Effect of Emulsifiers and Food Gum on Nonfat Ice Cream

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Abstract

Nonfat ice cream was made with a mix composition of 12% milk SNF, 12% sucrose, 5% corn syrup solids, 3.5% maltodextrin, and 0.25% stabilizer blend. Two emulsifiers at three levels each and one gum at three levels were evaluated in nonfat ice creams. Emulsifiers were 52% α-monoglyceride and 72% α-monoglyceride, and the gum was hydroxypropylmethyl cellulose. A portion of the mix was retained as the control, which contained no emulsifier or additional food gum, and was evaluated in addition to the nine treatments. Mean fat content of the mix was 0.14%, and total solids content was 34.16%. Results indicated differences between treatments in whipability and stability to heat shock; however, there were no differences in meltdown. There was about a 10-μm increase in mean ice crystal size for treatments when compared after 1 and 12 wk of storage. Addition of either emulsifier to nonfat ice cream reduced the mean ice crystal size when compared with the control or gum, which is a major factor in improvement of the texture of nonfat ice cream.

The sensory panel preferred the nonfat ice cream with 0.25% added monoglyceride and diglyceride with 72% α-monoglyceride content stabilizer over the control with respect to coarseness and iciness, coldness intensity, and overall body and texture scores.

Key words: nonfat ice cream, emulsifier, food gum, ice crystals

INTRODUCTION

Consumption of low fat and nonfat foods has become a way of life for many health conscious people. It is recommended (24) that not more than 30% of calories consumed in the human diet should come from fat, which has led to a surge in the development, production, and consumption of low fat and nonfat products. The 1994 revision of labeling standards by the Food and Drug Administration has permitted the use of appealing names such as reduced fat, low fat, and nonfat ice creams for products containing less than 10% milk fat that are targeted at health conscious consumers (22). Milk fat is the main contributor to the rich flavor and mouthfeel associated with ice cream. Removal of the fat brings a host of body and textural problems such as coarseness and iciness, crumbly body, shrinkage, and flavor defects.

Emulsifiers added to ice cream have several important functions such as reduced whipping time, controlled fat destabilization, enhanced smoothness of texture, increased resistance to melting and shrinkage, and improved dryness (2, 22). Usually, blends of stabilizer and emulsifier designed to function best in full fat, low fat, or nonfat ice creams are used. Although emulsifiers are incorporated in most commercial nonfat ice creams, little information is available on their functionality.

Limited information exists about how emulsifiers and gums function in nonfat ice cream. The first objective of this study was to evaluate the effect of emulsifier 1 (EM1) containing 52% α-monoglyceride and emulsifier 2 (EM2) containing 72% α-monoglyceride at three commercially recommended usage levels in a typical nonfat ice cream mix formulation. Emulsifiers do add cost to nonfat ice cream mix formulations. A second objective was to study the effect of using a food gum or stabilizer, hydroxypropylmethyl cellulose (HPC), at three commercially recommended usage levels in nonfat ice cream. This part of the study was designed to reveal the effects of inclusion of food gum in addition to the

**Abbreviation key:** EM1 = emulsifier 1 containing 52% α-monoglyceride, EM115 = EM1 at 0.15%, EM120 = EM1 at 0.20%, EM125 = EM1 at 0.25%, EM2 = emulsifier 2 containing 72% α-monoglyceride, EM215 = EM2 at 0.15%, EM220 = EM2 at 0.20%, EM225 = EM2 at 0.25%, HPC = hydroxypropylmethyl cellulose, HPC15 = HPC at 0.15%, HPC20 = HPC at 0.20%, HPC25 = HPC at 0.25%.
0.25% stabilizer blend already added to the nonfat ice cream mix and in the absence of emulsifier.

MATERIALS AND METHODS

Manufacture of Nonfat Ice Cream Mix

Nonfat ice cream was made with a mix composition of 12% milk SNF (source was NDM; Associated Milk Producers, Inc., Freeman, SD), 12% sucrose (United States Sugar Corp., Minneapolis, MN), 5% 36 dextrose equivalent corn syrup solids (American Maize Products Co., Hammond, IN), 3.5% 18 dextrose equivalent maltodextrin (Grain Processing Corporation, Muscatine, IA), and 0.25% stabilizer blend (CC 305, locust bean gum, guar gum, and carrageenan, standardized with sucrose; Continental Colloids, Inc., West Chicago, IL). Water was placed in a 750-L vat that was heated to 43.3°C, and dry ingredients were added with the aid of a powder funnel. The stabilizer blend was mixed with sucrose and incorporated to ensure proper mixing. The mix was batch pasteurized at 72.8°C for 30 min and was separated into 10 batches of 34 kg each, one of which was retained as the control treatment with no added emulsifier or additional food gum. Six of the treatments were prepared by adding the following emulsifiers (Continental Colloids, Inc.) independently at the concentrations specified: EM1 at concentrations of 0.15 (EM115), 0.20 (EM120), or 0.25% (EM125) (wt/wt); and EM2 at concentrations of 0.15 (EM215), 0.20 (EM220), or 0.25% (EM225). The EM1 contained 52% α-monoglyceride, and the remaining 48% was diglycerides standardized with vegetable fat. The EM2 contained 72% α-monoglyceride and 28% diglycerides standardized with vegetable fat. The remaining three treatments were prepared by adding HPC (Continental Colloids, Inc.), a food gum, at concentrations of 0.15 (HPC15), 0.20 (HPC20), and 0.25% (HPC25). Thus, there was a total of 10 treatments including the control. All treatments were replicated 5 times, and a total of 50 batches of nonfat ice cream were made. Mixes were homogenized (Manton-Gaulin Manufacturing Co., Inc., Everett, MA) at 13.8 MPa during the first stage and at 3.45 MPa during the second stage. Mixes were cooled in an ice-water bath to 4°C and were aged overnight at 2°C in a cooler.

Composition Analyses of Mix

The nonfat ice cream mix was analyzed in triplicate for fat and TS by the Mojonnier method (4), protein by macro-Kjeldahl method (3), and ash by muffle furnace (3). The pH of the mix was determined using a pH meter (Orion model 701; Orion Research, Inc., Cambridge, MA), and titratable acidity was determined by adding 0.1N NaOH to the phenolphthalein endpoint (4). Consistency of the mix was measured as the time to empty a 50-ml pipet at 21°C (2). Freezing points of only the control and HPC treatment mixes were determined by the osmometer method (5) because initial studies revealed no differences between the freezing points of the control, EM1, and EM2 treatments. Whipping abilities of the mix were determined using a mixer (Mixmaster Deluxe; Sunbeam Appliance Co., Milwaukee, WI). The mix (150 ml) was placed in a 1-L stainless steel mixing bowl, calibrated with known volumes of water, and placed inside a 2.5-L bowl. Between the bowls, a mixture of ice and salt cooled the mix as it was whipped by two 3-cm blades. A mixer speed setting of 10 was used for whipping the nonfat ice cream mix. Changes in volume were recorded at 2, 5, 10, 15, and 20 min (6).

Manufacture of Nonfat Ice Cream

A 2× bourbon vanilla extract (Nielsen-Massey Vanillas, Inc., Waukegan, IL) was added to the mixes at 7.2 ml/kg. Mixes were subsequently frozen in an 18.9-L single barrel batch freezer (Emery Thompson Machine and Supply, Bronx, NY). Draw temperatures were recorded using a mercury thermometer, and whipping times were recorded. Overrun was determined for all treatments using an overrun scale, which is based on the weight-volume method of overrun percentage determination (2). An overrun of 90 to 95% was targeted. Nonfat ice creams were filled in 1.9-L containers, hardened at –30°C for 24 h, and then stored at about –18°C until all analyses were complete.

Analyses of Nonfat Ice Cream

The meltdown of the nonfat ice creams was measured (no. 6 USA Standard Testing Sieve; W. S. Tyler, Inc., Mentor, OH) (6). A 50-g sample cut as a cube was allowed to melt at about 21°C, and the weight of the melted sample was noted every 5 min until the entire sample had melted. The percentage meltdown at the end of 20 min was calculated for purposes of comparison. The freeze-thaw method was used to evaluate the stability of the ice cream during heat shock at 4 wk after manufacture (2). A 2-L sample of ice cream was stored at –20°C then transferred to a temperature-controlled area at 20°C for 1.5 h and returned to –20°C. Over the next 6 d, this procedure was repeated except time was for 0.5 h. Samples were also evaluated visually for shrinkage, appearance, and whey separation after heat shock.
Ice crystal sizes of nonfat ice cream were measured for control, EM115, EM125, EM215, EM225, HPC15, and HPC25 treatments at 1 and 12 wk after manufacture using a microscope (BH-2; Olympus Optical Co., Ltd., Tokyo, Japan). Samples for measuring ice crystal sizes were prepared by the squash mount method with a 50:50 (vol/vol) mixture of amyl alcohol and kerosene at –18°C (8). Measurements of ice crystals were taken across a transect of the mount. Ice crystal sizes were determined by measuring the largest diameter of each ice crystal with the eyepiece micrometer. Ice crystal sizes were measured in a walk-in freezer at –18°C, and a minimum of 150 ice crystals were measured per sample (6). The mounting medium and all instruments used for measuring ice crystals were tempered at –18°C prior to use.

Sensory Evaluation

Randomly coded nonfat ice creams were evaluated for flavor, body, and texture characteristics at 1 and 12 wk after manufacture by a four-member panel trained with at least 3 or more yr of experience in evaluation of frozen desserts and dairy products (21). Panelists evaluated 10 samples per session (week) on their own time, and samples for evaluation were scooped by the panelist. Samples were evaluated for vanilla flavor, overall flavor, and overall body and texture scores on a nine-point scale where 1 = poor, 5 = average, and 9 = excellent. Other parameters such as cooked flavor, weak, greasy, gummy, coarse and icy, and coldness intensity were evaluated on another nine-point scale where 1 = extreme defect, 5 = definite defect, and 9 = no defect. After heat shock, the samples were evaluated for coarse and icy defects on a nine-point scale where 1 = extreme defect, 5 = definite defect, and 9 = no defect. Panelists were invited to write comments or criticisms on all scoresheets.

Statistical Analyses

The experiment was designed as a randomized, complete block. Data from five replicates were analyzed using ANOVA or general linear model procedure except data for whipability, meltdown, and sensory evaluation, which were analyzed using the mixed procedure (23). Least squares means were used to determine significance at $P = 0.05$.

RESULTS AND DISCUSSION

Composition of Nonfat Ice Cream Mix

The five replicates of nonfat ice cream mix had a mean fat content of 0.14% ± 0.03, total protein content of 4.48% ± 0.04, ash content of 1.05% ± 0.04, and TS content of 34.16% ± 0.46. The nonfat ice cream was in compliance with the legal requirement that it should contain not more than 0.5 g of fat per serving. The mean TS content of commercial nonfat ice cream is 35 to 37% (22). Adequate TS content is important for obtaining a good product with a smooth texture and firm body (22).

Characteristics of Nonfat Ice Cream Mix

The pH of nonfat ice cream mix ranged from 6.59 to 6.62, and the titratable acidity ranged from 0.21 to 0.22%. There were no differences ($P > 0.05$) in pH and titratable acidity among nonfat ice cream mix treatments. The normal pH of ice cream mix containing 12% milk SNF is about 6.3 (2). Limited published information exists on the pH and titratable acidity of nonfat ice cream mix. Acidity and pH are related to mix composition; as the content of milk SNF is increased, acidity is increased, and pH is reduced.

Flow times of treatment mixes were measured as the time required to flow between two fixed points of a pipette under atmospheric pressure. Flow times were measured relative to water, which had the lowest ($P < 0.05$) time of 24.4 s compared with all treatments. No differences ($P > 0.05$) existed among flow times of control, EM1, and EM2 treatments, which ranged from 70.3 to 75.2 s, except for the EM225 treatment, which had a higher ($P < 0.05$) flow time than the control (77.4 s vs. 70.3 s). Nonfat ice cream mixes containing HPC had higher ($P < 0.05$) flow times when compared with other treatments and water. As the concentration of added HPC increased, the flow time increased ($P < 0.05$). The HPC25 treatment had the highest ($P < 0.05$) flow time (171.6 s) followed by HPC20 (140.0 s) and HPC15 (127.6 s). This increased flow time and, therefore, increased viscosity, is due to the water-binding ability of HPC (13). Hydroxymethyl cellulose gels upon heating, which is similar to HPC, and therefore mixes containing HPC would not need to be aged for viscosity buildup, unlike gelatin, which has to be aged for at least 4 h for gel formation and subsequent increase in viscosity (2). The water-binding ability of hydrocolloids has been reported (9) to decrease heat of fusion of water in hydrocolloid-water solutions, which implies that less water was able to freeze, thus controlling ice crystal formation. However, Cottrell et al. (11) failed to find a correlation between increased viscosity of ice cream mix and control of ice crystal growth in ice cream.
Emulsifiers have little effect on the pH or viscosity of mixes and, in general, an increase in viscosity increased the resistance to melting and improved smoothness of body but reduced the whipping rate (1). Although there is no set standard for a desirable mix viscosity, a certain viscosity is desirable for proper whipping and retention of air (2).

There were no differences \((P > 0.05)\) among whipping times of all treatments in the batch freezer, which was contrary to the expectation that addition of emulsifiers would result in a reduction of whipping time as reported for ice cream mix (2, 14) and 2% fat ice cream mix (6). The normal whipping time of ice cream mix is about 420 s to reach an overrun of 90\% in a batch freezer (2). Ice cream mix with a whipping time of 300 s has a high whipping rate. Therefore, all of the nonfat ice cream mixes with whipping times ranging from 229.3 to 264.5 s had high whipping rates. Whipping rate is dependent upon the efficiency of the whipping mechanism, viscosity of the partially frozen mix, and ability to retain the incorporated air (2, 14).

The freezing point of most ice cream mixes varies between −2.2 to −2.8°C (20). It is a colligative property influenced by the number of molecules in solution, which in ice cream are mainly sugar (18, 20). Milk fat, proteins, flavoring agents, emulsifiers, and stabilizers have a minor effect on the freezing point of mix (5). Initial studies revealed no differences between the freezing points of control, EM1, and EM2 treatments. However, HPC15, HPC20, and HPC25 treatment mixes had lower \((P < 0.05)\) freezing points (−2.83, −2.86, and −2.90°C, respectively) than did the control (−2.75°C). Because the difference between the freezing points of HPC and control treatment mixes is small, it is not of practical importance. Heat shock stability of ice cream increased as the freezing point of the mix increased (5).

Whipping ability determines the ease with which air can be incorporated into the mix and the subsequent dispersion and stability of air cells in ice cream (7). Air cells in ice cream are stabilized by surface-active components such as proteins, phospholipids, and added emulsifiers (22). Thus, addition of emulsifier increases whipping ability of ice cream mix. However, EM1 and EM2 treatment mixes had a lower whipping ability than did control. At the end of 20 min of whipping, final mix volumes of EM1 and EM2 treatments were lower \((P < 0.05)\) than that of the control (605 ml) and ranged from 340 to 490 ml (Table 1). There were no differences \((P > 0.05)\) between EM215, EM220, and EM225 treatments in the final mix volumes at 20 min, indicating that level of EM2 addition did not influence the whipping ability of the nonfat ice cream mix. Comparison of mix volumes after different times of whipping revealed no differences \((P > 0.05)\) after 15 and 20 min of whipping for each of the EM1 and EM2 treatment mixes. For the HPC treatments, there was a higher \((P < 0.05)\) whipping ability after 20 min compared with the control (Table 2). There were no differences \((P > 0.05)\) in the whipping ability of HPC treatment mixes.
after 10, 15, or 20 min of whipping, indicating that there was no further increase in mix volume following 10 min of whipping.

Milk fat exerts an inhibitory effect on the whipping ability of ice cream mix because during freezing coalesced fat displaces protein from the air-mix interphase and acts as a foam depressant. Fat also limits the thinness to which lamellae between air cells can be whipped (7). Thus, in the absence of fat, as in nonfat ice cream mixes, whipping ability is higher than in mixes that contain fat. Emulsifiers added to the nonfat ice cream mix may be behaving similarly to fat in acting as foam depressants and preventing excessive whipping of the mix. Emulsifiers have an important role in the development and stabilization of the foam matrix in ice cream (19). In skim milk, it has been reported (27) that the lower the fat content is, the greater is the tendency to foam. Phospholipids, monoglycerides, and fatty acids depress foaming when added to skim milk, which may be similar to the foam depression by emulsifiers observed for nonfat ice cream mixes.

Characteristics of Nonfat Ice Cream

Draw temperature is a measure of heat removal in the freezer and is dependent on conditions of freezing, type of freezer, and characteristics of the mix (17). There were no differences (P > 0.05) between nonfat ice cream treatments in the draw temperatures, which ranged from –2.82 to –2.98°C. The typical draw temperature for ice cream in a batch freezer is between –3.3 and –4.4°C, but in a continuous freezer it is between –5.56 and –6.11°C (2). In general, as the draw temperature is reduced, smaller ice crystals are obtained in the product. Therefore, smaller ice crystals are formed in ice cream that is produced in a continuous freezer when compared with a batch freezer. From 33 to 67% of the water in ice cream is frozen depending on draw temperature. At a draw temperature of –3.89°C, approximately 33% of the water in ice cream is frozen (2). Therefore, at the draw temperatures obtained for nonfat ice cream, less than 33% of the water may have frozen, and the bulk of the freezing might have occurred in the hardening room. In a previous study (6) using the same batch freezer, the draw temperatures of 2% fat ice cream ranged from –4.30 to –5.04°C. At a draw temperature of –4°C, an overrun of 100%, and hardening at –35°C in a blast freezer, the mean ice crystal diameter in ice cream is 63 and 85 μm at the edge and center, respectively, of a 1-L package (26). Higher draw temperatures of nonfat ice cream might have been due to the insulating effect of air during freezing.

Overrun is defined as the volume of ice cream obtained in excess of volume of mix and is expressed as a percentage (2). The increased volume is due to incorporation of air into ice cream during the freezing process. There were no differences (P > 0.05) in overruns between treatments, which ranged from 87.0 to 101.0%.

There were no differences (P > 0.05) in meltdown among nonfat ice cream treatments. This result is contrary to reports (2, 16) of ice cream in which increased destabilization of fat and resulting stabilization of foam by emulsifiers increased the melting resistance. A slow, uniform melting of ice cream is desirable, and this property is a result of improved dryness due to presence of emulsifiers. In 2% low fat ice cream, no differences in meltdown were found between treatments with or without emulsifier (6).

Ice crystal size is a major factor influencing the texture of ice cream and is influenced by several factors such as formulation, freezing point, draw temperature, freezer efficiency, hardening conditions, and storage conditions (2). The treatment × time (weeks) interaction was not significant (P > 0.05) (i.e., the change in mean ice crystal size from 1 to 12 wk of storage was the same for all treatments) (Table 2). Mean ice crystal sizes averaged over week was used to compare treatments. Mean ice crystal sizes of the EM115, EM125, EM215, and EM225 treatments were smaller (P < 0.05) and ranged from 77.3 to 82.1 μm compared with the control, HPC15, and HPC25 treatments, which had ice crystals ranging from 91.4 to 96.6 μm. Results are similar to the report (1) that emulsifiers reduced ice crystal sizes in ice cream. The large mean ice crystal sizes might have been due to most of the freezing occurring in the hardening room. In 2% fat ice cream, emulsifiers reduced ice crystal sizes (6). The mechanism by which emulsifiers reduce the size of ice crystals is not clear.

The mean ice crystal sizes increased (P < 0.05) by about 10 μm from 80.4 to 90.6 μm from 1 to 12 wk of storage when averaged over treatments (Table 2). Donhowe et al. (12) reported that there was no increase in ice crystal size of ice cream after 7 wk of storage at –20°C and that the first 7 wk after manufacture was the important period of recrystallization. Therefore, the ice crystal sizes measured at 12 wk were probably close to the maximum ice crystal size attained by samples stored at –18°C.

Ice crystals measured in each treatment were divided into 8 different size categories, and the percentage of ice crystals in each size category was determined. Because the distributions as percentage values of ice crystals in different size categories were
The square root of percentage values was used for comparing treatments. There were no differences (P > 0.05) in vanilla flavor scores among treatments (Table 4). All treatments had

Sensory Evaluation

Panelists found no differences (P > 0.05) in flavor, body, and texture parameters between treatments during 1 and 12 wk of storage. Therefore, the mean scores for flavor, body, and texture during wk 1 and 12 were used for comparison of treatments. There were no differences (P > 0.05) in vanilla flavor scores among treatments (Table 4). All treatments had

TABLE 2. Mean ice crystal sizes1 of nonfat ice cream with and without emulsifier or additional food gum.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>wk 1</th>
<th>wk 12</th>
<th>Mean ice crystal size4 (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>91.4</td>
<td>101.8</td>
<td>96.6a</td>
</tr>
<tr>
<td>EM115</td>
<td>72.1</td>
<td>86.1</td>
<td>79.1c</td>
</tr>
<tr>
<td>EM125</td>
<td>71.7</td>
<td>84.6</td>
<td>78.1d</td>
</tr>
<tr>
<td>EM215</td>
<td>75.3</td>
<td>88.8</td>
<td>83.1b</td>
</tr>
<tr>
<td>EM225</td>
<td>71.8</td>
<td>82.7</td>
<td>77.3d</td>
</tr>
<tr>
<td>HPC15</td>
<td>87.9</td>
<td>94.9</td>
<td>91.4b</td>
</tr>
<tr>
<td>HPC25</td>
<td>92.3</td>
<td>95.0</td>
<td>93.6ab</td>
</tr>
<tr>
<td>Mean</td>
<td>80.4b</td>
<td>90.6a</td>
<td>. . .</td>
</tr>
<tr>
<td>SEM</td>
<td>1.1c</td>
<td>. . .</td>
<td>. . .</td>
</tr>
</tbody>
</table>

4Mean ice crystal sizes averaged over treatments.
5Mean of five replicates.
6Standard error of least square means.
7Standard error of means averaged over treatments.
8Standard error of means averaged over week.

Addition of HPC at 0.25% to nonfat ice cream did not reduce (P > 0.05) the ice crystal size, which was comparable to that of the control (Table 2). However, addition of HPC at 0.15% to nonfat ice cream resulted in smaller (P > 0.05) mean ice crystal size than for the control. The HPC15 and HPC25 treatments had similar (P > 0.05) square root of percentage values of ice crystals in the size category 8 at 1 and 12 wk and had similar (P > 0.05) percentages to that of the control at 1 wk. Although polysaccharides used as stabilizers have been reported (25) to reduce ice crystal sizes by reducing the diffusion kinetics of water molecules in the unfrozen phase, doubling the hydrocolloid concentration from 1 to 2% in hydrocolloid-water solutions of guar gum, carboxymethylcellulose, and locust bean gum did not double the amount of unfreezable water (bound water) (10). The fact that there is a limit to how much water hydrocolloids can bind may be the reason that additional food gum (in addition to stabilizer) in nonfat ice cream did not further reduce the ice crystal size.

Sensory Evaluation

Panelists found no differences (P > 0.05) in flavor, body, and texture parameters between treatments during 1 and 12 wk of storage. Therefore, the mean scores for flavor, body, and texture during wk 1 and 12 were used for comparison of treatments. There were no differences (P > 0.05) in vanilla flavor scores among treatments (Table 4). All treatments had

low and had a high variability, values were transformed into square roots of the percentage values. The square root of percentage values was used for comparing treatments (Table 3). We found that EM115, EM125, EM215, and EM225 treatments had higher (P < 0.05) square root of percentage values of ice crystals than did the control in the smallest size category (<49 µm) at 1 and 12 wk. For all treatments, the square root of percentage values decreased (P < 0.05) from 1 to 12 wk in the smallest size category (<49 µm). The EM115, EM125, EM215, and EM225 treatments had lower (P < 0.05) square root of percentage values than did the control at 1 and 12 wk in the largest size category, which included all ice crystals ≥103 µm. The EM115, EM125, EM215, EM225, and control treatments had an increase in square root of percentage values from 1 to 12 wk in the largest size category (≥103 µm). Addition of emulsifier restricted growth of ice crystals in nonfat ice cream, although no differences (P > 0.05) were found between different concentrations of emulsifiers. Emulsifiers assist in the formation of small, evenly distributed air cells and of a stable foam (19). Fat destabilization, promoted by emulsifiers, limits the thinness to which lamellae between air cells can be whipped (7). Monoglycerides, when compared with polysorbates, are powerful foaming agents rather than destabilizing agents (19). Foaming agents may improve the thinness of lamellae between air cells and, therefore, the concentration of the unfrozen phase in the lamellae may increase sufficiently to decrease the movement of water molecules and, thus, limit ice crystal growth. The concentration of stabilizer in the unfrozen phase may also be increased and, thus, emulsifiers may assist the stabilizers in controlling ice crystal size. Also, emulsifiers promote adsorption of destabilized fat at the surface of air cells (7) or in the absence of fat; emulsifiers are adsorbed at the air cells and displace protein from the air-mix interface, which may leave more protein free to bind water and leave less water available for freezing in nonfat ice cream with added emulsifier. The quantity of water bound by protein may be influenced slightly, depending on whether the protein is in contact with water or air (28).

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similar (P < 0.05) cooked flavor scores, except for HPC20, which had a lower (P < 0.05) score than did the control. Treatments EM215 and HPC20 had lower (P < 0.05) overall flavor scores than did the control. The cause of the slight differences in flavor among some of the treatments is unknown. Overall flavor scores ranged for all treatments from 5.54 to 6.16 (better than acceptable flavor scores).

All treatments except EM215 and EM220 had a higher (P < 0.05), more desirable score for weak defect than did the control (Table 5). A weak body is usually due to a low TS content combined with insufficient stabilization and is undesirable (2). All treatments had similar (P > 0.05) scores for greasy defect ranging from 5.72 to 7.59, indicating that the nonfat ice creams were not overemulsified. Treatments HPC15, HPC20, and HPC25 were more (P < 0.05) gummy than were other treatments and had scores ranging from 5.69 to 5.78. Excessive stabilization and high levels of hydrocolloids (>0.16%) or too much corn syrup may cause gummy defect in ice cream (15). Low heat shock scores were expected and were due to the severe temperature and time combinations used in conducting the test. The EM1 and EM2 treatments had more (P < 0.05) stability to heat shock than did the control and HPC treatments (Table 5). This result agrees with

### TABLE 3. Distribution as square root of percentage value of ice crystals (Sqrt %) in different size categories of nonfat ice cream with or without emulsifier or additional food gum.

<table>
<thead>
<tr>
<th>Crystal size</th>
<th>&lt;49 μm</th>
<th>≥49&lt;58 μm</th>
<th>≥58&lt;67 μm</th>
<th>≥67&lt;76 μm</th>
<th>≥76&lt;85 μm</th>
<th>≥85&lt;94 μm</th>
<th>≥94&lt;103 μm</th>
<th>≥103 μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (wk)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>1</td>
<td>3.29&lt;bcde</td>
<td>2.96&lt;bcf</td>
<td>3.31&lt;bcde</td>
<td>3.50&lt;abc</td>
<td>2.06&lt;bcde</td>
<td>3.03&lt;abc</td>
<td>3.79&lt;abc</td>
</tr>
<tr>
<td>12</td>
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<td>5.91&lt;ab</td>
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<td>2.46&lt;ef</td>
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<td>3.65&lt;abc</td>
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<td>HPC25</td>
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<td>3.47&lt;abcd</td>
<td>3.23&lt;bcde</td>
<td>3.65&lt;abc</td>
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<td></td>
</tr>
</tbody>
</table>

*Means within a column without a common superscript differ (P < 0.05).

1Mean of five replicates at 1 and 12 wk after manufacture.

Treatment2<sup>2</sup> HPC15 = hydroxypropyl methylcellulose at 0.15%, HPC20 = hydroxypropyl methylcellulose at 0.20%, EM215 = 72% α-monoglyceride at 0.15%, EM220 = 72% α-monoglyceride at 0.25%, EM115 = 52% α-monoglyceride at 0.15%, EM125 = 52% α-monoglyceride at 0.20%, EM120 = 52% α-monoglyceride at 0.25%, EM225 = 72% α-monoglyceride at 0.25%, HPC15 = hydroxypropyl methylcellulose at 0.15%, and HPC25 = hydroxypropyl methylcellulose at 0.25%.

### TABLE 4. Flavor scores of nonfat ice cream with and without emulsifier or additional food gum.

<table>
<thead>
<tr>
<th>Treatment2</th>
<th>Vanilla flavor&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Cooked flavor&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Overall flavor&lt;sup&gt;4&lt;/sup&gt;</th>
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</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.08&lt;ab</td>
<td>7.50&lt;abc</td>
<td>6.16&lt;ab</td>
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<td>EM115</td>
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<td>7.45&lt;ab</td>
<td>6.03&lt;ab</td>
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<tr>
<td>EM120</td>
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<td>7.54&lt;ab</td>
<td>6.03&lt;ab</td>
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<td>6.08&lt;ab</td>
<td>7.55&lt;ab</td>
<td>6.07&lt;ab</td>
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<tr>
<td>EM215</td>
<td>5.91&lt;ab</td>
<td>7.46&lt;ab</td>
<td>5.67&lt;ab</td>
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<tr>
<td>EM220</td>
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<td>7.64&lt;ab</td>
<td>6.21&lt;ab</td>
</tr>
<tr>
<td>EM225</td>
<td>6.18&lt;ab</td>
<td>7.66&lt;ab</td>
<td>6.24&lt;ab</td>
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<tr>
<td>HPC15</td>
<td>5.97&lt;ab</td>
<td>7.34&lt;bc</td>
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<td>HPC20</td>
<td>5.95&lt;ab</td>
<td>7.11&lt;bc</td>
<td>5.54&lt;bc</td>
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<tr>
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<td>6.11&lt;ab</td>
<td>7.45&lt;ab</td>
<td>5.81&lt;bc</td>
</tr>
</tbody>
</table>

*Means within a column without a common superscript differ (P < 0.05).

1Mean of five replicates at 1 and 12 wk.

2Treatments: EM115 = 52% α-monoglyceride at 0.15%, EM120 = 52% α-monoglyceride at 0.20%, EM125 = 52% α-monoglyceride at 0.25%, EM215 = 72% α-monoglyceride at 0.15%, EM220 = 72% α-monoglyceride at 0.25%, EM225 = 72% α-monoglyceride at 0.25%, HPC15 = hydroxypropyl methylcellulose at 0.15%, HPC20 = hydroxypropyl methylcellulose at 0.20%, and HPC25 = hydroxypropyl methylcellulose at 0.25%.

3Where 1 = extreme defect, 5 = definite defect, 9 = no defect.

4Where 1 = poor, 5 = average, 9 = excellent.
TABLE 5. Body and texture scores of nonfat ice cream with and without emulsifier or additional food gum.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weak</th>
<th>Gummy</th>
<th>Coarse and icy</th>
<th>Stability to heat shock</th>
<th>Coldness intensity</th>
<th>Overall body and texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>4.77d</td>
<td>6.67a</td>
<td>4.24b</td>
<td>1.80d</td>
<td>5.27c</td>
<td>4.60bcd</td>
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<tr>
<td>EM115</td>
<td>5.83bc</td>
<td>6.87a</td>
<td>4.20bc</td>
<td>2.50b</td>
<td>5.74abc</td>
<td>4.85abcd</td>
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<tr>
<td>EM120</td>
<td>6.12b</td>
<td>6.78a</td>
<td>4.76bcd</td>
<td>2.60b</td>
<td>6.03ab</td>
<td>5.06abde</td>
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<tr>
<td>EM125</td>
<td>5.88bc</td>
<td>6.62a</td>
<td>4.61abc</td>
<td>2.80b</td>
<td>5.75abc</td>
<td>4.98abc</td>
</tr>
<tr>
<td>EM215</td>
<td>5.40d</td>
<td>6.64a</td>
<td>4.23b</td>
<td>2.80b</td>
<td>5.65abc</td>
<td>4.67bcd</td>
</tr>
<tr>
<td>EM220</td>
<td>5.74bcd</td>
<td>6.49a</td>
<td>4.94ab</td>
<td>2.70b</td>
<td>5.90ab</td>
<td>5.15abc</td>
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<td>6.46a</td>
<td>5.23a</td>
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<td>5.38a</td>
</tr>
<tr>
<td>HPC15</td>
<td>6.13abc</td>
<td>5.69b</td>
<td>4.10c</td>
<td>1.90c</td>
<td>5.49bc</td>
<td>4.41de</td>
</tr>
<tr>
<td>HPC20</td>
<td>5.91bc</td>
<td>5.78b</td>
<td>4.01c</td>
<td>1.30c</td>
<td>5.31c</td>
<td>4.13e</td>
</tr>
<tr>
<td>HPC25</td>
<td>6.62a</td>
<td>5.75b</td>
<td>4.13c</td>
<td>1.40d</td>
<td>5.50bc</td>
<td>4.51de</td>
</tr>
</tbody>
</table>

Means within a column without a common superscript differ \((P < 0.05)\).

1Mean of five replicates at 1 and 12 wk.

2Treatments: EM115 = 52% α-monoglyceride at 0.15%, EM120 = 52% α-monoglyceride at 0.20%, EM125 = 52% α-monoglyceride at 0.25%, EM215 = 72% α-monoglyceride at 0.15%, EM220 = 72% α-monoglyceride at 0.20%, EM225 = 72% α-monoglyceride at 0.25%, HPC15 = hydroxypropyl methylcellulose at 0.15%, HPC20 = hydroxypropyl methylcellulose at 0.20%, and HPC25 = hydroxypropyl methylcellulose at 0.25%.

3Where 1 = extreme defect, 5 = definite defect, 9 = no defect.

4Where 1 = poor, 5 = average, 9 = excellent.

The report by Keeney (19) that ice creams containing emulsifiers will be perceived to be smoother organoleptically following temperature fluctuations in storage. He attributed this phenomenon to the “muting influence on the feel of large crystals related to emulsifier mediation of stabilized-foam, destabilized lipid emulsion structures,” (page 69). In a previous study (6), 2% fat ice creams containing emulsifiers (polysorbate 80 blend, 40% α-monoglyceride, or 70% α-monoglyceride) were more stable to heat shock than was the control containing no emulsifier. Stabilizer blends containing gums have been reported (25) to delay ice crystal growth during storage and extend shelf-life, but the mechanism is not clear. However, additional food gum in HPC15 and HPC25 treatments did not improve the heat shock stability of nonfat ice cream, and scores were similar \((P > 0.05)\) when compared with the control. The HPC20 treatment was less stable \((P < 0.05)\) to heat shock than was the control. No visual shrinkage was observed in any of the heat shocked, nonfat ice cream treatments. Treatment EM225 had more desirable \((P < 0.05)\) scores for coldness intensity and for overall body and texture than did the control. This result may be due to air preventing excessive coolness perception when ice cream is consumed (28), and emulsifiers improve incorporation of finely emulsified air into ice cream (19). Surface phenomena are important for the physical characteristics of ice cream (19). The mean ratio of the number of air cells:ice crystals:fat globules has been reported (7) to be 1:1:183,000 in full fat ice cream. Body and texture characteristics of ice cream are dependent upon size, number, and distribution of air cells and ice crystals; the presence or absence of fat, and, if present, its extent of destabilization; and the nature of the unfrozen phase in the ice cream.

CONCLUSIONS

The addition of EM1 and EM2 to nonfat ice cream had several beneficial effects. They imparted a desirable resistance to heat shock in nonfat ice cream. Addition of emulsifiers also resulted in smaller ice crystals, a major factor in improving the texture of nonfat ice cream. The mechanism by which emulsifiers inhibit formation of larger ice crystals is not clear. The sensory panel found the EM225 treatment to be better than the control with respect to the coarseness and iciness, coldness intensity, and overall body and texture scores. The EM1 and EM2 had no effect on the whipping time of nonfat ice cream in the batch freezer, and they reduced the whipability of the nonfat ice cream mixes, irrespective of their final concentrations.

Addition of HPC resulted in an increase in flow time of nonfat ice cream mix, and flow time increased with increasing concentrations of HPC. Addition of HPC increased the whipability of the nonfat ice cream mix and did not improve the heat shock stability of nonfat ice cream when compared with the control. Ice crystal sizes of HPC25 were comparable with the control. Therefore, addition of HPC in the absence of emulsifiers did not improve heat shock stability or decrease ice crystal size in the nonfat ice cream. The
sensory panel found nonfat ice cream containing HPC to be more gummy than other treatments.

Emulsifiers and food gums are ingredients that are used at a fraction of a percentage, and yet, they produce dramatic body and texture effects in ice cream lower in fat. It is important to tailor them to suit the application, depending on the processing conditions encountered and their interaction with other ingredients in the mix formulation. Development of low fat and nonfat ice cream that has excellent flavor, body, and texture is still a formidable challenge for the dairy industry, and further research is needed.

ACKNOWLEDGMENTS

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REFERENCES