticulated whey protein may interact with the protein network and have synergistic effects on the β-lactoglobulin found in whey protein, leading to a high viscosity of the mix [22].

Among the carbohydrate-based fat replacers, the use of Mo led to a pronounced increase in the consistency index when compared to the control and the value was significantly different from those of all the other samples ($p<0.05$), while the addition of I and M had no significant effect ($p>0.05$). The increase in viscosity of the samples containing Mo was probably caused by an increase in serum concentration due to the contribution of soluble matter to the composition of the aqueous phase [17]. In addition, the Mo used in this study had a much higher molecular weight (MW>10,000), which might have caused the formation of larger aggregates, resulting in a more viscous behaviour when compared to M and I (MW of 1,801 and 4,050 respectively). A macropolysaccharide can have more interactions with water, providing desirable viscosity, texture and suspending characteristics [23]. Marshall et al. [1] reported that the water holding capacity and degree of polymerisation and branching are among the most critical factors influencing the development of viscosity in ice cream mixes.

Thermal properties

The effects of different protein-based and carbohydrate-based fat replacers on the thermal properties of the ice cream mixes are shown in Table 3. The freezing point of the control coconut-milk ice cream mix was -2.90 to -2.01 °C, which was similar to that of milk-fat ice cream (-2.4 to -2.42 °C) reported by Whelan et al. [13] and Soukoulis et al. [24]. The addition of fat replacers led to a slight but significant increase in the freezing point compared to control ($p<0.05$). However, no significant differences in freezing point were observed among the ice cream mixes with added protein-based fat replacers. Generally, the freezing point is depressed as the serum phase concentration is increased or as the solute molecular weight is decreased [25]. However, the addition of high-molecular-weight biopolymers, e.g. polysaccharides, does not induce significant freezing-point depression [1]. The slight increase in freezing point of the fat-replacer-substituted samples was most likely due to the lower solid content as mentioned previously. Marshall et al. [1] found that ice cream with a low total solid content tends to have a high freezing point. In addition, Soukoulis et al. [24] reported that the addition of apple fibre or 4% carbohydrate-based fat replacer (inulin) affected the freezing-point depression in the same manner as did hydrocolloids, which generally increase the freezing point of an ice cream mix.

The determination of T_g is of critical importance for ice cream products as it is associated with the stability of both recrystallisation and deterioration behaviours. At temperatures above the T_g, the mobility of the components in a frozen system increases. Thus, an elevation of T_g through ingredient formulation or storage at temperatures below the T_g results in the cryostabilisation of frozen dairy products [24, 26]. The T_g values of ice cream containing protein-based and carbohydrate-based fat replacers are shown in Table 3. The T_g of the regular fat coconut-milk ice cream ranged from -32.97 to -31.98 °C. The T_g of ice cream may range from -23 to -43 °C, depending on the formulation [22]. In general, the addition of either protein-based or carbohydrate-based fat replacers leads to an increase in T_g. Proteins and polysaccharides, which usually exist in complex multicomponent forms, are used for controlling the transition from a highly viscous-rubbery state to a glassy state. The elevation of T_g observed in ice cream containing fat replacers

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might be associated with the restriction of the mobility of water molecules via their binding capacity, leading to increased viscosity (see Table 3) [24].

Hardness

The physical properties of the coconut-milk ice cream with different protein-based and carbohydrate-based fat replacers are shown in Table 4. Ice cream hardness represents an objective measurement related to many parameters including overrun, viscoelasticity of the serum phase and thermal properties [27]. Among the samples containing protein-based fat replacers, only the LFS sample had a significantly higher hardness value than the control ($p<0.05$), while the hardness of the other samples was not significantly different. All ice creams containing the carbohydrate-based fat replacers had significantly higher hardness than the control ($p<0.05$), regardless of the type of fat replacer used. Increase in fat substitution resulted in an increase in the hardness of the resulting ice cream. The hardness of ice cream is related to its structure. The air cells in the structure are essentially spherical, although there is some distortion due to fat and ice crystal formation [28]. Reduction in the fat content and addition of a fat replacer most probably changes the characteristics of the fluid surrounding the air cells [4, 7]. In addition, it has been reported that the force deformation measured with a texture analyser in a low-fat low-solid ice cream is greater than that in a high-fat high-solid sample owing to the presence of ice crystals [10, 29]. The results in the present study are in agreement with those by Karaca et al. [7], who reported that the hardness of an S-containing ice cream was significantly ($p<0.05$) higher than that of a control. Moreover, the use of S or Mo increased the viscosity as measured by the K value (Table 3). This could have prevented air incorporation, which led to a denser structure and a harder ice cream [30]. Nevertheless, although the LFM mix had a low solid content and hence more ice crystals, it displayed the lowest hardness value. This is probably due to the crumbly character of the sample when force is applied.

Melting rate

All the samples with added fat replacers had significantly lower melting rates than the control ($p<0.05$) (Table 4) and this might have been associated with the solid content. The study showed that the total solids in the control sample were 40.72±0.10% while those of the RF and LF samples ranged from 34.85±0.08 to 28.59±0.08%. Marshall et al. [1] found that ice cream which has a high total solid content tends to have a lower freezing point than that of ice cream with a low total solid content. In addition, both types of fat replacer may contribute to the ability of the ice cream to retain its shape and resist melt-down. The results in the present study are in accordance with those of Aykan et al. [31], who reported that non-fat and reduced-fat ice cream samples had a slightly lower melting rate due to the higher water binding capacity of carbohydrate-based fat replacers. Moreover, Ohmes et al. [11] reported that fat-free ice cream containing D had a slower melting rate than a control sample.

Table 4. Physical properties of coconut-milk ice cream containing different protein-based and carbohydrate-based fat replacers

Treatment	Hardness (g)***	Melting rate* (g/min.)	Overrun* (%)	Colour**		
				L*	a*	b*
Protein-based fat replacers						
Control	839.62 ± 280.36^{b}	1.43 ± 0.03^{a}	23.74 ± 2.85^{c}	89.50 ± 1.16^{b}	-0.93 ± 0.21^{a}	14.89 ± 0.69^{d}
RFS	905.43 ± 284.99^{b}	1.26 ± 0.01^{b}	29.89 ± 2.86^{b}	90.47 ± 0.30^{a}	-0.86 ± 0.14^{a}	17.38 ± 0.26^{c}
RFD	786.81 ± 119.04^{b}	1.20 ± 0.01^{b}	33.97 ± 2.13^{a}	90.42 ± 0.31^{a}	-1.20 ± 0.10^{b}	17.39 ± 0.32^{c}
LFS	1184.06 ± 340.43^{a}	1.25 ± 0.02^{b}	29.15 ± 0.69^{b}	89.13 ± 0.33^{b}	-1.27 ± 0.15^{b}	18.47 ± 0.39^{b}
LFD	820.68 ± 139.45^{b}	1.22 ± 0.06^{b}	35.70 ± 1.85^{a}	86.04 ± 0.39^{c}	-2.26 ± 0.14^{c}	19.65 ± 0.39^{a}
Carbohydrate-based fat replacers						
Control	809.11 ± 106.82^{d}	1.50 ± 0.01^{a}	25.03 ± 1.51^{b}	89.94 ± 0.33^{c}	-1.19 ± 0.17^{bc}	14.88 ± 1.21^{cd}
RFI	2870.76 ± 875.43^{b}	1.21 ± 0.16^{d}	35.26 ± 1.75^{a}	92.27 ± 0.14^{a}	-1.14 ± 0.17^{abc}	13.32 ± 0.31^{d}
RFM	2836.10 ± 636.45^{b}	1.28 ± 0.07^{bcd}	24.56 ± 2.56^{b}	90.45 ± 1.17^{bc}	-1.33 ± 0.04^{c}	17.34 ± 1.85^{b}
RFMo	2931.57 ± 644.61^{b}	1.36 ± 0.04^{bc}	33.07 ± 2.54^{a}	91.37 ± 0.30^{ab}	-1.07 ± 0.11^{ab}	13.85 ± 0.66^{d}
LFI	3512.06 ± 898.23^{ab}	1.34 ± 0.00^{bcd}	34.17 ± 2.37^{a}	91.61 ± 0.24^{a}	-1.30 ± 0.19^{c}	15.83 ± 0.21^{bc}
LFM	1664.56 ± 622.68^{c}	1.38 ± 0.02^{ab}	26.49 ± 1.88^{b}	89.46 ± 1.34^{c}	-1.88 ± 0.19^{d}	19.69 ± 2.28^{a}
LFMo	3874.67 ± 687.69^{a}	1.24 ± 0.00^{cd}	34.77 ± 2.60^{a}	90.12 ± 0.20^{c}	-0.93 ± 0.20^{a}	16.00 ± 0.76^{bc}

Notes: 1) All values are means ± standard deviation (n = 3). For each run, three (*) or five (**) or ten (***) determinations were conducted.
2) Mean values in the same column for the same type of fat replacer followed by different superscripts ($^{a-c}$) are significantly different (p<0.05).

Overrun

All the ice cream samples with part of the fat content substituted with fat replacers had overrun values significantly higher than the control (p<0.05) (Table 4). These results are in agreement with those by Aykan et al. [31], who found that whey protein-based fat replacers have a positive effect on the overrun of ice cream. The ability of whey protein to form and stabilise foam is dependent on the rapid diffusion of molecules in the air/water interface, the amphiphilic structure, solubility and flexibility [32]. Despite a similar fat content, S-containing ice cream had a significantly lower overrun value than that of D-containing ice cream (p<0.05). This might have been due to the more viscous behaviour of S , which could have prevented air incorporation. Adapa et al. [30] reported that a highly viscous system does not favour foam capacity. Despite having a higher viscosity than the ice cream mixes containing the other carbohydrate-based fat replacers, the ice cream containing Mo exhibited a higher overrun. The macromolecular carbohydrates might affect foam formation and stability through their impacts by way of an increase in viscosity of the ice cream mix during the whipping-freezing process as well as through their contribution to the formation of entanglements, which entrap and stabilise air cells [13].

Colour

As can be seen from Table 4, substituting fat with either protein-based or carbohydrate-based fat replacers had a slight but in many cases significant effect on the L* and a* colour values of the coconut-milk ice cream ($p<0.05$). On the other hand, the b* value tended to increase with increasing percentage of fat substitution. Among samples with carbohydrate-based fat replacers, the sample with Mo had the highest b* value due to the reduction of whiteness from the coconut milk. In addition, this might have been caused by the transparency of the Mo solution which could not mask the yellowness of the skimmed milk in the formulation. The colour effect of S or D which are yellow also contributed to the increase in b* values of the ice cream. This result is in agreement with that by Roland et al. [33] who reported that ice cream with added lactose, reduced freeze-concentrated skimmed milk or polydextrose showed significant increases in yellowness as compared to regular (10%) fat ice cream.

Sensory Analysis

Generic descriptive analysis

The mean scores for sensory attributes obtained from the ice cream with different protein-based and carbohydrate-based fat replacers are presented in Figures 1A and 1B respectively. No significant differences in firmness were detected between the samples containing protein-based fat replacers, except for LFS which showed the highest value ($p<0.05$). However, the panelists noted that the ice cream samples with carbohydrate-based fat replacers substituted for fat were approximately two or three times firmer than the control. This is in agreement with the measured hardness results shown in Table 4, where the LFM sample can be seen to have a significantly lower hardness score than those for samples with other carbohydrate-based fat replacers added ($p<0.05$), which is mostly due to the crumbly character of the LFM sample as previously mentioned.

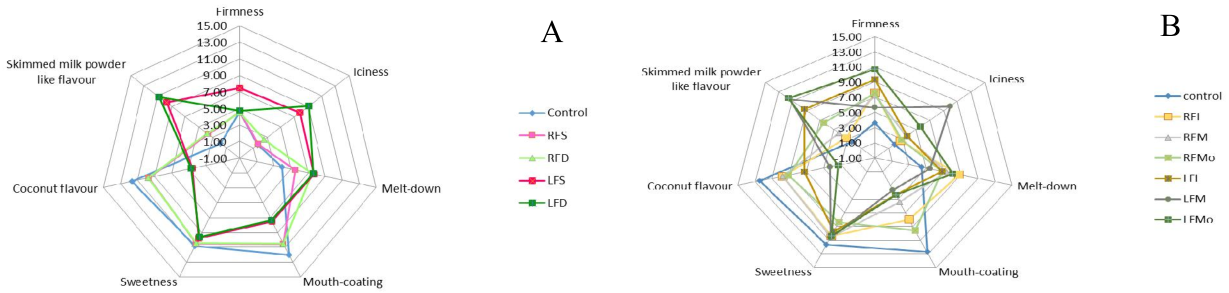

Figure 1. Mean sensorial property scores for coconut-milk ice cream with different protein-based (A) and carbohydrate-based (B) fat replacers

The amounts of fat and fat replacers in the ice cream mixes influence their rheological properties and affect the characteristics of the resulting ice cream [8]. In addition, it has been reported that ice cream with a lower fat and lower total solid content is firmer [29] due to a higher amount of ice and a lower level of fat which is a softer component than ice [4]. For the starch-based fat replacers, it is possible that the polysaccharide polymers in the firmer products interact to form gelled particles of inulin or starch, for example. Such particles would increase the resistance of the sample to deformation by the tongue [4]. There were significant positive correlations ($p<0.01$) between sensory firmness and the measured hardness of the ice-cream samples supplemented both with protein-based and carbohydrate-based fat replacers ($r = 0.961$ and $r = 0.979$ respectively). It was found in this study that the use of D as a fat substitute in RF or LF coconut-milk ice creams was most effective in mimicking the hardness of the control sample with higher fat content.

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The results on the iciness attribute indicated that the RFS ice cream had an iciness score which was comparable to that of the control sample, while the LFM sample had the highest iciness score. Simplesse® 100 is a microparticulated whey protein with a particle size ranging from 0.1 to 3 μm in diameter. The size of these particles provides a creamy mouthfeel similar to fat [8]. However, a significant increase in iciness intensity was observed when the fat level was decreased ($p<0.05$). Aime et al. [4] found a strong correlation between ice cream smoothness and fat content. This is in agreement with previously published results where a decrease in smoothness of ice cream was noticed when the fat level was reduced from 10% to 0.5% and 0.1% [11], and from 12% to 8% or 8% to 3% [26]. In addition, maltodextrin with a lower molecular weight compared to other carbohydrate-based fat replacers might promote the formation of large ice crystals, probably due to a low effectiveness in forming the hydrated particles that provide the perception of creaminess.

A slower melting was observed in samples containing both types of fat replacers when compared to the control. This might have been due to the solid content as described previously. In addition, the sensory melt-down of the ice creams containing protein-based and carbohydrate-based fat replacers was significantly negatively correlated with the melting rate ($r = -0.898$ and -0.913 ($p<0.01$) respectively, see Table 4).

The mouth-coating quality is generally associated with the fat content, with the intensity decreasing with decrease in fat level. Fat in ice cream provides desirable flavours and affects textural attributes, namely viscosity, tenderness, elasticity, emulsification, ice crystallisation and other desirable attributes such as richness, smoothness and mouth-coating [2]. The results in this study were similar to those by Aime et al. [4], who replaced fat with modified pea starch in vanilla ice cream. Although fat replacers provide lubricity, mouthfeel and other characteristics, it is possible that the nature of the mouth-coating in the RF ice cream was different from that in regular fat ice cream.

Regardless of fat replacer type, an increase in percentage fat substitution led to a significant increase in the skimmed-milk-powder-like flavour, with a decrease in the coconut-milk flavour ($p<0.05$). In addition, all the fat-replacer-containing samples received significantly lower sweetness scores compared to control ($p<0.05$). In this study coconut-milk fat was used in place of milk fat, so the reduction in the amount of coconut milk resulted not only in a decrease in coconut-milk flavour, but also in increased skimmed-milk-powder-like flavour obtained from skimmed milk. Moreover, the coconut milk contained 3.34% total sugar (data not shown), which would have affected the sweetness intensity. It could reasonably be suggested that coconut milk was the main factor influencing the flavour perception of coconut-milk ice cream. Ohmes et al. [11] found that a whey-based fat replacer imparts more undesirable flavour than do non-fat milk and milk fat. Moreover, it has been reported that protein tends to chemically bind some flavour components, causing them to lose intensity or to contribute to an 'off' flavour [5].

Acceptance test

The liking scores for the coconut-milk ice creams with fat replacers are displayed in Figure 2, which shows that the liking scores tend to decrease when the fat level is decreased. The liking scores for all the attributes of the RFS ice cream sample are comparable to those for the control. The results agree with those of the generic descriptive analysis (see Figure 1A), which shows that the sensory characteristic scores for the RFS ice cream are closest to those for the regular fat control sample. On the other hand, the LFD sample obtains the lowest overall liking score. This is

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attributable to the fact that this sample has the highest iciness value and skimmed-milk-powder-like flavor, as well as the lowest coconut-milk flavour intensities among all the ice creams. For the carbohydrate-based fat replacers, although the trained panelists scored the sensory characteristics of the RF samples and the control differently (Figure 2B), there were no significant differences in the liking scores for any of the attributes among the RFI, RFM and control samples ($p>0.05$). It is noticed that among the LF samples, only the LFI ice cream gains liking scores which are comparable to those for the control, although for the odour quality, its score is significantly lower than the control sample's ($p<0.05$). Among the LF samples, the LFI has significantly lower ($p<0.05$) iciness and higher coconut-milk flavour scores than those for the other LF samples (see Figure 1B). Inulin is therefore the most effective fat replacer in mimicking fat in the coconut-milk ice cream system via the formation of gel particles as described previously and also in providing the sweet aroma which is a part of the coconut flavour.

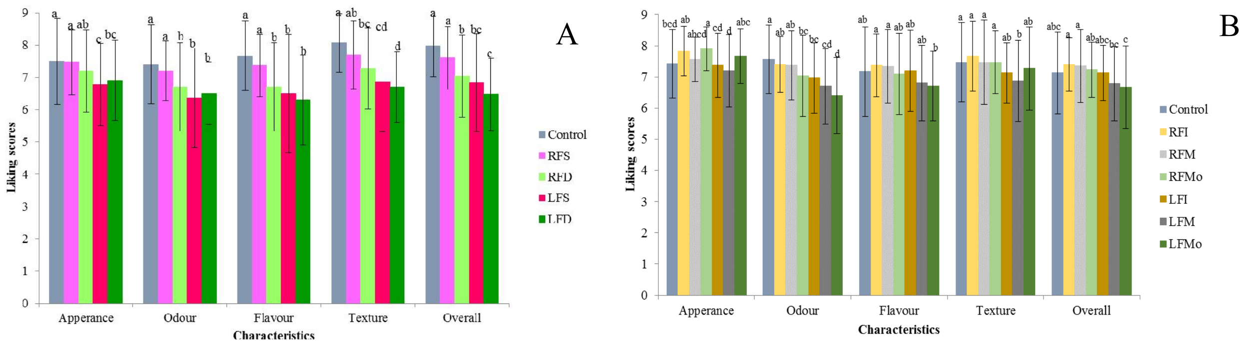

Figure 2. Liking scores for coconut-milk ice creams with different protein-based (A) and carbohydrate-based (B) fat replacers. Bars represent mean scores from 35 panelists. Different letters on the bars indicate significant differences ($p<0.05$).

CONCLUSIONS

Substituting both types of fat replacer for fat in coconut-milk ice cream affects its physical and sensory characteristics, in many cases significantly so. All the ice cream mixes exhibit shear thinning behaviour. An increase in fat replacer level results in a decreased total solid content and increased hardness, especially with the carbohydrate-based fat replacers. In addition, all the samples with fat replacers added have a higher freezing point and T_g as well as higher overrun but a slower melting rate than the regular fat control sample. However, both types of fat replacer increase the yellowness of the ice cream. The LF ice creams have higher firmness, iciness and skimmed-milk-powder-like flavour but lower mouth-coating and coconut-milk flavour than those of the RF samples. The RFS sample exhibits the sensory characteristics which are most similar to those of the control. Overall, the liking scores for both the RFI and LFI ice creams are not significantly different from those for the control ($p<0.05$). For the protein-based fat replacers, only the RF ice cream provides an overall liking score comparable to that of the control. As a consequence, inulin and Simplesse® 100 seem to have the potential to be used for partly replacing coconut milk in LF and RF coconut-milk ice cream products.

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