Influence of Various Milk Protein Isolates on Ice Cream Emulsion Stability

ABSTRACT

The adsorption of protein to the fat globule surface in an emulsion such as ice cream mix has a large influence on the resulting emulsion stability and on the fat destabilization process that occurs upon whipping and freezing the mix into ice cream. The performance of several milk protein preparations in an ice cream system have been examined. Enhanced levels of whey proteins at the fat globule surface, arrived at through either a selective homogenization process or an enhancement of the whey protein:casein ratio in the mix by addition of whey protein concentrate (36% protein), contributed to a decrease in the lipid-serum interfacial tension, a slight increase in mix viscosity, an increase in ice cream dryness upon freezing, and an increase in the amount of fat destabilization in the frozen ice cream. However, 95% whey protein isolate contributed more to desirable properties in the ice cream mix and frozen product. Several caseinates were also examined and sodium caseinate contributed to enhanced overrun in the ice cream but resulted in an emulsion that was too stable to produce the desired degree of fat destabilization upon ice cream manufacture.

INTRODUCTION

Many food proteins are amphiphilic in nature, i.e., contain regions of hydrophobicity (11). As a result, food proteins play a major role in the stabilization of various food emulsions (7). This topic has been the subject of much investigation (9, 21). When protein polymers contact a fat interface, hydrophobic regions adsorb at the interface whereas more hydrophilic regions extend into the serum phase. The proportions of adsorbed segments and segment distribution perpendicular to the surface will determine the function of the polymer and the resulting emulsion stability (7). This is largely a function of the composition of the polymer. The time scale for rearrangement of the adsorbed polymer becomes critical and in ice cream is related to the aging time of the mix (6). The nonadsorbed regions will extend from the dispersed phase into the continuous phase and are known as hairy regions on the surface of the globule (9). Interactions between polymer groups and the surface of the particle, polymer polymer interactions, and polymer solvent interactions all play a role in emulsion stability. When two particles approach each other, interpenetration of segments from the different polymers occurs and compression also takes place if the distance is sufficiently small. Thus, the approach alters the free energy of the system. Depending on the relative importance of the vanderWaals attraction and steric repulsion forces, flocculation or stabilization will occur (7, 22).

In the ice cream mix, a variety of amphiphilic milk proteins exist, and these proteins play a major role in formation of the newly adsorbed membrane following homogenization (1, 2, 3, 16, 18). Oortwijn et al. (19) reported that both serum proteins and casein participate in forming membranes in recombined milk. This was supported by Darling and Butcher (3), who examined the membranes of homogenized fat globules in cream. Spreading of the casein micelles on the surface of the fat droplet can occur (10, 19). Also small molecule surfactants can displace protein from the surface of the fat globule.
globule (19). Oortwijn and Walstra (18) found the surface excess, the amount of protein adsorbed per surface area of fat in an emulsion (mg/m²), for recombined milk fat globules in skim milk to be 20 mg/m². However, the surface excess for casein micelles alone was 40 mg/m². When recombined milk fat globules were emulsified in a solution of whey proteins, the excess was reported as 1 mg/m². The surface excess was higher for smaller fat globules. They also reported that the casein particles were preferentially adsorbed over the serum proteins. Serum proteins have been reported to cover 25% of the globule surface but account for only 5% of membrane protein due to the different molecular conformations of the two classes of proteins (3, 23).

In an emulsion destined for destabilization, such as an ice cream mix emulsion, the proteins must lower the interfacial tension and adsorb at the interface and yet form a membrane capable of allowing partial coalescence during freezing, which implies a small surface excess (9). Based on the results of Oortwijn and Walstra (18), whey proteins are amphiphilic and have the ability to lower the surface excess over caseins. Thus the use of whey protein concentrates (WPC) in ice cream mix may lead to beneficial interfacial properties. The functional properties of WPC have been reviewed (4, 5, 12, 13, 14) with the basic conclusions being that the whey proteins are bland in flavor, have high nutritional value, have good emulsifying properties, undergo a heat-induced gelation and interaction with casein micelles, and have highly variable solubility and foaming based on heat treatment, isolation procedures, and pH.

The denaturation temperature of β-lactoglobulin, the primary serum protein, is about 70°C. Maximum heat stability is at pH 6.7 and minimum at pH 6.9 (5). deWit (4) reported that increases in the whey protein-casein ratio from .2, that ratio found in skim milk, to .4 led to a spreadable or squeezable texture, and increase to 1.0 led to a cuttable texture in a milk product due to the gelation properties of the whey proteins and their interactions with casein components.

The contradicting results, reported on the functional properties of the WPC result from the fact that the milk used in preparation may or may not have been pasteurized, and the UF or isolation procedure may result in a variable pH, which has a large influence on properties. As a result, both composition and functional properties of the WPC can change from one lot to the next, even with the same process employed (15).

Parsons et al. (20) investigated the acceptability of ice cream made with processed wheys and sodium caseinate as determined by organoleptic evaluation. They reported that sodium caseinate, even at very low levels, scored very poorly, but that WPC blends were not significantly different than an NDM control. Musselwhite and Walker (17) employed a novel technique to examine the control of protein buildup on the fat globule in an ice cream mix. By homogenizing the fat in the presence of only a portion of the milk solids, they were able to influence the adsorption by limiting the availability of adsorbing material. Limiting casein at the surface led to maximum fat destabilization. Standup or melt resistance of the frozen ice cream was best at medium ranges of fat destabilization.

Alteration of the adsorption process at the fat interface in the mix may result in beneficial properties to the structure and texture of the frozen ice cream. We think from prior work that one function of the emulsifier usually added to an ice cream mix is to control the adsorption of the amphiphilic proteins such that a weakly stable emulsion, one which will break down under shear, results (8). Several milk protein preparations, based on both serum proteins and caseins, have been examined in an ice cream mix in the absence of emulsifier for their emulsion stabilizing role as determined by interfacial tension values at the interface and fat destabilization during freezing. The objective was to arrive at an interfacial layer, which was capable of undergoing the proper amount of fat destabilization for resulting acceptable structure, texture, and flavor.

MATERIALS AND METHODS

Ingredient Description

The following milk protein powders were used in this experiment: low heat NDM, 36% protein (Land O' Lakes, MN); high heat NDM, 36% protein (Oatka Milk Products, NY); sweet

MILK PROTEINS IN ICE CREAM

whey powder, 10% protein (Land O’ Lakes, MN); WPC, 36% protein (Leprino Foods, Denver, CO); WPC, 75% protein (Kerry Foods, Chicago, IL); whey protein isolate (WPI), 95% protein (BiPro, LeSueur Isolates, LeSueur, MN); Kerrynor KH11 sodium caseinate, 95% protein; Kerrynor KO31 calcium caseinate, 95% protein; Kerrynor KO22 calcium plus sodium caseinate, 95% protein; and Kerrynor R190 rennet casein, 95% protein (Kerry Foods, Chicago, IL). Protein levels were confirmed to +1% by Kjeldahl analyses.

Experimental Procedure

Selective Homogenization. Following the lead of Musselwhite and Walker (17), we examined the mix viscosity, gloss, and fat destabilization resulting from a selective homogenization of the ingredients desired at the interface in the presence of the milk fat; other ingredients were added posthomogenization. A selective homogenization trial was performed with 75% WPC so as to keep the protein concentration during the homogenization step constant at 2.8% in each case. Ice cream mixes (10 kg) were prepared with the following composition: 10% milk fat from anhydrous milk fat (Mid American Dairymen, Springfield, MO), 7.4% NDM, 3.7% WPC, 10% sucrose, 5% corn syrup solids, and 64% water. Homogenization was conducted immediately following pasteurization (72°C/30 min) in a Gaulin (APV Gaulin, Everett, MA) two-stage homogenizer (17.2 MPa/3.4 MPa). The WPC and 10% of the water (to equal 36% solids in each fraction) were withheld from the homogenizer in one set of mixes and the NDM and 20% of the water were withheld from the homogenizer in the second set of mixes. The experiment was replicated four times. Viscosity was measured with a Brookfield LVF viscometer (Brookfield Engineering Labs, Stoughton, MA) at 30 rpm, spindle 1. The mixes were frozen in a Taylor (Taylor Freezers, Rockton, IL) batch freezer to −5°C with a 15-min whipping time. Gloss was measured with a Glossgard II 85° Glossmeter (Pacific Scientific Gardner Instrument Division, Silver Spring, MD) by drawing a 175-ml sample of ice cream from the barrel of the freezer into a metal dish, scraping the top level, and measuring gloss on the surface of the level ice cream. Fat destabilization was measured by spectroturbidity on a Bausch and Lomb Spectronic 21 (Fisher Scientific, Linden, NJ) at 540 nm using aliquots removed from the batch freezer every 2.5 min and diluted 1:500 with distilled water as reported earlier (8).

A selective homogenization experiment was also performed with 36% WPC. Ice cream mixes were made to the following composition: 10% milk fat using anhydrous milk fat, 5.5% NDM, 5.5% WPC, 10% sucrose, 5% corn syrup solids, and 64% water. The WPC and 16% of the water were withheld from the homogenizer in one set of mixes, the NDM and 16% of the water were withheld from the homogenizer in the second set of mixes, and a control mix homogenized in its entirety made up the third set of mixes. The protein content of the WPC and the NDM were approximately equal. Thus, 36% solids were in each fraction, and 2.4% protein was available to the fat globule in each case. The experiment was performed in quadruplicate.

Whey Protein Concentrate Trials. In a continuing examination of the relative importance of caseins and whey proteins in fat destabilization, we prepared mixes in which the proportions of the two fractions were progressively altered while homogenizing the whole mixes. The composition of the ice cream mixes were: 10% milk fat using anhydrous milk fat, 11% serum solids using NDM and 36% WPC, 10% sucrose, 5% corn syrup solids, and 64% water. Homogenization was conducted immediately following pasteurization (72°C/30 min) in a Gaulin (APV Gaulin, Everett, MA) two-stage homogenizer (17.2 MPa/3.4 MPa). The WPC and 10% of the water (to equal 36% solids in each fraction) were withheld from the homogenizer in one set of mixes and the NDM and 20% of the water were withheld from the homogenizer in the second set of mixes. The experiment was replicated four times. Interfacial tensions between these serum solids solutions and anhydrous milk fat at 70°C were measured with a Fisher Surface Tensiometer (Fisher Scientific, Linden, NJ) using a duNuoy ring as reported earlier (8).

Isolated Milk Protein Powders. Several isolated milk protein powders (95% protein), including sodium caseinate, sodium plus calcium caseinate, calcium caseinate, and WPI, were examined for their functional properties in ice cream mixes. Ice cream mixes of the following composition were prepared by standard means: 10% milk fat, 11% serum solids, 10% sucrose, and 5% corn syrup solids. Cream and skim milk were used to supply all of the milk fat, water, and 56.1% of the serum solids (6.2% of the mix). Thus, the protein powders were only supplying 43.9% of the serum solids (4.8% of the mix). A control mix with the
balance of the serum solids supplied from NDM was also run. The protein content of the control mix was 4%, whereas the protein concentration of the experimental mixes was 6.8%. Aged mix viscosity, overrun, fat destabilization, and interfacial tensions between the serum solution and anhydrous milk fat at 70°C were measured.

*Whey Protein Isolate Trials.* On the basis of the results obtained from the previous section, a further examination of the WPI was in order. Ice cream mixes were prepared by standard means with the following compositions: 10% milk fat, 11% serum solids, 10% sucrose, and 5% corn syrup solids. Cream and skim milk were used to supply the milk fat, water, and 6.2% (as percent of mix) of the serum solids as before. The balance of the serum solids (4.8% of the mix) comprised 4.8% NDM; 4.8% sodium caseinate; 1% WPI with 3.8% of either NDM or sodium caseinate; 2% WPI with 2.8% of either NDM or sodium caseinate; 3% WPI with 1.8% of either NDM or sodium caseinate; and 4.8% WPI. Aged mix viscosity, overrun, and fat destabilization were measured. The experiment was performed in quadruplicate.

*Taste Panels*

Ice cream mixes were prepared with the following compositions: 10% milk fat, 11% milk SNF, 10% sucrose, and 5% corn syrup solids. Cream and skim milk were used to supply the milk fat, water, and 6.2% of the milk SNF. The balance of the serum solids comprised 3% WPI plus 1.8% NDM; 3% WPI plus 1.8% sodium caseinate; and 4.8% NDM. A proprietary stabilizer-emulsifier (Summit, Germantown Manufacturing Co.) was added at .3% to the mix with 4.8% NDM as a control to assess the stabilizing and emulsifying abilities of the WPI. The mixes (40 kg) were frozen in a Vogt continuous freezer (Cherry Burrell, Cedar Rapids, IA). Aged mix viscosity and fat destabilization were measured.

Twenty-six panelists evaluated in taste panel facilities, the three ice creams for overall acceptability on a 125-ram line scale anchored on the left with “dislike very much” and on the right with “like very much”. The ice cream samples were presented to the panelists randomly at −15°C in styrofoam cups. Water was provided for rinsing between samples if desired. Lines were measured from the left to the panelists slash and the data were analyzed by analysis of variance, blocking by panelist, and least significant difference techniques.

**RESULTS AND DISCUSSION**

*Adsorption Control Through Selective Homogenization*

It was thought that the possibility existed to design a protein membrane that would give the desired properties by making available to the fat globule at the time of homogenization only the particular protein to be adsorbed. Because the evidence suggested that the whey proteins would lower the surface excess and thus enhance destabilization, homogenizing fat in the presence of the whey proteins and adding the casein protein post-homogenization would potentially lead to optimal structure and texture in the ice cream.

In the 75% WPC experiment, mix viscosity increased from 19.4 to 22.1 cP and the ice cream gloss decreased from 13.1 to 4.5 units when WPC was present in the homogenizer and caseins were withheld. The WPC-homogenized mix exhibited twice the fat destabilization as when WPC was withheld, increasing from 23% in the casein-homogenized mix to 45% in the WPC-homogenized mix (Figure 1). It was thus evident that an increase in fat destabilization and dryness resulted from the selective homogenization process; whey protein led to a less stable emulsion upon freezing than the casein proteins.

This experiment confirms the results of Musselwhite and Walker (17). Exclusion of the casein proteins and the availability of the whey proteins at the time of homogenization led to an ice cream with enhanced fat destabilization and dryness. Differences in surface excess were no doubt responsible for this result. The difficulty encountered with this 75% protein WPC trial, however, was that the 36% solution of 75% WPC was extremely viscous and very difficult to disperse into the cold mix post-homogenization. Considerable self-association of the whey protein into a gel structure was evident. It was desirable to reduce this viscosity, and this was done by incorporating a 36% protein WPC into the mix rather than the 75% protein WPC.
Mixes were prepared as described in Materials and Methods section. The protein content of the WPC and the NDM were approximately equal. There was 36% solids in each fraction of the mix and 2.4% protein available to the fat globule at the time of homogenization. The same general trends were seen as earlier; however, analyses were somewhat inconclusive. Some calculations based on the observations of Oortwijn and Walstra (18) led to the assumption that the adsorption of 6 to 20 mg protein/m² was possible. An approximate surface area of these emulsions was 1.5 m²/ml. Thus, 10 to 30 mg protein/ml would be potentially adsorbed. A mix protein of 2.4% yields 22 mg/ml. Total protein in these mixes may have been limiting.

It was concluded that the additional processing steps involved in the selective homogenization procedure, and the rather inconclusive or

**TABLE 1.** Interfacial tension, aged mix viscosity, and gloss values upon freezing of mixes in which the serum solids were derived from blends of 36% protein whey protein concentrate (WPC) and 36% protein nonfat dry milk.¹

<table>
<thead>
<tr>
<th>Serum solids source</th>
<th>Interfacial tension²</th>
<th>Mix viscosity</th>
<th>Gloss</th>
</tr>
</thead>
<tbody>
<tr>
<td>11% NDM + 0% WPC</td>
<td>5.33</td>
<td>15.0⁻</td>
<td>24.6⁻</td>
</tr>
<tr>
<td>9% NDM + 2% WPC</td>
<td>4.82</td>
<td>15.0⁻</td>
<td>24.5⁻</td>
</tr>
<tr>
<td>7% NDM + 4% WPC</td>
<td>4.21⁻</td>
<td>15.3⁻</td>
<td>16.3</td>
</tr>
<tr>
<td>4% NDM + 7% WPC</td>
<td>4.06⁻</td>
<td>19.0</td>
<td>13.6</td>
</tr>
<tr>
<td>2% NDM + 9% WPC</td>
<td>4.07⁻</td>
<td>20.3</td>
<td>6.8</td>
</tr>
<tr>
<td>0% NDM + 11% WPC</td>
<td>3.85⁻</td>
<td>21.7</td>
<td>4.8</td>
</tr>
</tbody>
</table>

¹ Values followed by the same letter are not significantly different (P<.05).
² Serum solution versus anhydrous milk fat.
unimpressive results that were obtained, would limit this technique to academic studies only with little or no commercial potential.

Comparison of Proteins

Whey Protein Concentrate. The conclusion arrived at from the selective homogenization trails, barring the difficulties encountered, was that the enhanced levels of whey proteins versus caseins at the interface led to emulsions that exhibited more fat destabilization during freezing. An experiment was designed in which the protein levels during homogenization were maintained at or above the normal 4% in the mix, and the relative amounts of caseins versus whey proteins were progressively altered. The interfacial tension between the serum solution and anhydrous milk fat under homogenization conditions, the aged mix viscosity, and the gloss readings at the time of ice cream extrusion were measured. Results are reported in Table 1.

It can be seen from Table 1 that the enhanced levels of WPC at the expense of NDM led to a decrease in interfacial tension, a slight increase in mix viscosity, and a definite increase in the dryness of the ice cream at the time of drawing. The interfacial tension values would predict that the whey proteins would be preferentially adsorbed over the caseins, as this leads to a lowering of the net free energy. The ratio of caseins to whey proteins in skim milk is approximately 3:1. In situations where this ratio was enhanced, it appears that the preferential adsorption of the whey proteins would lower the surface excess with resulting increased fat destabilization during freezing.

Fat destabilization measurements of the ice creams during freezing were made. The results are plotted in Figure 2. The percent of fat destabilized progressively increased as the ratio of WPC to NDM favored the whey proteins. This could be predicted from the preceding discussion. However, even at the highest level of WPC, fat destabilization only reached 40%. Typical values from mixes prepared with the addition of a chemical surfactant reached much higher levels, typically 60 to 80%.
The conclusion reached was that the whey proteins were resulting in a more desirable level of emulsion stability than the caseins in the absence of emulsifiers. However, when the entire serum solids content was derived from the WPC, levels of fat destabilization were still not satisfactory. A surfactant would be required to attain optimal structure. Although not quantified through sensory analysis, ice cream prepared with anhydrous milk fat and WPC was of poorer quality although the intent was to gain functional properties. This lower quality ice cream also would not be acceptable.

Isolated Milk Proteins

In addition to the WPC, a number of other commercial milk protein preparations were available and were investigated for their role at the interface in promoting emulsion stability or instability. These included sodium, sodium plus calcium, calcium caseinates, and a whey protein isolate prepared from sweet whey passed through an ion exchange column and concentrated by UF prior to drying. Because all of the protein preparations were >95% protein, it was decided to use cream and skim to supply the fat and moisture. The powders contributed only 44% of the serum solids content as described in the Materials and Methods section.

The interfacial tension between solutions of the milk protein preparations adjusted to give constant protein concentrations (3.7%; equivalent to 10% NDM) and anhydrous milk fat at 70°C is presented in Table 2. The caseinates lowered the interfacial tension beyond that found with the NDM control. The WPI lowered the interfacial tension further than the caseinates. This would indicate that it is more favorable for the caseinates to be adsorbed compared to natural milk protein and that the whey proteins would be favorable over the caseinates to lower the net free energy of the system. Preferential adsorption is the necessary first step in building the desired interfacial layer; a lowering of the surface excess must also be operative for the emulsion to exhibit destabilization during freezing.

Ice cream mixes were prepared using these protein preparations as partial sources of the serum solids content of the mix. The aged mix viscosity was increased slightly by the caseinates; sodium caseinate produced slightly more viscosity than the other two (Table 2). However, the WPI produced a tremendous viscosity increase, almost to the point of gelation, when homogenized and aged. This gelation reaction has been reported in the literature (5) as was discussed in the Introduction. This mix viscosity increase would not be acceptable in the commercial production of ice cream. The mixes were frozen in the Taylor batch freezer. Noticeable differences existed in the overrun of the ice creams at the end of the 15 min freezing time (Table 2). Sodium caseinate was a tremendous whipping agent, and the overrun of the mix employing sodium caseinate was much greater than the other mixes. Despite the tremendously high viscosity of the WPI mix, it

<table>
<thead>
<tr>
<th>Serum solids source</th>
<th>Interfacial tension (mN/m, 70°C)</th>
<th>Mix viscosity (mPa·s)</th>
<th>Overrun (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low heat NDM</td>
<td>4.62</td>
<td>13.8</td>
<td>69.4</td>
</tr>
<tr>
<td>Sodium plus calcium caseinate</td>
<td>4.06</td>
<td>21.2a</td>
<td>84.1a</td>
</tr>
<tr>
<td>Calcium caseinate</td>
<td>3.48a</td>
<td>23.8a</td>
<td>89.0a</td>
</tr>
<tr>
<td>Sodium caseinate</td>
<td>3.48a</td>
<td>45.2</td>
<td>166.4</td>
</tr>
<tr>
<td>Whey protein isolate</td>
<td>2.48</td>
<td>&gt;5000</td>
<td>43.2</td>
</tr>
</tbody>
</table>

*Means followed by the same letter are not significantly different (P<.05).

1 n = 4.

2 Serum solution versus anhydrous milk fat.
Fat destabilization was measured during the freezing of the ice creams. The resulting curves are presented in Figure 3. All caseinate preparations produced significantly less fat destabilization than the NDM control. The sodium caseinate produced a very stable emulsion that underwent negligible fat destabilization. In light of its foaming ability, the interfacial properties of sodium caseinate make it a very interesting protein to study. The WPI also produced very interesting fat destabilization results. Much difficulty was encountered in introducing the WPI mix to the freezer because of high viscosity of WPI, as was mentioned. However, fat destabilization neared 80% at the end of the 15-min freezing time: the highest level of fat destabilization obtained in any mix in the absence of surfactant.

The question that remained was whether the viscosity of the WPI mix could be substantially reduced to a typical mix viscosity of 100 to 150 cP while still maintaining the desired fat destabilization. If this could be accomplished, not only would the WPI be valuable as an emulsifier, but its viscosity control could also be utilized in mix stabilization and heat shock control, thereby reducing or eliminating the need for ice cream stabilizers and emulsifiers when the WPI was incorporated into the mix. To this end, an experiment was designed in which the WPI concentration was varied in an effort to reduce the viscosity and yet maintain the functional properties related to fat destabilization. The WPI levels chosen were 1, 2, 3, and 4% of the mix. The balance of the serum solids (4.8% from the powders) was made up with either NDM or sodium caseinate. The sodium caseinate had good flavor characteristics and beneficial whipping properties, although it produced a very stable emulsion. The mixes containing WPI and caseinate (both at 95% protein) had a protein concentration of 6.86% in the mix. Mixes containing NDM (36% protein) had a mix protein concentration that was introduced to the freezer and frozen. The resulting overrun was significantly lower than the NDM control, possibly as a result of the mix viscosity.

Figure 3. Fat destabilization resulting from the freezing of the ice cream mixes prepared using the various milk protein preparations as a partial source of the serum solids of the mix. The 95% confidence intervals are shown. Whey protein isolate (○); NDM (●); sodium-calcium caseinate (×); calcium caseinate (○); and sodium caseinate (●).
varied from 4.53% to 6.36%, depending on the relative proportions of WPI and NDM.

The aged mix viscosity and the resulting overrun upon freezing of the mixes with varying WPI concentrations in the presence of either NDM or sodium caseinate are presented in Table 3. The sodium caseinate produced a higher viscosity than the NDM at low WPI, less than 3% of the mix. At 4% WPI in the mix, the viscosity in the presence of NDM was 127.8 cP and in the presence of sodium caseinate was 102.8 cP, measured at constant shear. At some concentration between 4% WPI in the mix and the 4.8% WPI used earlier, the association reaction responsible for mix viscosity increase and partial gelation took place. Therefore, fairly high concentrations of WPI can be introduced into ice cream mix before this viscosity increase occurs. However, the reaction seems to occur within a fairly narrow range, and this would necessitate caution in the utilization of the isolate.

deWit (5) reported the denaturation temperature of β-lactoglobulin at or slightly above 70°C. It is likely that the gelation or viscosity increase seen involves a reaction between the denatured or partially unfolded form of β-lactoglobulin and one of the casein proteins. The WPI has been passed through an ion exchange column and the β-lactoglobulin concentration in the preparation is consequently very high. Pasteurization was occurring at or near the denaturation temperature, and this was having a strong influence on resulting mix viscosity.

The sodium caseinate was responsible for the production of tremendously high overruns beyond a concentration of 2 or 3% in the mix (Table 3). However, it appeared that the WPI was having an overrun depressing effect, independent of any viscosity effect. This was especially evident with the sodium caseinate data where the overrun decreased from 166 to 65% as the WPI concentration increased from 0 to 3%, whereas no effect was seen on the mix viscosity over this range. The WPI concentrations of 3 or 4% in the presence of NDM decreased the overrun from 70% to 50 to 55%. This overrun depressing effect would be a negative attribute of the WPI. However, the whipping ability of a mix plays less of a role in the continuous freezing of ice cream where air is either drawn into the mix under vacuum or injected in as compressed air than it does in batch freezing of ice cream mix as was done here.

The fat destabilization resulting from the freezing of these WPI mixes is presented in Figure 4. The upper plot of the figure shows the results in the presence of the NDM. It can be seen that concentrations of 3, 4, or 4.8% WPI all produced fat destabilization values in the range of 60 to 80%. There was no significant difference between these concentrations. These destabilization values represent the formation of desirable or optimal structure in the ice cream. The frozen ice creams were very

<table>
<thead>
<tr>
<th>Serum solids source</th>
<th>Viscosity (mPa*s)</th>
<th>Overrun (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NDM</td>
<td>Sodium caseinate</td>
</tr>
<tr>
<td>0% WPI + 4.8%</td>
<td>13.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>45.2&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>1% WPI + 3.8%</td>
<td>15.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>41.1&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>2% WPI + 2.8%</td>
<td>19.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>35.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>3% WPI + 1.8%</td>
<td>39.6&lt;sup&gt;c&lt;/sup&gt;</td>
<td>42.2&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>4% WPI + 0.8%</td>
<td>127.8</td>
<td>102.8</td>
</tr>
<tr>
<td>4.8% WPI</td>
<td>&gt;5000</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a,b,c,d</sup> Values followed by the same letter are not significantly different (P<.05).

<sup>1</sup><em>n</em> = 4.
Figure 4. Fat destabilization resulting from the freezing of ice cream mixes. Upper plot shows mixes prepared with 4.8% whey protein isolate (WPI) (○); 4% WPI plus .8% NDM (●); 3% WPI plus 1.8% NDM (x); 2% WPI plus 2.8% NDM (○); 1% WPI plus 3.8% NDM (●); or 4.8% NDM (◊). Lower plot shows mixes prepared with 4.8% WPI (○); 4% WPI plus .8% sodium caseinate (●); 3% WPI plus 1.8% sodium caseinate (x); 2% WPI plus 2.8% sodium caseinate (○); 1% WPI plus 3.8% sodium caseinate (●); or with 4.8% sodium caseinate (◊). The 95% confidence intervals are shown.

stiff and dry upon extrusion with good smooth-ness and meltdown. The lower plot of Figure 4 demonstrates resulting fat destabilization in the presence of sodium caseinate. The sodium caseinate produced very stable emulsions. At 4% WPI and .8% sodium caseinate, the fat destabilization was reduced to less than 40% and at concentrations of 1.8% sodium caseinate
or greater, fat destabilization was reduced to negligible amounts. It is evident that the sodium caseinate is playing a much greater role at the interface than is the NDM, because very great differences in the corresponding levels of WPI with each of the other powders were seen.

The ice creams prepared with the WPI had an acceptable flavor. At concentrations as low as 3% in the presence of NDM, the viscosity, overrun, and level of fat destabilization were all very acceptable. Sodium caseinate greatly enhanced emulsion stability and produced a less desirable flavor. Although the WPI was showing some beneficial functional properties in terms of emulsion destabilization, the resultant mix viscosity increase would need to be controlled to maintain mix viscosity no higher than 150 cP if the WPI was to be introduced commercially.

Product Development Potential

The functional properties of the various milk protein preparations in ice cream formulations have been discussed. The WPI was shown to have desirable properties in emulsion destabilization. Sodium caseinate produced a very stable emulsion but enhanced the whipping ability of the mix. It was decided to examine two possible formulations for their freezing characteristics in the continuous freezer and for their sensory acceptability. One mix consisted of 3% WPI and 1.8% NDM and the other consisted of 3% WPI and 1.8% sodium caseinate as described in the Materials and Methods section. A control mix consisting of 4.8% NDM and .3% stabilizer-emulsifier was also frozen. The objective was to determine whether the properties of the WPI or the sodium caseinate would produce an ice cream similar in characteristics to the control and acceptable to the taste panel.

The viscosity of the control mix was 37.4 cP. The viscosity of the WPI plus NDM mix at constant shear was 15.0 cP and the WPI plus sodium caseinate mix was 20.0 cP. Because heat treatment was minimal, the whey protein did not exhibit the viscosity increase discussed herein. All mixes were slightly lower in viscosity than optimal.

During freezing of the mixes, no problem was encountered in obtaining the targeted 90% overrun with any mix. The control and the WPI plus NDM mixes were extruded with a smooth, dry appearance. The WPI plus sodium caseinate was not as dry as the other two. The levels of fat destabilization at extrusion were 21.8% for the control, 19.3% for the WPI plus NDM mix, and 3.0% for the WPI plus sodium caseinate mix.

The analysis of variance from the sensory data showed significant difference between products. The control ice cream and the WPI plus NDM ice cream both rated very acceptable with no significant difference between the two. The WPI plus sodium caseinate ice cream was significantly less acceptable to the taste panelists than the other two (Table 4). The WPI was utilized at levels high enough to arrive at beneficial functional properties, i.e., fat destabilization or dryness, without reaching the level where extreme mix viscosity became a problem, and produced a product acceptable to the taste panel. It appears that there could be potential for product development work and incorporation of WPI into ice cream formulations. Beneficial properties would be gained, no sacrifice in produce acceptability is made, and the need for

<table>
<thead>
<tr>
<th>Serum solids source</th>
<th>Acceptability1,2</th>
</tr>
</thead>
<tbody>
<tr>
<td>3% Whey protein isolate + 1.8% NDM</td>
<td>76.9</td>
</tr>
<tr>
<td>3% Whey protein isolate + 1.8% sodium caseinate</td>
<td>37.7</td>
</tr>
<tr>
<td>4.8% NDM</td>
<td>83.6</td>
</tr>
</tbody>
</table>

1 0 = Dislike very much; 125 = like very much.
2 95% Confidence limits.
added stabilizers and emulsifiers would be reduced or eliminated.

CONCLUSIONS

Considerable work has been done with various milk protein preparations to examine their usefulness in ice cream formulations in providing the beneficial effects normally associated with the emulsifiers and the stabilizers. Several observations were made and conclusions can now be drawn.

Many of the experiments were aimed at the emulsion stabilization properties of the whey proteins. These experiments concur with the conclusion that enhanced concentrations of the whey proteins led to desirable increases in fat destabilization during freezing. This is, in part, related to their interfacial properties. The whey proteins reduce the interfacial tension further than the caseins, thus favoring their adsorption at the interface. Their molecular configuration also leads to adsorption of the protein polymers in such a way as to lower the surface excess further than the caseins. As a result, when the whey protein to casein ratio in a mix is enhanced to favor the whey proteins, there is a reduction in emulsion stability and formation of desirable structure and texture in the frozen ice cream.

These effects, however, are very complex in nature. In addition to competition for a place at the interface, proteins in solution are also undergoing self-association reactions, protein-protein interactions, and protein-solvent interactions. This was evidenced by the influence of the sodium caseinate on the WPI stability and by the viscosity increase of the WPI, for example. The serum proteins are further complicated by the influence of denaturation. The reactions of the native versus the partially denatured protein are very different as seen by the temperature dependence on viscosity.

These complications make it difficult to predict conclusively the functional properties of the protein preparations under a variety of different processing conditions. It can be speculated, however, that advantage can be gained from the use of WPI in ice cream formulations. It is also important to recognize that the advantages were derived in the absence of chemical surfactant; the presence of surfactant masks the fat destabilization and dryness properties of the whey proteins. This is in agreement with the hypothesis of surfactant action as reported earlier (8).

Mix viscosity, particularly in the unfrozen phase of the ice cream, may play an important role in ice cream stabilization and heat shock protection. The viscosity increase attributed to an interaction between partially denatured serum proteins and caseins may also be useful in ice cream stabilization and heat shock protection. If the viscosity could be controlled within standard operating conditions, then the WPI may act to replace all or a portion of the ice cream stabilizer in addition to replacement of the emulsifier.

ACKNOWLEDGMENTS

Gratitude is expressed to the Wisconsin Milk Marketing Board for their financial support of this project.

REFERENCES


