

THE EFFECTS OF INULIN ON THE PHYSICOCHEMICAL CHARACTERISTICS OF REDUCED-FAT ICE CREAM

Tiraporn Junyusen*, Ganokporn Petnom, and Bowarn Chienwiboonsook

Received: February 21, 2017; Revised: March 26, 2017; Accepted: March 29, 2017

Abstract

This study investigates the effects of inulin on the physicochemical properties of reduced-fat ice cream (6% fat content) and its potential as a fat replacer. To this end, the rheology, thermal properties, particle size distributions, texture, and melting characteristics of 2% and 4% inulin-containing reduced-fat ice creams were determined and compared with those of regular ice cream with 10% fat content (control) and inulin-free reduced-fat ice cream. The experiments showed that the lower fat content (6%) significantly influenced the physicochemical characteristics of the ice cream products. Despite the minimal improvement in the rheology given to the 2% and 4% inulin contents, the glass transition temperature (T_g) of the inulin-containing reduced-fat ice creams was significantly elevated, resulting in enhanced product stability during frozen storage. The presence of inulin in the reduced-fat ice cream also induced the clustering of fat globules, resulting in the increase of the larger sized particles (1-10 μm), but it significantly decreased the hardness of the reduced-fat ice cream. Moreover, the presence of 4% inulin lowered the melting rate of the reduced-fat ice cream to more resemble that of the regular ice cream. All in all, the experimental findings verify the prospects of inulin, especially at the level of 4%, as a fat replacer in the reduced-fat ice cream product.

Keywords: Reduced-fat ice cream, inulin, rheological behavior, thermal property, texture, melting rate

Introduction

There is mounting evidence of the association between dietary fat content and the risks of non-communicable diseases, e.g. obesity, diabetes, and coronary heart diseases. Therefore,

an increasing number of modern consumers are attaching greater importance to their dietary intake and gradually switching to low-fat, low-calorie food products. Nevertheless,

School of Agricultural Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima, 30000, Thailand. Tel. 0-4422-4775; Fax. 0-4422-4610; E-mail: tirapo@sut.ac.th

** Corresponding author*

due to the major role of fats in the overall physical characteristics of many foods, their removal often deteriorates the appearance and palatability of the final food products (McClements and Decker, 2008).

Typically a high-fat content product, ice cream is a complex food matrix that consists of ice crystals, air bubbles, partially coalesced fat globules, polysaccharides, protein, lactose, and mineral salts (Soukoulis *et al.*, 2009). Since the fat content plays a crucial role in the ice crystallization, hardness, melting rate, creaminess, and flavor of an ice cream, its removal thus has a direct impact on the ice cream's appearance and taste quality (El-Nagar *et al.*, 2002). Consequently, the enhancement of a high quality low-fat ice cream, especially for consumers concerned with the dietary fat intake, is a challenge. To mitigate the problem, existing research has proposed the use of dietary fibers, such as inulin, as a fat replacer to improve the quality of low-fat ice cream products (El-Nagar *et al.*, 2002; Franck, 2002). Specifically, inulin helps bind the water molecules and thereby improves the textural characteristics of ice cream products (El-Nagar *et al.*, 2002; Franck, 2002; Akbari *et al.*, 2016).

Inulin is a linear carbohydrate polymer consisting of fructose molecules. It can be safely used without specific limits in a wide variety of food products as a food ingredient, a soluble dietary fiber, and a fat replacer (Franck, 2002; Chaito *et al.*, 2016). Inulin, which is low in calories, possesses many health benefits, especially the prebiotics that stimulate the growth of beneficial intestinal bacteria (Paul and Coussement, 1999; Karimi *et al.*, 2015). In addition, inulin has been effectively used to achieve textural modification and organoleptic improvement in food products (Karimi *et al.*, 2015).

Previous research studies focused on the effects of inulin as the fat replacer on the physicochemical and sensorial characteristics of low-fat dairy products (Meyer *et al.*, 2011; Karimi *et al.*, 2015). Specifically, inulin was used to improve the quality of a low-fat yogurt (Guggisbert *et al.*, 2009), a reduced-fat cheese (Juan *et al.*, 2013) and low-fat ice cream products (El-Nagar *et al.*, 2002; Soukoulis *et al.*, 2009; Tiwari *et al.*, 2015). However, studies pertaining to the effects of inulin on

reduced-fat ice cream are very limited. This experimental study thus investigates the effects of inulin, as the fat replacer, on the rheological and thermal properties, particle size distributions, hardness, and melting rates of 2% and 4% inulin-containing reduced-fat ice creams. The results are then compared with those of regular ice cream and inulin-free reduced-fat ice cream.

Materials and Methods

Materials

Pasteurized milk containing 4% milk fat was obtained from Suranaree University of Technology (Nakhon Ratchasima, Thailand), margarine (Imperial brand) from KCG Corporation Co., Ltd. (Bangkok, Thailand) and the inulin (Fibruline® S20) from Cosucar-Groupe Warcoing SA, (Pecq, Belgium. In addition, xanthan gum (Ziboxan® F80, Deosen Biochemical Ltd., Shandong, China) and egg yolk powder (Michael Foods, Inc., Minnetonka, MN, USA) were used as the stabilizer and emulsifier, respectively. Sucrose and skim milk power were purchased from local suppliers.

Ice cream Mixes Formulation

In this study, the ice cream mixes contained 15% sugar, 11% milk solids-not-fat (MSNF), 6% or 10% fat, 0.2% stabilizer, 0.2% emulsifier, and 0%, 2%, or 4% inulin, following the formula in Goff (2016) with some modification. There were 4 experimental ice cream mixes: the regular ice cream mix with 10% fat content (control), the inulin-free reduced-fat (6% fat) ice cream mix (sample 1), the 2% inulin-containing reduced-fat ice cream mix (sample 2), and the 4% inulin-containing reduced-fat ice cream mix (sample 3).

In the ice cream making, the raw materials were blended and heated in a double boiler at 50°C for 15 min. The mixtures were cooled and homogenized using a two-stage homogenizer (Model 15MR- 8TA, APV-Gaulin Inc., Wilmington, MA, USA) with 13.8 MPa (2000 psi) and 3.9 MPa (560 psi) for the first and second stages. The homogenized products were pasteurized at 80°C for 2 min and rapidly cooled to 4°C in an ice bath before being left to age overnight at 4°C to allow the fat to crystallize and the stabilizer to hydrate.

The aged ice cream mixes were then divided into 2 portions. The first portion was retained as it was for the subsequent experiments and the other was frozen for 10 min using a batch freezer (Model 103, Taylor Company, Rockton, IL, USA). After the 10 min, 80 g each of the frozen ice cream mixes was transferred to 150 mL plastic cups and stored in a hardening chamber at -20°C for 2 weeks prior to further analysis.

Rheological Measurement

The rheological properties of the experimental aged ice cream mixes were determined using a Brookfield DV-II+ viscometer (Brookfield Engineering Laboratories Inc., Middleboro, MA, USA) equipped with a circulating cooling tank. The measurements were taken in triplicate at 4°C with a spindle no. 21. The shear stress was measured at the shear rates of 2 - 80.s⁻¹, with the resulting 40 measurements. A power law model was utilized to determine the rheological behaviors of the aged ice cream mixes:

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

where τ is the shear stress (Pa), K is the consistency coefficient (Pa.sⁿ), γ is the shear rate (s⁻¹), and n is the flow behavior index (dimensionless). The apparent viscosity was evaluated at the shear rate of 50 s⁻¹ (Mellado, 1998).

Differential Scanning Calorimeter Measurement

The thermal analysis of the experimental aged ice cream mixes was carried out using a differential scanning calorimeter (DSC) (NETZSCH DSC 204 F1 Phoenix®, Erich Netzsch GmbH & Co. Holding KG, Selb, Germany) operated by the NETZSCH Proteus® software. In the analysis, approximately 15 mg each of the aged ice cream mixes was transferred into aluminum pans and sealed before placing into the DSC. In this study, an empty aluminum pan was used as the reference. The DSC protocol was as follows: heating the sample to 50°C at 10°C min⁻¹; cooling to -60°C at 5°C min⁻¹ and isothermal holding for 5 min; and reheating from -60°C to 20°C at 5°C min⁻¹ (Alvarez *et al.*, 2005). The measurements were performed in duplicate.

The DSC thermograms were interpreted as per Alvarez *et al.* (2005) and Soukoulis

et al. (2009). The enthalpy of fusion (ΔH) was determined by summing the deviations of the DSC melting curve (from the initial to final melting temperatures) from the baseline. The onset temperature (T_o) was the intersection point of the tangents to the thermogram at the initial melting temperature and the downslope of the heat flow. The glass transition temperature (T_g) was the temperature at the midpoint of the transition before the ice melting curve. The freezable water was determined by dividing the enthalpy of fusion of the aged ice cream mixes by that of pure ice ($\Delta H = 334 \text{ J g}^{-1}$). The percentage of unfreezable water (UFW) was determined by subtracting the percentage of moisture content by the percentage of freezable water (Alvarez *et al.*, 2005).

Particle Size Distribution Measurement

The particle size distributions of the aged and frozen ice cream mixes were analyzed using a laser scattering particle size distribution analyzer (Partica LA-950V2, Horiba Ltd., Kyoto, Japan). The refractive indexes of fat and water were 1.47 and 1.33, respectively, with an absorbance of 0.001 (Cheng *et al.*, 2015). In the analysis, the ice cream specimens were diluted with water in a ratio of 1:100, following Cheng *et al.* (2015). The measurements were taken at room temperature in duplicate.

Texture Analysis

The texture analysis was carried out using a texture analyzer (TA.XTPlus, Texture Technologies Corp., Hamilton, MA, USA) equipped with a 25 mm diameter clear acrylic cylindrical probe. Prior to the analysis, the frozen ice cream specimens stored at -20°C for 2 weeks were tempered at 25°C for 1.5 min. The analysis condition followed Akalin *et al.* (2008), in which the penetration distance was 15 mm, the probe speed during penetration was 3.3 mm s⁻¹, and the pre- and post-penetration probe speeds were 3.0 mm s⁻¹. The analysis was performed in triplicate. The hardness and the adhesiveness were the peak compression force during penetration and the negative peak force during the probe removal, respectively.

Melting Rate Analysis

The melting rate analysis was conducted on the frozen ice cream mixes. In the analysis,

approximately 80 g each of the frozen ice cream mixes was transferred onto a 1 mm mesh stainless steel sieve on top of a beaker and left to melt at 25°C. The drained weights were recorded every 5 min for 80 min. The measurements were taken in triplicate. The relationship between the drip loss (%) and the melting time was determined and the slope of the linear region of the relationship was used as the melting rate (Segall and Goff, 2002).

Data Analysis

In this study, a completely randomized design was performed. All the analyses were carried out either in duplicate or triplicate, and the results expressed as the means \pm standard deviations. A one-way analysis of variance (ANOVA) was applied to evaluate the effects of the variable fat and inulin contents on the physical properties of the ice cream mixes. The Tukey-Kramer multiple comparison was used to compare the mean values given that significant differences at $p < 0.05$ were observed. The statistical analysis was performed using RStudio version 3.2.2 (RStudio, Inc., Boston, MA, USA).

Results and Discussion

Rheological Measurement

Table 1 tabulates the rheological properties of the experimental aged ice cream mixes. The rheological behaviors were characterized using the power law model and the shear rate and shear stress data with $R^2 \geq 0.98$. In the Table, the apparent viscosity (μ) and the consistency coefficient (K) of the regular ice cream (control) were significantly higher than those

of the inulin-free (sample 1) and inulin-containing (samples 2 and 3) reduced-fat ice cream mixes. The findings indicated that the fat content and the apparent viscosity and consistency coefficient were positively correlated. In other words, the decrease in the fat content (i.e. the reduced-fat ice cream) contributed to the decrease in the apparent viscosity and consistency coefficient.

The composition of an ice cream mix, e.g. the stabilizer and polysaccharide concentrations, influences its viscosity and consistency coefficient and thereby the rheological behaviors of the ice cream product (Bahramparvar and Tehrani, 2011; Cheng *et al.*, 2015). Specifically, Goff and Hartel (2013) documented that the viscosity increased with the increased proportions of the stabilizer, protein, corn syrup solids, fat, and total solids, with the contribution of each decreasing in that order.

In this study, the apparent viscosity and the consistency coefficient of the reduced-fat ice cream increased with the increased inulin content from 2% to 4%. This is consistent with El-Nagar *et al.* (2002) and Soukoulis *et al.* (2009), who investigated the effect of the dietary fiber enrichment in reduced-fat ice cream on the rheological properties and reported that the increased proportion of inulin inclusion significantly increased the viscosity and consistency coefficient due to the ability of inulin to retain water. In contrast, Tiwari *et al.* (2015) reported that the introduction of inulin (0% - 6%) into reduced-fat and low-fat ice cream mixes reduced both the apparent viscosity and the consistency coefficient. The discrepancy suggested that there are other factors at play.

Table 1. Rheological properties of the experimental aged ice cream mixes

Treatments ¹	Apparent viscosity ² (μ , mPa.s) at 50 s ⁻¹	Consistency coefficient ³ (K, Pa.s ⁿ)	Flow behavior in (n, -)
Control	306.28 \pm 19.87 ^c	32.65 \pm 1.22 ^d	0.315 \pm 0.013 ^a
Sample 1	164.30 \pm 5.90 ^a	18.58 \pm 1.09 ^a	0.402 \pm 0.001 ^c
Sample 2	167.40 \pm 1.61 ^a	21.10 \pm 0.46 ^b	0.389 \pm 0.015 ^c
Sample 3	178.50 \pm 1.42 ^b	23.53 \pm 0.17 ^c	0.353 \pm 0.004 ^b

¹ Control denotes the regular ice cream; Sample 1 denotes the inulin-free reduced-fat ice cream; Sample 2 denotes the 2% inulin-containing reduced-fat ice cream; Sample 3 denotes the 4% inulin-containing reduced-fat ice cream.

^{2,3,4} The values represent the means of triplicate \pm standard deviations. The different letters in the same column indicate the differences among treatments at $p < 0.05$.

The flow behavior indexes (n) of the experimental ice cream mixes were below 1 (<1), indicating the non-Newtonian pseudoplastic behavior. In Table 1, the flow behavior index of the regular ice cream mix (control) was significantly lower than those of the inulin-free (sample 1) and inulin-containing (samples 2 and 3) reduced-fat ice cream mixes. The increased inulin concentration decreased the flow behavior index, thus improving the pseudoplastic fluid. According to Bahramparvar and Tehrani (2011), the small flow behavior index (i.e. approaching 0) indicated the low Newtonian behavior of a fluid. As previously stated, the reduced fat content significantly influenced the rheological behaviors of the ice cream products. In fact, the 2% and 4% inulin contents in the reduced-fat ice cream

mixes only partially restored their rheological properties to that of the regular ice cream. However, the 4% inulin content noticeably improved the rheology of the reduced-fat ice cream (sample 3) vis-à-vis the inulin-free reduced-fat ice cream mix (sample 1).

DSC Measurement

Figure 1 illustrates the DSC thermograms of the experimental aged ice cream mixes, with their respective endothermic peaks indicating the ice melting (Alvarez *et al.*, 2005). Meanwhile, Table 2 tabulates the thermal properties and the percentages of unfreezable water (UFW) of the aged ice cream mixes. The results indicated that neither the fat reduction nor the higher inulin content significantly influenced the enthalpy of fusion (ΔH),

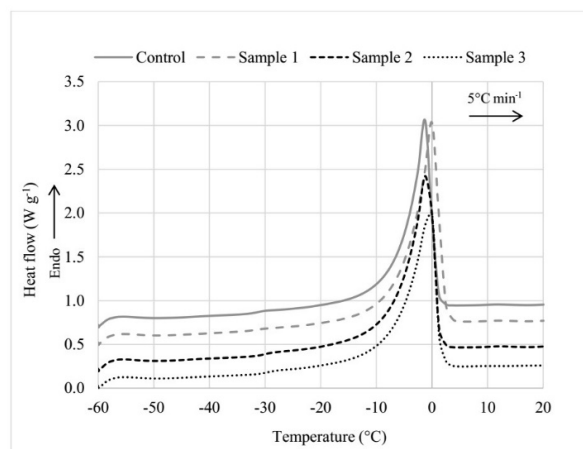


Figure 1. DSC melting curves of the aged ice cream mixes, where Control denotes the regular ice cream, Sample 1 denotes the inulin-free reduced-fat ice cream, Sample 2 denotes the 2% inulin-containing reduced-fat ice cream, and Sample 3 denotes the 4% inulin-containing reduced-fat ice cream

Table 2. Thermal properties of the experimental aged ice cream mixes

Treatment ¹	ΔH^2 (J g ⁻¹)	T_o^3 (°C)	ΔT^4 (°C)	T_g^5 (°C)	UFW ⁶ (%)
Control	133.0 ± 6.0	-5.3 ± 0.1	22.4 ± 1.6	-30.3 ± 0.5 ^a	18.8 ± 2.1
Sample 1	135.6 ± 23.8	-4.9 ± 0.5	23.1 ± 0.9	-30.3 ± 0.4 ^a	23.5 ± 4.8
Sample 2	133.6 ± 11.9	-5.3 ± 0.1	22.1 ± 1.3	-27.8 ± 0.4 ^b	20.2 ± 2.9
Sample 3	128.9 ± 5.3	-5.3 ± 0.3	22.0 ± 0.7	-28.7 ± 0.6 ^b	20.9 ± 0.4

¹ Control denotes the regular ice cream; Sample 1 denotes the inulin-free reduced-fat ice cream; Sample 2 denotes the 2% inulin-containing reduced-fat ice cream; Sample 3 denotes the 4% inulin-containing reduced-fat ice cream.

^{2,3,4,5,6} ΔH is the enthalpy of fusion; T_o is the onset temperature; ΔT is the melting temperature range; T_g is the glass transition temperature; UFW is the unfreezable water. The values represent the means of duplicate ± standard deviations. The different letters in the same column indicate the differences among treatments at $p < 0.05$.

the onset temperature (T_o), and the melting temperature range (ΔT), relative to the regular ice cream mix. Nevertheless, the introduction of inulin contributed to the increased glass transition temperature (T_g), suggesting that inulin improved the storage stability of the reduced-fat ice cream. The finding was consistent with Soukoulis *et al.* (2009) and Balthazar *et al.* (2017).

According to Goff *et al.* (1993) and Goff (1994), protein and polysaccharide stabilizers were commonly used to regulate the phase transition of ice cream products from the rubbery to glassy state, resulting in thermodynamic stability during storage. Specifically, this current study has demonstrated that inulin could help restrict the mobility of the water molecules. Thus, water diffusion and recrystallization decreased, resulting in the improved product stability during frozen storage (Soukoulis *et al.*, 2009).

The unfreezable water of the experimental ice cream mixes was in the range of 18.8 – 23.5%, without statistically significant differences. A similar finding was reported in Balthazar *et al.* (2017), who documented that the unfreezable water of inulin-containing non-fat sheep milk ice cream (27%) was insignificantly different from that of full-fat sheep milk ice cream (21.7%). In contrast,

Soukoulis *et al.* (2009) reported that 4% inulin in reduced-fat ice cream significantly increased the unfreezable water (17%), compared with inulin-free reduced-fat ice cream (15.9%). The discrepancy could be attributed to the difference in total soluble solids. According to Alvarez *et al.* (2005), the intensity of ice formation was inversely correlated to the soluble solids content.

Despite the minimal effects of inulin on the enthalpy of fusion (ΔH), onset temperature (T_o), melting temperature range (ΔT), and unfreezable water (UFW), the statistically significantly elevated glass transition temperatures (T_g) indicated that inulin could be utilized to enhance the storage stability of the reduced-fat ice cream.

Particle Size Distribution Measurements

The particle size distributions of the fat globules of the aged and frozen ice cream mixes were determined using the laser light scattering technique, whereby the differences in the fat globule sizes were analyzed, indicating the change in the emulsion as a result of fat destabilization (Goff and Hartel, 2013). In Figure 2, the aged ice cream mixes exhibited a bimodal distribution (solid line). After being frozen for 2 weeks, however, the first and second peaks of the regular ice cream

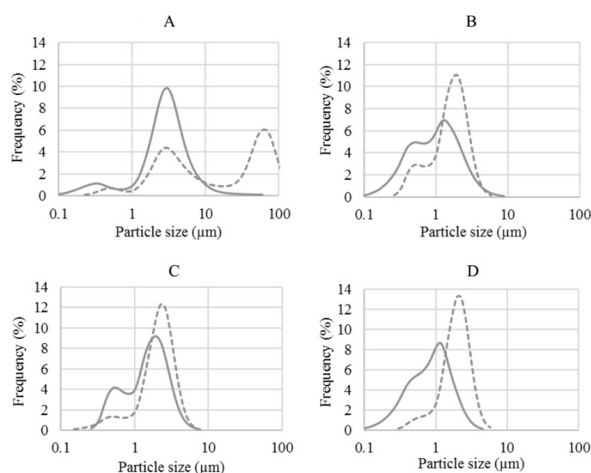


Figure 2. Particle size distributions of the aged (solid line) and frozen (dashed line) ice cream mixes: (A) the regular ice cream (control), (B) the inulin-free reduced-fat ice cream (Sample 1), (C) the 2% inulin-containing reduced-fat ice cream (Sample 2), and (D) the 4% inulin-containing reduced-fat ice cream (Sample 3)

(control) noticeably decreased (dashed line) with the emergence of a third peak (Figure 2(a)). Meanwhile, the frozen reduced-fat ice cream mixes with 0%, 2%, and 4% inulin still exhibited a bimodal distribution with a lower first peak but a taller second peak (Figures 2(b-d)).

The results revealed the incidences of fat destabilization or partial coalescence over the course of freezing, especially in the regular ice cream, as evident in the presence of large-sized particles ($>10\ \mu\text{m}$). Unlike the inulin-free reduced-fat ice cream, the presence of inulin in the reduced-fat ice cream induced the clustering of fat globules, resulting in the increase of the large-sized particles ($1\text{--}10\ \mu\text{m}$). The observations were consistent with Balthazar *et al.* (2017), who reported that the fat destabilization of the full-fat ice cream was significantly higher than that of the non-fat ice cream containing inulin. According to Goff and Hartel (2013) and Daw and Hartel (2015), the fat globule size distribution during the initial emulsion was in the range of $0.8\text{--}2.0\ \mu\text{m}$, while the distribution of the fat globule clusters due to the partial coalescence was largely $10\ \mu\text{m}$.

Texture Analysis

In Figure 3, the lower fat content significantly increased the hardness of the reduced-fat ice cream, relative to the regular ice cream (control). This is because the removal of fat resulted in the increased ice crystal volume, which subsequently contributed to a harder texture (Guinard *et al.*, 1997; El-Nagar *et al.*, 2002; Akalin *et al.*, 2008; Tiwari *et al.*, 2015; Akbari *et al.*, 2016). In this study, the 2% and 4% inulin contents significantly decreased the hardness of the reduced-fat ice cream. The finding was consistent with Akbari *et al.* (2016), who reported that the reduction in the hardness was probably due to the absorption of water by inulin, resulting in the increase in the unfreezable water in ice cream and the subsequent decrease in the ice crystal volume.

Moreover, the hardness of an ice cream was subject to other factors, such as the freezing point of the ice cream, total solids, overrun, and stabilizer (Goff and Hartel, 2013). Thus, the addition of inulin could increase the solute concentrations, subsequently lowering the freezing point of ice cream and the hardness.

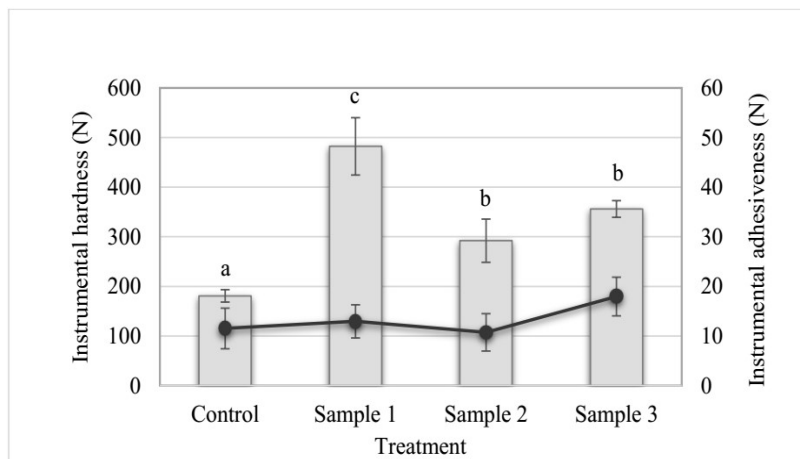


Figure 3. The hardness (bar chart) and adhesiveness (line chart) of the frozen ice cream mixes, where Control denotes the regular ice cream, Sample 1 denotes the inulin-free reduced-fat ice cream, Sample 2 denotes the 2% inulin-containing reduced-fat ice cream, and Sample 3 denotes the 4% inulin-containing reduced-fat ice cream. The values represent the means of triplicate \pm standard deviations. The different letters in each column indicate the differences among treatments at $p < 0.05$

Unlike the hardness, the variations in the adhesiveness were less pronounced between the experimental ice cream mixes. In fact, neither the lower fat content nor the presence of inulin significantly influenced the adhesiveness of the ice cream mixes, relative to the regular ice cream. The findings were however in contrast with Tiwari *et al.* (2015), who reported that inulin increased the adhesiveness of low-fat ice cream, whereas Akbari *et al.* (2016) argued that the inulin content in low-fat ice cream and the adhesiveness were inversely correlated.

In short, the hardness of the ice cream increased as its fat content decreased. Nevertheless, the introduction of inulin into the reduced-fat ice cream reduced the hardness and thus improved its texture to more resemble that of the regular ice cream.

Melting Rate Analysis

In Figure 4, the melting rate of the inulin-free reduced-fat ice cream (sample 1) was significantly higher than that of the other ice cream mixes, indicating that the fat content and the melting rate were inversely correlated. The

finding was consistent with El-Nagar *et al.* (2002) and Akbari *et al.* (2016). Moreover, several other factors influence the melting rate of an ice cream, including the air cell and ice crystal size, the amount of partially coalesced fat, and the rheological properties (Muse and Hartel, 2004; Daw and Hartel, 2015). Specifically, the ice cream mixes with a high fat content tended to gradually melt due to the lower heat transfer, thus improving the insulation effect (Akalin *et al.*, 2008; Goff and Hartel, 2013; Balthazar *et al.*, 2017).

In Figure 4, the addition of inulin reduced the heat transfer rate and the subsequent melting rate of the reduced-fat ice cream to the level comparable to that of the regular ice cream (control). Interestingly, the melting rate was inversely correlated with the apparent viscosity and the consistency coefficient. This observation was consistent with El-Nagar *et al.* (2002), who reported that the increased inulin content contributed to the increase in the serum viscosity and the lower melting rate. According to Bahramparvar and Tehrani (2011), the melting rate and the viscosity of an ice cream were inversely correlated.

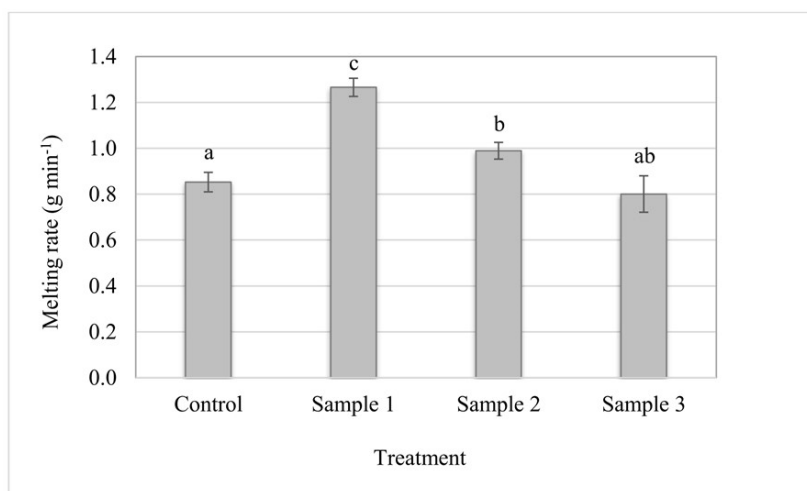


Figure 4. Melting rates of the frozen ice cream mixes, where Control denotes the regular ice cream, Sample 1 denotes the inulin-free reduced-fat ice cream, Sample 2 denotes the 2% inulin-containing reduced-fat ice cream, and Sample 3 denotes the 4% inulin-containing reduced-fat ice cream. The values represent the means of triplicate \pm standard deviations. The different letters in each column indicate the differences among treatments at $p < 0.05$

Conclusions

In this study, the replacement of fat by the use of inulin, especially at the level of 4%, in the reduced-fat ice cream significantly enhanced the physicochemical characteristics of the ice cream. Meanwhile, the introduction of inulin (2% and 4%) into the reduced-fat ice cream minimally improved the rheology of the final products, but it significantly increased the glass transition temperature (T_g) indicating an enhancement of product stability during frozen storage. The inclusion of 2% and 4% inulin in the reduced-fat ice cream decreased the hardness values. Moreover, the addition of 4% inulin significantly slowed the rate of melting of the reduced-fat ice cream similar to that of the regular ice cream.

Acknowledgements

The authors would like to extend deep gratitude to Suranaree University of Technology for the analytical tools.

References

- Akalin, A.S., Karagozlu, C., and Unal, G. (2008). Rheological properties of reduced-fat and low-fat ice cream containing whey protein isolate and inulin. *Eur. Food Res. Technol.*, 227:889-895.
- Akbari, M., Eskandari, M.H., and Niakosari, M. (2016). The effect of inulin on the physicochemical properties and sensory attributes of low-fat ice cream. *Int. Dairy J.*, 57:52-55.
- Alvarez, V.B., Wolters, C.L., Vodovotz, Y., and Ji, T. (2005). Physical properties of ice cream containing milk protein concentrates. *J. Dairy Sci.*, 88: 862-871.
- Baharmparvar, M. and Tehrani, M.M. (2011). Application and functions of stabilizers in ice cream. *Food Rev. Int.*, 27(4):389-407.
- Balthazar, C.F., Silva, H.L.A., Vieira, A.H., Neto, R.P.C., Cappato, L.P., Coimbra, P.T., Moraes, J., Andrade, M.M., Calado, V.M.A., Granato, D., Freitas, M.Q., Tavares, M.I.B., Raices, R.S.L., Silva, M.C., and Cruz, A.G. (2017). Assessing the effects of different prebiotic dietary oligosaccharides in sheep milk ice cream. *Food Res. Int.*, 91:38-46.
- Chaito, C., Judprasong, K., and Puwastien, P. (2016). Inulin content of fortified food products in Thailand. *Food Chem.*, 193:102-105.
- Cheng, J., Ma, Y., Li, X., Yan, T., and Cui, J. (2015). Effects of milk protein-polysaccharide interactions on the stability of ice cream mix model systems. *Food Hydrocolloid.*, 45:327-336.
- Daw, E. and Hartel, R.W. (2015). Fat destabilization and melt-down of ice creams with increased protein content. *Int. Dairy J.*, 43:33-41.
- El-Nagar, G., Clowes, G., Tudorica, C.M., Kuri, V., and Brennan, C.S. (2002). Rheological quality and stability of yog-ice cream with added inulin. *Int. J. Dairy Technol.*, 55(2):89-93.
- Franck, A. (2002). Technological functionality of inulin and oligofructose. *Br. J. Nutr.*, 87(2):S287-S291.
- Goff, H.D. (1994). Measuring and interpreting the glass transition in frozen foods and model systems. *Food Res. Int.*, 27:187-189.
- Goff, H.D. (2016). The ice cream ebook. University of Guelph, Ontario, Canada. Available from: www.uoguelph.ca/foodscience/book-page/ice-cream-ebook. Accessed date: Jan 15, 2016.
- Goff, H.D. and Hartel, R.W. (2013). Analyzing frozen desserts. In *Ice Cream*. 7th ed. Goff, H.D. and Hartel, R.W., (eds). Springer, New York, NY, USA, p. 403-435.
- Goff, H.D., Caldwell, K.B., and Stanley, D.W. (1993). The influence of polysaccharides on the glass transition in frozen sucrose solutions and ice cream. *J. Dairy Sci.*, 76:1,268-1,277.
- Guggisbert, D., Cuthbert-Steven, J., Piccinali, P., Butikofer, U., and Eberhard, P. (2009). Rheological, microstructural and sensory characterization of low-fat and whole milk set yogurt as influenced by inulin addition. *Int. Dairy J.*, 19:107-115.
- Guinard, J.X., Zoumas-Morse, C., Mori, L., Uatoni, B., Panyam, D., and Kilara, A. (1997). Effect of sugar and fat on the acceptability of vanilla ice cream. *J. Food Sci.*, 5:1,087-1,094.
- Juan, B., Zamora, A., Quintana, F., Guamis, B., and Trujillo, A.J. (2013). Effect of inulin addition on the sensorial properties of reduced-fat fresh cheese. *Int. J. Dairy Technol.*, 66(4):478-483.
- Karimi, R., Azizi, M.H., Ghasemlou, M., and Vaziri, M. (2015). Application of inulin in cheese as prebiotic, fat replacer and texturizer: A review. *Carbohydr. Polym.*, 119:85-100.
- McClements, D.J. and Decker, E.A. (2008). Lipids. In: *Fennema's Food Chemistry*. 4th ed. Damodaran, S., Parkin, K.L., and Fennema, O.R., (eds). CRC Press, Boca Raton, FL, USA, p. 155-216.
- Mellado, A.F. (1998). Ice crystallization and recrystallization in frozen model solutions and ice cream as affected by polysaccharide gums. [MSc. thesis]. Faculty of Graduate Studies, University of Guelph, Canada.
- Meyer, D., Bayarri, S., Tarrega, A., and Costell, E. (2011). Inulin as texture modifier in dairy products. *Food Hydrocolloid.*, 25:1881-1890.
- Muse, M. and Hartel, R.W. (2004). Ice cream structural elements that affect melting rate and hardness. *J. Dairy Sci.*, 87:1-10.
- Paul, A. and Coussement, A. (1999). Inulin and oligofructose: safe intakes and legal status. *J. Nutr.*, 129(7):1412S-1417S.
- Segall, K.I. and Goff, H.D. (2002). A modified ice cream processing routine that promotes fat destabilization in the absence of added emulsifier. *Int. Dairy J.*, 12:1013-1018.
- Soukoulis, C., Lebesi, D., and Tzia, C. (2009). Enrichment of ice cream with dietary fibre: effects on rheological properties, ice crystallisation and glass

- transition phenomena. *Food Chem.*, 115:665-671.
- Tiwari, A., Sharma, H.K., Kumar, N., and Kuar, M. (2015). The effect of inulin as a fat replacer on the quality of low-fat ice cream. *Int. J. Dairy Technol.*, 68(3):374-380.