

Rheological and sensory properties of fat reduced vanilla ice creams containing milk protein concentrate (MPC)

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Abstract The purpose of this research was to evaluate the effect of various concentrations (0, 2, 4 and 6%) of MPC on the physicochemical and sensory properties of low fat (2%) and light (5%) vanilla ice creams. The total solid (TS), pH, acidity, protein contents and caloric values of ice cream mixes were measured as well as their rheological behaviors and apparent viscosities. Sensory attributes including coldness, firmness, viscosity, smoothness, mouth coating, melting rate and overall acceptance (OA) were evaluated on final ice cream samples. The TS, pH and acidity values of the ice cream mixes were in the ranges of 29.01–36.64, 6.33–6.46 and 0.29–0.42% respectively. By increasing the MPC content the pH and caloric values decreased whereas the TS, protein, acidity and consistency coefficient values increased. The rheological results showed that all samples had pseudoplastic behavior. Sensory analysis disclosed that by increasing the MPC content in both light and low fat ice creams the viscosity, mouth coating, smoothness, firmness and OA increased, while the coldness and melting rate decreased significantly. It could be concluded that using MPC in light and low fat ice creams could effectively increase their protein content, decrease their caloric values and improve their sensory attributes.

Keywords Ice cream · Low fat · MPC · Sensory

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Introduction

In recent years there has been a high demand for production of frozen desserts which are lower in fat in comparison with regular ice creams [1]. One of the most important reasons for the movement toward such products is mentioned to be the public concern over the increased risk of coronary heart disease which is related to saturated fat and cholesterol levels in the diet [2].

Although the production of lower fat frozen desserts is growing, the new lower fat ice creams suffer from low sensory quality in comparison with traditional ice creams. Therefore, additional work may be needed to improve structure and quality of low fat ice creams [3].

The structure of ice cream has been identified as a complex matrix consisting of air bubbles, fat globules and ice particles dispersed in a concentrated unfrozen aqueous solution [4]. Each of these phases affects the overall texture and quality of the final product [5]. Milk fat is one of the significant components responsible for ice cream structure. Various studies showed that fat globules concentrate at the surfaces of air bubbles during the freezing process of ice cream result in the richness, creaminess and mouth lubricating property in the final product. Fat also increases the viscosity of the ice cream mix and aids in producing desirable melting properties. It also decreases the sizes of ice particles by interrupting the space in which they have to form. Therefore, decreasing the fat content in ice cream formulation will cause the loss of several important textural properties in the final product [6].

In attempts to provide the desirable texture characteristics in low fat ice creams, several ingredients have been developed that mimic some functionalities of fat in the product [6]. Fat mimetics can be protein, or carbohydrate based [7]. Protein based fat replacers can both mimic the

fat globules functionalities and increase the nutritional value of the product. Milk proteins have been mentioned to be ideal materials for forming structural analogs of fat globules. Milk proteins can be structured through multiple techniques into microparticles that mimic the morphological properties of emulsified fat droplets. These aggregated proteins become hydrated and hold moisture. This moisture is adjusted to improve the texture and to modify the defects resulting from fat reduction in the ice creams [8].

Milk proteins are separated into whey and caseins. Whey proteins are commonly used as fat replacers in ice cream products. Several studies have assessed the effect of whey-based fat replacers on the sensory and physical characteristics of ice cream [8]. Yilsay et al. [9] assessed the effect of simplese (whey protein fat replacer) on the textural and sensory properties of low fat (6%) and fat free (0.5%) vanilla ice creams and compared them with the regular (10% fat) ice cream. That demonstrated the importance of fat as a flavour modifier and the improvement of texture by adding simplese. Akalın et al. [10] examined the use of 4% whey protein isolate as a fat replacer on the physical and rheological properties of reduced fat (6%) and low fat (3%) vanilla ice cream samples and reported that some textural characteristics including hardness and melting resistance were improved by using this fat replacer. Karaca et al. [11] examined the use of various fat replacers including simplese in reduced fat (6%), low fat (4%) and fat free (0.1%) ice creams. They reported that the use of simplese decreased the hardness of ice cream.

Whey proteins have been used as a protein based fat replacer by many researchers [9–11]. Alvarez et al. [12] mentioned that whey protein based fat replacers alter the original casein to whey ratio found in milk and can alter the physical properties and consequently, disturb the fat destabilization process during ice cream manufacturing. It has been reported that when the whey to casein ratio in a mix is changed in a way that whey protein value become higher, there is a reduction in emulsion stability and formation of desirable structure and texture in the ice cream product [13]. Adapa et al. [14] reported that using 6% of a whey protein fat replacer in an ice cream sample containing 6% milk fat increased the fat destabilization. That may lead to a less stable emulsion and cause some defects like phase separation. Also, some of the whey protein based fat replacers used in ice cream products have considerable levels of lactose. This mineral (lactose) lowers the freezing point of ice cream mixture and as a result increases the probability of sandiness in the ice cream [12, 15].

MPC is a high protein product which contains low amounts of lactose and maintains the original casein to whey ratio of milk [12]. The above properties of MPC provide an opportunity for it to be used as a suitable fat replacer in low fat ice cream products. MPC can be manufactured by any of

these processes: ultrafiltration, evaporation and spray drying of skim milk. MPC contains undenatured forms of caseins and whey proteins, which can function as fat replacers in ice cream structure. Substitution of higher levels of MPC in the ice cream may not be feasible as far as the economy is considered, hence, the present research is focused on lower substitution levels. Alvarez et al. [12] used MPC as an alternate source of milk solid non-fat (MSNF) in an ice cream mix and suggested that MPC could also be used as a fat replacer in ice cream manufacturing industries. Therefore, the objective of the present study was to determine the effect of varying concentrations of MPC on the physicochemical, rheological and sensory characteristics of light and low fat vanilla ice creams and to compare them with the full fat ice cream. The present research also aimed to evaluate the importance of MPC level on each of the above demonstrated attributes as well as determining the most important sensory attributes that affect the overall acceptance (OA) of the lower fat ice cream samples.

Materials and methods

Materials

The ingredients used in this study were homogenized and sterilized (ultra high temperature) milk (1.5% milk fat) purchased from Mihan Dairy industry, Eslamshahr, Iran. Homogenized and pasteurized cream (30% milk) and low heat non-fat dry milk were purchased from Pegah Dairy Industry, Mashhad, Iran. Stabilizer-emulsifier blend (IC90) and Milk protein concentrate (MPC80) were procured from Razavi Dairy Industry, Mashhad, Iran and Kian Meshkat, Tehran, Iran respectively. Other ingredients including sugar and vanilla extract were obtained from local markets of Iran.

Methods

Manufacturing of the ice cream mixes

Ice cream samples were made with 10, 5 and 2% milk fat to represent the full fat, light and low fat ice creams respectively. According to the manufacturer specifications, stabilizer-emulsifier blend (IC90) was used in the proportion of about 0.4% (W/V) of the total mix. Preliminary experiments were carried out to determine the MPC, sweetener and fat free dry milk concentrations. Formulations of the mixes are shown in Table 1.

For manufacturing the mixes, the liquid ingredients including milk and cream were mixed and heated up to 35°C. The premixed dry ingredients were then added and agitated thoroughly. The mix was heated up to 40°C in which the dry ingredients were soluble in the mix. A blender

Table 1 Ice cream mix formulations

| Ingredients (%) | 2% fat | | | | 5% fat | | | | 10% fat |
|------------------|--------|-------|-------|-------|--------|-------|-------|-------|---------|
| | 0 | 2 | 4 | 6 | 0 | 2 | 4 | 6 | 0 |
| MPC | | | | | | | | | |
| Milk | 78.89 | 76.79 | 74.68 | 72.58 | 68.16 | 66.05 | 63.95 | 62.05 | 50.6 |
| Cream | 2.7 | 2.81 | 2.92 | 3.02 | 13.24 | 13.35 | 13.45 | 13.55 | 30.8 |
| Sugar | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Non-fat dry milk | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Vanilla extract | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| S/E* | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |

Standard deviation = 0.001

*Stabilizer-emulsifier blend (IC90)

(Lm 600 E 40 Moulinex, France) was used to complete the mixing of the ingredients.

Ice cream mixes were then batch pasteurized at 80 °C for 25 s (HTST), cooled in an ice bath to 10 °C and aged for 12–48 h at 5 °C. Freezing process was carried out in a batch soft ice cream maker (Feller ice cream maker, Model IC 100; Feller Technologic GmbH, Düsseldorf, Germany) for 35 min. The frozen ice cream was drawn into 50 ml plastic containers, levelled off with a spoon and covered with the lids. Samples were coded and placed in a chest freezer (Electrosteel, Model ES. 453; Mashhad, Iran) for at least 24 h. All the mixes were produced with two replications.

Chemical analyses of the ice cream mixes

The fat, protein and caloric values of the ingredients including milk, cream, non-fat dry milk, sugar and MPC were analysed and reported which confirmed the respective specified values provided by the suppliers (Table 2). The total solid contents of the ingredients and the ice cream mixes were determined using the gravimetric method [16]. Ice cream mixes were also analyzed for pH and titratable acidity. The latter was expressed as the percentage of lactic acid and determined by adding 0.1 N NaOH to the phenolphthalein endpoint [17]. The fat, protein and NFMS (non-fat milk solid) content and the caloric values of the ice cream

Table 2 Chemical properties of the ice cream ingredients

| | Fat (%) | TS (%) | Moisture (%) | MSNF (%) | Protein (%) | Caloric value (Kcal/g) |
|------------------|---------|--------|--------------|----------|-------------|------------------------|
| Cream | 30 | 33.9 | 66.1 | 3.9 | 2.3 | 2.9 |
| Milk | 1.5 | 11.3 | 88.7 | 9.8 | 3.3 | 0.4 |
| Non-fat dry milk | 0.5 | 97 | 3 | 96.5 | 36 | 3.6 |
| Sugar | 0 | 100 | 0 | 0 | 0 | 3.8 |
| MPC | 1 | 94.4 | 5.5 | 96 | 80 | 3.7 |

samples were calculated according to the mix formulations. All chemical experiments were carried out with at least two replications.

Rheological behavior of the ice cream mixes

The rheological behavior of the ice cream mixes were evaluated after completion of the aging process using a rotational viscometer (Bohlin Model Visco88; Bohlin Instruments, UK) equipped with a heating circulator. Samples were tested at 5 ± 0.5 °C and the temperature was controlled during the viscosity measuring using the circulator. A C30 spindle was used and the apparent viscosity was measured at shear rate of 14.2–501.17 s⁻¹. The measurements were carried out in duplicate.

Sensory analysis of the ice creams

The sensory analysis was conducted at the Dairy laboratory, Ferdowsi University of Mashhad (FUM), Department of food science and technology. The panel was consisted of ten students (FUM), seven females and three males (between 23 and 30 years) who were willing to participate in the sensory evaluation test. The panel was trained to evaluate ice cream samples varying in fat content using the terms developed to quantify coldness, firmness, viscosity, smoothness, mouth coating, melting rate and OA using the 9 point hedonic scale. A higher score reflected an increasing intensity of the descriptive term. The higher score for OA represent the strong desirability of the sample. The optimum sample temperature and the serving size were determined during the training process. The sensory evaluation was conducted at room temperature (25 ± 2 °C) in the individual booths. Samples were tempered to -18 °C at least 24 h before sensory evaluations. The ice cream samples were taken out of the freezer 10 min before serving and their temperature was raised to -5 °C at the time of serving. Samples were served in 50 ml plastic containers with lids and panellists were instructed to clear their palates with distilled water and unsalted crackers between samples.

The control sample containing 10% fat was given as reference. Four test sessions were established and 4–6 samples were given during each test session.

Statistical analysis

The experiment was replicated (2–4 times) with two mixes made on different days. Data were analysed with mstatc statistical software (version 1.42, USA). The means were compared using the least significant differences (LSD) test and the results were considered significant for $P < 0.05$. Sig-mastat software (version 3.1) was used for modelling.

Results and discussion

Chemical properties of the ice cream mixes

The results related to the chemical properties of the ice cream mixes are shown in Table 3. The TS contents varied significantly between 29.16 and 36.63% and illustrated an increase which was induced by the rise in the fat and MPC content. Similar results for low fat ice creams were reported by Cody et al. [1].

Ice cream mix pH values ranged between 6.33 and 6.46 with significant differences ($P < 0.05$) among the treatment means. By removing the milk fat and adding MPC to the mixes, the MSNF content increased. Marshall and Arbuckle [6] mentioned that the titratable acidity and pH value of an ice cream mix is related to its MSNF content while an increase in MSNF raises acidity and lowers pH.

In the present study the ice cream mix titratable acidity values ranged between 0.29 and 0.42 with significant or non-significant differences among the treatment means. Titratable acidity in milk depends on the casein nitrogen, albumin, phosphates, citrates, and carbon dioxide values. By increasing the protein content in ice cream mix, the casein nitrogen and albumin content increase and this causes an increase in the titratable acidity value [18]. Patel et al. [19] also reported that the titratable acidity increase occurred via adding MPC to the ice cream mix.

The protein contents of the mixes increased greatly by adding MPC. The caloric values of low fat and light ice creams were significantly lower than that of full fat sample, which is due to the high caloric value of milk fat. This reduction ranged from 26.91 to 38.01% and from 12.65 to 23.79% in low fat light ice creams respectively.

Rheological properties of the ice cream mixes

Flow behavior

The flow curves of low fat and light ice cream mixes are shown in Figs. 1 and 2. The apparent viscosities of the

Table 3 Chemical properties of the ice cream samples

| MPC (%) | 2% fat | | | 5% fat | | | 10% fat | | |
|----------------------|----------------------------|----------------------------|----------------------------|-----------------------------|----------------------------|-----------------------------|----------------------------|----------------------------|----------------------------|
| | 0 | 2 | 4 | 6 | 0 | 2 | 4 | 6 | 0 |
| NFMS (%) | 11.57 ± 0.219 ^f | 13.57 ± 0.643 ^e | 15.57 ± 0.488 ^d | 17.57 ± 0.269 ^{bc} | 10.68 ± 0.233 ^e | 12.68 ± 0.467 ^{cd} | 14.68 ± 0.113 ^b | 16.68 ± 0.728 ^a | 3.41 ± 3.168 ^a |
| pH | 6.46 ± 0.042 ^a | 6.4 ± 0.007 ^e | 6.41 ± 0.000 ^c | 6.39 ± 0.035 ^f | 6.4 ± 0.007 ^d | 6.41 ± 0.014 ^c | 6.41 ± 0.014 ^b | 6.36 ± 0.056 ^s | 6.33 ± 0.042 ^h |
| Acidity (%w/w) | 0.32 ± 0.026 ^e | 0.34 ± 0.024 ^f | 0.37 ± 0.023 ^d | 0.42 ± 0.007 ^a | 0.29 ± 0.002 ^h | 0.33 ± 0.011 ^g | 0.38 ± 0.021 ^c | 0.38 ± 0.017 ^b | 0.29 ± 0.056 ^h |
| TS (%) | 29.16 ± 0.219 ^f | 30.69 ± 0.643 ^e | 32.58 ± 0.488 ^d | 33.92 ± 0.269 ^{bc} | 31.27 ± 0.233 ^e | 33.10 ± 0.467 ^{cd} | 34.38 ± 0.113 ^b | 36.63 ± 0.728 ^a | 29.01 ± 3.168 ^a |
| Protein (%) | 3.74 ± 0.02 | 5.27 ± 0.02 | 6.80 ± 0.02 | 8.37 ± 0.02 | 3.63 ± 0.02 | 5.17 ± 0.02 | 6.7 ± 0.02 | 8.24 ± 0.02 | 3.46 ± 0.02 |
| Caloric value (Kcal) | 113.05 ± 0.02 | 119.80 ± 0.02 | 119.46 ± 0.02 | 133.29 ± 0.02 | 138.99 ± 0.02 | 145.75 ± 0.02 | 145.38 ± 0.02 | 159.29 ± 0.02 | 182.37 ± 0.02 |

^{a–h}Means with different subscripts are significantly different

mixes decreased as a result of increasing shear rate and approached a constant value at the higher shear rates. This confirms their pseudoplastic (shear thinning) behavior. Ice cream mixes are colloidal systems containing fat droplets coated with proteins and emulsifiers [4]. The shear thinning behavior of the ice cream mixes have been related to the increased alignment of the constituent molecules in their structure and has been reported in the previous studies [2, 11, 20, 21].

Figures 1 and 2 show that the curves slopes, which represent the rate of viscosity reduction, rose through increasing the MPC content, while the viscosity of the mixes containing 6% MPC decreased more sharply than the others. It could be assumed that MPC may have an effect on increasing the alignment of the constituent molecules in the mixes.

Rheological modeling and parameters

There are several models for describing the rheological behavior of non-newtonian fluids. The power law model is mostly employed in a wide range for non-newtonian fluids [22]. This model showed excellent fitness of the data for the range of shear rate used in this study. Power law model is

shown in Eq. 1 where τ is the shear stress (pa), γ is the shear rate (s^{-1}), k is the consistency coefficient in ($pa s^n$) and n is the flow behavior index (dimensionless) which reflects the closeness to newtonian flow.

$$\tau = k\gamma^n \tag{1}$$

The correlation coefficients obtained with this model were considerably high ($R^2 > 0.99$), which meant that this model is adequately suitable for describing rheological behavior of the ice cream mixes in the present study.

The data in Table 4 shows that the flow behavior indices (n -values) of the mixes, which were all less than 1, represent their pseudoplastic behavior. The n -values ranged between 0.65 and 0.73 and there were no significant differences among the samples ($P < 0.05$). Aime et al. [2] reported that the n -values of the fat free, low fat, light and the regular fat ice creams containing 0–5.36% fat replacer ranged between 0.43 and 0.66. Karaca et al. [11] obtained the n -values of 0.36–0.50 for the ice cream mixes containing 0.1–6% milk fat. Akalın et al. [10] mentioned that the n -values of the ice cream mixes containing 3–10% milk fat and 0–4% fat replacer ranged between 0.19 and 0.74. The smaller n -values represent the departure from newtonian behavior which represents the higher pseudoplasticity of the sample [23].

The data in Table 4 also demonstrates that the increase in MPC content is associated with the decrease in n -values. It also shows that low fat and light samples containing MPC had lower n -values in comparison with the control (10% fat) sample. It has been suggested that the pseudoplastic behavior of ice cream mix could also be related to shear thinning behavior of aggregated material other than fat globules such as MPC [2]. Karaca et al. [11] reported that addition of fat replacers in the ice cream mixes increased their shear thinning behavior.

The consistency coefficients (k) were also obtained from power law model in this study. The data obtained (Table 4) showed that the k -values ranged between 0.264 and 1.994 $pa s^n$ and were increased which resulted from an increase in the MPC content. The lowest and the highest

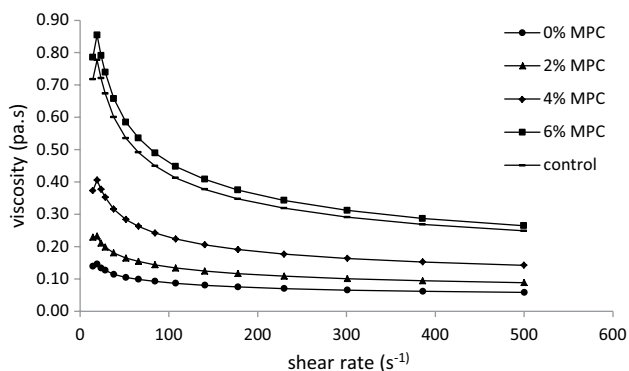


Fig. 1 Apparent viscosity vs. shear rate for low fat (2% fat) ice cream mixes containing 0–6% MPC and the control (10% fat) sample

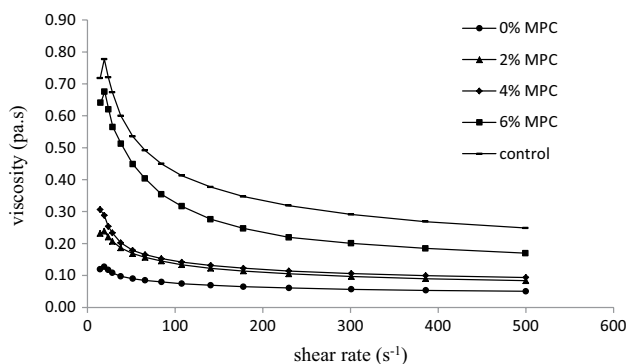


Fig. 2 Apparent viscosity vs. shear rate for light (5% fat) ice cream mixes containing 0–6% MPC and the control (10% fat) sample

Table 4 The power law model parameters for low fat (2% fat), light (5% fat) and full fat (10%) ice cream mixes containing 0–6% MPC

| % MPC | 2% fat | | 5% fat | | 10% fat | |
|-------|--------|-------|--------|------|---------|------|
| | k^a | n^b | k | n | k | n |
| 0 | 0.26 | 0.73 | 0.29 | 0.73 | 0.57 | 0.71 |
| 2 | 0.57 | 0.69 | 0.46 | 0.72 | | |
| 4 | 0.72 | 0.66 | 0.93 | 0.69 | | |
| 6 | 1.54 | 0.65 | 1.99 | 0.66 | | |

^aConsistency coefficient

^bFlow behavior index

k-values were related to the mixes containing 2% fat with 0% MPC and 5% fat with 6% MPC respectively. The *k*-values of the low fat and light mixes containing 4 and 6% MPC were higher than that of the control sample (10% fat). Similar results were obtained by Aime et al. [2] for fat free, low fat and light ice cream mixes whose *k*-values ranged between 0.073 and 1.260 pa sⁿ. They reported that the *k*-values increased due to the increase in the fat content. Muse and Hartel [24] and Bahramparvar et al. [21] reported that *k*-values of ice cream mixes ranged from 0.145 to 0.211 pa sⁿ and from 0.051 to 6.822 pa sⁿ respectively.

Sensory properties

Coldness

As ice cream melts within a mouth, larger ice crystals are momentarily left behind, registering a distinct sensation of coldness [25]. Table 5 shows the sensory mean values of ice creams containing 2, 5 and 10% fat with no fat replacer. Having compared the coldness sensation of low fat, light and full fat samples, it was observed that decreasing coldness sensation accompanied by the increasing of fat content as theorized by Clark et al. [25]. When the fat level in ice cream decreases, the water level increases so that more water is available to form more and larger ice particles [25]. Therefore, as the size and the quantity of the ice particles increase, the coldness sensation increases [2]. Similar results have been reported by Stampanoni Koeflerli et al. [26], Cody et al. [1] and Roland et al. [27] for low fat ice cream products.

Figure 3 shows the coldness sensation of the low fat, light and full fat ice creams containing 0–6% MPC; which demonstrate that the coldness sensation decreased as the MPC content increased. The light ice creams containing 6% MPC were observed to have a comparable coldness sensation with the full fat samples. This is because MPC particles bind with water in the ice cream mix. Thus, the growth of large ice particles would be restricted and the proportion of frozen water decreases. Also the individual gel particles of milk protein could confer lubricating effects, that decrease the perception of coldness [28]. Cody et al. [1] reported that the higher concentration of fat replacer decreased the coldness in low fat and fat free ice cream samples. Roland et al. [27] recommended that using 4.6% MPC in fat free (0.4%) ice cream sample could effectively decrease the coldness sensation. Table 6 shows the correlation coefficient between fat, MPC and sensory attributes. The correlation coefficient between the MPC content and the coldness sensation are partially comparable with the correlation coefficient between the fat content and the coldness sensation which means that MPC was partially capable of decreasing the sensation of coldness in light and low fat ice creams.

Table 5 Sensory mean values of low fat, light and full fat vanilla ice cream samples

| | Coldness | Viscosity | Mouth coating | Smoothness | Firmness | Melting rate | Overall acceptability |
|---------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| 2% fat | 5.93 ± 0.997 ^a | 3.47 ± 1.025 ^a | 4.12 ± 0.396 ^b | 4.17 ± 0.997 ^b | 4.34 ± 0.191 ^b | 5.92 ± 0.304 ^a | 3.74 ± 0.198 ^b |
| 5% fat | 5.35 ± 1.103 ^b | 3.72 ± 0.644 ^b | 4.18 ± 0.108 ^b | 4.58 ± 0.493 ^b | 4.39 ± 1.021 ^b | 5.61 ± 0.598 ^b | 3.87 ± 0.139 ^b |
| 10% fat | 4.60 ± 0.209 ^c | 5.43 ± 0.007 ^c | 5.58 ± 0.282 ^a | 6.23 ± 0.033 ^a | 6.11 ± 0.339 ^a | 4.35 ± 0.901 ^c | 5.71 ± 0.189 ^a |

^{a-c}Means (n = 10) with different subscripts are significantly different

Fig. 3 Effect of different concentrations of MPC on sensory properties of low fat (open), light (filled) and control (dashed) ice creams containing 0–6% MPC. *a–e* Means (n=10) with different *subscripts* are significantly different

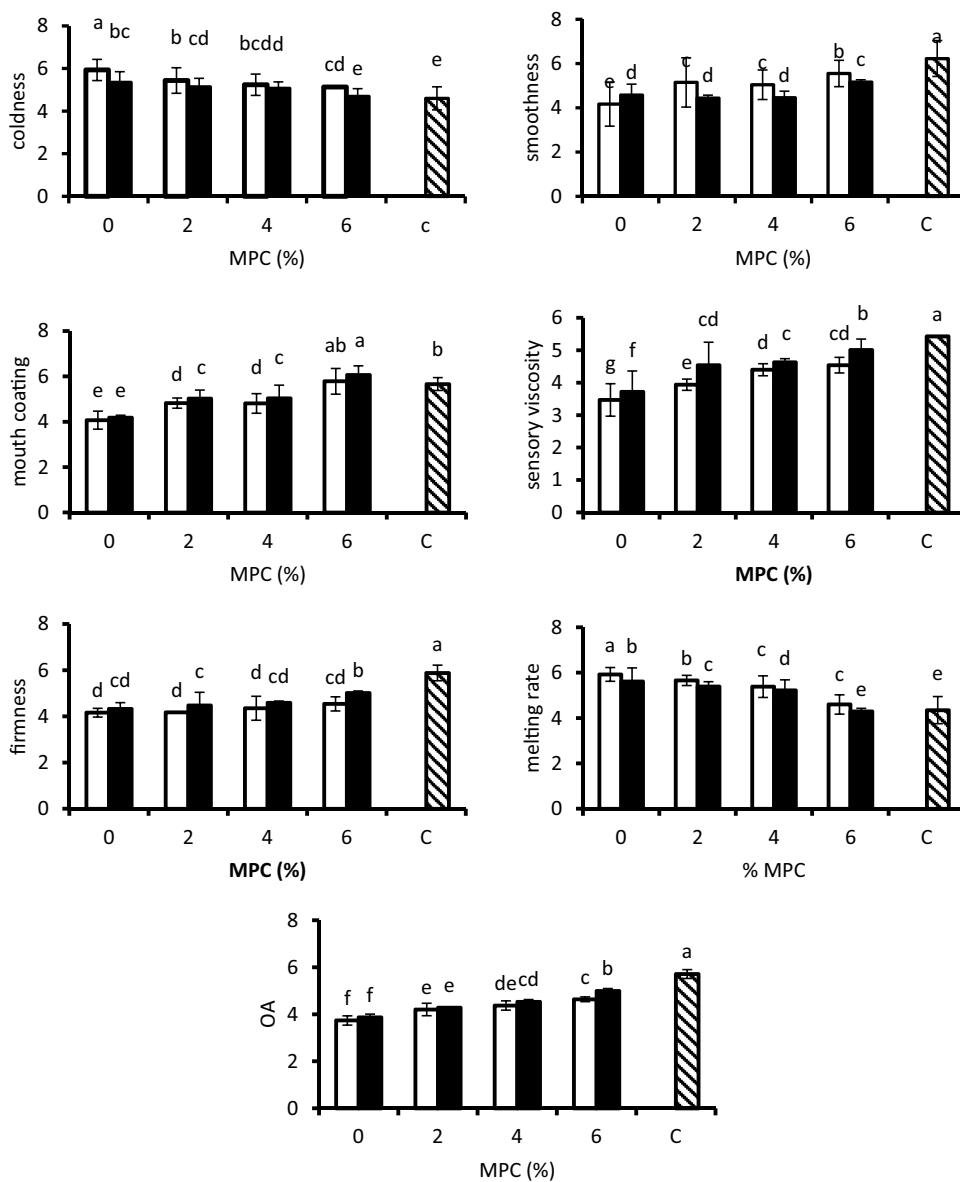


Table 6 Correlation coefficients between sensory attributes and fat or MPC content

| | Fat | MPC | R ² |
|-----------------------|--------|--------|----------------|
| Coldness | -0.143 | -0.113 | 0.94 |
| Viscosity | 0.215 | 0.173 | 0.887 |
| Mouth coating | 0.164 | 0.246 | 0.835 |
| Smoothness | 0.141 | 0.094 | 0.321 |
| Firmness | 0.205 | 0.0251 | 0.814 |
| Melting rate | -0.182 | -0.19 | 0.829 |
| Overall acceptability | 0.205 | 0.137 | 0.759 |

Smoothness

Smoothness has been reported to be inversely proportional to the friction force between the tongue and the roof of the

mouth [29]. It has been suggested that milk fat increases the smoothness of the ice cream texture [6]. The data in Table 5 show that increasing the fat level significantly increases the ice cream smoothness. These results are in agreement with the previously published results where decreases in smoothness were reported when the fat level was decreased from 9.4 to 2.4% [2], from 12 to 0.5% [9] and from 8 to 3% [26].

The results in Fig. 3 show that the smoothness sensation increased in both light and low fat ice creams as the MPC content increased from 0 to 6%, but even the light and low fat samples containing the highest amount of fat replacer (6%) could not reach the smoothness score of the full fat ice cream. The ability of fat replacers to effectively simulate the physical characteristics of milk fat might be verified by the colloidal properties of the fat replacers used in the product and their impact on mouth feel [28].

Mimicking the smoothness property of the fat by this fat replacer (MPC) could be due to the MPCs structure and colloidal properties in the mix. MPC consists of tiny individual particles with small size and round shape. These particles have such surfaces that can roll over each other with minimal force, thus repel fat globules [6]. In aqueous solutions, they can bind water, form micelles and crystallize into unique structures that have colloidal properties [25]. They can lubricate ice crystals and air bubbles in the final product. This property could influence the manner in which the frozen mass liquefies in the mouth and gives rise to lubricating property and creaminess [28]. Yilsay et al. [9] reported that adding 6% simplese to low fat ice cream could significantly increase its smoothness. This increase in the smoothness of the low fat ice cream has been related to the high water binding capacity of this protein based fat replacer (simplese).

According to the results in Table 6, the MPC coefficient is lower than the fat coefficient which firmly confirms the inability of the MPC to effectively mimic the smoothness property displayed by fat.

Mouth coating

Mouth coating property is the degree of which mouth remains coated after swallowing the ice cream [30]. This item is affected by different factors including the fat content. In the current study, mouth coating level of the samples decreased as the amount of fat decreased from 10 to 5 or 2% (Table 5). However, mouth coatings of light and low fat ice creams did not differ significantly ($p < 0.05$). Mouth coating levels of the samples increased as the amount of MPC increased in both light and low fat ice creams (Fig. 3).

Comparing the fat and MPC coefficients in Table 6 show that MPCs coefficient is considerably higher than the fat coefficient which implies the considerable effect of MPC in mimicking the mouth coating effect of fat in the ice cream matrix. As Fig. 3 depicts, mouth coating in the low fat ice cream containing 4% MPC did not differ significantly from the full fat sample and even the light ice cream containing 4% MPC had higher mouth coating rate than the full fat sample. Therefore, it could be concluded that using MPC at higher concentrations (4%) in light and low fat ice creams could result an ice cream product with satisfying mouth coating property worthy of comparison to full fat ice creams. Similar results indicating an increase in the mouth coating with the rise in the fat content has been reported by Aime et al. [2], Cody et al. [1] and Stampanoni Koeflerli et al. [26]. Cody et al. [1] reported that the mouth coating of full fat (10%) ice cream was not significantly different ($P < 0.05$) from the low fat (4.03%) and non-fat (0.42%) samples containing 4 and 6% fat replacers. Prindiville et al.

[31] reported that low fat ice creams coated the mouth significantly more than the fat free (0.7%) samples containing 2.5% simplese.

Viscosity

The results in Fig. 3 demonstrated that sensory viscosities increased with increasing the fat and MPC contents. However, both light and low fat samples with different concentrations of MPC showed significantly lower sensory viscosities than the full fat sample. Specter and Setser [27–29, 31–33] stated that hydrophilic colloids increase the viscosity of the continuous phase of the unfrozen mix. Proteins interact at the water and oil interface during homogenization to stabilize the fat emulsion, and during freezing, proteins control destabilization of fat. Increased amount of protein at the oil–water interface lowers the surface tension and slightly increases the mix viscosity.

Firmness

The results in Fig. 3 demonstrate that the firmness increased by increasing the fat and MPC contents. The firmness of the full fat ice cream was significantly higher than the other samples. This means that using MPC in light and low fat ice creams could not relieve the firmness decrease. Similar results were reported by Cody et al. [1] which measured the hardness of the low fat ice creams containing fat replacers. The correlation results (Table 6) show that the MPC coefficient is noticeably low, which implies the limited impact of MPC on the firmness of the ice cream.

Melting rate

The results in Fig. 3 show that the melting rate of the samples decreased by increasing the fat and MPC contents. The melting rate of the light sample containing 6% MPC did not have significant difference with the full fat sample ($p < 0.05$). According to the results in Table 6, the MPC coefficient was comparable with the fat coefficient. This implies the ability of MPC in slowing down the melting rate of light and low fat ice creams. The negative sign resembles the reverse relation between the ice cream melting rate and the fat or MPC content.

OA

OA of the light and low fat ice creams were significantly different ($p < 0.05$). The OA increased with increasing the fat and MPC concentrations. Guinard et al. [33] reported that the OA of ice cream increased as the fat level increased up to 14.77%.

OA is affected by the other sensory factors like coldness, viscosity, mouth coating, smoothness, firmness and melting rate. The correlation between OA and the other sensory factors were determined in this study to find the importance of different sensory factors on the OA of the ice cream samples (Eq. 2).

$$\begin{aligned} \text{OA} = & (0.4 \text{ coldness}) + (0.735 \text{ viscosity}) \\ & + (0.00895 \text{ mouth coating}) + (0.222 \text{ smoothness}) \\ & + (0.244 \text{ firmness}) - (0.116 \text{ melting rate}) \end{aligned} \quad (2)$$

The coefficients related to the viscosity and the mouth coating property were the highest and lowest respectively, which meant that the viscosity and the mouth coating of the ice creams had the highest and lowest importance in nominating the OA of ice creams. The negative coefficient of the melting rate shows that the samples with slower melting rates were more acceptable by the panellists.

Conclusions

Decreasing the fat content in ice creams could cause the loss of many important sensory properties including coldness, smoothness, mouth coating, viscosity, firmness and melting rate. The results in the current research demonstrated that addition of MPC to the light and low fat ice creams could effectively increase their viscosity, mouth coating, firmness, smoothness and decrease their coldness sensation and melting rate which cause an improvement in the OA of the product. A comparison between the sensory attributes showed that the mouth coating and the melting rate were more affected by the use of MPC as a fat replacer. From the results in this study it could be concluded that MPC could be suggested as an acceptable fat replacer in low fat and light vanilla ice creams.

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