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Stabilizer Usage has Greater Impact on Ice Cream Properties than High Hydrostatic Pressure

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Abstract: Effects of high hydrostatic pressure (HHP) on the viscosity of ice cream mix and overrun, microstructure and sensory quality of ice cream with and without stabilizer were investigated. Ice cream mixes were prepared and aged 1, 4 or 8 hr. After aging, either 0, 100, or 300 MPa HHP were applied to the mix for 30 sec. Ice cream was packaged in pint (473 mL) containers and stored at −30°C. Treatments of 300 MPa increased viscosity of ice cream mixes, and mixes without stabilizer never reached viscosity levels of mixes with stabilizer, regardless of HHP treatment level. Under scanning electron microscopy, ice cream containing stabilizer exhibited a smooth, continuous serum phase, but ice cream without stabilizer contained a high number of tiny pores. Ice cream without stabilizer exhibited fat globules that were more randomly distributed, less agglomerated, and less uniform in size and shape than ice cream with stabilizer. Sensory evaluation revealed that ice cream containing stabilizer was more greasy, more gummy, more fluffy, less cold, less crumbly, less heavy and less coarse than ice cream lacking stabilizer. Ice cream mix treated with HHP produced and ice cream that was more crumbly than ice cream mix not treated with HHP. It was concluded that HHP affected stabilizers and milk proteins, which influenced mix viscosity, but HHP did not profoundly alter ice cream overrun, microstructure, or sensory quality. The presence or absence of stabilizer had a greater impact on ice cream properties, and under the conditions studied, HHP should not be used to replace stabilizers. Although HHP was neither beneficial nor detrimental to ice cream quality, further study to determine HHP effects on individual ice cream components is warranted.

Key-words: Ice cream, high hydrostatic pressure, stabilizer, electron microscopy, sensory

Introduction

Ice cream is a complex food system produced by freezing, while whipping, a pasteurized mix consisting of one or more dairy ingredients, sweeteners and flavors. Acceptable ice cream can be made without stabilizers and emulsifiers, but a variety of stabilizers and emulsifiers are typically incorporated into ice cream to improve whipping, regulate ice crystal growth, promote a dry smooth texture, and improve melt down resistance (Marshall and Arbuckle, 1996 and Hasenhuettl and Hartel, 1997). One of the properties that stabilizers influence is viscosity. There is little agreement on a good mix viscosity value, but in general, as mix viscosity increases, the smoothness, retention of air in ice cream and resistance of ice cream to melting increase and whipping rate decreases (Marshall and Arbuckle, 1996). Ice cream mix viscosity is influenced by mix composition, processing and handling, and typically ranges from 50 to 300 cP (Hagiwara and Hartel, 1996; Marshall and Arbuckle, 1996). Like stabilizers, emulsifiers tend to contribute a smooth texture and resistance to melting, but they also improve whipping quality by reducing whipping time (Baer *et al.*, 1997). Emulsifiers create a stable emulsion in ice cream by adsorbing to fat globules and improving dispersion of fat and thus control fat agglomeration.

After ice cream mix is formulated, it is pasteurized and homogenized, then quickly cooled to 4°C and typically aged for 4 to 48 hr. Aging time is variable and depends on mix composition, particularly the type of stabilizer or emulsifier used. During aging, fat partially solidifies, proteins and emulsifiers adsorb to fat globules, viscosity increases and stabilizers bind with water. Aging improves whipping, freezing, meltdown, body and texture properties (Im and Marshall, 1998). Mix aging requires time and refrigeration energy, so reduction of aging could have financial implications.

During freezing, sensible heat is first removed from the ice cream mix, then latent heat is removed as tiny ice crystals form, and a viscous foam, stabilized by fat, protein and emulsifiers, is produced. Overrun, the increase in ice cream volume over mix volume due to air incorporation, can be manually controlled, typically between 40 to 100% in a continuous freezing process, but is constrained to smaller values in batch freezers, since the freezing cylinder is held at atmospheric pressure (Marshall and Arbuckle, 1996). Overrun must not be excessive, as it is limited by regulatory designation that ice cream weigh not less than 2.04 kg gal^{-1} and contain at least 0.73 kg of food solids/gal (Marshall and Arbuckle, 1996).

The importance of texture in foods can not be overstated. While flavor may come to mind as the most important food characteristic, a food will likely be rejected if the texture does not meet expectations (Holcomb, 1991). Ice cream is not exempt from textural criticisms. For instance, the presence of ice crystals of diameter greater than 40 μm and lactose crystals longer than 16 μm lead to coarse and sandy defects, respectively (Kalab, 1985). Scanning electron microscopy (SEM) is one method that has been successfully used to observe and correlate dairy foods microstructure with physical properties (Kalab, 1979; Kalab, 1985; Brooker, 1988; Holcomb, 1991 and Caldwell *et al.*, 1992). SEM uses scattered electrons, reflected from the illuminated specimen to examine the specimen (Kalab, 1979). Brooker (1988) and Caldwell *et al.* (1992) utilized low-temperature scanning electron microscopy to observe ice cream microstructure in the fully-hydrated state. Micrographs of ice cream revealed a four-phase structure containing rectangular ice crystals (up to 40 μm), spherical and smooth air cells (ranging from 10 to 60 μm) commonly surrounded by spherical fat globules (of 0.5 to 1.5 μm), and a continuous serum phase (Caldwell *et al.*, 1992). Microstructure of dairy foods has been correlated to physical properties of the respective foods (Kalab, 1979). Arbuckle (1950) showed that emulsifiers help produce smaller air cells and smaller ice crystals, which prevent coarse/icy defects. Additionally, overrun exhibits an inverse relationship with ice crystal and air cell size (Marshall and Arbuckle, 1996). It follows then, that changes in ice cream mix formulation and processing will impact not only microstructure but also physical properties of ice cream.

One processing technique that has received considerable attention during recent years, is high hydrostatic pressure (HHP) and its potential use in a variety of food science applications. Numerous studies have been done on different kinds of food including dairy products. Early papers on HHP primarily dealt with inactivation of microorganisms and food safety (Hoover, 1993; Knorr, 1993; Lechowich, 1993; Metrick *et al.*, 1989 and Styles *et al.*, 1991), but more recently, HHP is being considered as a method to improve functionality of ingredients or as a tool to improve or control food quality (Meyer, 2000; Pothakamury *et al.*, 1995; Yang *et al.*, 2001 and Yang *et al.*, 2003). For several optical and rheological properties of milk, Desobry-Banon *et al.* (1994) observed three stages of HHP effects. Between 0 and 230 MPa few effects were noted, between 230 and 430 MPa most changes occurred, and between 430 and 700 MPa stabilization occurred (Desobry-Banon *et al.*, 1994). In other studies, HHP treatments between 300 and 600 MPa improved the microbiological quality and coagulation characteristics of milk, and increased cheese yield and moisture retention, with minimal modification of other properties important for cheesemaking (Lopez-Fandino, 1996 and Drake *et al.*, 1997).

The effect of HHP on ice cream mix and ice cream has not been reported. This research was conceived with hopes to replace stabilizers or aging of ice cream mix with HHP to improve body and texture of the finished ice cream. The objective of the present work was to observe the effect of HHP upon ice cream mix viscosity and ice cream overrun, microstructure, and sensory quality.

Materials and Methods

Ice Cream Manufacture and Sample Preparation

Mix composition and ingredients: Two ice cream mixes, with the composition given in Table 1, were prepared at the Washington State University Creamery. Milk (3.7% fat), cream (40% fat), milk solids non fat (Dairy-X Lo heat non fat dry milk, Darigold, Seattle, WA), sucrose, 42 DE corn solids sweetener (FRODEX, manufactured by CERESTAR USA Inc., Hammond, IN) and vanilla (pure vanilla-vanillin extract 4 fold, Edgar A. Weber & Company, Wheeling, IL) were used as ingredients. Mixes were the same except that Mix A contained a commercial stabilizer/emulsifier blend, while Mix B did not. For the mix containing the commercial stabilizer/emulsifier blend, 0.26% Aristocrat stabilizer I.C. (Bunge Foods, Atlanta, GA) was added. Arsitocrat stabilizer/emulsifier blend called "stabilizer" within the remainder of this text, is composed of mono and diglycerides, locust bean gum, guar gum, calcium sulfate, polysorbate 80, carrageenan and cellulose gum.

Processing: Ice cream mixes A and B were made using the same ingredients (except for stabilizer), one day apart, and treated in the same fashion throughout the experiment (Fig. 1). Each mix was divided into three lots that were aged 1, 4, and 8 hr prior to further processing. During aging, mix was maintained at 4.4°C.

After the appropriate aging period, mix was divided into three portions. One portion did not receive high hydrostatic pressure (HHP) treatment and served as a control batch. Portions of ice cream mix were weighed into separate Lay-Flat Poly Tubing (Consolidated Plastics Company, Inc., Twinsburg, OH), 15 cm wide, 4 mil thick, cut to the desired lengeh for 1,500 mL mix, and heat sealed at the ends. Three bags of mix were treated with HHP at 100 MPa, and three bags were treated with 300 MPa, one bag at a time. High pressure treatments were done in a isostatic laboratory scale pressure vessel (Engineered Pressure Systems, Inc., Andover, MA) with a cylindrical pressure chamber (height = 0.25 m, dia = 0.10 m) at ambient temperature, and pressures were held for 30 sec. After HHP treatment, the three bags of a given pressure treatment were recombined prior to freezing. Because of the size of the ice cream freezer, three freezing runs were required, one after the other. Fifteen-hundred grams

Table 1: Composition of experimental ice cream A (containing stabilizer) and B (containing no stabilizer)

Component	Ice cream A (%)	Ice cream B (%)
Fat	11.7	11.7
Total solids	38.0	37.7
Milk solids non fat	12.0	12.0
Sugar from sucrose	12.0	12.0
Sugar from Frodex	2.0	2.0
Stabilizer blend	0.3	0.0

Table 2: Mean ice cream sensory scores[d] for attributes affected by high hydrostatic pressure (0, 100 or 300 MPa HHP) or stabilizer

	Mean Snesory Score (attributes rated 1 to 6)						
	Coarse	Fluffy	Greasy	Crumbly	Gummy	Cold	Heavy
HHP (MPa)							
0	2.06[a]	1.77[ab]	1.70[a]	1.86[a]	2.29[a]	3.20[a]	3.05[a]
100	2.10[a]	1.84[a]	1.72[a]	2.09[b]	2.20[a]	3.21[a]	3.05[a]
300	2.06[a]	1.69[b]	1.86[b]	2.40[c]	1.94[b]	3.19[a]	3.11[a]
Stabilizer							
With Stabilizer	2.17[a]	1.63[a]	1.63[a]	2.37[a]	1.83[a]	3.34[a]	3.24[a]
Without Stabilizer	1.98[b]	1.90[b]	1.89[b]	1.86[b]	2.46[b]	3.06[b]	2.91[b]

[a], [b] = numbers in the same column with different superscripts, within a category, are significantly different ($p < 0.050$).

[d] Data were obtained from 12 trained judges, mean of four months data (1 = lowest intensity, 6 = highest intensity).

of ice cream mix were frozen in a Taylor batch freezer (number 103-12, Rochton, IL) for 8 min. After freezing, ice cream was collected into one pint (473 mL) containers and put into a freezer at −30°C for storage.

Physical properties analysis

Viscosity: The viscosity of each ice cream mix was assayed in triplicate at 5°C ± 1°C, 30 RPM rotational speed, with a number 1 spindle, using a Viscometer (model LV-DVII, Brookfield Engineering Laboratories Inc., Stoughton, MA.). However, for the most viscous mix, mix with stabilizer and treated with 300 MPa, a number 2 spindle was used.

Overrun: The overrun of every batch of ice cream was determined in triplicate, by weighing equivalent volumes (300 mL) of mix and subsequent ice cream at draw, using the equation below:

$$\frac{\text{Weight of ice cream mix - weight of ice cream}}{\text{Weight of ice cream}} * 100\% \text{ overrun}$$

Microstructure analysis: Ice cream microstructure was observed with scanning electron microscopy (SEM). Ice cream samples were allowed to temper in a house-hold freezer for one day before testing. The upper layer of ice cream was scraped off and discarded prior to scooping. Ice cream was scooped into 150 mL beakers and freeze-dried overnight (Freezemobile 24, The VirTis Company, Inc, Gardiner, NY). Freeze dried ice cream samples were fractured using a razor blade, and mounted on studs. Samples were gold coated (300 ?m) in a sputter coater (Technics, San Jose, CA). Gold-coated ice cream samples were observed in a scanning electron microscope (S-570, Hitachi, Corp, Tokyo, Japan) at an acceleration voltage of 10 kV. Representative SEM pictures were taken.

Sensory evaluation: Twelve panelists (WSU students, faculty and staff) were selected to participate in sensory analysis of the ice cream. Four one-hour training sessions were conducted to familiarize panelists with the ten attributes selected for evaluating appearance, body and texture of ice cream. Attributes evaluated included: crumbly, gummy, heavy/soggy, weak, cold, coarse/icy, fluffy, greasy, and sandy.

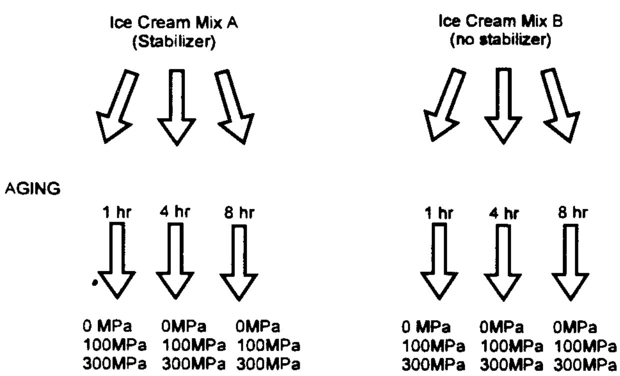

Fig. 1: Experimental scheme followed for treatment of ice cream mix with aging (hr) and high hydrostatic pressure (HHP) prior to freezing

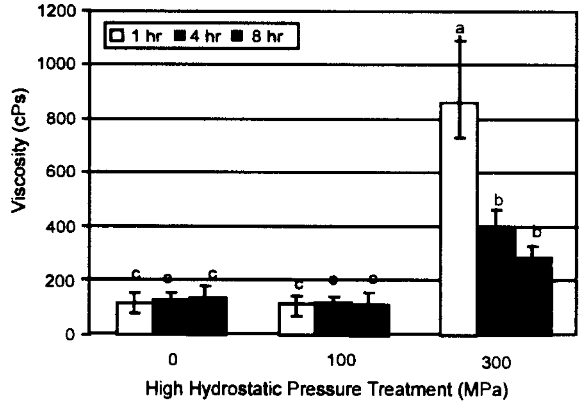

Fig. 2: Viscosity (cPS) of ice cream mix containing stabilizer, treated with high hydrostatic pressure (0, 100, 300 Mpa) aged 1, 4 or 8 hr. (Different letters on columns indicate significant differences exist, P<0.05)

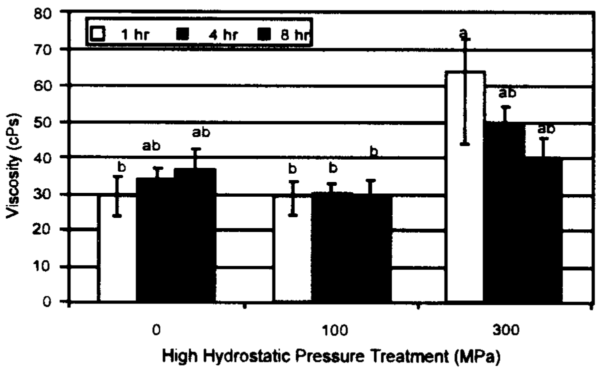

Fig. 3: Viscosity (cPs) of ice cream mix not containing stabilizer, treated with high hydrostatic pressure (0, 100, 300 Mpa) aged 1, 4 or 8 hr. (Different letters on columns indicate significant differences exit, P<0.05)

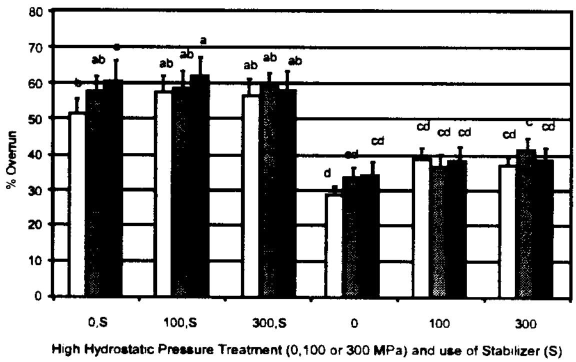

Fig. 4: Overrum (%) of ice cream made from mix containing or not containing stabilizer, treated with high hydrostatic pressure (0, 10, 300 Mpa) aged 1, 4 or 8hr. (Different letters on columns indicate significant differences exit, P<0.05)

Training proceeded as: Day 1. Panelists tasted different brands of ice cream, selected for a variety of quality attributes. The attributes were defined for panelists while tasting.

Day 2. Additional products were tasted and terms were defined more clearly. The ballot anchors for the ends of each scale, 1 being lowest intensity and 6 being highest intensity, were set to fit panelist definitions.

Day 3. Ballots were tested by panelists in private booths with unknown representative samples.

Day 4. Tasting session results and panelists deviations were discussed, and specific terms were clarified. Official product testing began the week following training.

Trained panelists evaluated products on two separate days (to minimize fatigue), once each month, for four months. Ice cream samples were tempered in a household freezer (−15°C) overnight prior to scooping. The upper layer of each ice cream was scraped off and discarded prior to scooping into containers labeled with random three-digit codes (Snedecor and Cochran, 1989), then returned to the household freezer. Samples were presented

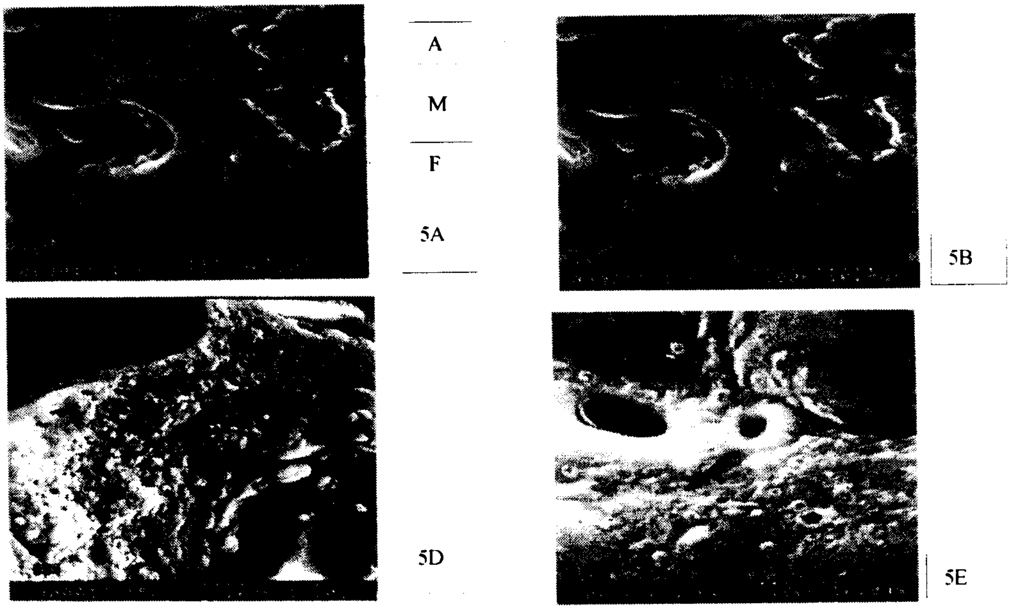

Fig. 5: Scanning electron micrographs of ice cream made from mix containing stabilizer (S) (5A) containing S, treated with 300 Mpa HHP (5D), containing no S (3B) containing S, treated with 300 Mpa HHP (5D), indicating fat globules (F), air (A) and serum (M)

randomly, evaluated one at a time, in counterbalanced order, in private booths. Water at room temperature and saltine crackers were provided for panelists to cleanse their palates between each ice cream.

Statistical analysis: Viscosity and overrun data were analyzed using Analysis of Variance (ANOVA) with Minitab Release 8 (1991). The significance level was established at $P \leq 0.05$. When the ANOVA was significant, the least significant difference method using Fishers individual error rate was used to separate treatment means.
For sensory analysis, the experimental design was a randomized complete block (panelists) with a three-way treatment structure (stabilizer, aging time and MPa). SAS Statistical software (SAS/STAT, 1989) was used for sensory data analysis. The significance level was established at $P \leq 0.05$. When the ANOVA was significant, the least significant difference method using Fishers individual error rate was used to separate treatment means.

Results and Discussion

Viscosity: When the stabilizer blend was incorporated into ice cream mix, mix viscosity was approximately 300% higher than mixes with no stabilizer (Figs. 2 and 3). The finding was not surprising, since stabilizers are known to bind water and increase viscosity (Hagiwara and Hartel, 1996 and Baer *et al.*, 1997). Hagiwara and Hartel (1996) reported ice cream mix viscosity values of 23 to 58 cP for unstabilized ice cream mixes and 579 to 687 cP for stabilized ice cream mixes. The higher viscosity values in the previous work may be best explained by the higher sweetener solids in the mix, 16.5%, versus 14% in the present work. An increase in viscosity due to aging was expected, due to adsorption of proteins and emulsifiers to fat globules, and hydration of proteins and stabilizers during aging (Marshall and Arbuckle, 1996). However, while mix viscosity increased with aging when no HHP was applied, the differences were not significant (Figs. 2 and 3).
Changes in viscosity with HHP (Figs. 2 and 3) were more profound in mix containing stabilizer (up to 600% increases) than in mix without stabilizer (up to 110% increases), suggesting that either stabilizers were directly affected by HHP or interactions among stabilizers, emulsifiers and other mix components were affected by HHP. Additionally, the fact that HHP had an impact on mixes with and without stabilizer indicates that HHP altered a componenent present in both mixes, such as caseins and/or whey proteins. With pressure greater than 200 MPa (Lopez-Fandino *et al.*, 1996) or 300 MPa (Felipe *et al.*, 1997), mean casein micelle size decreases and micelles

disintegrate into chains or clusters of submicelles, which can enhance viscosity. The smaller casein micelles form finer protein matrices than native micelles, which results in improved water holding capacity (Needs *et al.*, 2000 and Harte *et al.*, 2002). Additionally, HHP above 200 or 300 MPa causes partial or full denaturation of the primary whey protein, beta-lactoglobulin (β-LG), while bovine serum albumin and α-lactalbumin appear to be resistant to denaturation by HHP at ≤ 400 MPa for 60 min (Lopez-Fandino *et al.*, 1996 and Felipe *et al.*, 1997). At higher pressures, β-LG denaturation or unfolding of monomers, enhanced hydrophobicity, and aggregation occur (Pittia *et al.*, 1996). Kinetic studies by Kelly *et al.* (2002) and Harte *et al* (2002) showed that holding time of pressurization had a greater effect on β-LG denaturation than casein micelle disruption, which was maximum at pressures higher than 300 MPa.

When protein polymers come into contact with fat, hydrophobic regions adsorb to fat surfaces, while hydrophilic regions extend into the serum, thus enabling proteins to act as emulsifiers (Goff *et al.*, 1989). β-LG in the molten globule state, induced by HHP, exhibits enhanced hydrophobicity, suggesting that binding sites are more accessible in the molten globule state than in the native state of β -LG (Yang *et al.*, 2003). Since HHP ehnaces hydrophobicity, enhanced absorption and increased viscosity are expected.

Viscosity of mixes treated with HHP remained nearly the same (100 MPa) or increased (300 MPa) compared to control. The viscosity of skim milk responded to pressure treatments similarly as reported for ice cream mix in the present work (Desobry-Banon *et al.*, 1994). At pressures between 0 to 230 MPa little change in viscosity was observed, between 230 to 430 MPa a rise in viscosity was observed, and between 430 and 700 MPa stabilization of viscosity was attained (Desobry-Banon *et al.*, 1994). The increase in viscosity between 230 and 430 MPa can be accounted for by disintegration and reduction in size of casein particles, resulting in a rise in the fraction of casein particles in the total volume (Desobry-Banon *et al.*, 1994). At low protein concentrations and pressures up to nearly 300 MPa, pressure-induced denaturation of β-LG tends to be reversible, but at pressures above 300 MPa, more extensive, non-reversible effects result (Pittia *et al.*, 1996). This may explain, in part, why more profound changes were observed at 300 MPa than 100 MPa.

In the present study, with increased aging time prior to HHP, the viscosity of mixes increased to a lesser extent (Figs. 2 and 3). Specifically, after 300 MPa treatment of ice cream mix aged 1 hr, a 600% and 110% increase in viscosity was observed compared to the untreated mix with or without stabilizer, respectively. After 4 and 8 hr aging, the viscosities of mixes treated with 300 MPa also increased compared to the untreated mix, but to a lower degree. A 220% and 65% increase in viscosity were observed in mixes aged 4 hr treated with 300 MPa with and without stabilizer, respectively. A 140% and 30% increase in viscosity were observed in mixes aged 8 hr treated with 300 MPa with and without stabilizer, respectively. The reduced impact of HHP upon viscosity after aging is interesting and worth further investigation. Since aging results in an ordered matrix of fat globules surrounded by proteins and emulsifiers (Marshall and Arbuckle, 1996), it is possible that after 8 hr aging, 300 MPa partially disrupted the orderly ice cream mix matrix that had formed during aging, resulting in smaller increases in viscosity after HHP.

Overrun: Overrun is inversely related to both ice crystal size and air cell size, thus higher overrun may be associated with higher quality ice cream, as long as mix viscosity is adequate to stabilize the foam and air cell linings do not get too thin (Marshall and Arbuckle, 1996). In the present study, all ice cream containing stabilizer, whether treated with HHP or not, exhibited significantly higher overrun than ice cream that did not contain stabilizer (Table 4), which is not surprising since stabilizers and emulsifiers are known to enhance whipping properties (Marshall and Arbuckle, 1996 and Baer *et al.*, 1997). Overrun of ice cream made from mixes not treated with HHP increased about 11 to 17% after 4 hr of mix aging, and an additional 4 to 5% after 8 hr of mix aging, indicating that aging alone increased overrun of the ice cream with or without stabilizer. Again, this was expected since during aging, proteins and emulsifiers adsorb to the milk fat globule membrane and proteins and stabilizers hydrate, thus improving whipping properties (Marshall and Arbuckle, 1996).

Overrun values for ice cream made from mixes treated with HHP were not significantly higher than ice cream made from corresponding untreated mixes aged 1, 4 or 8 hr. Since viscosity values of mixes were significantly increased by HHP, it was expected that corresponding overrun values would concomitantly increase as well. The fact that they did not, may suggest that significant differences in viscosity do not always translate to significant differences in overrun. On the other hand, since the whipping time (8 min) was not altered for different treatments, it is possible that maximum overrun was not attained for some of the samples. Previous research (Adapa *et al.*, 2000) has shown that overrun of ice cream peaks at a certain point, decreases, then levels off; thus, significant differences in overrun may be found at one time (e.g. 4 min) but not at others (e.g. 8 min). It is possible that the protein structural changes modified their ability to entrap air, but future research will have to be conducted to investigate the specific effects of HHP upon mix whipping time.

Microstructure: In Fig. 5, the micrograph labeled 5A represents ice cream made from mix which contained stabilizer and was neither aged nor treated with HHP prior to freezing. The micrograph labeled 5D represents ice cream made from mix that did not contain stabilizer and was neither aged nor treated with HHP prior to freezing. Micrograph 5B is ice cream made from mix that contained stabilizer, which was frozen after 4 hr of aging and treated with 300 MPa of HHP. Micrograph 5E is ice cream that does not contain stabilizer and was frozen after 4 hr of aging and treated with 300 MPa of HHP.

The large round openings (A) seen in the micrographs represent air, with diameters of 5 to 300 μm. Fat globules (F) are the solid, round structures that range in size from 0.5 to 2 μm. The serum phase is labeled S. The samples wêre magnified 3,000X with the bars representing 10.0 μm. Our micrographs resembled micrographs of homogenized whipped cream (Schmidt and Hooydonk, 1980 and Kalab, 1985) and ice cream (Caldwell *et al.*, 1992). In ice cream micrographs, air cells, ice crystals, fat, and a continuous serum phase (containing dissolved and/or colloidal sugars, salts, proteins and stabilizers) were visible (Caldwell, *et al.*, 1992). Micrographs of whipped cream exhibited more fat globules adsorbed at the air-serum interfaces than in the cream. This is because more serum and less fat exist in ice cream than cream. In both ice cream and cream micrographs, fat globules partially protrude into air cells.

It is evident from the micrographs that physical differences exist between ice cream that contained stabilizer versus those which did not. All of the ice cream samples with stabilizer (for example 5A and 5B) had a smooth, continuous serum phase when observed at high magnification (3,000X). In contrast, all ice cream samples without stabilizer (5D and 5E) contained a high number of very small pores, contributing to a less continuous serum phase. The role of stabilizer is to bind free water in ice cream (Marshall and Arbuckle, 1996). Since stabilizers were not included in some ice cream (e.g. 5D and 5E), it is believed the tiny pores may be skeletons of small ice crystals (0.1 to 1.0 μm) removed by the freeze-drying process. Conversely, stabilizers led to a more homogenous serum in the ice cream with stabilizer. When observed at low magnification (300X, micrographs not shown), ice cream without stabilizer had an high proportion of intermediate-sized air cells (40 to 100 m), while the ice cream samples with stabilizer had a higher proportion of small air cells (up to 40 μm).

Another trend in the ice cream samples with stabilizer was a greater extent of fat globule agglomeration and lining of air cells. This is not entirely surprising, since one role of emulsifiers is to enhance fat agglomeration and reduce the size of air cells (Marshall and Arbuckle, 1996). Fat globules can be seen lining and protruding into the air sacs in micrographs 5A and 5B. In contrast, the ice cream corresponding to 5A but not containing stabilizer (5D) exhibited very few distinct fat globules. In general, the ice cream samples without stabilizer (5D and 5E) had fat globules that were more randomly distributed, less agglomerated, and less uniform in size and shape. Agglomeration also appeared to increase with aging for ice cream made with and without stabilizer (compare 5B and 5E to their respective counterparts 5A and 5D). These micrographs supported El-Rahman *et al.* (1997), who reported that emulsifiers increase agglomeration of fat. Shearing during freezing ruptures the fat globule membranes then the liquid fat flows out and agglomerates with other globules.

No large ice crystals or lactose crystals were noted by SEM. If ice cream had been stored for a longer period of time or temperature-shocked, crystals may have become notable. Mean crystal size does not increase significantly at −20°C, but at −5°C, mean crystal size may increase from 40 μm to 220 μm in just 5 days (Hagiwara and Hartel, 1996). Oscillating temperatures (+/- 1°C) also result in significantly higher recrystallization rate than constant temperature (+/- 0.01°C) (Hagiwara and Hartel, 1996).

Sensory Analysis: Mean scores of four months of data collected about ice cream sensory quality are summarized in Table 2. Although ice cream mix viscosity was enhanced by HHP treatment conditions selected, as with overrun, few meaningful changes in ice cream sensory attributes were found. Thus, only meaningful HHP and stabilizer effects are summarized in Table 2. When observing sensory data, it is important for the reader to remember that attributes correspond to important factors observed in treatments and the descriptors do not necessarily represent defects. The mean scores describing sensory attributes were small, ranging from 1 to 3.87, indicating low to mid-range intensities and only minor changes for all attributes studied.

The use of HHP at the selected conditions exhibited little effect on the improvement or degradation of ice cream quality, regardless of ice cream mix aging time. Sensory quality of ice cream was more profoundly affected by the presence or absence of stabilizer rather than by aging or HHP treatment. Ice cream that did not contain stabilizer were more crumbly, cold, coarse and heavy ($P \leq 0.05$) than ice cream containing stabilizer. Ice cream that contained stabilizer were more gummy, fluffy and greasy ($P \leq 0.05$) than ice cream that did not contain stabilizer. However, it is important to note that attribute values were small, and potentially not meaningfully different. Follow-up with consumers could elucidate if the ice cream differences rendered a given ice cream unacceptable to consumers, which would perhaps be more meaningful than descriptive data.

The most meaningful effects of HHP were seen in attributes crumbly and gummy. Specifically, ice cream from mixes treated with 300 MPa were more crumbly than ice cream from mixes treated with 100 MPa, which were also more crumbly than ice cream from untreated mixes ($P \leq 0.05$). Ice cream resulting from treatment with 300 MPa were more gummy than ice cream resulting from treatment with 0 or 100 MPa. Although statistically significant, implications of these differences may not be practically different due to the small scores (below 2.50) obtained in all cases.

After 4 mo of storage (data not shown), the mean scores for crumbly, cold and heavy attributes were significantly higher than the mean scores for the defects after 1 mo of storage, but mean scores were low and storage effects were not highly practical. This is likely due to the fact that ice cream were held at −30°C, without temperature fluctuations, which could have led to increases in coarse and sandy defects. These findings are in agreement with microstructural observations, where no lactose or large ice crystals were observed.

Since HHP is an expensive technology and these results do not indicate profound improvements in ice cream quality, investment of HHP equipment for ice cream processing facilities is not recommended at this time. However, research is underway to determine if HHP of select ingredients may improve ice cream quality. Particular interest is being paid to HHP treatment of β- lactoglobulin, whey protein concentrate, stabilizers and emulsifiers to improve body, texture and flavor of reduced fat ice cream. Future research will be done to look more closely at the effects that HHP has upon the specific ingredients in ice cream. Additionally, since these analyses were done on ice cream that was held under ideal −30°C conditions, temperature abuse tests will be conducted to asses the effectiveness of HHP for maintaning quality of abused ice cream.

Conclusion

Ice cream quality parameters including viscosity, overrun, microstructure and sensory analysis were influenced by the presence of stabilizer blend more than by aging or HHP treatment of ice cream mix. Ice cream mix containing stabilizer exhibited significantly greater viscosity, particularly after 300 MPa, and produced ice cream with greater overrun than mix that did not contain stabilizer. The impact of HHP upon stabilizers and proteins and resulting physical properties may be more profound prior to extensive aging of mixes. Although HHP at or above 300 MPa may enhance mix viscosity, the selected HHP or freezing conditions did not significantly alter microstructure, body or texture of ice cream. Incorporation of HHP technology to eliminate stabilizers or accelerate aging of ice cream mix is not recommended at this time.

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