Effect of Emulsifiers on the Body and Texture of Low Fat Ice Cream[1]

R. J. BAER,[2] M. D. WOLKOW,[3] and K. M. KASPERSON
Minnesota-South Dakota Dairy Foods Research Center,
Dairy Science Department,
South Dakota State University,
Brookings 57007–0647

ABSTRACT

Four emulsifiers at three levels each were evaluated in low fat ice creams (2% fat). Emulsifiers were a polysorbate 80 blend with monoglycerides and diglycerides, 40% α-monoglyceride, 70% α-monoglyceride, and lecithin. The lowest flavor scores were obtained for samples containing lecithin. Emulsifiers increased the consistency of viscosity of low fat ice cream mix and reduced whipping times and ice crystal sizes. Sensory scores for coarse and icy were related to ice crystal size. Emulsifiers also provided increased stability to heat shock. Higher levels of emulsifiers increased whipping ability, but only polysorbate 80 blend and 70% α-monoglyceride increased whipping ability above that of the control. All emulsifiers improved the body and texture of low fat ice cream.
(**Key words**: low fat ice cream, emulsifiers, ice crystals)

INTRODUCTION

Recent changes in FDA food labeling standards have created new descriptors for ice cream (25). The ice cream standard has remained the same; however, the ice milk standard has been abolished, and four new descriptors have been introduced for ice cream: reduced fat, light, low fat, and nonfat or fat-free. Ice creams that are appropriate for each of the new descriptors may require different types or amounts of emulsifiers for optimal quality. Limited controlled research has been conducted on the effects of addition of emulsifiers to ice cream made with lower amounts of fat.

Emulsifiers have the ability to reduce surface tension at the interface of two normally immiscible phases, which will then mix and form an emulsion (13). Emulsifiers are also effective in destabilizing the fat emulsion during the freezing of an ice cream mix. These properties allow emulsifiers to enhance desirable qualities in ice cream by enhancing whipping ability, increasing overrun capacity, reducing whipping time, improving resistance to meltdown, reducing ice crystal growth, increasing dryness and stiffness, imparting a smooth texture and a desirable slightly greasy mouthfeel, and enhancing product uniformity (2, 19, 20). However, ice cream mixes must be homogenized to obtain maximum benefit from emulsifiers, and overemulsification may cause shrinkage, curdy meltdown, or an undesirable greasy mouthfeel (11, 27).

There is little published information about how emulsifiers function in ice creams with lower amounts of fat. The objective of this study was to evaluate four emulsifiers at three commercially recommended usage levels on the physical, chemical, and sensory properties of low fat ice cream (2% fat). This research should lead to an expanded knowledge base from which dairy processors can better select emulsifiers for use in low fat ice cream.

MATERIALS AND METHODS

Manufacture of Low Fat Ice Cream Mix

Low fat ice cream mix contained 2% milk fat and 11.5% serum solids (fat source was cream and serum solids sources were milk, cream, and nonfat dry milk; South Dakota State University Dairy Plant, Brookings), 11.5% sucrose (Holly Sugar Corp., Colorado Springs, CO), 6.5% 36 DE (dextrose equivalent) corn syrup solids (American Maize Products Co., Hammond, IN), 2.5% 10 DE maltodextrin (Grain Processing Corp., Muscatine, IA), and 0.3% stabilizer (CC305: blend of locust bean gum, guar gum, and carrageenan, standardized with dextrose; Continental

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Colloids, Inc., West Chicago, IL). Liquid ingredients (2°C) were placed into a 450-L vat and heated to 43.3°C into which all dry ingredients (except emulsifiers) for the mix were incorporated with use of a powder funnel. Individual emulsifiers were added to 29.5-kg batches of the base mix. Four emulsifiers (Continental Colloids, Inc.) were added at three levels to create 12 treatments. Emulsifiers were P, polysorbate 80 with an 80:20 ratio of mono- and diglycerides added to polysorbate 80; F, 40% α-monoglyceride; S, 70% α-monoglyceride; and L, lecithin. Emulsifier F contained 40% α-monoglycerides, and the other 60% was diglycerides standardized with vegetable fat. Emulsifier S contained 70% α-monoglyceride, and the other 30% was diglycerides standardized with vegetable fat. The control contained no emulsifier. The four emulsifiers and three levels of addition to the mix included the polysorbate 80 blend at the rate of 0.12% (P12), 0.17% (P17), and 0.22% (wt/wt) (P22); 40% α-monoglyceride at 0.15% (F15), 0.20% (F20), and 0.25% (F25); 70% α-monoglyceride at 0.15% (S15), 0.20% (S20), and 0.25% (S25); and lecithin at 0.06% (L6), 0.10% (L10), and 0.14% (L14) (Continental Colloids, Inc.). The emulsifiers were added at commercially recommended minimum, median, and maximum levels. The 12 treatments and the control were replicated five times to produce a total of 65 low fat ice creams.

Mixes were pasteurized at 72.7°C for 30 min, homogenized in a two-stage homogenizer (Manton-Gaulin Manufacturing Co., Inc., Everett, MA) with 13.8-MPa pressure during the first stage and 3.45 MPa pressure during the second stage. Mixes were cooled in an ice water bath until the mix temperature was 4°C and were placed in a cooler overnight at 2°C.

Composition Analyses of Mix

Low fat ice cream mixes were analyzed in triplicate for fat by the Mojonnier method (4), protein by the macro-Kjeldahl method (3), ash by muffle furnace (3), TS by the Mojonnier method (4), and freezing point by the osmometer method (5). Mix pH was determined (model 701; Orion Research, Inc., Cambridge, MA) with a combination pH electrode (Orion Research, Inc.), and titratable acidity was determined using 0.10*N* NaOH and phenolphthalein (4). The consistency of the mix was measured as the time to empty a 50-ml pipette (2). Whipping abilities of low fat ice cream mix were calculated using a mixer at speed setting 7 with 3-cm whipping blades (Mixmaster Deluxe; Sunbeam Appliance Co., Milwaukee, WI). A 1-L stainless steel mixing bowl was calibrated with known volumes of water and placed inside a 2.5-L bowl. An ice and salt mixture was placed between the bowls to cool the mix as it was whipped. An initial volume of 350 ml of mix was used, and measurements were taken at 2, 5, 10, and 20 min during

TABLE 1. Mix characteristics[1] of low fat ice creams with and without added emulsifier.

	pH	Titratable acidity	Flow time	Whipping time
Individual treatment[2]		(%)	(s)	(min)
Control	6.48[ab]	0.22[a]	77.38[e]	9.55[a]
P12	6.50[a]	0.22[a]	78.59[de]	7.79[bcd]
P17	6.49[ab]	0.22[a]	80.21[cd]	7.17[cd]
P22	6.48[ab]	0.22[a]	81.70[bc]	7.20[cd]
F15	6.48[ab]	0.22[a]	79.20[cde]	8.51[b]
F20	6.50[a]	0.22[a]	81.32[bc]	8.03[bc]
F25	6.46[b]	0.22[a]	83.52[ab]	7.76[bcd]
S15	6.49[ab]	0.22[a]	80.38[cd]	7.96[bc]
S20	6.47[ab]	0.22[a]	83.19[ab]	6.97[d]
S25	6.49[ab]	0.22[a]	85.56[a]	7.70[bcd]
L6	6.46[b]	0.22[a]	79.62[cde]	8.48[b]
L10	6.49[ab]	0.22[a]	79.71[cde]	7.91[bcd]
L14	6.50[a]	0.22[a]	80.44[cd]	8.47[b]
SE	0.01	0.01	0.92	0.35
Emulsifier type[3]				
C	6.48[a]	0.22[a]	77.38[c]	9.55[a]
P	6.49[a]	0.22[a]	80.16[b]	7.39[d]
F	6.48[a]	0.22[a]	81.34[b]	8.10[bc]
S	6.48[a]	0.22[a]	83.04[a]	7.54[cd]
L	6.48[a]	0.22[a]	79.93[b]	8.29[b]
SE	0.01	0.01	0.55	0.22
Emulsifier level[4]				
C	6.48[a]	0.22[a]	77.38[d]	9.55[a]
1	6.48[a]	0.22[a]	79.45[c]	8.18[b]
2	6.49[a]	0.22[a]	81.11[b]	7.52[c]
3	6.48[a]	0.22[a]	82.81[a]	7.78[bc]
SE	0.01	0.01	0.34	0.14

[a,b,c,d,e]Means in the same column within each grouping (individual treatments, emulsifier type, and emulsifier level), without a common superscript differ ($P < 0.05$).

[1]Means of five replicates.

[2]Treatments: control, P12 = polysorbate 80 blend (0.12%), P17 = polysorbate 80 blend (0.17%), P22 = polysorbate 80 blend (0.22%), F15 = 40% α-monoglyceride (0.15%), F20 = 40% α-monoglyceride (0.20%), F25 = 40% α-monoglyceride (0.25%), S15 = 70% α-monoglyceride (0.15%), S20 = 70% α-monoglyceride (0.20%), S25 = 70% α-monoglyceride (0.25%), L6 = lecithin (0.06%), L10 = lecithin (0.10%), and L14 = lecithin (0.14%).

[3]Emulsifier types: control (no emulsifier), P = polysorbate 80 blend, F = 40% α-monoglyceride, S = 70% α-monoglyceride, and L = lecithin means of all usage levels.

[4]Emulsifier levels: control (no emulsifier): 1 = minimum recommended usage level for each emulsifier (mean of P12, F15, S15, and L6); 2 = median recommended usage level for each emulsifier (mean of P17, F20, S20, and L10); and 3 = maximum recommended usage level for each emulsifier (mean of P22, F25, S25, and L14).

TABLE 2. Whipping ability[1] of low fat ice cream mix as affected by addition of an emulsifier.

Treatment[2]	Time 0 min	2 min	5 min	10 min	20 min
	(ml)				
Control	350[a]	445[cd]	475[cd]	500[bc]	515[cd]
P12	350[a]	455[bcd]	480[c]	505[b]	530[bc]
P17	350[a]	490[b]	535[ab]	555[a]	565[ab]
P22	350[a]	530[a]	570[a]	590[a]	595[a]
F15	350[a]	405[ef]	435[defg]	455[cd]	480[de]
F20	350[a]	425[def]	450[cdef]	475[bcd]	475[def]
F25	350[a]	450[cd]	470[cd]	490[bc]	500[cd]
S15	350[a]	425[def]	460[cde]	495[bc]	505[cd]
S20	350[a]	440[de]	470[cd]	495[bc]	510[cd]
S25	350[a]	480[bc]	525[b]	560[a]	580[a]
L6	350[a]	400[f]	400[g]	405[e]	405[g]
L10	350[a]	405[ef]	420[efg]	430[de]	430[fg]
L14	350[a]	405[ef]	415[fg]	430[de]	435[efg]
SE	0.01	12.95	15.16	16.60	16.50

[a,b,c,d,e,f,g]Means in the same column without a common superscript differ ($P < 0.05$).

[1]Means of five replicates.

[2]Treatments: control, P12 = polysorbate 80 blend (0.12%), P17 = polysorbate 80 blend (0.17%), P22 = polysorbate 80 blend (0.22%), F15 = 40% α-monoglyceride (0.15%), F20 = 40% α-monoglyceride (0.20%), F25 = 40% α-monoglyceride (0.25%), S15 = 70% α-monoglyceride (0.15%), S20 = 70% α-monoglyceride (0.20%), S25 = 70% α-monoglyceride (0.25%), L6 = lecithin (0.06%), L10 = lecithin (0.10%), and L14 = lecithin (0.14%).

whipping to detect changes in mix volume. Mixes were analyzed for microbiological quality by determining standard plate counts and coliform counts (24).

Manufacture of Low Fat Ice Cream

Vanilla extract (Massey's 2X Bourbon; Nielsen-Massey Vanillas, Inc., Waukegan, IL) was thoroughly incorporated into the mix at a rate of 7.8 ml/kg of mix before the mix was frozen in a batch freezer (18.9-L single barrel; Emery Thompson Machine and Supply, Bronx, NY). Draw temperatures were obtained using a mercury thermometer, and whipping times were recorded for all treatments. An overrun of about 85% was desired in the low fat ice cream and was determined using the weight-volume method of overrun percentage determination using an overrun scale (2). Low fat ice creams were placed in a hardening room at –30°C until analyses and evaluations were completed.

Analysis of Low Fat Ice Cream

Low fat ice creams were examined 6 wk after manufacture using a microscope (BH-2; Olympus Optical Co., Ltd., Tokyo, Japan) to size and count ice crystals. A squash mount of each low fat ice cream was prepared using a 50:50 (vol/vol) mixture of amyl alcohol and kerosene at –18°C (9). Each mount was viewed under the microscope at –18°C, and 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 using an eyepiece micrometer. A minimum of 150 ice crystals were counted per treatment for every replication. Ice crystals were measured in treatments P12, P22, F15, F25, S15, S25, L6, and L14 and in the control because preliminary studies indicated that the level of emulsifier had no effect on ice crystal size. Meltdown of the low fat ice creams using 50-g samples was evaluated (number 6 U.S.A. Standard Testing Sieve; W. S. Tyler, Inc., Mentor, OH) (2). Stability to heat shock was evaluated by the freeze-thaw method at 4 wk after manufacture (2). Low fat ice creams were visually monitored for shrinkage and wheying off throughout the evaluation period and also after the stability to heat shock testing.

Sensory Evaluation

A trained nine-member sensory panel evaluated randomly coded low fat ice creams for flavor, body, and texture (22). Flavor, body, and texture were each evaluated on a nine-point scale (1 = extreme defect, 5 = definite defect, and 9 = no defect). Each sample was given an overall score for flavor and for body and texture on a nine-point scale (1 = poor, 5 = average, and 9 = excellent). Panelists had the opportunity to write comments or criticisms on all scoresheets.

Statistical Analyses

Data were analyzed using general linear models procedure (26). Low fat ice creams were arranged as a 3 × 4 factorial design, were analyzed as individual treatments, and were grouped as emulsifier type and emulsifier level. Emulsifiers were added at the minimum (level 1 = mean of P12, F15, S15, and L6), median (level 2 = mean of P17, F20, S20, and L10), and maximum (level 3 = mean of P22, F25, S25, and L14) recommended usage level. Significance was determined by least squares means and was $P < 0.05$ unless stated otherwise.

RESULTS AND DISCUSSION

Composition of Low Fat Ice Cream

Mean fat content of the five replicates of mix was 2.04%. Mean concentrations of total protein, TS, and ash in the mix were 4.20, 33.92, and 0.98%, respectively. There were no differences among treatments for all mix components.

TABLE 3. Characteristics[1] of low fat ice creams with and without added emulsifier.

	Draw temperature	Ice crystal size	Meltdown	Overrun	Stability to heat shock[2]
Individual treatment[3]	(°C)	(μ)	(min)	(%)	
Control	–4.68[bcde]	86.1[a]	33.66[a]	81.00[c]	4.10[d]
P12	–4.32[ab]	65.7[b]	31.58[a]	85.40[abc]	6.40[a]
P17	–4.22[a]	. . .	31.26[a]	87.80[ab]	6.20[ab]
P22	–4.48[abc]	65.2[b]	33.43[a]	89.00[ab]	6.20[ab]
F15	–4.84[cde]	61.3[b]	32.16[a]	84.00[bc]	6.90[a]
F20	–4.80[cde]	. . .	32.32[a]	84.60[bc]	6.70[a]
F25	–4.36[ab]	63.0[b]	33.58[a]	86.00[abc]	6.80[a]
S15	–4.56[abcd]	62.6[b]	32.71[a]	84.60[bc]	6.50[a]
S20	–4.30[ab]	. . .	33.16[a]	91.00[a]	6.70[a]
S25	–4.44[abc]	60.6[b]	33.23[a]	91.00[a]	6.40[a]
L6	–4.98[de]	68.4[b]	33.24[a]	65.00[d]	5.20[c]
L10	–4.96[de]	. . .	33.45[a]	64.10[d]	5.50[bc]
L14	–5.04[e]	68.8[b]	33.94[a]	62.60[d]	5.40[bc]
SE	0.15	3.3	4.92	2.11	0.30
Emulsifier type[4]					
C	–4.68[b]	86.1[a]	33.66[a]	81.00[a]	4.10[c]
P	–4.34[a]	65.4[b]	32.09[a]	87.40[a]	6.27[ab]
F	–4.67[b]	62.1[b]	32.69[a]	84.87[a]	6.80[a]
S	–4.43[a]	61.6[b]	33.03[a]	88.87[a]	6.53[a]
L	–4.99[c]	68.0[b]	33.54[a]	63.90[b]	5.37[b]
SE	0.08	2.8	0.45	1.48	0.30
Emulsifier level[5]					
C	–4.68[a]	86.1[a]	33.66[a]	81.00[ab]	4.10[b]
1	–4.68[a]	64.5[b]	32.42[b]	79.75[b]	6.25[a]
2	–4.57[a]	. . .	32.55[b]	81.88[a]	6.28[a]
3	–4.58[a]	64.4[b]	33.55[a]	82.15[a]	6.20[a]
SE	0.07	1.0	0.30	0.62	0.09

[a,b,c,d,e]Means in the same column within each grouping (individual treatment, emulsifier type, and emulsifier level) without a common superscript differ ($P < 0.05$).

[1]Mean of five replicates.

[2]1 = Extremely coarse and icy, 5 = definitely coarse and icy, and 9 = not coarse and icy.

[3]Individual treatments: control, P12 = polysorbate 80 blend (0.12%), P17 = polysorbate 80 blend (0.17%), P22 = polysorbate 80 blend (0.22%), F15 = 40% α-monoglyceride (0.15%), F20 = 40% α-monoglyceride (0.20%), F25 = 40% α-monoglyceride (0.25%), S15 = 70% α-monoglyceride (0.15%), S20 = 70% α-monoglyceride (0.20%), S25 = 70% α-monoglyceride (0.25%), L6 = lecithin (0.06%), L10 = lecithin (0.10%), and L14 = lecithin (0.14%).

[4]Emulsifier types: control (no emulsifier), P = polysorbate 80 blend, F = 40% α-monoglyceride, S = 70% α-monoglyceride, and L = lecithin means of all usage levels.

[5]Emulsifier levels: control, 1 = minimum recommended usage level for each emulsifier (mean of P12, F15, S15, and L6), 2 = median recommended usage level for each emulsifier (mean of P17, F20, S20, and L10), and 3 = maximum recommended usage level for each emulsifier (mean of P22, F25, S25, and L14).

Characteristics of Low Fat Ice Cream Mix

Differences among treatment pH values of the low fat ice cream mixes were observed but are of no practical importance (Table 1). The pH ranged from 6.50 in P12, F20, and L14 to 6.46 in F25 and L6. These values approximated the mean pH of ice cream mix, which is 6.3 (2). The type of emulsifier and level had no influence on mix pH. Titratable acidities did not differ between individual treatments, emulsifer types, and emulsifier levels. The consistency of low fat ice cream mix, as measured by the flow time from the 50-ml pipette, differed between treatments. Flow times ranged from 77.38 s for the control to 85.56 s for S25. In comparison of the emulsifier types, the flow time for the control was significantly lower than those of the samples containing emulsifiers; flow times were similar for mixes containing the polysorbate 80 blend, 40% α-monoglyceride, and lecithin. The flow time of the mix containing 70% α-monoglyceride emulsifier was higher than the mixes containing polysorbate 80 blend, 40% α-monoglyceride, lecithin, and the control. As the level of emulsifier increased, the flow time also increased, and the control had the lowest flow time. A certain level of viscosity is essential for proper whipping and for retention of air. In general, as the viscosity increases, the resistance to melting and the smoothness of body increases, but the rate of whipping decreases (2). The range of whipping times was from 9.55 min in the control to 6.97 min in S20. As expected, the control mix had the longest whipping time because a function of emulsifiers is to decrease whipping time (2, 14). The polysorbate 80 blend and 70% α-monoglyceride mixes had the lowest whipping times. Recommended usage levels 1, 2, and 3 had lower whipping times than those of the control. Only treatment S20 and S25 obtained 90% overrun within 8 min. All other treatments were considered to have a low whipping rate based on these criteria (2). Whipping rate is also dependent upon the efficiency of the whipping mechanism, the viscosity of the partly frozen mix, and the completeness with which air, once incorporated, is retained (2, 14, 15, 17, 19).

Whipping abilities of mixes varied among treatments (Table 2). The P22, S25, and P17 had the highest whipping abilities at 20 min of 595, 580, and 565 ml, respectively, and L6, L10, and L14 had the lowest. Overemulsification of ice cream can reduce whipping ability while producing a greasy mouthfeel (2). Whipping ability is improved by high processing temperatures, proper homogenization, and aging the mix for 2 to 4 h (2, 6). The whipping ability of the control was higher than that of the mixes containing 40% monoglyceride and lecithin emulsifiers and levels 1 and 2.

TABLE 4. Percentages[1] of ice crystals in different size categories observed in low fat ice creams with and without added emulsifier.

	Crystal size								
	≤35 μ	36–49 μ	50–62 μ	63–74 μ	75–87 μ	88–99 μ	100–112 μ	113–124 μ	≥125 μ
	(%)								
Individual treatment[2]									
Control	1.5	3.9	6.8	16.4	35.2	18.1	6.5	3.8	7.8
P12	3.8	7.5	30.2	31.8	17.9	4.8	1.8	0.7	1.6
P22	3.4	14.8	37.2	25.9	10.1	4.6	2.5	0.5	1.1
F15	2.8	17.3	38.1	27.5	8.8	3.7	1.2	0.3	0.3
F25	4.8	16.8	38.4	24.0	7.4	4.3	2.3	0.9	1.2
S15	4.8	10.8	38.7	31.0	8.0	2.6	1.6	1.0	1.3
S25	5.4	14.3	40.7	28.0	7.6	1.4	1.1	0.8	0.7
L6	3.0	8.4	16.6	37.0	22.5	6.6	3.0	1.0	2.0
L14	2.5	3.6	14.6	40.1	22.9	10.0	3.7	0.9	1.8
Emulsifier level[3]									
C	1.5	3.9	6.8	16.4	35.2	18.1	6.5	3.8	7.8
1	3.6	11.0	30.9	31.8	14.3	4.4	1.9	0.8	1.3
3	4.0	12.4	32.7	29.5	12.0	5.1	2.4	0.7	1.2

[1]Mean of five replicates.

[2]Individual treatments: control, P12 = polysorbate 80 blend (0.12%), P17 = polysorbate 80 blend (0.17%), P22 = polysorbate 80 blend (0.22%), F15 = 40% α-monoglyceride (0.15%), F20 = 40% α-monoglyceride (0.20%), F25 = 40% α-monoglyceride (0.25%), S15 = 70% α-monoglyceride (0.15%), S20 = 70% α-monoglyceride (0.20%), S25 = 70% α-monoglyceride (0.25%), L6 = lecithin (0.06%), L10 = lecithin (0.10%), and L14 = lecithin (0.14%).

[3]Emulsifier levels: control (no emulsifier), 1 = minimum recommended usage level for each emulsifier (mean of P12, F15, S15, and L6), 2 = median recommended usage level for each emulsifier (mean of P17, F20, S20, and L10), and 3 = maximum recommended usage level for each emulsifier (mean of P22, F25, S25, and L14).

Standard plate counts and coliform counts of all replicates were within legal standards.

Characteristics of Low Fat Ice Cream

Draw temperatures of the low fat ice creams differed among treatments and emulsifier types, but emulsifier levels yielded similar temperatures (Table 3). Ice cream containing the polysorbate 80 blend and 70% monoglyceride had the highest draw temperatures, and products with lecithin had the lowest. Mean ice crystal sizes differed between the control and all other treatments, emulsifiers, and levels, as expected. It is generally accepted that the major function of stabilizers is to decrease ice crystal size in frozen desserts. One of the functions of emulsifiers is to reduce ice crystal size in frozen desserts (1). This effect was evident, and the control had a higher mean ice crystal size than all other treatments. The mechanisms by which emulsifiers reduce ice crystal size in low fat ice cream are unknown, but emulsifiers likely interact with the water phase of the mix and possibly affect surface tension. An electrophoretic study showed that added emulsifiers do not affect milk proteins, and interactions between emulsifiers and milk proteins was not detectable (23). Emulsifi-

TABLE 5. Flavor scores[1] of low fat ice creams with and without added emulsifier.

	Cooked[2]	Storage[2]	Syrup[2]	Vanilla flavor intensity[2]	Overall flavor[3]
Individual treatment[4]					
Control	7.99[a]	7.75[ab]	7.13[ab]	7.21[ab]	7.32[ab]
P12	8.03[a]	7.96[a]	7.07[ab]	7.05[abcd]	7.27[ab]
P17	8.01[a]	7.97[a]	7.08[ab]	7.21[ab]	7.19[bc]
P22	8.00[a]	7.99[a]	7.12[ab]	7.19[ab]	7.22[abc]
F15	8.03[a]	7.99[a]	7.01[ab]	7.16[ab]	7.43[a]
F20	7.96[a]	7.85[a]	7.00[ab]	7.16[ab]	7.28[ab]
F25	8.01[a]	7.73[ab]	7.16[a]	7.27[a]	7.31[ab]
S15	7.95[a]	7.85[a]	7.04[ab]	7.11[abc]	7.21[abc]
S20	7.95[a]	7.87[a]	7.05[ab]	7.11[abc]	7.13[bc]
S25	7.96[a]	7.75[ab]	7.00[ab]	7.00[bcde]	6.99[cd]
L6	8.01[a]	7.53[bc]	6.93[b]	6.93[cde]	6.79[de]
L10	7.99[a]	7.43[c]	7.09[ab]	6.81[e]	6.82[de]
L14	7.95[a]	7.36[c]	6.99[ab]	6.87[de]	6.60[e]
SE	0.03	0.11	0.08	0.08	0.08
Emulsifier type[5]					
C	7.99[a]	7.75[a]	7.13[a]	7.21[a]	7.32[a]
P	8.01[a]	7.97[a]	7.09[a]	7.15[a]	7.22[ab]
F	8.00[a]	7.86[a]	7.06[a]	7.20[a]	7.34[a]
S	7.95[a]	7.82[a]	7.03[a]	7.07[a]	7.11[b]
L	7.98[a]	7.44[b]	7.00[a]	6.87[b]	6.74[c]
SE	0.02	0.06	0.04	0.05	0.05
Emulsifier level[6]					
C	7.99[a]	7.75[a]	7.13[a]	7.21[a]	7.32[a]
1	8.00[a]	7.83[a]	7.01[a]	7.06[a]	7.17[a]
2	7.98[a]	7.78[a]	7.06[a]	7.07[a]	7.10[a]
3	7.98[a]	7.71[a]	7.07[a]	7.08[a]	7.03[a]
SE	0.02	0.05	0.05	0.04	0.04

[a,b,c,d,e]Means in the same column without a common superscript differ ($P < 0.05$).

[1]Means of five replicates.

[2]1 = Extreme defect, 5 = definite defect, and 9 = no defect.

[3]1 = Poor, 5 = average, and 9 = excellent.

[4]Individual treatments: control, P12 = polysorbate 80 blend (0.12%), P17 = polysorbate 80 blend (0.17%), P22 = polysorbate 80 blend (0.22%), F15 = 40% α-monoglyceride (0.15%), F20 = 40% α-monoglyceride (0.20%), F25 = 40% α-monoglyceride (0.25%), S15 = 70% α-monoglyceride (0.15%), S20 = 70% α-monoglyceride (0.20%), S25 = 70% α-monoglyceride (0.25%), L6 = lecithin (0.06%), L10 = lecithin (0.10%), and L14 = lecithin (0.14%).

[5]Emulsifier types: control (no emulsifier), P = polysorbate 80 blend, F = 40% α-monoglyceride, S = 70% α-monoglyceride, and L = lecithin means of all usage levels.

[6]Emulsifier levels: control (no emulsifier), 1 = minimum recommended usage level for each emulsifier (mean of P12, F15, S15, L6), 2 = median recommended usage level for each emulsifier (mean of P17, F20, S20, L10), 3 = maximum recommended usage level for each emulsifier (mean of P22, F25, S25, L14).

ers and protein may interact in the emulsion formation, thus creating a complex food emulsion (20). Another possibility is that α-monoglycerides bind with some of the milk protein. A third, more likely possibility is that the hydrophilic terminus of the emulsifier binds water in the low fat ice cream mix; therefore, there is less water to freeze, resulting in smaller ice crystals. This area needs to be investigated further. The percentage of ice crystals in the designated size categories also depict the increased ice crystal size in the control ice cream (Table 4). Donhowe et al. (12) used 50 μ as the size at which ice crystals were detectable by sensory evaluation. A report by Kuntz (21) indicated that coarseness and iciness could be detected by sensory evaluation in frozen desserts with a mean ice crystal size of 30 to 40 μ. Table 3 indicates that the mean ice crystal size of the control is 86.1 μ, and the control, therefore, should be coarse and icy. Also, the percentage of ice crystals >125 μ in the control is 7.8%, which is higher than that of all other treatments (Table 4), which ranged from 0.3% in F15 to 2.0% in L6.

Meltdown times were similar for treatments and emulsifiers (Table 3). The control and level 3 had longer meltdown times than did levels 1 and 2. Overrun differed among treatments, emulsifiers, and levels. Overrun was decreased by lecithin compared with overrun of all other treatments and emulsifiers. Over-

TABLE 6. Body and texture scores[1] of low fat ice creams with and without added emulsifier.

	Coarse and icy[2]	Coldness intensity[2]	Greasy[2]	Gummy[2]	Weak[2]	Overall body and texture[3]
Individual treatment[4]						
Control	6.48[f]	6.39[e]	7.88[a]	7.47[a]	7.16[c]	6.43[f]
P12	7.35[bcde]	6.88[bcd]	8.03[a]	7.51[a]	7.59[ab]	7.11[bcd]
P17	7.15[cde]	6.88[bcd]	7.91[a]	7.40[a]	7.44[ab]	6.93[de]
P22	7.27[bcde]	7.01[abc]	7.93[a]	7.48[a]	7.61[a]	7.09[cde]
F15	7.64[a]	7.08[ab]	8.00[a]	7.51[a]	7.60[a]	7.33[a]
F20	7.44[ab]	7.23[a]	7.84[a]	7.51[a]	7.55[ab]	7.32[ab]
F25	7.52[ab]	7.11[ab]	7.93[a]	7.40[a]	7.47[ab]	7.27[abc]
S15	7.38[abcd]	7.00[abc]	7.97[a]	7.45[a]	7.57[ab]	7.12[bcd]
S20	7.39[abc]	7.05[abc]	7.91[a]	7.47[a]	7.41[ab]	7.12[bcd]
S25	7.33[bcde]	7.12[ab]	7.93[a]	7.39[a]	7.39[b]	7.06[de]
L6	7.09[e]	6.71[d]	7.95[a]	7.48[a]	7.60[a]	6.91[de]
L10	7.11[de]	6.79[cd]	7.89[a]	7.61[a]	7.55[ab]	6.95[de]
L14	7.12[cde]	6.68[d]	7.95[a]	7.44[a]	7.43[ab]	6.89[e]
SE	0.10	0.09	0.04	0.06	0.07	0.07
Emulsifier type[5]						
C	6.48[d]	6.39[d]	7.88[a]	7.47[a]	7.16[b]	6.43[d]
P	7.25[b]	6.92[b]	7.96[a]	7.46[a]	7.55[a]	7.04[bc]
F	7.53[a]	7.14[a]	7.92[a]	7.47[a]	7.54[a]	7.31[a]
S	7.37[b]	7.06[ab]	7.94[a]	7.44[a]	7.46[a]	7.10[b]
L	7.10[c]	6.72[c]	7.93[a]	7.51[a]	7.52[a]	6.92[c]
SE	0.05	0.06	0.02	0.04	0.04	0.05
Emulsifier level[6]						
C	6.48[b]	6.39[b]	7.88[a]	7.47[a]	7.16[b]	6.43[b]
1	7.36[a]	6.92[a]	7.99[a]	7.49[a]	7.59[a]	7.12[a]
2	7.31[a]	6.99[a]	7.89[a]	7.50[a]	7.49[a]	7.08[a]
3	7.27[a]	6.98[a]	7.94[a]	7.43[a]	7.47[a]	7.08[a]
SE	0.06	0.07	0.03	0.03	0.04	0.04

[a,b,c,d,e]Means in the same column without a common superscript differ ($P < 0.05$).

[1]Means of five replicates.

[2]1 = Extreme defect, 5 = definite defect, and 9 = no defect.

[3]1 = Poor, 5 = average, and 9 = excellent.

[4]Individual treatments: control, P12 = polysorbate 80 blend (0.12%), P17 = polysorbate 80 blend (0.17%), P22 = polysorbate 80 blend (0.22%), F15 = 40% α-monoglyceride (0.15%), F20 = 40% α-monoglyceride (0.20%), F25 = 40% α-monoglyceride (0.25%), S15 = 70% α-monoglyceride (0.15%), S20 = 70% α-monoglyceride (0.20%), S25 = 70% α-monoglyceride (0.25%), L6 = lecithin (0.06%), L10 = lecithin (0.10%), and L14 = lecithin (0.14%).

[5]Emulsifier types: control (no emulsifier), P = polysorbate 80 blend, F = 40% α-monoglyceride, S = 70% α-monoglyceride, and L = lecithin means of all usage levels.

[6]Emulsifier levels: control (no emulsifier), 1 = minimum recommended usage level for each emulsifier (mean of P12, F15, S15, and L6), 2 = median recommended usage level for each emulsifier (mean of P17, F20, S20, and L10), and 3 = maximum recommended usage level for each emulsifier (mean of P22, F25, S25, and L14).

run, which is directly related to the amount of air in ice cream, is important because it influences product quality and profits and is involved in meeting legal standards (2, 10). The incorporation of too much air produces a fluffy ice cream, and too little produces a soggy, heavy product.

The control had the lowest stability to heat shock of all treatments, emulsifiers, and levels, as expected. Stability to heat shock involves alternate thawing and refreezing of a portion of water because of temperature fluctuations, which can produce large ice crystals and result in a coarser, icier texture. The method to evaluate stability to heat shock involved the storage of ice cream at –20°C, then temperature abuse at 20°C for 1.5 h, and return of the ice cream to –20°C (2). The ice cream underwent this treatment each day for 6 d for 30 min of temperature abuse. The ice cream was then evaluated for coarse and iciness. Emulsifiers protected frozen desserts from heat shock during storage (2, 19, 20). Ice creams containing the polysorbate 80 blend, 40% monoglyceride, and 70% monoglyceride emulsifiers exhibited the highest stability to heat shock, compared with the control, which contained no emulsifier (Table 3). No shrinkage or wheying off was observed in any of the treatment ice creams at 1, 4, or 12 wk.

Sensory Evaluation

Sensory evaluation scores of all low fat ice cream treatments are listed in Tables 5 and 6. Scores for cooked flavor for treatments and emulsifiers were similar (Table 5). Level of emulsifier had no effect on any flavor scores. Scores for storage flavor differed among treatments and emulsifiers, and L had the lowest scores. Scores for syrup flavor differed among treatments but were similar for types of emulsifiers. Scores for vanilla flavor intensity and overall flavor scores differed among emulsifiers, and L was the lowest. The control ice cream and samples containing the polysorbate 80 blend and 40% α-monoglyceride emulsifiers were given the highest overall flavor scores. Because the control scored higher for overall flavor than did ice creams with 70% monoglyceride and lecithin, emulsifiers may negatively affect product flavor. High levels of lecithin have been reported to result in a soy-like off-flavor (13). Polysorbate 80 has also been known to produce undesirable off-flavors, especially over time (13, 18); however, in this study, off-flavors were not observed.

Body and texture scores of low fat ice creams are shown in Table 6. Coarse and icy scores differed among the treatments, emulsifier types, and levels; the control had the lowest score of 6.48. This result

TABLE 7. Flavor and body and texture scores[1] during storage of low fat ice creams made with and without added emulsifier.[2]

	Flavor					
Time	Cooked[3]	Vanilla flavor intensity[3]	Storage[3]	Syrup[3]	Overall flavor[4]	
(wk)						
1	8.04[a]	7.02[a]	7.92[a]	7.09[a]	7.17[a]	
4	7.97[a]	7.02[a]	7.72[a]	7.01[a]	7.06[a]	
12	7.95[a]	7.20[a]	7.68[a]	7.05[a]	7.13[a]	
SE	0.04	0.08	0.16	0.04	0.06	
	Body and texture					
	Coldness intensity[3]	Greasy[3]	Gummy[3]	Coarse and icy[3]	Weak[3]	Overall body and texture[4]
1	7.06[a]	8.05[a]	7.50[a]	7.56[a]	7.55[a]	7.32[a]
4	6.77[a]	7.85[a]	7.31[a]	7.15[a]	7.49[a]	6.95[b]
12	6.92[a]	7.89[a]	7.60[a]	7.04[a]	7.43[a]	6.86[b]
SE	0.08	0.06	0.09	0.14	0.11	0.09

[a,b]Means in the same column without a common superscript differ ($P < 0.05$).

[1]Means of five replicates.

[2]Treatments: control, P12 = polysorbate 80 blend (0.12%), P17 = polysorbate 80 blend (0.17%), P22 = polysorbate 80 blend (0.22%), F15 = 40% α-monoglyceride (0.15%), F20 = 40% α-monoglyceride (0.20%), F25 = 40% α-monoglyceride (0.25%), S15 = 70% α-monoglyceride (0.15%), S20 = 70% α-monoglyceride (0.20%), S25 = 70% α-monoglyceride (0.25%), L6 = lecithin (0.06%), L10 = lecithin (0.10%), and L14 = lecithin (0.14%).

[3]1 = Extreme defect, 5 = definite defect, and 9 = no defect.

[4]1 = Poor, 5 = average, and 9 = excellent.

was consistent with the observation that the mean ice crystal size of the control was largest (Table 4). Both methods, the sensory and microscopic evaluation, showed that the control had higher coarse and icy scores and a higher mean ice crystal size, which indicated a reduction in the quality of body and texture. The ice cream with F emulsifier exhibited the lowest degree of coarse and icy characteristics, followed by S and P emulsifiers. The ice cream with lecithin was less coarse and icy than the control, but was coarser and icier than emulsifiers F, S, and P. Another function of emulsifiers is to reduce the perceived coldness intensity of a product. Coldness intensity values differed within treatments, emulsifiers, and levels, and the control rated as the coldest, which indicated that the emulsifiers performed their function of improving coldness intensity. The F and S emulsifiers reduced coldness intensity most: scores were 7.14 and 7.06 versus 6.39 for the control. Greasiness was similar for all individual treatments, emulsifier types, and emulsifier levels, indicating that overemulsification was not a problem. Gumminess scores were similar for all individual treatments, emulsifier types, and emulsifier levels. Weak body differed among individual treatments, emulsifier types, and emulsifier levels, and the control exhibited the weakest body, as expected. Because emulsifiers assist in preventing a weak frozen dessert body that melts down rapidly in the mouth (2, 7, 8, 11, 14), all emulsifier types and levels provided a stiffer bodied ice cream than the control. Overall body and texture scores differed among individual treatments, emulsifier types, and emulsifier levels; the control had the lowest scores. The F emulsifier exhibited the highest overall scores for body and texture of all emulsifiers, followed by the P and S, P and L, and then the control. As expected, the control ice cream had the lowest overall scores for body and texture because emulsifiers retard ice crystal growth, enhance resistance to meltdown, increase dryness, increase stiffness, produce a smoother texture, provide a slightly greasy mouthfeel, and enhance product uniformity.

Flavor scores remained constant during storage as shown in Table 7. Body and texture scores during storage were similar for all characteristics, except overall body and texture, for which scores at wk 1 were higher than at 4 and 12 wk, which concurs with previous observations that body and texture of frozen desserts deteriorate over time (2, 16, 20).

CONCLUSIONS

Use of emulsifiers in 2% low fat ice cream produced desirable effects in product quality. All emulsifiers evaluated in this study improved the body and texture of low fat ice cream. The flavor scores were lowest when lecithin was used. Emulsifiers increased the consistency of low fat ice cream mix, which is desirable. Whipping times and ice crystal sizes were reduced in all emulsified low fat ice creams. Sensory scores for coarseness and iciness related to the size of ice crystals as determined by direct microscopic examination. This relationship validates the effectiveness of emulsifiers in reducing coarse and iciness in low fat ice cream. Emulsifiers also provided increased stability to heat shock.

The recommended usage level affected some characteristics of mix and low fat ice cream but had no effect on others. A maximum level was required to obtain a whipping ability that was greater than that of the control, but level had no effect on ice crystal size. The level must be selected for individual emulsifiers to obtain the desired effect of the emulsifier chosen to perform the task required.

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REFERENCES

1 Arbuckle, W. S. 1950. Emulsifiers in ice cream. Ice Cream Trade J. 46(10):106.
2 Arbuckle, W. S. 1986. Ice Cream. 4th ed. AVI Publ. Co., Westport, CT.
3 Association of Official Analytical Chemists. 1990. Methods 920.105 and 945.46. Page 807 *in* Official Methods of Analysis. 15th ed. AOAC, Arlington, VA.
4 Atherton, V. H., and J. A. Newlander. 1977. Chemistry and Testing of Dairy Products. 4th ed. AVI Publ. Co., Inc., Westport, CT.
5 Baer, R. J., and T. P. Czmowski. 1985. Use of the osmometer for quality control of ice cream mix. J. Food Prot. 48:976.
6 Barfod, N. M., N. Krog, G. Larsen, and W. Buchheim. 1991. Effects of emulsifiers on protein-fat interaction in ice cream mix during aging I: quantitative analyses. Fat Sci. Technol. 93(1): 24.
7 Bassett, H. 1988. Stabilization and emulsification of frozen desserts. Dairy Field 171(3):18.
8 Bassett, H. 1988. Stabilization and emulsification of frozen desserts. Dairy Field 171(5):22.
9 Berger, K. G., and G. W. White. 1979. Ice cream. Page 499 *in* Food Microscopy. J. G. Vaughan, ed. Academic Press, New York, NY.
10 Buck, J. S., C. E. Walker, and M. M. Pierce. 1986. Evaluation of sucrose esters in ice cream. J. Food Sci. 51:489.
11 Crowhurst, B. 1990. Emulsification of ice cream. Dairy Ind. Int. 55(10):37.
12 Donhowe, D. P., R. W. Hartel, and R. L. Bradley. 1991. Determination of ice crystal size distributions in frozen desserts. J. Dairy Sci. 74:3334.
13 Dziezak, J. D. 1988. Emulsifiers: the interfacial key to emulsion stability. Food Technol. 42(10):172.
14 Goff, H. D. 1988. Emulsifiers in ice cream: how do they work? Modern Dairy 67(3):15.

15 Goff, H. D. 1988. The role of chemical emulsifiers and dairy proteins in fat destabilization during the manufacture of ice cream. Ph.D. Diss., Cornell Univ., Ithaca, NY.
16 Goff, H. D., and K. B. Caldwell. 1991. Stabilizers in ice cream: how do they work? Modern Dairy 70(3):14.
17 Goff, H. D., and W. K. Jordan. 1989. Action of emulsifiers in promoting fat destabilization during the manufacture of ice cream. J. Dairy Sci. 72:18.
18 Goff, H. D., M. Loboff, W. K. Jordan, and J. E. Kinsella. 1987. The effects of polysorbate 80 on the fat emulsion in ice cream mix: evidence from transmission electron microscopy studies. Food Microstruct. 6:193.
19 Hegenbart, S. 1990. Maintaining harmony in the base. Dairy Foods 90(2):83.
20 Keeney, P. G. 1982. Development of frozen emulsions. Food Technol. 36(11):65.
21 Kuntz, L. A. 1995. Freeze/thaw-stability: keeping your assets frozen. Food Prod. Design 4:11.
22 Larmond, E. 1977. Laboratory Methods for Sensory Evaluation of Food. Agric. Can. Publ. No. 1637. Canada Dep. Agric., Ottawa, ON.
23 Lin, P.-M., and J. G. Leeder. 1974. Mechanism of emulsifier action in an ice cream system. J. Food Sci. 39:108.
24 Marshall, R. T., ed. 1992. Standard Methods for the Examination of Dairy Products. 16th ed. Am. Publ. Health Assoc., Washington, DC.
25 Marshall, R. T., and W. S. Arbuckle. 1996. Ice Cream. 5th ed. Chapman and Hall, New York, NY.
26 SAS® User's Guide: Statistics, Version 6.0 Edition. 1990. SAS Inst., Inc., Cary, NC.
27 Schmidt, K. A., and D. E. Smith. 1988. Effects of homogenization on sensory characteristics of vanilla ice cream. J. Dairy Sci. 71:46.