# Effect of Ultrafiltration Retentates and Whey Protein Concentrates on Ice Cream Quality During Storage

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## ABSTRACT

Ultrafiltration retentates (concentrated to three times) and whey protein concentrates were used to replace different levels of SNF in vanilla ice cream at 25, 50, or 75% and 25, 50, 75, or 100%, respectively. All mixes were formulated to make an ice cream containing 12% fat, 9.7% SNF, 12% sucrose, 4% corn syrup solids, and .3% stabilizer-emulsifier. Ice cream mixes were evaluated for pH and viscosity after 24 h of aging. These mixes were processed through an HTST pilot plant system and a 4.73-L (5-qt) batch freezer at 80% overrun. The drawing temperature was measured at this time. The ice creams were evaluated for chemical composition, microbiological quality, and sensory properties at 1, 30, and 90 d of storage. Heat shock stability and meltdown properties were tested after 30 d of storage. The results showed that the pH was affected significantly ($P < .05$) by substitutions of whey protein concentrate and UF retentate. The pH and viscosity increased as the percentage of UF retentate substitution increased, but these two parameters decreased as the percentage of substitution with whey protein concentrate increased. Substitution with the concentrate at 75 and 100% significantly ($P < .05$) decreased the viscosity compared with the UF retentate products. The protein and lactose values were affected by replacing different levels of UF retentate in ice cream mixes. Protein values of 3.88 to 4.53% in UF retentate products were higher than those of ice cream with whey protein concentrate at 3.18 to 3.55% ($P < .05$). Sensory evaluation results showed that ice cream made with substitution of SNF with UF retentate had higher flavor and body and texture scores than that made with whey protein concentrate. Substitution with 25% UF retentate produced the highest mean flavor score of 8.31.
(**Key words**: retentate, ice cream, ultrafiltration)

**Abbreviation key**: SPC = standard plate count, WPC = whey protein concentrate.

## INTRODUCTION

The major advantage of UF is that it yields a higher protein and lower lactose milk ingredient with excellent nutritional and functional properties. Furthermore, UF has been used to produce whey protein concentrate (WPC) from cheese whey to improve nutrition and reduce costs. The WPC containing 35% protein is used commonly as a replacement for SNF because of a cost advantage (11). The amount of whey solids that may be used in ice cream is limited due to lactose crystallization and flavor. Actual legal requirements currently allow 25% substitution of whey solids for SNF in frozen dairy products (5). Considerable studies have been conducted by incorporating different types of whey products such as whey powders (1, 4, 21), whey (16, 19), hydrolyzed whey, (7, 8, 13, 27), UF whey concentrate (4, 7), and whey protein concentrates (10, 17, 24) into ice cream and other related dairy products. Based on taste panel results, some experimental products were considered as acceptable as the control ice cream. Gregory (7) concluded that the use of SNF with dried whey did not cause a sandiness texture problem due to lactose crystallization.

Some studies have been conducted on the use of UF retentate in ice cream manufacture

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TABLE 1. Composition of the ingredients used to provide milk solids for ice cream.

| Component | NDM[1] | WPC[2] | UF Retentate |
|---|---|---|---|
| | (%) | | |
| Total solids | 96.5 | 97.2 | 22.2 |
| Fat | 1.0 | 2.5 | 9.5 |
| Protein | 33.6 | 35.7 | 7.7 |
| Lactose | 54.9 | 53.0 | 4.1 |
| Ash | 8.0 | 6.0 | .9 |

[1]Grade A NDM.

[2]WPC = Foremost Daritek 35 (Wisconsin Dairies, Baraboo, WI) whey protein concentrate.

TABLE 2. Formulation of ice cream.

| Ingredient | Percentage (wt/wt) |
|---|---|
| Milk fat | 12 |
| SNF | 9.7 |
| Sucrose[1] | 12 |
| Corn syrup solids[2] | 4 |
| Stabilizer[3] | .3 |
| Total solids | 38 |

[1]Domino extra fine granulate cane sugar (Mastar, NY).

[2]Dri-sweet 24 corn syrup solids (Hubinger, Keokuk, IA).

[3]Kontrol (Germantown Manufacturing Co., Broomall, PA).

(12, 14). Because lactose can cause sandiness in ice cream under some conditions and because some people cannot eat high lactose products, reduction of the lactose content of whey products by UF can be beneficial to the ice cream industry. Honer and Horwich (9) stated that the lactose content in ice cream can be reduced by 75% and sodium content by 40 to 60% with UF retentate from whey. Due to the reduction of lactose content, the chances of sandiness occurring in the ice cream were minimized. Also, this kind of ice cream product was suggested to be suitable for lactose-intolerant people.

The purpose of this study was to evaluate and compare ice cream made by substituting various levels of UF retentate or WPC for SNF. The comparison was based on physicochemical properties, microbiological quality, heat shock, and sensory evaluation during storage.

## MATERIALS AND METHODS

### Preparation of Ice Cream

All processing procedures such as UF, ice cream preparation, and storage were performed in the dairy processing plant of the Dairy Science Department at Mississippi State University.

Standardized (3.5% fat) pasteurized milk was delivered cold (7°C) to a sanitized UF recirculation vat (567 l). Ultrafiltration was performed using a Romicon Model HF 10SSS pilot plant (Romicon, Woburn, MA). The system contains six PM50 Romicon hollow fiber cartridges. The pressure was maintained at 17,577.5 kg/m$^2$ inlet and 3515.5 kg/m$^2$ outlet, and the temperature was maintained at 48.9°C (118°F). Milk was concentrated to a total solids level of 17% as measured with a hand-held refractometer. The volume was reduced to one-third the original volume. The UF retentate was then collected in sanitized stainless steel cans and cooled in an ice water bath to below 10°C. It was transferred to a cooler (4°C) and held for ice cream making the following day. Samples were taken to measure the fat and total solids content for restandardization and control purposes.

### Ice Cream Manufacture

The ice cream mixes were prepared in 13.64-kg (30-lb) batches consisting of 12% fat, 9.7% SNF, 12% sucrose, 4% corn syrup solids, and .3% stabilizer-emulsifier. The composition of ingredients used to provide SNF is listed in Table 1. Sucrose, corn syrup solids, and stabilizer-emulsifiers were constant for all the ice cream mix formulations (Table 2). The source of SNF for each formulation was varied by substituting UF retentate and WPC to assess the effect of the experimental blends. The WPC (Foremost Daritek 35, Wisconsin Dairies, Baraboo, WI) was purchased commercially in sufficient quantity to ensure that all treatments using WPC were made from the same batch. Blends were made by substituting UF retentate for 25, 50, or 75% of the SNF and WPC for 25, 50, 75 or 100% of the SNF. The control mix was made with no substitution of UF retentate or WPC for SNF.

The dry ingredients, previously weighed, were mixed and added with the liquid material and agitated and heated until the temperature reached 48.9°C (120°F). Heating was continued to 65.5°C (150°F) for 10 min and cooled to ambient temperature before being transferred to a HTST pasteurizer. The mix was pasteurized at 79.4°C (175°F) for 25 s and homogenized in a two-stage homogenizer at 1407.4 g/cm$^2$ (2000 psi) pressure in the first stage and 351.8 g/cm$^2$ (500 psi) pressure in the second stage. A plate cooler was used to cool the mix to 7°C (45°F). All mixes were stored overnight at 4°C in sanitized 18.93- or 37.85-L (5- or 10-gal) stainless steel milk cans. During freezing, 2.3 ml/L of fourfold vanilla extract were added to each mix. Mixes were frozen by a 4.73-L (5-qt) Emery Thompson batch freezer (Emery Thompson Machine and Supply Co., Bronx, NY) at 80% overrun, portioned into 473-ml (1-pt) plastic cartons, and immediately placed in a hardening room at –29°C (–20°F).

#### Analytical Procedures

Samples of ice cream mixes were taken after 24 h of aging and measured for viscosity and pH. Ice cream was manufactured and samples were analyzed after 1, 30, and 90 d of frozen storage for fat, total solids, protein, lactose, standard plate count (SPC), and coliforms. Sensory evaluation for flavor and body and texture was performed after 1, 30, and 90 d of storage at –29°C.

*Chemical Analyses.* The Mojonnier method (15) was used to determine the percentage of fat and total solids in the ice cream mixes. Samples were analyzed for protein using the Labconco Semi-Micro Kjeldahl Digestion unit (Labconco Co., Kansas City, MO) with the modified AOAC method (3), using copper sulfate as the catalyst. Two grams of a Kjeltab Pot Sulf/Cu Sulf (Fisher Scientific Co., Ltd., St. Louis, MO) were added to a 100-ml Semi-Micro-Kjeldahl flask. A 1-g sample was then added. Digestion was accomplished with 5 ml of concentrated sulfuric acid. Distillation was performed with a Labconco distillation unit model 6500. Sodium hydroxide thiocyanate (50% wt/wt water solution) was used to neutralize the sample during distillation. Tashiors indicator (four drops) was used to determine the blue-gray endpoint in the distilled sample. Protein was calculated by multiplying total nitrogen by 6.38. The calculation formula was

$$\text{percentage of protein} = \frac{(\text{milliliters of acid}) \times .1 \times 14 \times 100}{(\text{weight of sample}) \times 1000} \times 6.38.$$

Lactose determination was performed by using the HPLC method of Warthesen and Kramer (25). The HPLC system included a Waters Associates chromatography 6000A pump (Waters Associates Inc., Milford, MA), a Waters model U6K injector, a differential refractometer electronics unit (Waters Associates), and an Omni Scribe recorder (Huston Instruments, Austin, TX). The column (3.9 mm i.d. × 30 cm) was packed with Bondapak/carbohydrate packing material (Waters Associates). The solvent, 80% acetonitrile, was pumped at a flow rate of 2.2 ml/min. A 2-μm disposable membrane filter (Fisher Scientific Co.) was used for sample preparation. Dry lactose standards (Fisher Scientific Co.) were prepared using distilled water. A standard curve was drawn to estimate the percentage of lactose in ice cream. The peak height of the sample was used for estimation of lactose.

*Physical Analyses.* The drawing temperature of the ice cream was measured at the time the ice cream was removed from the 4.73-L (5-qt) batch freezer. Viscosities were measured at 7°C using a Brookfield digital viscometer (LVT model, Brookfield Engineering Labs, Inc., Stoughton, MA) and Zahn cup (number 2, Fisher Scientific, Norcross, GA) after 24 h of aging at 4°C. A T-bar spindle (T-A) was used in the testing period when using the viscometer. The speed was set up at 12 rpm. Three readings, 30 s apart, were recorded, averaged, and converted to centipoise units. The time required for the mixes to drain from the Zahn cup was measured using a stopwatch that provided readings to two decimal points. All readings were the means of duplicates. All the pH values were performed using a Fisher Accumet Model 610 pH meter (Fisher Scientific Co.). The electrode was standardized with pH 4 and 7 buffers (Fisher SB101 and SB107). A 473-ml (1-pt) block of ice cream that had been stored at –29°C (–20°F) was placed on a wire gauze (10 wires/in$^2$) in a low temperature incubator (Precision, GCA Co., Chicago, IL) maintained at 15.5°C (60°F). Liquid was drained from the

TABLE 3. Characteristics of ice cream[1] mixes made by substituting various percentages of UF retentate or whey protein concentrate (WPC) for SNF.

| Substituent | Amount | Drawing temperature | pH | Viscosity 2 | Viscosity 3 |
|---|---|---|---|---|---|
| | (%) | (°C) | | (centipoise) | (s) |
| None (control) | . . . | –2.8[a] | 6.57[c] | 412.54[bc] | 40.53[ab] |
| UF Retentate | 25 | –2.8[a] | 6.60[bc] | 523.54[a] | 46.43[a] |
| UF Retentate | 50 | –2.9[ab] | 6.63[ab] | 557.15[a] | 46.51[a] |
| UF Retentate | 75 | –2.9[ab] | 6.65[a] | 557.39[a] | 46.67[a] |
| WPC | 25 | –2.9[ab] | 6.53[d] | 415.35[bc] | 41.91[ab] |
| WPC | 50 | –3.1[ab] | 6.42[e] | 416.25[bc] | 42.00[ab] |
| WPC | 75 | –3.3[b] | 6.36[f] | 383.29[c] | 40.20[b] |
| WPC | 100 | –3.1[ab] | 6.27[g] | 308.02[c] | 38.02[b] |

[a,b,c,d,e,f]Means not followed by the same letter in each column are different ($P < .05$).

[1]Each value represents a mean of four replications and two samples for each replication.

[2]Measured by viscometer.

[3]Measured by Zahn cup (Fisher Scientific, Norcross, GA).

gauze and collected in a graduated cylinder. The time for collection of the first 10 ml of liquid was recorded. The volume of liquid collected in each subsequent 10-min period was measured, and the graph was obtained by plotting the time against the volume collected. The milliliters of meltdown per hour were noted up to 4 h (2).

*Microbial Analyses.* Microbial analysis was based on procedures outlined in *Standard Methods for the Examination of Dairy Products* (20). Total bacteria counts were performed using SPC agar, and coliform counts were made using violet red bile agar.

*Heat Shock Stability and Sensory Evaluation.* Heat shock tests were conducted by removing 473-ml (1-pt) containers of ice cream from the hardening room after 1 mo of storage and placing them at room temperature (25 to 26°C) for 30 min. The samples were then returned to the hardening room. This heat shock procedure was conducted for 10 consecutive d. Heat shocked ice cream was evaluated for sensory properties 1 wk after completion of this treatment (10). Ice cream for sensory evaluation was removed from the hardening room (–29°C). Samples were coded with three-digit numbers. Sensory evaluation was performed by a three-member experienced panel. The official ADSA Intercollegiate Dairy Products Evaluation Contest Score Card for flavor (10-point scale, 10 = best quality and 1 = worst quality) and body and texture (5-point scale, 5 = best quality and 1 = worst quality) was used.

*Statistical Analyses.* All data were analyzed by the general linear models completely randomized block design with split-plot in time by SAS (22). The ANOVA procedure was used to identify the major effect (23). The means were separated by use of the least significant difference test. Significant differences were determined at $P < .05$.

## RESULTS AND DISCUSSION

### Properties of Ice Cream Mix

Ice cream mixes were measured for viscosity and pH after 24-h aging periods. The data are shown in Table 3. They indicate that the mean drawing temperature of both the control and the 25% UF retentate substitution was higher than that of the other ice cream treatments. Among all of the ice creams, the ice cream with 75% WPC replacement possessed the lowest drawing temperature. Compared with the control and 25% replacement of SNF with UF retentate, ice cream made with 75% replacement of SNF with WPC had a significantly ($P < .05$) lower drawing temperature. The drawing temperature of ice cream supplemented with UF retentate was as high or higher than that of the ice cream made with WPC. Guy (8) reported that as whey solids increased, the freezing was lowered. Huse et al. (10) indicated that decreased viscosity in mixes containing low total solids or high levels of whey solids did not affect the freezing properties of ice cream mix.

TABLE 4. Mean values of chemical compositions in ice cream made by substituting various percentages of UF retentate or whey protein concentrate (WPC) for SNF at 1, 30, and 90 d of storage.

| Substituent | Amount | Fat | | | | Protein | | | | Lactose | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 d | 30 d | 90 d | $\bar{X}$ | 1 d | 30 d | 90 d | $\bar{X}$ | 1 d | 30 d | 90 d | $\bar{X}$ |
| | (%) | | | | | | | | | | | | |
| None (control) | . . . | 12.02 | 12.13 | 11.76 | $11.97^{ab}$ | $2.94^{a}$ | $2.85^{d}$ | $29.3^{c}$ | $2.91^{e}$ | $6.13^{a}$ | $5.77^{ab}$ | $5.61^{ab}$ | $5.84^{bc}$ |
| UF Retentate | 25 | 12.31 | 12.26 | 12.06 | $12.21^{a}$ | $4.13^{ab}$ | $3.63^{bc}$ | $3.89^{ab}$ | $3.88^{b}$ | $5.60^{ab}$ | $5.62^{abc}$ | $5.26^{b}$ | $5.49^{c}$ |
| UF Retentate | 50 | 12.21 | 12.04 | 11.98 | $12.07^{ab}$ | $4.24^{ab}$ | $4.20^{ab}$ | $3.96^{ab}$ | $4.13^{b}$ | $4.85^{bc}$ | $4.82^{cd}$ | $5.06^{bc}$ | $4.91^{d}$ |
| UF Retentate | 75 | 11.70 | 11.77 | 11.42 | $11.63^{c}$ | $4.67^{a}$ | $4.55^{a}$ | $4.37^{a}$ | $4.53^{a}$ | $4.23^{c}$ | $4.34^{d}$ | $4.34^{c}$ | $4.30^{e}$ |
| WPC | 25 | 11.80 | 11.59 | 11.55 | $11.65^{c}$ | $3.70^{bc}$ | $3.52^{c}$ | $3.44^{bc}$ | $3.55^{c}$ | $5.53^{ab}$ | $5.36^{bc}$ | $6.06^{ab}$ | $5.65^{c}$ |
| WPC | 50 | 11.95 | 11.92 | 11.77 | $11.88^{bc}$ | $3.51^{cd}$ | $3.15^{cd}$ | $3.21^{c}$ | $3.29^{cd}$ | $6.24^{a}$ | $6.33^{a}$ | $6.23^{a}$ | $6.26^{ab}$ |
| WPC | 75 | 12.26 | 12.11 | 11.81 | $12.06^{ab}$ | $3.42^{cd}$ | $3.22^{cd}$ | $3.03^{c}$ | $3.22^{de}$ | $6.28^{a}$ | $6.28^{a}$ | $6.26^{a}$ | $6.27^{a}$ |
| WPC | 100 | 11.09 | 12.03 | 11.71 | $11.91^{abc}$ | $3.32^{cd}$ | $3.02^{cd}$ | $3.20^{c}$ | $3.18^{de}$ | $6.39^{a}$ | $6.05^{ab}$ | $6.26^{a}$ | $6.23^{ab}$ |

[a,b,c,d,e]Means not followed by the same letter in each column are different ($P < .05$).

[1]Each value represents a mean of four replications and two samples for each replication.

The pH condition of the ice cream mixes varied with the different treatments. The pH of the mixes made by substituting UF retentate for SNF was higher ($P < .05$) than that of the mixes made by substituting WPC. The higher the percentage of UF retentate in ice cream mix, the higher the pH. In contrast, the higher the WPC in the ice cream mix, the lower the pH. These results support those of Naidu et al. (16), who found that increased substitution levels of whey solids in ice cream mix tended to reduce pH.

As more UF retentate was added, viscosity appeared to increase. All UF mix was significantly ($P < .05$) more viscous than the control (viscometer). The viscometer readings for the UF mixes were also higher ($P < .05$) than for the WPC mixes. With regard to Zahn cup readings (time to pass through small orifice), only the higher (75 and 100%) WPC mixes had substantially ($P < .05$) lower viscosity than the UF mixes. Replacement of 75 and 100% of SNF with WPC decreased the viscosity significantly ($P < .05$) compared with UF retentate ice cream mix. These results support those of Guy (8), Huse et al. (10), and Naidu et al. (16). These researchers stated that the relative viscosity decreased as the whey solids increased. Generally, the viscosities of the ice cream mixes made by substituting with UF retentate were higher than those of mixes made by substituting with WPC.

#### Chemical Composition of Ice Cream

The composition of ice cream is usually expressed as a percentage of its constituents. In this study, the total solids, fat, protein, and lactose contents of ice cream were measured at 1, 30, and 90 d. No difference ($P > .05$) was found among treatments in the total solids content. The data presented in Table 4 indicate that differences ($P < .05$) occurred in the mean fat content among treatments. For the three storage periods, the 25% UF retentate product consistently had the highest fat content. The fat content tended to decrease ($P > .05$) as the storage time increased. We cannot explain this slight decrease. The UF retentate products contained more measurable protein ($P < .05$) than the WPC products. Most of the products seemed to decrease in protein content over time. Because the protein content of NDM and WPC are close, increasing the relative proportion of WPC simply caused a slight protein change in the ice cream. As mentioned, protein slightly decreased when the substitution percentage of WPC increased. This decrease in measurable protein was probably caused by the poorer solubility of the heat-denatured proteins in the WPC. With regard to protein content in all of the treatments, the ice cream made with both UF retentate and WPC had higher values than the control. This difference was significant ($P < .05$) for the products containing UF retentate. These results suggest that UF retentate and WPC increased the protein content in ice cream. Guy (8) discussed a proposed change in the standards of identity for frozen desserts (in 1978), permitting ice creams to be formulated from any milk-derived ingredient with a minimum of 2.7% protein. Although the proposal was dropped, we note that all products in this experiment satisfied this minimum protein requirement.

If the water portion of the ice cream mix contains 9% lactose, a sandiness defect may occur (2). Thus, reducing lactose by UF could be utilized in the ice cream industry. The data indicate that ice cream made with 50 and 75% UF retentate substitution had significantly ($P < .05$) lower lactose levels than that of the control. These results agreed with those of Masters and Kosikowski (14). They demonstrated that lactose was not increased as protein increased in ice creams in which corn syrup solids were used to compensate for the increased solids. In contrast, no major difference was found in lactose content of ice cream made with 50, 75, and 100% substitution of WPC. Slightly reduced lactose values ($P < .05$) during 90 d of storage were noted in the control, 25% UF retentate, and 100% WPC substitution products. In contrast, the lactose content of 50 and 75% UF retentate substitution products increased slightly ($P > .05$) at 90 d of storage. Except for the 25% WPC substitution products, no significant difference was found in the lactose content among the WPC products.

The mean composition values of the ice cream over all periods are summarized in Table 4. Ice cream made with 25 and 50% UF retentate contained higher ($P < .05$) fat values than that made with 75% UF retentate. As the substitution percentage of UF retentate increased, the fat content of ice cream decreased. Furthermore, increasing the substitution percentage of WPC from 25 to 75% increased ($P < .05$) the fat content. Replacement of the SNF with 75% UF retentate in ice cream affected significantly ($P < .05$) the protein and lactose content. Except at the 25% replacement level, no significant differences were detected for WPC substitution. Overall, as the percentage substitution with UF retentate increased, the lactose content decreased ($P < .05$). However, increasing the percentage of WPC substitution from 25 to 50% increased significantly ($P < .05$) the lactose content. This was not noticeable from 50 to 100%.

#### Bacterial Quality of Ice Cream During Storage

Ice cream samples were subjected to SPC and coliform tests to determine how the replacement of SNF with UF retentate and WPC affected bacterial growth during storage. The log SPC values and coliform counts are shown in Table 5. No significant difference was detected among treatments, except for the 100% WPC substitution at 1 d of storage, which had the highest ($P < .05$) total bacterial count. Products substituted with UF retentate tended to have lower bacterial counts at 1 d storage than did the control or the WPC products. Moreover, after 30 d of storage, the SPC of all experimental products was lower than those of the control ice cream. The SPC decreased with time in the control and in the 25 and 50% UF retentate products. For the fresh products (1 d), as the percentage of UF retentate substitution increased, the bacterial counts appeared to decrease slightly, whereas as substitution percentage of WPC increased, bacterial counts increased. However, only the 100% WPC substitution products were significantly different. According to Premaratne and Cousin (18) and Glover (6), bacterial counts increased during UF processing from two- to fivefold. However, in this study, increased substitution with UF retentate did not increase bacterial counts in the ice cream. This suggests that ingredients are not the only factor affecting the microbiological quality of ice cream. Pasteurization, other processing steps, and cleaning and sanitizing procedures are also quite important.

The lowest coliform count at 1 d of storage was found in the product with replacement of

TABLE 5. Total bacterial counts[1] and coliform counts[2] of ice cream made by substituting various percentages of UF retentate or whey protein concentrate (WPC) for SNF at 1, 30, and 90 d of storage.

| Substituent | Amount | Standard plate count 1 d | Standard plate count 30 d | Standard plate count 90 d | $\overline{X}$ | Violet red bile agar 1 d | Violet red bile agar 30 d | Violet red bile agar 90 d | $\overline{X}$ |
|---|---|---|---|---|---|---|---|---|---|
| | (%) | (log cfu/ml) | | | | (cfu/ml) | | | |
| None (control)[3] | . . . | 3.03$^{ab}$ | 2.93 | 2.46 | 2.807 | 3.75$^{a}$ | 1.75 | 1.25 | 2.250$^{a}$ |
| UF Retentate | 25 | 2.48$^{b}$ | 2.33 | 2.20 | 2.335 | .75$^{b}$ | .25 | 1.25 | .750$^{b}$ |
| UF Retentate | 50 | 2.46$^{b}$ | 2.23 | 2.22 | 2.302 | 1.00$^{ab}$ | .25 | .50 | .583$^{b}$ |
| UF Retentate | 75 | 2.29$^{b}$ | 2.07 | 2.61 | 2.322 | 1.75$^{ab}$ | .75 | .75 | 1.083$^{ab}$ |
| WPC | 25 | 2.50$^{b}$ | 2.20 | 2.93 | 2.542 | 2.75$^{ab}$ | .75 | 2.25 | 1.917$^{ab}$ |
| WPC | 50 | 2.67$^{b}$ | 2.44 | 2.53 | 2.545 | 1.50$^{ab}$ | .50 | .75 | .917$^{b}$ |
| WPC | 75 | 2.75$^{b}$ | 2.61 | 2.69 | 2.681 | 3.00$^{ab}$ | 1.50 | 2.50 | 2.333$^{a}$ |
| WPC | 100 | 3.83$^{a,x}$ | 2,31$^{y}$ | 2.48$^{y}$ | 2.873 | 2.50$^{ab}$ | 1.75 | 1.75 | 2.000$^{ab}$ |

[a,b]Means not followed by the same letter in each column are different ($P < .05$).

[x,y]Means not followed by the same letter in each row are different ($P < .05$).

[1]Total aerobic bacterial count as determined on standard plate count (SPC) agar at 32°C.

[2]Coliform counts as determined on violet red bile agar at 32°C.

[3]Each value represents a mean of four replications and two samples for each replication.

SNF with 25% UF retentate. No difference ($P >$ .05) was detected in coliform counts between other levels of substitution with UF retentate or WPC. Generally, slightly higher coliform counts were found in WPC products than in UF retentate products. The data in Table 5 were also used as quality control tools to estimate the expected quality and shelf-life of the newly developed product. Glover (6) concluded that microbial growth during UF is not a serious problem if carried out as a continuous process at a temperature of about 50°C. According to White and Bishop (26), cleaning and sanitizing of processing equipment are critical in controlling the microbiological quality of ice cream manufacture.

With regard to the SPC values of all the products across all storage times, no differences ($P > .05$) occurred. However, the coliform counts were different ($P < .05$) between the control and the 25 and 50% UF retentate products. This difference may be partially explained by the heat treatment the UF retentate received during the actual UF process.

## Melting Quality of Ice Cream

The effect of treatment on meltdown property is shown in Table 6. No significant differences were detected in this experimental trial. Huse et al. (10) stated that the freezing process was the major source of variability that affected melting resistance during ice cream manufacture, because overrun and drawing temperature were too difficult to control.

The time needed to collect the first 10 ml of melted liquid showed that as the relative amount of UF retentate increased, the melting resistance also slightly decreased ($P > .05$). Even though no significant differences were detected, replicate variation resulted in longer times required to reach the first 10 ml than would be expected when observing the 1-h readings. Each of the readings at 1, 2, 3, and 4 h represents the mean value of three replications.

These meltdown values appear to agree with those of Reddy et al. (19), who stated that as the replacement of whey solids in ice creams increased, the time needed for meltdown decreased. Guy (8) reported no significant difference between replacement with whey and the control ice cream.

Total meltdown volumes increased almost linearly from 1 to 3 h, and then maintained a constant level as the ice cream mass was depleted (Figure 1). The total meltdown liquid collected per 10 min after the first 10-ml collection period is shown (Figure 2). The volume increased steadily until 60 to 70 min and decreased dramatically after 120 min. In addition, among all the treatments, the WPC substi-

TABLE 6. Effect of substituting UF retentate or whey protein concentrate (WPC) for SNF on ice cream meltdown.

| Substituent | Amount | First 10 ml[1] | Amount of liquid collected 1 h | 2 h | 3 h | 4 h |
|---|---|---|---|---|---|---|
| | (%) | (min) | (ml) | | | |
| None (control)[2] | . . . | 63.67[a] | 12.0[a] | 127.3[a] | 223.7[a] | 242.3[a] |
| UF Retentate | 25 | 64.67[a] | 10.0[a] | 111.0[a] | 218.0[a] | 251.0[a] |
| UF Retentate | 50 | 61.17[a] | 18.0[a] | 140.7[a] | 286.0[a] | 296.0[a] |
| UF Retentate | 75 | 55.27[a] | 18.3[a] | 150.0[a] | 263.3[a] | 283.0[a] |
| WPC | 25 | 66.27[a] | 14.7[a] | 90.0[a] | 176.3[a] | 217.3[a] |
| WPC | 50 | 66.77[a] | 23.7[a] | 135.3[a] | 235.7[a] | 260.7[a] |
| WPC | 75 | 65.43[a] | 16.0[a] | 116.0[a] | 195.3[a] | 222.3[a] |
| WPC | 100 | 64.27[a] | 21.3[a] | 135.7[a] | 221.7[a] | 242.3[a] |

[a]Means followed by the same letter in each column are not different ($P > .05$).

[1]Time needed to collect first 10 ml of liquid at 15.5°C.

[2]Each value represents a mean of three replications.

tution samples tended to give higher meltdown resistance than the UF retentate ice cream samples ($P > .05$).

## Sensory Evaluation of Ice Cream

The average flavor and body or texture scores are presented in Table 7. Ice cream made with UF retentate did not differ from the control but had higher ($P < .05$) scores for flavor and body and texture than the ice cream made with WPC. Replacement of 25% of the SNF with UF retentate in ice cream resulted in the highest flavor score for all of the treatments. Replacement of 100% of the SNF with WPC in ice cream imparted a whey taste, thus causing lower scores. However, no significant flavor differences were detected among the four levels of WPC. Even though lower flavor scores were obtained compared with the UF retentate products, the WPC ice cream was still considered acceptable at all levels of substitution after 90 d of storage. No significant difference was found in flavor scores among the UF products, except for the 75% UF product, which had a lower ($P < .05$) score at 30 d storage than did the 25% UF product. All of these products were judged equal to or better than the control ice cream in most of the sessions. Moreover, no differences ($P > .05$) in body and texture scores were found among ice creams made with WPC.

With regard to the overall flavor and body and texture scores, no significant differences were detected among the UF retentate products.

TABLE 7. Mean flavor scores and body and texture scores of ice cream made by substituting various percentages of UF retentate or whey protein concentrate (WPC) for SNF at 1, 30, and 90 d of storage.

| Substituent | Amount | Flavor scores[1] 1 d | 30 d | 90 d | Mean | Body and texture scores[2] 1 d | 30 d | 90 d | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | (%) | | | | | | | | |
| None (control) | . . . | 8.42[a] | 6.50[b] | 7.96[ab] | 7.96[a] | 4.00[a] | 4.04[ab] | 3.54[a] | 3.86[ab] |
| UF Retentate | 25 | 8.42[a] | 8.20[a] | 8.34[a] | 8.31[a] | 3.96[ab] | 4.21[a] | 3.92[a] | 4.03[a] |
| UF Retentate | 50 | 8.17[a] | 7.63[ab] | 8.21[ab] | 8.00[a] | 3.84[ab] | 3.92[ab] | 3.84[a] | 3.86[ab] |
| UF Retentate | 75 | 8.38[a] | 7.54[b] | 8.38[a] | 8.10[a] | 4.00[a] | 3.79[ab] | 3.92[a] | 3.90[a] |
| WPC | 25 | 7.17[b] | 7.54[b] | 7.50[b] | 7.40[b] | 3.33[b] | 3.54[b] | 3.50[a] | 3.46[c] |
| WPC | 50 | 7.09[b] | 7.13[bc] | 8.00[ab] | 7.40[b] | 3.59[ab] | 3.58[b] | 3.71[a] | 3.63[bc] |
| WPC | 75 | 6.88[b] | 7.13[bc] | 7.79[b] | 7.26[b] | 3.42[b] | 3.59[b] | 3.46[a] | 3.49[c] |
| WPC | 100 | 6.71[b] | 6.79[c] | 7.92[ab] | 7.14[b] | 3.42[b] | 3.59[b] | 3.75[a] | 3.58[bc] |

[a,b,c]Means not followed by the same letter in each column are different ($P < .05$).

[1]On a scale of 1 to 10, with 10 being highest quality.

[2]On a scale of 1 to 5, with 5 being highest quality.

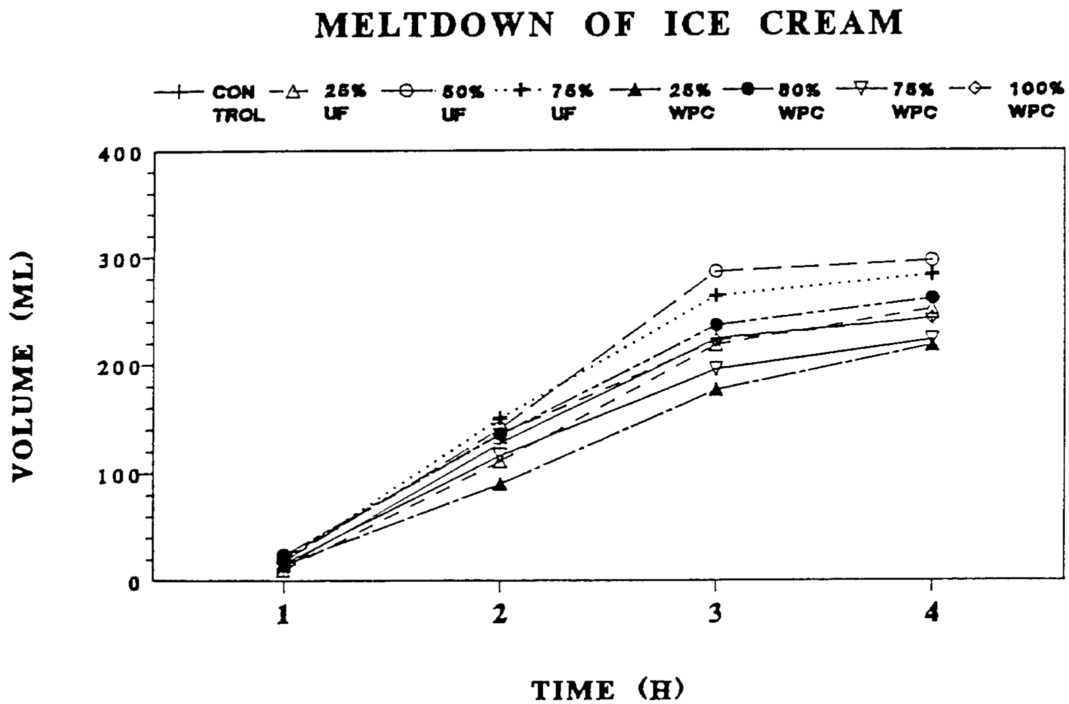


Figure 1. Volume of ice cream meltdown liquid collected at 15.5°C for 1, 2, 3 and 4 h; WPC = whey protein concentrate.

Also, similar results were noted in the WPC products. However, products with UF retentate had higher ($P < .05$) flavor scores than the WPC products. Replacement of 100% of the SNF with WPC resulted in lower ($P > .05$) scores compared with the other WPC products. Generally, replacement with 25% UF retentate was considered to have a better flavor than the control ice cream. No significant differences were detected in the body and texture scores among the UF retentate products or among the WPC products. In general, the UF retentate products had higher body and texture scores than the WPC products. The WPC ice cream was judged as coarse, icy, and weak, probably because of the high lactose content.

TABLE 8. Effect of substituting UF retentate or whey protein concentrate (WPC) for SNF on heat shocked ice cream flavor and body and texture scores.

| Substituent | Amount | Flavor scores[1] | Body and texture scores[2] |
|---|---|---|---|
| | (%) | | |
| None (control) | . . . | 6.92[b] | 3.00[ab] |
| UF Retentate | 25 | 7.83[a] | 3.17[ab] |
| UF Retentate | 50 | 7.67[a] | 3.25[a] |
| UF Retentate | 75 | 7.42[ab] | 3.17[ab] |
| WPC | 25 | 7.33[ab] | 2.92[ab] |
| WPC | 50 | 6.92[b] | 2.92[ab] |
| WPC | 75 | 7.00[b] | 2.92[ab] |
| WPC | 100 | 7.25[ab] | 2.75[b] |

[a,b]Means not followed by the same letter are different ($P < .05$).

[1]On a scale of 1 to 10, with 10 being highest quality.

[2]On a scale of 1 to 5, with 5 being highest quality.

### Heat Shock

Sensory evaluation results of heat shocked ice cream are shown in Table 8. Ice cream made with 25% UF retentate had the highest ($P < .05$) flavor score, whereas ice cream made with 50% UF retentate had what was considered to be the best ($P < .05$) body and texture. Ice cream made with UF retentate generally had better heat shock protection than either the control or the ice cream made with WPC. The flavor of UF retentate ice cream appeared to be better than the WPC products, even though the results were not significant for the highest level

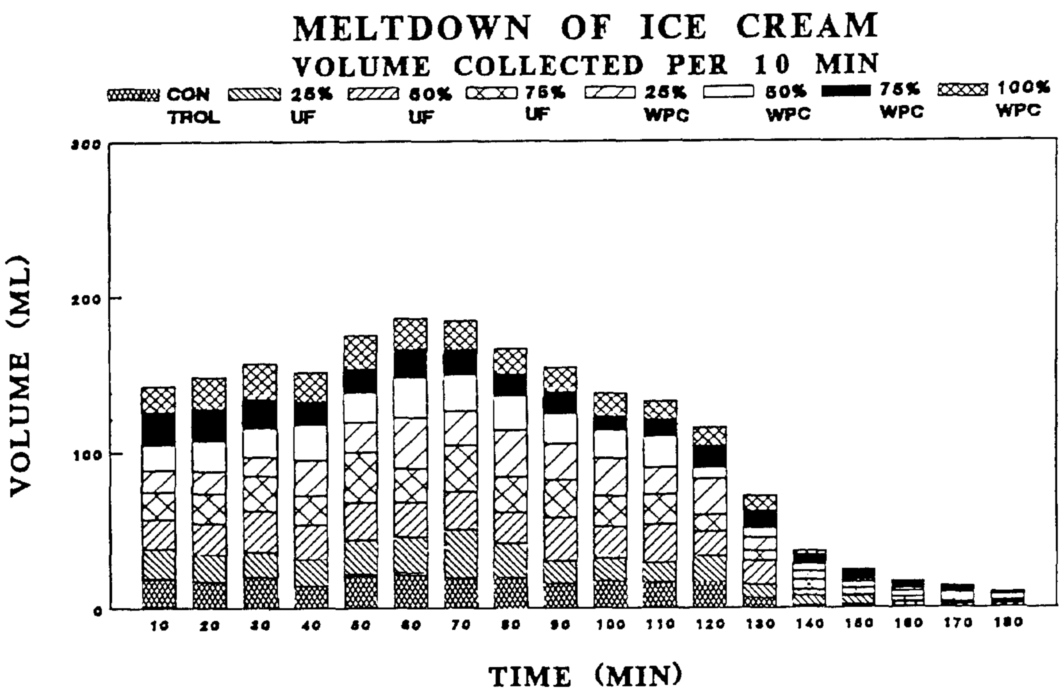


Figure 2. Total volumes of ice cream meltdown liquid collected at 15.5°C for each 10-min period; WPC = whey protein concentrate.

of UF retentate and the lowest level of WPC.

## CONCLUSIONS

The different levels of UF retentate appeared to affect the protein and lactose content of the experimental ice cream in this study. Protein contents that ranged from 3.88 to 4.53% were obtained for substitution levels of 25 to 75% UF retentate in ice cream during storage. The protein values of UF retentate ice cream treatments were significantly ($P < .05$) higher than that of ice cream where only NDM was used.

Ice cream with different levels of WPC substituted for SNF did not differ ($P > .05$) from controls for lactose content but had higher protein values. The control tended to have higher flavor and body and texture scores than the WPC samples. Generally, ice cream made with UF retentate was judged as having higher flavor and body and texture scores than that made with WPC. Furthermore, substitution of UF retentate for SNF yielded ice cream with better heat shock stability. The UF retentate ice cream had excellent heat stability, flavor, functional properties, and storage quality.

The meltdown characteristics evaluated in this study showed no significant ($P > .05$) difference among the treatments. This may be explained by the fact that one of the major factors recognized to affect melting resistance is the freezing point, and the freezing point of ice cream is a function of the sugar content of the mix. In this study, all sugar levels (except for lactose) were kept constant. The UF retentate mixes were more viscous than WPC mixes after 24 h of aging. This increased viscosity was caused by the elevated total solids and protein content of the retentate due to the UF process. Because of the higher level of casein in the UF retentate products, the water binding capacity of the mixes would be increased. As a result, an improvement would be expected in the stability of the body and texture.

No difference ($P > .05$) was detected in the SPC among the ice cream treatments during storage. This suggests that if processing procedures are done correctly in properly cleaned and sanitized equipment, microbial contamination should not be a problem.

Even though a change in the protein and lactose content occurred by replacing the SNF with UF retentate, the body and texture scores failed to show improvement ($P > .05$). The flavor scores tended to be higher ($P < .05$) when UF retentate replaced SNF than when WPC was used. This study demonstrated that additional research is needed to determine whether the use of varying levels of UF retentate can improve the body and texture of ice cream during freezing and storage. Consumer acceptance tests are also needed to determine acceptability of ice cream from these new ingredient formulations.

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