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Effects of Fat Replacers and Stabilizers on Rheological, Physicochemical and Sensory Properties of Reduced-fat Ice Cream

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ABSTRACT

Current interests towards lowering fat content in food products and producing healthier and safer foods, have convinced ice cream manufacturers to substitute milk fat in ice cream with either carbohydrate or protein based fat replacers. In the present work, reduced-fat ice cream (5% fat) was produced using milk protein concentrate (65%) and inulin as fat replacers (0, 2 and 4%) as well as two types of commercial stabilizer-emulsifier blends (Stab-IC80 and Stab-6924) at levels of 0.3 and 0.4%. Rheological, physicochemical and sensory properties of ice cream mix and final ice cream were evaluated. All the mixes were pseudoplastic fluids with apparent viscosity values decreasing with increasing shear rate. Mix viscosity and consistency coefficient increased while flow behaviour index decreasing by use of MPC (Milk Protein Concentrate) and inulin and as well with an increase in either type of stabilizer level. Ice cream hardness was not affected by type and amount of fat replacer and stabilizer but overrun values decreased with increasing MPC, inulin and stabilizers' level in the product formulation. In general, samples containing Stab-IC80 had greater values of overrun and melting resistance than samples with Stab-6924. According to panel test results, the highest score for sensory evaluation was given to sample containing 2% inulin.

Keywords: Formulation, Quality, Reduced-fat ice cream, Stabilizer, Viscosity, Texture.

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INTRODUCTION

Nowadays, consumers have directed their interest towards reduced or low-fat products as they associate them with a reduced risk of obesity and coronary heart diseases (Akalin *et al.*, 2008). Typically, ice cream contains 10–16% fat that is the main component affecting flavour and textural properties of the product. Milk fat interacts with other ingredients to develop the texture, mouthfeel, creaminess, and overall sensation of lubricity. In recent years, the dairy industry has developed a variety of low-fat and fat-free ice cream products (Adapa *et al.*, 2000). The challenge in working with low fat ice cream is related to the fact that the fat globule network would either be disrupted or absent and this could seriously impact flavour and texture of the product (Aime *et al.*, 2001). Devereux *et al.* (2003) reported that texture was more important than flavour in determining overall acceptability of the low-fat foods. Removal of fat causes such body and textural problems as coarseness and iciness, crumbly body, shrinkage and flavour defects (Berger 1990; Marshal and Arbuckel, 1996).

Ice cream manufacturers have made a practice to use milk fat replacers to form products that meet the demands of health-conscious consumers. Accepted fat substitutes for ice cream are made up of carbohydrates

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and proteins, instead of being based on lipid, which may form lipophilic particles (Schirle-Keller *et al*., 1992). It has been reported that the use of carbohydrate based fat replacers increased ice cream mix viscosity (Schmidt *et al*., 1993; Adapa *et al*., 2000; Akalin *et al*., 2008).

Inulin is widely used in functional foods throughout the world for their health-promoting and technological properties. Several commercial grades of inulin are available that have a neutral, clean flavour and are used to improve mouthfeel, stability as well as acceptability of low-fat foods as a low caloric texturising agent. Schaller-Povolny and Smith (1999) reported an increase in the viscosity *vs.* decrease in the freezing point of reduced-fat ice cream containing inulin along with an improvement in the sensory properties. The effect of using inulin as fat replacer on rheological properties of low fat and reduced fat ice cream was studied and compared with Whey Protein Isolate (WPI) (Akalin *et al*., 2008).

Protein based fat replacers have also been used in ice cream formulation (Ohmes *et al*., 1998; Roland *et al*., 1999; Adapa *et al*., 2000; Prindeville *et al*., 2000; Akalin *et al*., 2008). Alvarez *et al*. (2005) reported that the use of Milk Protein Concentrate (MPC 65 and 85%) in ice cream composition improved viscosity and melting properties, compared with the control. Also the use of MPC in ice cream was studied and product quality compared with the samples containing maltodextrin, polydextrose and lactose-reduced freeze concentrated skim milk (Roland *et al*., 1999).

Other factors contributing to ice cream texture include stabilizers and emulsifiers. Stabilizers are of high water binding capacity and therefore their type and content can affect rheological properties of ice cream mix. It was reported that increasing the stabilizer content in ice cream formulation leads to increasing viscosity that has an important effect on melting behaviour of the product (Guinard *et al*., 1994; Muse and Hartel, 2004; Sofjan *et al*., 2004; Moeenfard and Mazaheri, 2008). In work with full fat ice cream, it has been demonstrated that stabilizers promote viscosity development in the aqueous phase and control ice crystal growth (Aime *et al*., 2001).

The objective followed throughout this study was to evaluate the suitability of using inulin as a functional fat mimetic in comparison with MPC in ice cream formulation and to determine the most appropriate type and level of stabilizer-emulsifier blend for such ice cream formulations.

MATERIALS AND METHODS

Milk with 2.4% fat and 8.75% solid non fat (Pegah milk industry, Mashhad, Iran), low fat milk powder with 1.32% fat and 96.15% total milk solids (Golshad Co, Iran), cream with 30% fat (Pegah milk industry, Mashhad, Iran), inulin (Merck, Germany), and milk protein concentrate 65% (Pegah milk industry, Mashhad, Iran) as fat replacers and stabilizer-emulsifier blends (Stab25-IC 80, Roberte, France and Stab-6924, Behingard, Iran) were made use of. Sugar powder (Chenaran sugar plant) and vanillin were obtained from local suppliers.

Ice Cream Preparation

Product formulation was comprised of 12% SNF, 5% fat, fat replacer (0, 2 and 4%), 15% sucrose, stabilizer-emulsifier blend (0.3 and 0.4%) and 0.1% vanillin. The content level of any ingredient was found out through mathematical calculation, and for a batch size of 500 g (Chagani and Meshkat, 2006). Cream was added to the milk at 25°C and the temperature elevated to 45-50°C making use of a hot water bath. The thoroughly premixed dry ingredients (low fat milk powder, fat replacer and stabilizer-emulsifier blend) were then added. The mixes were batch pasteurized at 85 °C for 5 minutes and then cooled in an ice bath to 5°C. Following the addition of vanillin, all mixes were aged at 4°C for 24 hours to ensure complete hydration of all the ingredients. Ice cream mixes were frozen in a domestic batch type ice cream maker equipped with a compressor (1liters, Feller IC 100, Germany). Freezing took 20 minutes (at -18°C) before having 50 g portions filled into plastic cups and to be hardened at -18°C for about 24 hours.

Reduced fat ice cream was produced by incorporation of a carbohydrate-based fat replacer (inulin) and a protein-based fat replacer (MPC) at three levels of 0, 2 and 4% and two types of stabilizer-emulsifier blends at levels of 0.3 and 0.4%. Ice cream production was done in triplicates, so 48 samples were evaluated for physicochemical and sensory properties.

Physio-chemical Analyses

The total solids of milk and of low fat dried milk were determined by drying the samples at 105±1ºC for 5.0 hours using air draft forced oven (PAAT-ARIYA Co. SH2006, Iran) till constant weight as prescribed in AOAC, 1997. Fat content was determined through Gerber method (ISIRI number 2450, 2005).

Flow behaviour of ice cream mixes was evaluated using rotational viscometer (Bohlin Model Visco88, Bohlin Instruments, UK) equipped with a circulator. Product temperature was controlled at 5±0.5°C by a refrigerated/heating circulator (Julabo, Model F12-MC; Julabo Labortechnik, Seelbach, Germany). Apparent viscosity was expressed in Pa s at a shear rate of 51.7 s^{-1} (Morris 1983).

The overrun of ice cream samples was determined using the formula of Marshal and Arbuckle (1996).

The melting resistance of ice cream samples was determined according to Sakurai *et al*. (1996). The ice cream (30 g in weight at -18ºC was placed on a Buchner funnel at ambient temperature (25°C). The weight of the melted material was recorded after 15 minutes past and expressed as percentage weight melted.

Texture analysis was conducted at room temperature (20±1°C) using a Texture Analyser (CNS Farnell, Hertfordshire, UK) equipped with a 2.5 cm diameter stainless steel cylindrical probe. Ice cream samples were tempered to -10°C before analysis. The conditions for analysis were as follows: Penetration distance= 15 mm, Force= 5.0 g, Probe speed during penetration= 3.3 mm s^{-1}, Probe speed pre and post penetration= 3.0 mm s^{-1}. The ice cream, remaining in the plastic cup, was penetrated in two places on its largest smooth surfaces and four measurements carried out for each product. Hardness was measured as the peak compression force (*N*) during the penetration into the sample (Akalin *et al*., 2008).

Sensory Evaluation

The sensory evaluation of reduced-fat ice cream performed through the judgement of 18 trained panelists. Ice cream samples were taken out from frozen storage (-18ºC) after 24 hours past of hardening and promptly offered to the panelists. The samples were coded with three digit random numbers in odourless plastic cups with all the orders of servings completely randomized. A 9-point hedonic scale was employed to determine the degree of liking of the products (9= Extreme like, 5= Neither like nor dislike, 1= Extreme dislike). The samples were rated for colour and appearance, flavour/taste, body/texture and overall acceptability as prescribed by Herald *et al.* (2008).

Physicochemical and sensory analyses of the final products were conducted 1 day past production.

Statistical Analysis

The data related to the three replications were obtained by applying a two factor completely randomized block design with the results being analyzed through MSTAT-C software. Analysis of Variance along with Significant Difference (P≤0.05) were accomplished through Duncan's Multiple Range Test (Steel *et al*, 1997). Excel software was employed to plot curves.

RESULTS AND DISCUSSION

Flow Behaviour of Ice-cream Mixes

According to primary test results, all samples were Non-Newtonian, time independent fluids in conformity with previous reports (Cottrel *et al*., 1980; Goff and Davidson, 1994; Kaya and Tekin, 2001).

Profiles of shear stress and of viscosity versus shear rate revealed shear thinning behaviour of all mixes where viscosity values decreased with increasing shear rate. The reason for such behaviour is that in low shear rates, molecules are in such an irregular arrangement that leads to high viscosity values. With increasing shear rate, these molecules get aligned in more similar directions and consequently intermolecular friction and viscosity values decrease (Rha, 1975; Glichsman, 1982).

In this study shear stress and shear rate values were fitted using Herschel-Bulkley model:

$$\sigma = \sigma_0 + k\gamma^n$$

Where, σ is shear stress (Pa), σ_0 is yield stress (Pa), γ is shear rate (s^{-1}), k is consistency coefficient (Pa s^n) and n flow behaviour index.

Yield stress (σ_0), flow behaviour indices (n), consistency coefficients (k) and correlation coefficients (r^2) of the model for samples containing fat replacers at three levels and two types and levels of stabilizers are presented in Tables 1, and 2 respectively. Values of n for all the samples obtained were less than 1, showing the shear thinning behaviour of all the mixes reported previously (Cottrel *et al*., 1980; Goff and Davidson, 1994; Kaya and Tekin, 2001).

No significant difference was observed between yield stress values of samples containing MPC where these values decreased significantly with increasing inulin ($P< 0.05$).

Consistency coefficients of the mixes containing fat replacers were significantly higher than that of control ($P< 0.05$). The highest value was obtained for the samples of 2% MPC and 4% inulin. Consistency coefficient is an important parameter for

Table1. Yield stress (σ_0), consistency coefficients (k), flow behaviour indices (n) and correlation coefficients (r^2) of Herschel-Bulkley model for reduced-fat ice cream mixes containing fat replacers at three levels

	MPC			Inulin		
	0%	2%	4%	0%	2%	4%
σ_0	1.43±1.90 [a]	1.32±0.72	1.43±1.12	1.43±1.90	1.08±1.08	0.26±1.24
k	0.19±0.12c	0.9±0.22a	0.62±0.27b	0.19±0.12c	0.33±0.18c	0.88±0.33a
n	0.85±0.21a	0.62±0.03b	0.68±0.04b	0.85±0.21a	0.73±0.06ab	0.63±0.05b
r^2	0.99a	0.99a	0.99a	0.99a	0.99a	0.99a

[a] Values are average±standard error (n= 3), [a, b]: Values in a column which do not share a common letter are statistically different (P= 95%).

Table 2. Yield stress (σ_0), consistency coefficients (k), flow behaviour indices (n) and correlation coefficients (r^2) of Herschel-Bulkley model for reduced-fat ice cream mixes containing tow types and levels of stabilizers.

	Stab25-IC80		Stab-6924	
	0.3%	0.4%	0.3%	0.4%
σ_0	0.87±0.64 [a]	2.9±1.76	0.46±1.15	1.02±0.98
k	0.4±0.27b	0.39±0.49b	0.31±0.45b	0.62±0.36a
n	0.72±0.06b	0.9±0.31a	0.74±0.10b	0.67±0.06b
r^2	0.99a	0.99a	0.99a	0.99a

[a] Values are average±standard error (n= 3), [a, b]: Values in a column which do not share a common letter are statistically different (P= 95%).

estimating viscous nature of food products (Sopade and Kassum, 1992). It was reported to be within the ranges of 0.0733 to 1.260 Pa. s^n *vs.* 0.145 to 0.0211 Pa. s^n by Muse and Hartel (2004), and Minhas *et al*. (2002) respectively.

As can be seen from Table1, the highest value for flow behaviour index was obtained for the control. The *n* values for the mixes with both types of fat replacers decreased with their increasing levels but th differences were not significant (P> 0.05). The flow behaviour index gives an indication of how close the ice cream mix is to a Newtonian fluid. Flow behaviour index of 0.7 was reported for ice cream mixes (Goff and Davidson, 1994). According to Chinan *et al.* (1985), pseudoplasticity increased with decreasing n. Similarly, Soukoulis *et al.* (2009) demonstrated that the use of dietary fibres in ice cream mix formulation significantly increased viscosity and shear thinning behaviour.

In a study by Schmidt *et al.* (1993) ice milk made with a carbohydrate-based fat mimetic was found to be of a greater viscosity and consistency coefficient and a smaller flow behaviour index than those of either the control or ice milk made with a protein-based fat mimetic. In contrast, greater viscosity and consistency coefficients and a smaller flow behaviour index were reported for reduced-fat and low-fat ice cream containing WPI when compared with inulin (Akalin *et al*., 2008).

According to data presented in Table 2, yield stress values for the mixes containing Stab-IC80 were significantly higher than those for mixes containing Stab-6924 stabilizer. Also increasing the level of stabilizer would lead to an increase in yield stress values for both types of stabilizers (P< 0.05).

Increasing the level of stabilizer from 0.3 to 0.4% led to increasing consistency coefficient in the sample containing Stab-6924 but presented no significant effect on this property in Stab-IC80 containing samples (P> 0.05). The highest value of *k* was obtained for the sample containing 0.4% Stab-6924. It was reported that increasing Salep concentration from 0.4 to 1% in ice cream formulation, led to increasing the values of *k* at temperatures between 10 to 50°C (Kaya and Tekin, 2001). According to Sopade and Kassum (1992), *k* is a factor for estimating viscous nature of food products. Stabilizers are of high water binding capacities and therefore type and quantity of stabilizers can affect the rheological properties of ice cream mix. It was reported that increasing stabilizer content in ice cream formulation leads to increasing viscosity which in turn exerts an important effect on melting behaviour of the product (Guinard *et al.,* 1994; Muse and Hartel, 2004; Sofjan *et al.*, 2004; Moeenfard and Mazaheri, 2008).

The values obtained for flow behaviour indices for samples with two levels of Stab-6924 and 0.3% Stab-IC80 were within the same range with no significant difference detected between them (P> 0.05). The *n* value for ice cream mix of 0.4% Stab-IC80 was significantly higher than that in the other mixes. Kaya and Tekin (2001) reported that with increasing Salep concentration from 0.4 to 1%, *n* values decreased from 0.93 to 0.77 and the mix behaviour changed from Newtonian to Non-Newtonian. Also it was reported that *n* values decreased from 0.98 to 0.68 and from 0.88 to 0.48 with respectively increasing the levels of guar gum and locust bean gum from 0.05 to 0.4% (Cottrel *et al*., 1980). The results obtained for flow behaviour indices of mixes containing Stab-IC80 were in contradictory with previous reports. This might be due to the composition of this type of stabilizer.

Physio-chemical Properties

Physicochemical characteristics of ice cream mix and the final ice cream containing fat replacers at their three levels are presented in Table 3.

Viscosity values increased with an increase of fat replacers in the ice cream formulation. Mixes containing MPC, were

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Table 3. Physicochemical properties of reduced-fat ice cream mixes and ice cream containing fat replacers at three levels.

	MPC			Inulin		
	0%	2%	4%	0%	2%	4%
Viscosity (Pa s) at 5 ºC	0.113±0.02c [a]	0.232±0.04ab	0.355±0.16a	0.113±0.02c	0.128±0.05bc	0.204±0.05b
Overrun (%)	46.96±20.60a	33.18±4.37ab	12.95±7.64c	46.96±20.6a	28.7±8.09b	39.3±15.47ab
Melting Resistance (% melted after 15 minutes at 25ºC)	74.60±9.25ab	70.31±13.8ab	66.42±19.72b	74.60±9.25ab	79.23±1.12ab	70.28±8.79ab
Hardness (N)	21.98±8.76c	37.55±17.05a	30.11±14.93b	21.98±8.76c	21.94±9.45c	19.25±6.6c

[a] Values are average±standard error (n= 3), [a, b]: Values in a column which do not share a common letter are statistically different (P= 95%).

of higher values of viscosity with the highest value obtained for mix with 4% of MPC (P< 0.05). It has been reported that the use of MPC, WPC, WPI, SPC and SPI as substitutes for milk solid non fat in ice cream mix, increases the mixes' viscosity significantly (Thompson *et al.,* 1983; Lee and White, 1991; Alvarez *et al.,* 2005; Dervisouglou *et al.,* 2005; Herald *et al.,* 2008). Also Alfaifi and Stathopoulos (2010) reported that use of WPC as a substitute for egg yolk in Gelato ice cream containing 9% egg yolk, and increasing its level from 20 to 100% increased mix viscosity significantly. Schaller-Povolny and Smith (1999) reported an increase in the viscosity *vs.* decrease in the freezing point of reduced-fat ice cream containing inulin. According to Aime *et al*. (2001) consistency coefficients were positively correlated with the apparent viscosity values (r^2= 0.910) so the greater viscosity values obtained for samples containing MPC may be the result of higher consistency coefficients for these samples.

Using fat replacers in reduced fat ice cream decreased overrun values. Overrun values for samples with inulin were in the same range with the control but MPC contained samples bore lower values of overrun (P< 0.05). Surfactants like milk protein and some emulsifiers as well as stabilizers improve whipping trait and decrease the size of air cells where fat and other emulsifiers have negative effect on overrun because the foam volume depends on protein concentration. Despite the results obtained in this study, Schmidt *et al.* (1993) indicated that using carbohydrate based fat replacers led to decreasing overrun value in comparison with samples containing protein based fat replacer and with control. Similarly, Alfaifi and Stathopoulos (2010) reported an increase in overrun value of Gelato ice cream when the level of WPC was raised from 1.8 to 9 g.

No significant difference was observed between melting resistance of samples and the different type and amounts of fat replacers (P> 0.05) but the melting resistance of samples containing inulin was a bit more with the maximum value being associated with 2% inulin sample. Fat destabilization is the most important parameter affecting ice cream melting rate (Muse and Hartel, 2004). Fat destabilization is related to viscosity and ice cream ingredients. Herald *et al*. (2008) reported that increasing ice cream mix viscosity resulted in lower melting rate and improved product smoothness. Roland *et al.* (1999) reported that low fat ice cream samples containing MPC had higher melting rates than the samples of 10% fat. Using WPC as a substitute for egg yolk in Gelato ice cream and increasing the substitution level from 20 to 100% had resulted in decreasing melting rate while increasing product stability (Alfaifi and Stathopoulos, 2009). Also the melting rate for Gelato ice cream of 9% egg yolk and WPI, was lower than no WPI added sample (Alfaifi and Stathopoulos, 2010b).

As can be seen from Table 3, using MPC and inulin in ice cream formulation led to increasing hardness of the product. In this case samples with MPC showed higher values of hardness than those with inulin and than the control sample. Similarly, it was shown that using inulin and WPI in low fat and reduced fat ice cream led to increasing hardness of the product in comparison with conventional (10% fat) ice cream (Akalin *et al*., 2008). Similar results have been reported regarding the use of WPI as substitute for egg yolk in Galacto ice cream by Alfaifi and Stathopoulos (2010b). They concluded that increasing WPI for substitution of 20 to 100% of egg yolk led to hardness over storage time. Viscosity of the ice-cream mix prior to freezing is a major factor determining the texture of the ice cream. As found out in the course of the present study, an increase in samples viscosity resulted in firmer texture where the highest values for mix viscosity and ice cream hardness were associated with the samples containing MPC. In contrast, Roland *et al*. (1999) reported that all the fat replacers they made use of decreased the hardness of the samples. On the other hand, Aime *et al*. (2001) concluded that there were no differences observed in firmness values for fat-free, low fat and reduced fat ice cream preparations. Despite the findings, it was reported that ice cream samples containing 9% egg yolk were harder than samples of 4.5% egg yolk the reason for which might be the higher fat content in these products (Alfaifi and Stathopoulos, 2010a).

Physicochemical characteristics of ice cream mix and final ice cream containing two types and levels of stabilizers are presented in Table 4.

Viscosity values increased with an increase in the level of stabilizer for both stabilizers but the differences were not significant for Stab-6924. Maximum viscosity value (0.26 Pa s) was associated with the sample containing 0.4% Stab-IC80. The function a stabiliser in ice cream preparation is considered to be related to its water binding capacity by forming a three-

Table 4. Physicochemical properties of reduced-fat ice cream mixes and ice cream containing tow types and levels of stabilizers.

	Stab25-IC80		Stab-6924	
	0.3%	0.4%	0.3%	0.4%
Viscosity (Pa s) at 5 ºC	0.141±0.06b [a]	0.257±0.17a	0.168±0.10b	0.197±0.07b
Overrun (%)	26.64±4.3b	32.29±22.16ab	38.64±25.54ab	41.13±30.27a
Melting Resistance (% melted after 15 minutes at 25 ºC)	73.72±8.34ab	79.64±3.50a	65.76±13.64b	71.17±11.24b
Hardness (N)	25.32±9.00bc	25.07±10.04bc	22.37±13.34c	29.13±16.93a

[a] Values are average±standard error (n= 3), [a, b]: Values in a column which do not share a common letter are statistically different (P= 95%).

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dimensional network of hydrated molecules throughout the system. Water retention is associated with the mobility of the free water molecules to become limited and consequently. The bulk viscosity increased. In this way they retard ice crystal formation and growth, improving mix viscosity, air incorporation, body and texture as well as melting properties (Nielsen, 1984). Similarly, many researchers have reported that using higher levels of stabilizers would led to increasing viscosity in ice cream and as well in frozen yogurt (Cottrel *et al*., 1980; Guinard *et al*., 1994; Kaya and Tekin, 2001; Minhas *et al*., 2002; Muse and Hartel, 2004; Sofjan *et al*., 2004; Moeenfard and Mazahri, 2008; Soukoulis and Tzia, 2008; Milani and Koocheki, 2010).

With increase in the level of stabilizer, the overrun value improved for both types of stabilizers. Samples containing Stab-6924, benefited from higher overrun values than samples with Stab-IC80. Similarly, Moeenfard and Mazahri (2008) indicated that increasing Panisol ex, Salep and a blend of stabilizer/emulsifier concentration from 0.144 to 0.254% in frozen yogurt formulation increased the overrun value of the products. The same result was reported for guar gum by Milani and Koocheki (2010).

Melting resistance of reduced fat ice cream was affected by the type of stabilizer. In fact, samples containing Stab-IC80 showed more resistance to melting in comparison with those with Stab-6924. No significant difference was observed between samples containing 0.3 *vs.* 0.4% stabilizer ($P > 0.05$). Fat destabilization is the most important parameter affecting ice cream melting rate (Muse and Hartel, 2004). Herald *et al*. (2008) reported that increasing ice cream mix viscosity resulted in lower melting rate and as well improved product smoothness. In this case, increasing stabilizer content could increase viscosity and consequently improve the melting resistance (Moeenfard and Mazahri, 2008; Milani and Koocheki, 2010). Also, melting rate in frozen dairy desserts, was affected by overrun values where samples with higher values of overrun showed more resistance to melting (Sakurai *et al*., 1996; Moeenfard and Mazahri, 2008; Milani and Koocheki, 2010).

Increasing stabilizer level had no significant effect on hardness of samples containing Stab-IC80 while as regards the samples containing Stab-6924, 0.4% stabilizer containing sample benefited from a significantly higher hardness than the 0.3% sample. Instrumental hardness may reflect the impact of ingredients (fat, sugars, proteins and hydrocolloids) as well as the processing conditions on the final frozen product (Guinard *et al*. 1994; Muse and Hartel 2004). Despite the results obtained in the present study, Soukoulis *et al*. (2008) reported a decrease in hardness of ice cream containing some types of hydrocolloids when the concentration increased from 0.1 to 0.2%. Also hardness decreased when the guar gum concentration increased from 0.1 to 0.3% in frozen yogurt formulation (Milani and Koocheki, 2010). The decrease of instrumental hardness with increased hydrocolloid content may be attributed to the freeze concentration in their serum phase (Bolliger *et al*., 2000).

Sensory properties of reduced-fat ice cream containing fat replacers at three levels are presented in Table 5.

As seen from the table, in the case of all sensory attributes, using either MPC or inulin did not have any negative effect on these properties and further than this, flavour, texture, colour and overall acceptability of ice cream samples, containing inulin, were more appealing than control. Considering the scores of all sensory properties, the most acceptable sample was reduced-fat ice cream, containing 2% inulin. Similarly, Akalin *et al.* (2008) indicated that the use of inulin in low fat ice cream led to increasing viscosity, decreasing freezing point and while improving the sensory properties of the product. Also it was reported that sensory quality of low fat ice cream containing carbohydrate based fat replacers was more

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Table 5. Sensory properties of reduced-fat ice cream containing fat replacers at three levels.

	MPC			Inulin		
	0%	2%	4%	0%	2%	4%
Flavour [b]	6.5±1.03b [a]	6.7±0.99ab	6.4±1.16b	6.5±1.03b	7.3±1.23a	6.7±1.75ab
Texture [b]	6.5±1.40b	6.3±1.38b	6.2±1.15b	6.5±1.40b	7.2±1.36ab	6.7±1.43ab
Colour [b]	6.7±0.78b	7.6±0.62a	7.1±0.67ab	6.7±0.78b	7.6±0.8a	7.2±0.9ab
Overall acceptance [b]	6.9±0.52abc	6.8±0.78bc	6.7±1.0c	6.9±0.52abc	7.4±1.56ab	6.9±1.0abc

[a] Values are average±standard error (n= 3); [a, b]: Values in a column which do not share a common letter are statistically different (P= 95%), [b] Based on 9-point hedonic scoring: 9 for excellent, 1 for very poor.

satisfying than samples with protein based fat replacers like MPC (Roland *et al*., 1999). In the case of WPC and WPI use, it was reported that whiteness (L) and yellowness (b) values were affected by the level of WPC and WPI contents in Galacto ice cream containing 9% egg yolk (Alfaifi and Stathopoulos; 2009, 2010b).

Sensory properties of reduced-fat ice cream containing the two types and their levels of stabilizers are presented in Table 6.

Texture, colour and overall acceptance of reduced fat ice cream samples containing either of the two types of stabilizers at their 0.3 *vs.* 0.4% contents did not significantly differ (P> 0.05). Flavour score of the sample containing 0.3% Stab-IC80 was somehow lower than for the other samples but its difference with 0.4% sample of this stabilizer and also with 0.4% Satab-6924 sample was not significant (P> 0.05). Overall, the most acceptable sample as regards sensory attributes was the reduced fat ice cream with 0.3% of Stab-6924. it has been, in a similar manner, reported that type and amount of stabilizers did not significantly affect the flavour and mouthfeel of frozen dairy desserts (Moeenfard and Mazahri, 2008) but texture scores were recorded higher for samples containing higher levels of stabilizer (Moeenfard and Mazahri, 2008; Soukoulis and Tzia, 2008).

CONCLUSIONS

All reduced-fat ice cream mixes were pseudoplastic (Non-Newtonian, time independent) fluids with shear thinning behaviour and viscosity values decreased with increase in shear rate. Incorporation of MPC or inulin as fat replacers, resulted in increasing consistency coefficient and decreasing flow behaviour index of ice cream mixes. Stabilizers' concentration had different effects on k and n of the mixes, but increase in yield stress as a result of increasing stabilizer level was significant as regards the stabilizers Stab-IC80 and Stab-6924. Use of MPC in ice cream formulation along with increasing its level from 2 to 4%

Table 6. Sensory properties of reduced-fat ice cream containing tow types and levels of stabilizers.

	Stab25-IC80		Stab-6924	
	0.3%	0.4%	0.3%	0.4%
Flavour [b]	6.5±0.41b [a]	6.7±1.09ab	7.0±0.55a	6.8±0.98ab
Texture [b]	6.4±1.97a	6.4±1.38a	6.9±1.47a	6.7±1.52a
Colour [b]	7.4±0.82a	7.3±0.82a	7.3±0.89a	7.0±0.41a
Overall acceptance [b]	7.3±0.89a	6.8±0.84a	6.8±1.03a	7.2±1.72a

[a] Values are average±standard error (n= 3); [a, b]: Values in a column which do not share a common letter are statistically different (P= 95%), [b] Based on 9-point hedonic scoring: 9 for excellent, 1 for very poor.

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resulted in increasing mix viscosity and ice cream hardness, while decreasing the overrun value. The same pattern was observed for the samples containing inulin as regards the viscosity and overrun values. Hardness of the inulin containing samples along with the melting resistance of all the reduced fat ice cream samples were not affected by the quantity of fat replacers. Viscosity values increased with increasing stabilizer quantities for both types of stabilizers. Reduced-fat ice cream samples containing Stab-IC80 bore higher overrun values and showed more resistance to melting as compared with the samples containing Stab-6924. as regards the two stabilizers under study, the concentration did not significantly affect the product hardness. Reduced-fat ice cream samples containing inulin benefited from more acceptable sensory qualities than the samples containing MPC and than the control sample. The type and content of stabilizer was found to have no significant effect on the final product's acceptability.

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اثر جایگزین های چربی و پایدارکننده ها بر خصوصیات رئولوژیکی، فیزیکوشیمیایی و حسی بستنی کم چرب

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چکیده

تمایل اخیر به کاهش میزان چربی در محصولات غذایی و تولید فراورده های سالم تر، منجر به جایگزینی چربی شیر در بستنی با جایگزین های چربی بر پایه کربوهیدرات و پروتئین شده است. در تحقیق حاضر، بستنی کم چرب با استفاده از کنسانتره پروتئینی شیر (۶۵ درصد) و اینولین به عنوان جایگزین چربی (۰، ۲ و ۴ درصد) و دو نوع ترکیب پایدارکننده/امولسیفایر تجاری (Stab-IC80 و Stab-6924) در سطوح ۰/۳ و ۰/۴ درصد تولید شد. خصوصیات رئولوژیکی، فیزیکوشیمیایی و حسی در مخلوط بستنی و بستنی نهایی مورد ارزیابی قرار گرفت. مخلوط کلیه نمونه ها سیال رقیق شونده با برش بوده و ویسکوزیته ظاهری با افزایش درجه برش کاهش یافت. استفاده از MPC و اینولین و همچنین افزایش درصد هر دو نوع پایدارکننده منجر به افزایش ویسکوزیته و ضریب قوام و کاهش شاخص رفتار جریان در مخلوط نمونه ها گردید. سختی نمونه های بستنی تحت تأثیر جایگزین های چربی و پایدارکننده ها قرار نگرفته اما افزایش درصد MPC، اینولین و همچنین پایدارکننده ها منجر به کاهش ضریب افزایش حجم گردید. به طور کلی نمونه های بستنی کم چرب حاوی پایدارکننده Stab-IC80 مقادیر ضریب افزایش حجم و مقاومت به ذوب بالاتری در مقایسه با نمونه های حاوی پایدارکننده Stab-6924نشان دادند. بر اساس نتایج ارزیابی حسی توسط داوران چشایی بالاترین امتیاز حسی مربوط به نمونه حاوی ۲ درصد اینولین بود.

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