Effect of Double Homogenization and Whey Protein Concentrate on the Texture of Ice Cream¹

P. R. Ruger,² R. J. Baer, and K. M. Kasperson³

Dairy Science Department,
South Dakota State University,
Brookings 57007-0647

ABSTRACT

Ice cream samples were made with a mix composition of 11% milk fat, 11% milk solids-not-fat, 13% sucrose, 3% corn syrup solids (36 dextrose equivalent), 0.28% stabilizer blend, or 0.10% emulsifier and vanilla extract. Mixes were high temperature short time pasteurized at 80°C for 25 s, homogenized at 141 kg/cm² pressure on the first stage and 35 kg/cm² pressure on the second, and cooled to 3°C. The study included six treatments from four batches of mix. Mix from batch one contained 0.10% emulsifier. Half of this batch (treatment 1), was subsequently frozen and the other half (upon exiting the pasteurizer) was reheated to 60°C, rehomogenized at 141 kg/cm² pressure on the first stage and 35 kg/cm² pressure on the second (treatment 2), and cooled to 3°C. Mix from batch two contained 0.28% stabilizer blend. Half of this batch was used as the control (treatment 3), the other half upon exiting the pasteurizer was reheated to 60°C, rehomogenized at 141 kg/cm² pressure on the first stage and 35 kg/cm² pressure on the second (treatment 4), and cooled to 3°C. Batch three, containing 0.10% emulsifier and 1% whey protein concentrate substituted for 1% nonfat dry milk, upon exiting the pasteurizer was reheated to 60°C, rehomogenized at 141 kg/cm² pressure on the first stage and 35 kg/cm² pressure on the second (treatment 5), and cooled to 3°C. Batch four, containing 0.28% stabilizer blend and 1% whey protein concentrate substituted for 1% nonfat dry milk, upon exiting the pasteurizer was reheated to 60°C, rehomogenized at 141 kg/cm² pressure on the first stage and 35 kg/cm² pressure on the second (treatment 6), and cooled to 3°C. Consis-

tency was measured by flow time through a pipette. Flow time of treatment 3 was greater than all treatments, and the flow times of treatments 4 and 6 were greater than treatments 1, 2, and 5. Flow time was increased in ice cream mix by the addition of stabilizer. Double homogenization lowered ice cream mix flow time in the presence of stabilizer, but no difference in flow time was observed without stabilizer addition. Treatment 4 had a lower mean ice crystal size at 10 d postmanufacture compared with treatment 3; however, overall texture acceptability between treatments 3 and 4 was similar. Mean ice crystal size of treatment 6 was less at 18 wk postmanufacture compared with treatment 3; however, overall texture acceptability for treatments 3, 4, and 6 was similar. Mean ice crystal sizes of treatments 1, 2, and 5 were greater at 10 d and 18 wk compared with treatment 3. Sensory evaluation indicated that treatments 3, 4, and 6 had higher mean scores for icy, coldness intensity, and creaminess than treatments 1, 2, and 5 at 10 d and 18 wk postmanufacture.

(**Key words:** ice cream, double homogenization, whey protein concentrate, ice crystals)

Abbreviation key: MSNF = milk SNF, T1 = treatment with no stabilizer added, T2 = treatment 2 with no stabilizer added and double homogenized, T3 = treatment 3 the control, T4 = treatment 4 was double homogenized, T5 = treatment 5 with no stabilizer added, double homogenized, and 1% WPC substituted for 1% NDM, T6 = treatment 6 was double homogenized and 1% WPC substituted for 1% NDM, WPC = whey protein concentrate.

INTRODUCTION

Milk fat is an important constituent influencing the texture of ice cream by mechanically obstructing ice crystal growth (Marshall and Arbuckle, 1996). Homogenization of fat is employed to provide a stable emulsion and is considered an essential procedure during ice cream mix processing (Berger, 1997). Homogenizing under the same conditions repeatedly (multipass homogenization) further decreases the fat globule size,

Received December 13, 2001.

Accepted February 14, 2001.

Corresponding author: R. J. Baer; e-mail: robert_baer@sdstate.edu.

¹Published with the approval of the director of the South Dakota Agricultural Experiment Station as Publication No. 3280 of the Journal Series.

²Wells' Dairy, Inc., Le Mars, Iowa 51031.

³Station Biochemistry, South Dakota State University, Brookings, South Dakota 57007-1217.

narrowing the size distribution (Leviton and Pallansch, 1959). Lowering homogenization pressure and omitting the emulsifier resulted in ice cream with characteristics similar to commercial ice cream (Schmidt and Smith, 1989). Properly controlling the physical properties of an ice cream mix by further processing can favorably alter the texture and physical appearance of ice cream (Goff, 1997). Repeated homogenization has shown benefits in other dairy products, such as sour cream where "dual homogenization" is recommended if a heavier bodied product is desired (Kosikowski and Mistry, 1997).

Whey protein concentrate (**WPC**) has been included in ice cream mix formulations for its contribution to favorable sensory and textural qualities (Tirumalesha and Jayaprakasha, 1998; Hofi et al., 1993; Parsons et al., 1985). Functional characteristics such as water binding, emulsification, and foaming are important in ice cream. Water binding is a property of WPC that can be utilized in frozen desserts to delay development of coarseness (Morr, 1989). The water-binding capacity of WPC is influenced by protein concentration, mineral content, and the extent of heating during manufacture (Sienkiewicz and Riedel, 1990). Whey protein concentrates can also be utilized for their emulsifying properties. Proteins interact at the oil/water interface during homogenization to stabilize the fat emulsion, and, during freezing, proteins function to control destabilization of fat (Goff, 1997; Goff et al., 1989; Mangino, 1992). Increased amounts of whey proteins at the oil/water interface lower surface tension and slightly increase mix viscosity that produces a drier ice cream and enhances partial coalescence in the freezer (Goff et al., 1989). The tremendous foaming properties of whey proteins allow fine dispersion of air cells (Zayas, 1997), which will lower the ice crystal size in ice cream (Flores and Goff, 1999).

A coarse texture is the most frequently cited defect in ice cream (Marshall and Arbuckle, 1996). As this defect becomes pronounced, a gritty or icy mouthfeel is followed by a relatively cold sensation in the mouth caused by excessively large ice crystals. To achieve small initial ice crystals, the ice cream mix must be rapidly subcooled to the point of maximal nucleation rate (Hartel, 1996). This allows the greatest number of ice crystals to form and the least amount of ice crystal growth in the freezer. Upon extrusion from the freezer, ice cream must immediately be hardened to minimize recrystallization. The temperature and rate of hardening determines the final ice crystal size and the physical and sensory properties of the product (Sutton and Bracey, 1996). The texture defect icy is eminent as ice crystals grow throughout storage. The objective of this research was to study the effect of double homogenization and WPC on ice crystal size in ice cream.

MATERIALS AND METHODS

Manufacture of Ice Cream Mix

Ice cream mix contained 11% milk fat (fat source was cream, Dean Foods North Central Inc., Sioux Falls, SD), 11% milk SNF (**MSNF**) (MSNF sources were cream Dean Foods North Central Inc.), skim milk (South Dakota State University Dairy Plant, Brookings, SD), and NDM (Associated Milk Producers Inc., Freeman, SD), 13% sucrose (United Sugar Corp., Minneapolis, MN), 3% corn syrup solids (Cerestar USA, Inc., Hammond, IN), and 0.28% stabilizer blend (guar gum, mono and diglycerides, locust bean gum, polysorbate 80, carrageenan, standardized with dextrose; CC-392) (Continental Colloids, Inc., West Chicago, IL) or 0.10% emulsifier (mono and diglycerides and polysorbate 80; CC-280) (Continental Colloids, Inc.), or WPC (36% protein) (Dairy-Lo, Cultor Food Science, Inc., Thomson, IL). Ice cream mix was made in four batches by first heating the liquid ingredients (cream and skim milk) to 46°C. These ingredients were transferred to a liquefier, where dry ingredients were added in the order of NDM, WPC sucrose, corn syrup solids (36 dextrose equivalent), and stabilizer blend or emulsifier. The stabilizer blend or emulsifier was mixed with sucrose before liquefaction to ensure proper mixing. Dry ingredients were mixed for 1 to 2 min. Mixes were pasteurized by HTST in a model EOS-75 Cherry-Burrell pasteurizer (Cherry-Burrell Corp., St. Paul, MN) at 80°C for 25 s and homogenized in a Manton-Gaulin model 600/M-12 two-stage homogenizer (Associated Dairy Equipment Manufacturers, Inc., Everett, MA) with 141 kg/cm² pressure on the first stage and 35 kg/cm² pressure on the second. Six treatments were prepared from four batches of mix (Table 1). Mix from batch one contained 0.10% emulsifier. After pasteurization, half of this batch, treatment 1 (**T1**), was cooled to 3°C; and the other half upon exiting the pasteurizer was reheated to 60°C, rehomogenized at 141 kg/cm² and 35 kg/cm² (**T2**), and cooled to 3°C. Mix from batch two contained 0.28% stabilizer blend. Half of this batch was used as the control (**T3**) and cooled to 3°C; the other half upon exiting the pasteurizer was reheated to 60°C, rehomogenized at 141 and 35 kg/cm² (**T4**), and cooled to 3°C. Batch three contained 0.10% emulsifier and 1% WPC substituted for 1% NDM, and, upon exiting, the pasteurizer was reheated to 60°C, rehomogenized at 141 and 35 kg/cm² (**T5**), and cooled to 3°C. Batch four contained 0.28% stabilizer blend and 1% WPC substituted for 1% NDM, and, upon exiting, the pasteurizer was reheated to 60°C, rehomogenized at 141 and 35 kg/cm² (**T6**), and cooled to 3°C. The six treatments were replicated five times, and a total of 30 ice creams were made. Mixes were aged overnight at 2°C.

Table 1. Ice cream mix treatments.

Treatment	Single homogenization ¹	Double homogenization ²	Stabilizer added ³	Emulsifier added ⁴	Whey protein concentrate added ⁵
T1	✓			✓	
T2		✓		✓	
T3	✓		✓		
T4		✓	✓		
T5		✓		✓	✓
T6		✓	✓		✓

¹Ice cream mix passed through a homogenizer once with 141 kg/cm² pressure on the first stage and 35 kg/cm² pressure on the second stage.

²Ice cream mix passed through a homogenizer twice with 141 kg/cm² pressure on the first stage and 35 kg/cm² pressure on the second stage.

³Ice cream mix with stabilizer blend added at 0.28%.

⁴Ice cream mix with emulsifier added at 0.10%.

⁵Ice cream mix with 1% whey protein concentrate substituted for 1% NDM.

Analysis of Mix

Ice cream mixes were analyzed in duplicate for fat and total solids by the Mojonnier methods (Atherton and Newlander, 1977). Mix pH was measured with a Corning model 350 pH analyzer (Corning, Inc., Corning, NY). Freezing point of the mixes was determined by the osmometer method (Baer and Czmowski, 1985), and flow time was measured through a 50-ml pipette (pipet method) (Arbuckle, 1986; Baer et al., 1999). Coliform counts of mixes were determined (Marshall, 1992).

Manufacture of Ice Cream

Twofold vanilla extract (Beck Flavors, St. Louis, MO) was added at a rate of 85 ml to 22.7 kg of ice cream mix before freezing. Ice cream mix was at 2°C before freezing. Ice cream mix was frozen (Baer et al., 1999) to a target overrun of 90 to 95%, calculated by weight (Arbuckle, 1986). Whipping time of the ice cream was recorded. A digital thermometer was used to measure drawing temperature of the ice cream upon extrusion from the freezer. Ice cream was placed in a hardening room at -26°C.

Storage of Ice Cream

Ice cream was stored in a hardening room with temperatures fluctuating between -22 to -28°C for 13 wk. Ice cream samples were moved to an upright freezer with temperatures fluctuating between -19 to -24°C for 5 wk.

Analysis of Ice Cream

A light microscope (Olympus BH-2, Olympus Optical Co., Ltd., Tokyo, Japan) was used to determine the

mean ice crystal size of each treatment. The top 4 cm of ice cream was removed from the ice cream and samples were obtained about 4 cm from the edge of the container. Samples were prepared by the squash mount method (Berger and White, 1979) using a 50:50 mixture of amyl alcohol and kerosene. Ice crystal sizes were determined by measuring each ice crystal at its widest point using an eyepiece micrometer. A minimum number of 150 ice crystals were counted per sample. The microscope, ice cream samples, utensils, and the mounting medium were tempered in a walk-in freezer (Kol-Gard Cooler, serial #K32353N, Kolpak Industries, Inc., Parsons, TN.) at -18°C before examination. Ice crystal measurements were taken at 10 d and 18 wk postmanufacture.

Sensory Evaluation

A six-member sensory panel with previous ice cream evaluation experience evaluated three-digit randomly coded ice cream samples for flavor and texture (Larmond, 1977). Scores were assigned to six attributes (vanilla flavor intensity, overall flavor acceptability, icy, coldness intensity, creaminess, and overall texture acceptability) on a scale from 1 to 9 (1 = extreme defect or poor quality; 9 = no defect or excellent quality). The evaluation was performed at 10 d and 18 wk postmanufacture. Panelists were encouraged to write additional comments on the evaluation worksheet.

Statistical Analysis

Data were analyzed using general linear models procedure (SAS, 1990). Complete randomized block design was used to evaluate the effect of individual treatments. Significance was determined by Fisher's least significant difference at $P < 0.05$.

Table 2. Ice cream mix composition and characteristics.¹

Treatment ²	Milk fat (%)	Total solids (%)	pH	Flow time (sec)	Whipping time (min)	Freezing point (°C)
T1	11.17	38.08	6.40 ^b	43.7 ^c	7.26	-2.48
T2	11.17	38.08	6.40 ^b	40.4 ^c	7.28	-2.47
T3	11.14	37.93	6.48 ^a	122.5 ^a	7.22	-2.49
T4	11.14	37.93	6.48 ^a	85.4 ^b	7.21	-2.48
T5	11.09	37.90	6.48 ^a	42.1 ^c	7.17	-2.45
T6	11.21	38.20	6.51 ^a	85.3 ^b	7.27	-2.46

^{a,b,c}Means in the same column without common superscripts differ ($P < 0.05$). Means in the same column without superscripts do not differ ($P > 0.05$).

¹Mean of five replicates.

²Treatments: T1 = No stabilizer added; T2 = no stabilizer added, double homogenized; T3 = control; T4 = double homogenized; T5 = no stabilizer added, double homogenized, 1% whey protein concentrate substituted for 1% NDM; T6 = double homogenized, 1% whey protein concentrate substituted for 1% NDM.

RESULTS AND DISCUSSION

Ice Cream Mix Composition

Milk fat content of the ice cream mix ranged from 11.09 to 11.21% and was similar ($P > 0.05$) among treatments (Table 2). This is important, as increases in fat content have been shown to reduce ice crystal size (Keeney and Kroger, 1974) and affect sensory evaluation by causing a lubricating sensation in the mouth (Arbuckle, 1986; Keeney, 1979). Often fat is added to ice cream mix at the expense of water, this lowers the ice phase volume of the ice cream, which provides a smoother product (Hartel, 1996).

Total solids ranged from 37.90 to 38.20% and were similar ($P > 0.05$) among treatments. Ice cream mix with lower TS (high water content) has proportionately more water to freeze than a higher TS mix (low water content) hardened to the same storage temperature. The percent TS of the ice cream mix is directly related to ice crystal size distribution (Flores and Goff, 1999), and lower TS ice cream contains larger ice crystals (Donhowe et al., 1991). Variation in solids content of just a few percent greatly influences ice crystal growth (Keeney, 1979). These reasons make uniformity in TS content among treatments essential.

Ice Cream Mix Characteristics

Ice cream mix pH values ranged from 6.40 to 6.51 with differences ($P < 0.05$) among treatments (Table 2). The pH of an ice cream mix is related to the MSNF content; as the MSNF portion of a mix increases, the normal acidity is elevated and the pH is lowered (Arbuckle, 1986). The pH of an ice cream mix can be used as an indicator of mix quality.

Ice cream mixes were tempered to 21°C due to the dependence of flow time on temperature. Large differences were observed in ice cream mix flow times among

treatments ($P < 0.05$; Table 2). The composition of an ice cream mix influences viscosity, with fat and stabilizer being the largest contributors (Arbuckle, 1986). Fat content remained constant among the treatments; however T1, T2, and T5 all were formulated without added stabilizer. This proved to have a profound effect on viscosity. Ice cream mixes without added stabilizer had lower flow times ($P < 0.05$) than the ice cream mixes with stabilizer, T3, T4, and T6. Stabilizers have also been shown by other researchers to increase ice cream mix viscosity (Flores and Goff, 1999; Miller-Livney and Hartel, 1997). Whey protein concentrate at a 1% usage rate had little effect on flow time in ice cream mix made without or in the presence of stabilizer. No difference ($P > 0.05$) was observed in flow time when comparing T5 (no added stabilizer, 1% WPC) to T2 (no added stabilizer) or T6 (stabilizer added, 1% WPC) to T4 (stabilizer added). The processing and handling of ice cream mix—especially pasteurization, homogenization, and aging—influence viscosity (Marshall and Arbuckle, 1996). Double homogenization of ice cream mix with added stabilizer (T4) decreased flow time ($P < 0.05$) compared with ice cream mix homogenized once (T3). However, ice cream mix that was double homogenized without added stabilizer (T2) did not differ ($P > 0.05$) from ice cream mix homogenized only once (T1). Since milk fat is a large contributor to viscosity, repeated homogenization will further decrease fat globule size and narrow the size distribution (Leviton and Pallansch, 1959); this process is accompanied by a decrease in viscosity (Keeney and Kroger, 1974). This may explain why T4 was less viscous than T3. However, the similar flow times for T1 and T2 and suggest that the presence of stabilizer affects flow time to a greater extent than homogenization. Another possibility is that the stabilizer was affected in T4 when the mix was double homogenized, which resulted in decreased flow time, compared with T3, which was single homogenized.

Marshall and Arbuckle (1996) stated that a certain level of viscosity is necessary for suitable whipping and retention of air in the ice cream freezer; as the viscosity in ice cream mix is raised, the resistance to melting and the smoothness of body increases but the whipping rate decreases. A certain ice cream mix viscosity cannot predict the outcome of the texture of ice cream. Generally speaking, ice cream mix with high viscosity accompanies good textured ice cream. To achieve the desired ice cream mix viscosity, the mix must be properly balanced for composition, concentration, and quality of ingredients and then appropriately processed.

Agitation in the ice cream freezer barrel causes shear forces that coalesce fat globules. These fat globule clumps form a matrix that stabilizes the air cells to maintain a fine distribution (Goff, 1988). The rate at which these air cells are incorporated and their resulting stabilization from coalesced fat determine the whipping time of the ice cream mix (Marshall and Arbuckle, 1996). The time required to whip the ice cream mix ranged from 7.17 to 7.28 min (Table 2), with no differences ($P > 0.05$) among treatments. The consequence of different whipping times is variation in the ice crystal size distribution of hardened ice cream (Hartel, 1996; Marshall and Arbuckle, 1996). The residence time of ice cream in the freezer must be balanced to give desired overrun and optimum texture (Marshall and Arbuckle, 1996).

Freezing point of an ice cream mix is a reflection of the molecules in solution, the most prevalent constituent being sugar (Arbuckle, 1986). Determination of the ice cream mix freezing point will detect variation in samples, assuring that solute is found in proper quantity (Baer and Czmowski, 1985). Variation in ice cream mix freezing points can alter the recrystallization rate at a specific storage temperature in ice cream (Hagiwara and Hartel, 1996). Ice cream mix freezing points ranged from -2.45 to -2.49°C and were similar ($P > 0.05$) among treatments (Table 2).

Ice Cream Characteristics

Draw temperature ranged from -3.08°C in T3 to -3.54°C in T1, with differences among treatments ($P < 0.05$) (Table 3). Normal draw temperatures of ice cream made in a batch freezer have been reported in the range of -3.3 to -4.4°C (Arbuckle, 1986).

Overrun is the increase in volume of ice cream over the volume of ice cream mix due to the incorporation of air (Marshall and Arbuckle, 1996). No differences ($P > 0.05$) were seen among treatments for overrun, which ranged from 90.3 to 96.6% (Table 3). An increase in overrun will decrease the size of ice crystals (Marshall and Arbuckle, 1996), and greater dispersion of air cells

Table 3. Ice cream characteristics.¹

Treatment ²	Draw temperature ($^{\circ}\text{C}$)	Overrun (%)
T1	-3.54^{c}	90.6
T2	-3.42^{bc}	90.3
T3	-3.08^{a}	90.6
T4	-3.16^{ab}	92.1
T5	-3.30^{abc}	96.5
T6	-3.22^{abc}	96.6

^{a,b,c}Means in the same column without common superscripts differ ($P < 0.05$). Means in same column without superscripts do not differ ($P > 0.05$).

¹Mean of five replicates.

²Treatments: T1 = No stabilizer added; T2 = no stabilizer added, double homogenized; T3 = control; T4 = double homogenized; T5 = no stabilizer added, double homogenized, 1% whey protein concentrate substituted for 1% NDM; T6 = double homogenized, 1% whey protein concentrate substituted for 1% NDM.

reduces the chance of collisions between ice crystals (Flores and Goff, 1999).

The size of ice crystals plays a large role in influencing the texture of ice cream (Hartel, 1996). Ice crystals will grow as a result of factors such as low TS, low freezing point, high draw temperature, inadequate stabilizer, slow hardening, long storage time, and high and variable storage temperatures (Marshall and Arbuckle, 1996). All treatments became more icy ($P < 0.05$) over storage time (Table 4), as expected (Marshall and Arbuckle, 1996). Quantification of ice crystal size at 10 d postmanufacture showed differences ($P < 0.05$) among treatments. At 10 d, T4 ($61.2 \mu\text{m}$) and T6 ($62.5 \mu\text{m}$) showed the lowest mean ice crystal size, with T4 having a smaller mean ice crystal size ($P < 0.05$) compared with T3 ($64.5 \mu\text{m}$). Treatment 1, T2, and T5 all had

Table 4. Mean ice crystal sizes¹ of ice cream at 10 d and 18 wk postmanufacture.

Treatment ²	Ice crystal size (μm)	
	10 d	18 wk
T1	$73.0^{\text{a,B}}$	$81.0^{\text{ab,A}}$
T2	$70.3^{\text{ab,B}}$	$77.5^{\text{b,A}}$
T3	$64.5^{\text{c,B}}$	$72.9^{\text{c,A}}$
T4	$61.2^{\text{d,B}}$	$69.2^{\text{cd,A}}$
T5	$69.4^{\text{b,B}}$	$83.8^{\text{a,A}}$
T6	$62.5^{\text{cd,B}}$	$68.9^{\text{d,A}}$

^{a,b,c,d}Means in the same column without common superscripts differ ($P < 0.05$).

^{A,B}Means in the same row without common superscripts differ ($P < 0.05$).

¹Mean of five replicates.

²Treatments: T1 = No stabilizer added; T2 = no stabilizer added, double homogenized; T3 = control; T4 = double homogenized; T5 = no stabilizer added, double homogenized, 1% whey protein concentrate substituted for 1% NDM; T6 = double homogenized, 1% whey protein concentrate substituted for 1% NDM.

Table 5. Distribution as percentage of ice crystals in different size categories¹ of ice creams.

Treatment ²	Time	Size category							
		1	2	3	4	5	6	7	8
		Ice crystal size (μm)							
		≤ 45	46–55	56–65	66–75	76–85	86–95	96–105	≥ 106
(% ³)									
T1	10 d	18.69 ^h	13.82 ^{ab}	12.82 ^{bc}	13.55 ^a	12.53 ^a	10.67 ^a	8.62 ^a	13.48 ^e
T1	18 wk	21.33 ^g	9.15 ^h	12.90 ^{bc}	11.12 ^d	10.74 ^{bc}	8.42 ^{de}	7.99 ^b	22.53 ^b
T2	10 d	22.24 ^g	13.24 ^{bc}	13.79 ^a	13.62 ^a	13.05 ^a	10.57 ^a	5.83 ^e	12.00 ^f
T2	18 wk	24.54 ^f	12.32 ^{de}	10.40 ^f	10.65 ^d	9.66 ^{de}	9.28 ^{bc}	7.37 ^c	23.06 ^b
T3	10 d	33.96 ^b	11.30 ^f	12.67 ^{bc}	8.61 ^f	9.11 ^e	8.95 ^{cd}	6.50 ^d	12.22 ^f
T3	18 wk	26.14 ^e	10.09 ^g	12.48 ^{bcd}	13.01 ^{ab}	9.63 ^{de}	8.13 ^e	7.44 ^c	17.73 ^c
T4	10 d	39.19 ^a	13.18 ^{bc}	11.07 ^{ef}	13.52 ^a	12.41 ^a	7.98 ^e	5.45 ^e	8.15 ^h
T4	18 wk	29.72 ^d	12.06 ^{de}	13.27 ^{ab}	11.86 ^c	8.35 ^f	9.27 ^{bc}	5.54 ^e	14.31 ^e
T5	10 d	25.01 ^{ef}	14.48 ^a	13.15 ^{ab}	12.81 ^b	11.18 ^b	9.56 ^{bc}	7.74 ^{bc}	11.78 ^f
T5	18 wk	21.61 ^g	9.90 ^g	11.84 ^{de}	9.83 ^e	8.09 ^f	9.73 ^b	8.62 ^a	25.73 ^a
T6	10 d	38.57 ^a	11.75 ^{ef}	12.61 ^{bcd}	9.61 ^e	9.68 ^{de}	9.11 ^{bcd}	7.48 ^{bc}	10.00 ^g
T6	18 wk	31.30 ^c	12.64 ^{cd}	12.10 ^{cd}	11.16 ^d	10.04 ^{cd}	7.21 ^f	4.89 ^f	15.50 ^d

^{a,b,c,d,e,f,g,h}Means in the same column without common superscripts differ ($P < 0.05$).

¹Mean of five replicates at 10 d and 18 wk postmanufacture.

²Treatments: T1 = No stabilizer added; T2 = no stabilizer added, double homogenized; T3 = control; T4 = double homogenized; T5 = no stabilizer added, double homogenized, 1% whey protein concentrate substituted for 1% NDM; T6 = double homogenized, 1% whey protein concentrate substituted for 1% NDM.

³Percentage of ice crystals within each range for a specific treatment.

larger ($P < 0.05$) mean ice crystal sizes than T3. The same general trend followed upon evaluation at 18 wk. Treatment 4 (69.2 μm) and T6 (68.9 μm) had the lowest mean ice crystal size, except at 18 wk, T6 had a lower mean ice crystal size ($P < 0.05$) than T3 (72.9 μm). Treatment 1, T2, and T5 had larger mean ice crystal sizes than T3.

Ice crystals measured within each treatment were divided into eight size categories; the percentage of ice crystals in each size category was calculated (Table 5). Generally, more ice crystals appeared at 10 d in size category 1 than at 18 wk for each treatment. In size category 8, the opposite was true, fewer ice crystals occurred at 10 d than at 18 wk for any given treatment. This displays the phenomenon of recrystallization or the growth of large ice crystals at the expense of smaller ones over time and is consistent with previous literature (Donhowe et al., 1991; Sutton and Bracey, 1996; Miller-Livney and Hartel, 1997; Flores and Goff, 1999). Treatment 4 and T6 had a higher percentage of ice crystals in size category 1 ($P < 0.05$) and a lower percentage of ice crystals in size category 8 ($P < 0.05$) for both time periods than for T3. Conversely, T1, T2, and T5 had a lower percentage of ice crystals in size category 1 ($P < 0.05$) and a higher ($P < 0.05$) percentage of ice crystals in size category 8 for both time periods compared with T3. This interpretation of the ice crystal distribution would indicate that T4 and T6 are less icy than T3, and that T1, T2, and T5 are more icy than T3. Hartel (1996) suggested that rather than the iciness of an ice cream being determined by the mean size of a

distribution; it should be based on the number of crystals over a threshold detection level. This initial detection size of ice crystals has been reported at 55 μm (Berger and White, 1979). Taking this perspective, T4 and T6 have a greater percentage ($P < 0.05$) of ice crystals less than 55 μm (size categories 1 and 2) compared with T3, illustrating that T4 and T6 would be perceived as ice creams that are less icy. Treatment 1, T2, and T5 have a higher percentage ($P < 0.05$) of ice crystals over 55 μm than T3, indicating that T1, T2, and T5 would be perceived as ice creams that are more icy.

Use of double homogenization reduced the mean ice crystal size of T4 at 10 d postmanufacture and of T6 at 18 wk postmanufacture compared with T3 (Table 4). The ice crystal size distribution shows T4 and T6 to have a greater percentage of small ice crystals (size category 1 and 2) compared with T3. Without added stabilizer to ice cream mix, double homogenization, T2, did not yield ice cream that differed ($P > 0.05$) in mean ice crystal size from ice cream mix homogenized once, T1 (Table 4). Treatment 2 had a higher percentage of small ice crystals (Table 5), less than 45 μm compared with T1, indicating a positive response to double homogenization in the absence of stabilizer.

Whey proteins have a demonstrated ability to enhance fat destabilization during freezing (Goff, 1997) and, when denatured, exhibit favorable water-binding characteristics (Morr, 1989). The use of WPC at a 1% usage level showed no improvement ($P > 0.05$) in mean ice crystal size comparing T4 to T6 and T2 to T5 (Table 4). Only between T2 and T5 at 10 d postmanufacture

Table 6. Flavor and texture scores¹ of ice cream at 10 d postmanufacture.

Treatment ²	Vanilla flavor intensity ³	Overall flavor acceptability ³	Icy ⁴	Coldness intensity ⁴	Creaminess ³	Overall texture acceptability ³
T1	6.6 ^b	6.7	5.8 ^b	4.5 ^b	5.2 ^b	5.0 ^c
T2	6.7 ^b	6.6	5.7 ^b	4.8 ^b	5.5 ^b	5.3 ^c
T3	7.2 ^{ab}	7.3	7.2 ^a	6.6 ^a	7.3 ^a	7.4 ^a
T4	7.4 ^a	7.3	6.9 ^a	6.3 ^a	7.2 ^a	7.1 ^{ab}
T5	6.7 ^b	6.8	5.3 ^b	4.7 ^b	5.1 ^b	4.9 ^c
T6	7.1 ^{ab}	7.1	6.9 ^a	6.5 ^a	7.0 ^a	6.9 ^b

^{a,b,c}Means in the same column without common superscripts differ ($P < 0.05$). Means in the same column without superscripts do not differ ($P > 0.05$).

¹Mean of five replicates.

²Treatments: T1 = No stabilizer added; T2 = no stabilizer added, double homogenized; T3 = control; T4 = double homogenized; T5 = no stabilizer added, double homogenized, 1% whey protein concentrate substituted for 1% NDM; T6 = double homogenized, 1% whey protein concentrate substituted for 1% NDM.

³1 = Poor, 5 = average, 9 = excellent.

⁴1 = Extreme defect, 5 = definite defect, 9 = no defect.

was there an increase in the percentage of ice crystals in size category 1 (Table 5). These modest results may be due to an inadequate WPC wage rate. Other researchers have demonstrated the benefits of whey protein when used in higher concentrations. Goff et al. (1989) ran a series of experiments incorporating different milk protein isolate combinations into ice cream mix. These researchers determined that a 95% whey protein isolate used at 3% combined with 1.8% NDM provided proper ice cream mix viscosity, allowed for adequate incorporation of air, had acceptable taste, and fat destabilization was at a rate that made inclusion of emulsifier unnecessary.

The absence of stabilizer negatively affected ($P < 0.05$) the mean ice crystal size at both 10 d and 18 wk, displayed by comparing T1 to T3 (Table 4). Treatment 1 also contained fewer ice crystals in size category 1 at both intervals when compared to T3 ($P < 0.05$; Table 5). Stabilizers are added to ice cream mix to resist recrystallization during temperature fluctuations throughout storage (Keeney and Kroger, 1974; Sharma, 1981), also ice cream made with added stabilizer has smaller ice crystals before and after storage (Caldwell et al., 1992; Goff et al., 1993).

Sensory Evaluation of Ice Cream

Sensory evaluation scores for ice cream treatments are listed in Tables 6 and 7. Differences ($P < 0.05$) were seen among treatments for vanilla flavor intensity at 10 d postmanufacture, with T3, T4, and T6 having the highest scores; however, no differences ($P > 0.05$) were observed among treatments at 18 wk postmanufacture. The overall flavor acceptability scores were similar ($P > 0.05$) at 10 d; however, differences ($P < 0.05$) were seen upon evaluation at 18 wk, with T3, T4, and T6 having better scores.

Treatment 3, T4, and T6 had higher scores for icy, coldness intensity, and creaminess ($P < 0.05$) than T1, T2, and T5 at both 10 d and 18 wk postmanufacture. Panelists found T3, T4, and T6 to have the higher scores for overall texture acceptability at 10 d postmanufacture than T1, T2, and T5. Overall texture acceptability at 18 wk showed no differences ($P > 0.05$) between T3, T4, and T6; however, T3, T4, and T6 had better than average scores ($P < 0.05$) than T1, T2, and T5. The profound differences in texture as determined from sensory evaluation are largely the result of stabilizer addition to T3, T4, and T6 and the lack of stabilizer in T1, T2, and T5.

Treatment 4 had a lower mean ice crystal size ($P < 0.05$) than T3 at 10 d postmanufacture (Table 4), but sensory evaluation showed no difference ($P > 0.05$) between T3 and T4 for overall texture acceptability (Tables 6 and 7). At 18 wk postmanufacture T6 showed a lower ($P < 0.05$) mean ice crystal size compared with T3 (Table 4), but sensory evaluation did not distinguish ($P > 0.05$) between T3 and T6 (Tables 6 and 7). Although the same general trends are seen between ice crystal measurements and sensory evaluation, these two methods are actually making slightly different comparisons. Direct count of ice crystals is an excellent way to objectively quantify the texture of ice cream; however, it does not consider all aspects of sensory perception. Sensory evaluation on the texture of ice cream takes into consideration the lubricating effect of fat as it melts on the pallet (Marshall and Arbuckle, 1996), the distribution and volume of air cells (Arbuckle, 1986), change in perception by stabilizers (Moore and Shoemaker, 1981; Bu-yong and Fennema, 1988) and other factors in addition to ice crystal size and distribution. One can deduce that the use of stabilizer and to a lesser degree double homogenization affect the texture of ice cream as deter-

Table 7. Flavor and texture scores¹ of ice cream at 18 wk postmanufacture.

Treatment ²	Vanilla flavor intensity ³	Overall flavor acceptability ³	Icy ⁴	Coldness intensity ⁴	Creaminess ³	Overall texture acceptability ³
T1	7.0	7.0 ^{bc}	5.2 ^b	5.0 ^b	5.3 ^b	5.2 ^b
T2	6.9	6.9 ^c	4.6 ^b	4.6 ^b	4.9 ^b	4.6 ^b
T3	7.2	7.5 ^a	6.6 ^a	6.4 ^a	6.7 ^a	6.6 ^a
T4	7.3	7.4 ^{ab}	6.4 ^a	6.5 ^a	6.6 ^a	6.5 ^a
T5	6.6	6.6 ^c	4.6 ^b	4.5 ^b	4.8 ^b	4.6 ^b
T6	7.3	7.5 ^a	6.3 ^a	6.2 ^a	6.5 ^a	6.4 ^a

^{a,b,c}Means in the same column without common superscripts differ ($P < 0.05$). Means in the same column without superscripts do not differ ($P > 0.05$).

¹Mean of five replicates.

²Treatments: T1 = No stabilizer added; T2 = no stabilizer added, double homogenized; T3 = control; T4 = double homogenized; T5 = no stabilizer added, double homogenized, 1% whey protein concentrate substituted for 1% NDM; T6 = double homogenized, 1% whey protein concentrate substituted for 1% NDM.

³1 = Poor, 5 = average, 9 = excellent.

⁴1 = Extreme defect, 5 = definite defect, 9 = no defect.

mined by mean ice crystal size and ice crystal distribution, but these differences may become blurred when evaluation is done by sensory perception due to the multitude of factors involved in this process.

CONCLUSIONS

The use of stabilizer in ice cream mix increased flow time. Double homogenization lowered ice cream mix flow time in the presence of stabilizer but not in the absence of stabilizer. One percent WPC substituted for 1% NDM in ice cream mix had no effect on mix flow time. The process of double homogenization with the addition of stabilizer lowered the mean ice crystal size of ice cream in some treatments; however, sensory evaluation found no difference between ice cream that had been double homogenized and the control. Also, no improvement in texture was seen by double homogenizing ice cream mix without added stabilizer. One percent WPC substituted for 1% NDM in ice cream mix did not improve texture of ice cream. Generally, the percentage of ice crystals under 45 μm decreased and the percentage of ice crystals over 106 μm increased between storage for 10 d and 18 wk, portraying the recrystallization process and the increase in icy defect of ice cream over time. Ice cream mix that was processed by double homogenization had a higher percentage of ice crystals under 45 μm and a lower percentage of ice crystals over 106 μm at both periods than did the control. Less growth of ice crystals was seen in the texture of ice cream that had added stabilizer at both 10 days and 18 wk of storage.

REFERENCES

Arbuckle, W. S. 1986. Pages 40, 187, 207–212, 317–322, 365 in *Ice Cream*. 4th ed. AVI Publ. Co., Westport, CT.

- Atherton, V. H., and J. A. Newlander. 1977. Pages 105–114, 142–143 in *Chemistry and Testing of Dairy Products*. 4th ed. AVI Publ. Co., Inc., Westport, CT.
- Baer, R. J., and T. P. Czmowski. 1985. Use of the osmometer for quality control of ice cream mix. *J. Dairy Sci.* 48:976–978.
- Baer, R. J., N. Krishnaswamy, and K. M. Kasperson. 1999. Effect of emulsifiers and food gum on nonfat ice cream. *J. Dairy Sci.* 82:1416–1424.
- Berger, K. G. 1997. Ice cream. Pages 413–490 in *Food Emulsions*. 3rd ed. S. E. Friberg and K. Larsson, ed. Marcel Dekker, Inc., New York.
- Berger, K. G., and G. W. White. 1979. Ice cream. Pages 499–530 in *Food Emulsions*. S. Friberg, ed. Marcel Dekker, Inc., New York.
- Buyong, N., and O. Fennema. 1988. Amount and size of ice crystals in frozen samples as influenced by hydrocolloids. *J. Dairy Sci.* 71:2630–2639.
- Caldwell, K. B., H. D. Goff, and D. W. Stanley. 1992. A low-temperature scanning electron microscopy study of ice cream. II. Influence of selected ingredients and processes. *Food Struct.* 11:11–23.
- Donhowe, D. P., R. W. Hartel, and R. L. Bradley, Jr. 1991. Determination of ice crystal size distributions in frozen desserts. *J. Dairy Sci.* 74:3334–3344.
- Flores, A. A., and H. D. Goff. 1999. Ice crystal distributions in dynamically frozen model solutions and ice cream as affected by stabilizers. *J. Dairy Sci.* 82:1399–1407.
- Goff, H. D. 1988. Emulsifiers in ice cream: How do they work? *Modern Dairy* 67(3):15–18.
- Goff, H. D. 1997. Instability and partial coalescence in whippable dairy emulsions. *J. Dairy Sci.* 80:2620–2630.
- Goff, H. D., K. B. Caldwell, D. W. Stanley, and T. J. Maurice. 1993. The influence of polysaccharides on the glass transition in frozen sucrose solutions and ice cream. *J. Dairy Sci.* 76:1268–1277.
- Goff, H. D., J. E. Kinsella, and W. K. Jordan. 1989. Influence of various milk protein isolates on ice cream emulsion stability. *J. Dairy Sci.* 72:385–397.
- Hagiwara, T., and R. W. Hartel. 1996. Effect of sweetener, stabilizer, and storage temperature on ice recrystallization in ice cream. *J. Dairy Sci.* 79:735–744.
- Hartel, R. W. 1996. Ice crystallization during the manufacture of ice cream. *Trends Food Sci.* 7:315–321.
- Hof, M., A. Fayed, Z. El-Awamry, and A. Hof. 1993. Substitution of non fat milk solids in ice cream with ultrafiltration whey protein concentrate. *Egyptian J. Food Sci.* 21:2, 139–145. CAB Abstracts, 940405053.
- Keeney, P. G. 1979. Confusion over heat shock. *Food Eng.* 51(6):116–118.
- Keeney, P. G., and M. Kroger. 1974. Frozen dairy products. Pages 879–913 in *Fundamentals of Dairy Chemistry*. 2nd ed. B. H.

- Webb, A. H. Johnson, and J. A. Alford, ed. The AVI Publ. Co., Inc., Westport, CT.
- Kosikowski, F. V., and V. V. Mistry. 1997. Page 9 in *Cheese and Fermented Milk Foods: Procedures and Analysis*. Vol. II. 3rd ed. F. V. Kosikowski, L. L. C., Westport, CT.
- Larmond, E. 1977. *Laboratory Methods for Sensory Evaluation of Food*. Agric. Can. Publ. No. 1637. Canada Dept. Agric., Ottawa, ON, Canada.
- Leviton, A., and M. J. Pallansch. 1959. Continuous recycling in the homogenization of relatively small samples. *J. Dairy Sci.* 42:20–27.
- Mangino, M. E. 1992. Properties of whey protein concentrates. Pages 221–270 in *Whey and Lactose Processing*. J. G. Zadow, ed. Elsevier Science Publ., Ltd., New York.
- Marshall, R. T. ed. 1992. Pages 251–252 in *Standard Methods for the Examination of Dairy Products*. 16th ed. Am. Public Health Assoc., Inc., Washington, DC.
- Marshall, R. T., and W. S. Arbuckle. 1996. Pages 59, 151–185, 263–267, 319 in *Ice Cream*. 5th ed. International Thomson Publ., New York.
- Miller-Livney, T., and R. W. Hartel. 1997. Ice recrystallization in ice cream: Interactions between sweeteners and stabilizers. *J. Dairy Sci.* 80:447–456.
- Moore, L. J., and C. F. Shoemaker. 1981. Sensory textural properties of stabilized ice cream. *J. Food Sci.* 46:399–402, 409.
- Morr, C. V. 1989. Beneficial and adverse effects of water-protein interactions in selected dairy products. *J. Dairy Sci.* 72:575–580.
- Parsons, J. G., S. T. Dybing, D. S. Coder, K. S. Spurgeon, and S. W. Seas. 1985. Acceptability of ice cream made with processed wheys and sodium caseinate. *J. Dairy Sci.* 68:2880–2885.
- SAS User's Guide: Statistics, Version 6.0 Edition. 1990. SAS Inst., Inc., Cary, NC.
- Schmidt, K. A., and D. E. Smith. 1989. Effects of varying homogenization pressure on the physical properties of vanilla ice cream. *J. Dairy Sci.* 72:378–384.
- Sharma, S. C. 1981. Gums and hydrocolloids in oil-water emulsions. *Food Technol.* 35(1):59–67.
- Sienkiewicz, T., and C.-L. Riedel. 1990. Pages 86–91 in *Whey and Whey Utilization*. 2nd ed. Verlag Th. Mann, Gelsenkirchen-Buer, Germany.
- Sutton, B., and J. Bracey. 1996. The blast factor. *Dairy Ind. Int.* 61(2):31, 33.
- Tirumalesha, A., and H. M. Jayaprakasha. 1998. Effect of admixture of spray dried whey protein concentrate and butter milk powder on physico-chemical and sensory characteristics of ice cream. *Indian J. Dairy Sci.* 51:13–19.
- Zayas, J. F. 1997. Pages 104–109, 276–278, 337–340 in *Functionality of Proteins in Food*. Springer-Verlag, Berlin, Germany.