Effects of Ingredients on the Functionality of Fat-free Process Cheese Spreads

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ABSTRACT: Emulsifying salts and hydrocolloids, cook time, cook temperature, and pH were evaluated to characterize their effects on firmness, meltability, and spreadability of fat-free process-cheese spreads. Disodium phosphate and trisodium citrate produced properties closest to those of a full-fat reference cheese, with trisodium citrate providing the most meltability. In all cases, incorporation of hydrocolloids resulted in increased firmness, decreased melt, with varying results on spreadability. Increases in cook time generally produced softer, more meltable cheeses, while increases in cook temperature decreased firmness and increased meltability and spreadability.

Key Words: process cheese, fat-free, functionality, hydrocolloids

Introduction

WITHIN THE PROCESS-CHEESE INDUSTRY today, information about the manufacture of fat-free process cheese is very limited. Some of the information lies within several patents for its manufacture. Davison and others (1993) developed a fat-free process cheese using hard skim-milk cheese along with a microreticulated microcrystalline cellulose slurry and polyanionic gum mixtures. Rybinski and others (1993) have been issued a patent for a nonfat cheese analog consisting of coagulated skim milk, rennet casein, and various emulsifying salts. Mehnert and Prince (1996) also have been issued a patent for the manufacture of a nonfat process cheese prepared by combining hard skim-milk cheese with a fatty substance that is nonabsorbable by the intestine. While use of technology described in patents such as these has led to production of useful fat-free process cheeses, they have not provided information on the more fundamental aspects of these products.

However, with a limited availability of information on the production of fat-free process cheese, some insight into the behavior of these products may be derived from observations made on other reduced-fat products. Among studies conducted on low-fat process cheeses, Hayter and others (1969) recommended the use of 40% hard skim-milk cheese, cured for 10 d, along with 20% aged cheddar cheese for optimum textural and flavor characteristics. Brummel and Lee (1990) have advocated the use of soluble hydrocolloids, such as carrageenan, pectin, and guar gum, at levels up to 2%, to compensate for fat-reductions in process cheeses. Chiu (1991) also has shown that hydrocolloids may improve the texture of reduced-fat process cheeses. Hwang and Lindsay (1993) have studied the effects of emulsifying salts in low-fat processed cheeses. In general, they indicated that emulsifying salt mixtures consisting of condensed phosphates produced cheeses with a lower degree of meltability than those prepared with disodium phosphate or trisodium citrate.

In addition to the existing patents and information on low-fat process cheeses, fat-replacers have been suggested for use in nonfat process-cheese products. Mitchell (1993) has recommended the use of the fat-replacer Dairy-Lo for the production of nonfat process cheese with good sensory properties. Other fat-replacing ingredients, such as the pectin-based Slendid, have been mentioned for use in nonfat process cheeses (Anonymous 1991). While the use of such fat-replacers may serve to produce better quality nonfat products, further research is needed to understand the influences of modifying ingredients and fundamental mechanisms involved in the textural behavior of nonfat process cheeses.

Results and Discussion

THROUGHOUT THE STUDY, FAT AND moisture compositions of fat-free process-cheese spreads were measured. Fat contents were 0.6 ± 0.2% and moistures were 58.5 ± 1.0%. Little variation in these values was observed throughout the study, which supported the view that the results reflected experimental treatments rather than compositional variations. Similarly, pH values of all fat-free process-cheese spreads were monitored, generally showing little variation throughout the study (5.6 ± 0.4).

Emulsifying salts

Effects of different emulsifying salts, at a 3% level, on textural attributes of fat-free process-cheese spreads are reported in Table 1. Trisodium citrate and disodium phosphate produced significantly softer cheeses and melted more easily than those prepared with condensed phosphate Joha-brand salts. For these trials, trisodium citrate produced the softest cheese, which also melted slightly more readily than the full-fat reference. In the case of Joha-brand emulsifying salts, firm cheeses with limited melt and minimal spreadability resulted.

Increasing the amount of trisodium citrate or disodium phosphate from 0.5% to 3% generally resulted in increased firmness, decreased melt, and decreased spreadability in all cases (data not shown). Additionally, mixtures of 1:2, 1:1, 2:1 of trisodium citrate and disodium phosphate, respectively, did not provide advantages over single emulsifier usage for any of the textural attributes (data not shown). The high degree of firmness for cheese spreads containing Joha-brand emulsifying salts might be explained by an increase in the amount of protein-protein interaction facilitated by greater Ca^{++} se-

Table 1—Effect of emulsifying salts used at a 3% level on the functional properties of fat-free process-cheese spreads

Emulsifying salt	Firmness[f] peak force (N)	Meltability[g] flow (mm)	Spreadability[h] total force (N*s)
Trisodium citrate	21.3[d]	155.8[a]	521.6[a,b]
Disodium phosphate	25.4[c]	46.5[c]	493.5[b]
Joha S9	33.0[b]	9.5[e]	NSTC
Joha SE	32.9[b]	8.0[e]	NSTC
Joha C New	66.0[a]	19.5[d]	552.2[a]
Full-fat reference	12.2[e]	145.5[b]	192.1[c]

[a,b,c,d,e] Means within a column with no common superscripts differ significantly ($p < 0.05$).
NSTC = Not spreadable under test conditions
[f] Means of triplicate determinations for 2 trials (n = 6)
[g] Means of duplicate determinations for 2 trials (n = 4)
[h] Means of duplicate determinations for 2 trials (n = 4), smaller values equal greater spreadability.
[i] Full-fat reference contained 3% disodium phosphate duohydrate as the emulsifying salt.

Table 2—Effect of hydrocolloids used at a 2% level on the functional properties of fat-free process-cheese spread

Emulsifying salt	Firmness[f] peak force (N)	Meltability[g] flow (mm)	Spreadability[h] total force (N*s)
Gelatin	45.0[b]	34.3[b]	524.0[b]
Carrageenan	45.1[b]	9.3[c]	485.3[c]
Locust-bean gum	53.0[a]	12.0[c]	593.1[a]
Guar gum	38.1[c]	6.5[c]	228.9[d]
Full-fat reference[i]	12.2[d]	145.5[a]	192.1[e]

a,b,c,d,e Means within a column with no common superscripts differ significantly ($p < 0.05$).[f] Means of triplicate determinations for 2 trials (n = 6)[g] Means of duplicate determinations for 2 trials (n = 4)[h] Means of duplicate determinations for 2 trials (n = 4), smaller values equal greater spreadability.[i] Full-fat reference contained 3% disodium phosphate duohydrate as the emulsifying salt.

Table 3—Effect of cook time on the functional properties of fat-free process-cheese spreads

Cook Time (min at 75°C)	Firmness[e] peak force (N)	Meltability[f] flow (mm)	Spreadability[g] total force (N*s)
0	31.7[a]	48.8[b]	518.0[a]
5	27.1[b]	57.5[b]	504.1[a]
10	26.3[b,c]	70.3[a]	500.2[a]
15	25.3[c,d]	78.0[a]	484.8[a]
20	24.1[d]	77.5[a]	485.5[a]

a,b,c,d Means within a column with no common superscripts differ significantly ($p < 0.05$).[e] Means of triplicate determinations for 2 trials (n = 6)[f] Means of duplicate determinations for 2 trials (n = 4)[g] Means of duplicate determinations for 2 trials (n = 4), smaller values equal greater spreadability.

Table 4—Effect of cook temperature on the functional properties of fat-free process-cheese spreads

Cook Temperature (°C)	Firmness[e] peak force (N)	Meltability[f] flow (mm)	Spreadability[g] total force (N*s)
60	32.9[a]	18.5[d]	533.5[a]
70	28.2[b]	37.8[c]	493.7[b]
80	23.9[d]	89.3[b]	431.9[c]
90	26.2[c]	98.0[a]	342.7[d]

a,b,c,d Means within a column with no common superscripts differ significantly ($p < 0.05$).
[e] Means of triplicate determinations for 2 trials (n = 6)
[f] Means of duplicate determinations for 2 trials (n = 4)
[g] Means of duplicate determinations for 2 trials (n = 4), smaller values equal greater spreadability.

questering abilities of these polyphosphate-containing ingredients. The similar consequences of increased firmness and decreased melt corresponding to increasing concentrations of emulsifying salts mentioned earlier also would be in agreement with this mechanistic hypothesis. Rayan and others (1980) as well as Fukushima and DeMan (1970) have earlier attributed textural attributes of full-fat process cheese to the amount of protein interaction and Ca++ sequestering abilities of emulsifying salts, and their conclusions also support those of our study. Swaitek (1964) has previously shown similar results in full-fat process cheeses where sodium citrate and disodium phosphate produced soft cheeses while polyphosphates produced considerably harder cheeses. Additionally, Gupta and others (1984) have shown full-fat process cheeses containing condensed phosphates exhibited nonmelting properties.

Hydrocolloids

Results of additions of commercial hydrocolloids to fat-free process-cheese spreads formulated with 3% disodium phosphate are summarized in Table 2. Overall, an increase in the firmness of the cheese spread and a decrease in meltability occurred for all treatments compared to process-cheese spread control samples without added hydrocolloids. Guar gum produced the softest texture of all hydrocolloids studied, with gelatin exhibiting the greatest overall meltability. The heat-reversible property of gelatin gels above 48.8 °C (Zehren and Nusbaum 1992) undoubtedly contributed to the melt characteristics of cheeses containing gelatin. However, the low meltability of cheese spreads containing carrageenan indicated that some polymers yielding heat-meltable gels perform differently in fat-free process cheeses than in model aqueous systems. Carrageenan's unique ability to interact with the phosphoprotein casein (Zehren and Nusbaum 1992) appeared to suppress the meltability of the gel complex in process-cheese spreads containing carrageenan. This suppression of meltability with carrageenan was also observed by Lazaridis and Rosenau (1980) in direct-acidified cheese products. Alternatively, gelatin does not exhibit similar milk protein-complexing abilities (Hsieh and others 1993), thereby yielding a more meltable fat-free cheese.

In regards to spreadability, guar gum additions yielded significantly more spreadability compared to control cheeses prepared without guar gum. This may be due to the thixotropic nature of guar-gum gels (Zehren and Nusbaum 1992) and may indicate that other hydrocolloids possessing this characteristic could enhance the spreadability of fat-free products.

While addition of hydrocolloids did not provide fat-free process-cheese spreads with textural properties simulating full-fat cheese spreads, qualitative observations indicated that products incorporating hydrocolloids had more uniform, smooth consistencies than those without. This was interpreted that certain hydrocolloids may have use in process cheeses, especially when used at lower levels or in process cheeses with high water contents. Brummel and Lee (1990) earlier had indicated that soluble hydrocolloids are useful to improve the texture of low-fat process cheeses containing more than 60% moisture.

Cook time

The length of time fat-free process-cheese spreads were held in the cooker at 75 °C was examined over incremental increasing times up to 20 min (Table 3). In all cases, approximately 4½ min was required to reach cook temperature. Effects of cook time on textural characteristics of experimental process-cheese spreads were most noticeable with respect to firmness and meltability. As cook time increased, significant decreases in the firmness of finished cheeses were observed. On the other hand, meltability tended to increase up to 10 min of cook time after which no further enhancement of melt was observed. Spreadability was not significantly affected by cook time.

Rayan and others (1980) have reported results opposite to these in full-fat processcheeses where increases in cheese firmness and decreases in cheese melt occurred as cook time increased. Rayan and others (1980) linked their results to a modification of native cheese proteins as cook time increased, which yielded finer and more uniform emulsions of fat, thus producing firmer and more readily meltable cheeses. With the absence of fat in cheeses in our study, the consequences of increased breakdown of young cheese proteins as cooking progressed might be explained by a different mechanism where less structure-building capability remained, and less opportunity for protein-protein interaction resulted. While this explanation appears consistent with the observations of this study, further investigation on molecular-weight profiles of cooked cheese must be conducted to verify this hypothesis.

Cook temperature

The effect of cook temperature on the textural attributes of fat-free process-cheese spreads is presented in Table 4. Time required to reach specified cook temperatures in all trials was approximately 4½ min. Results showed that as the cook temperature was increased, firmness generally decreased over the temperature range 60 to 80 °C.

A marked increase in ease of meltability, as well as spreadability, was observed as cook temperatures were raised from 60 to 90 °C. These results clearly showed that fat-free process-cheese spreads produced at higher cooking temperatures exhibited enhanced melting and spreading characteristics. Early reports by Templeton and Sommer (1930) indicated that the body of full-fat process cheeses became firmer as

Table 5—Effect of pH on the functional properties of fat-freeprocess-cheese spreads

pH	Firmness[d] peak force (N)	Meltability[e] flow (mm)	Spreadability[f] total force (N*s)
5.26	26.0[c]	42.8[b]	381.8[c]
5.64	27.1[c]	47.5[b]	472.8[b]
6.09	32.8[b]	85.0[a]	568.2[a]
6.88	46.8[a]	82.3[a]	NSTC

a,b,c Means within a column with no common superscripts differ significantly ($p < 0.05$).NSTC = Not spreadable under test conditions
d Means of triplicate determinations for 2 trials (n = 6)
e Means of duplicate determinations for 2 trials (n = 4)
f Means of duplicate determinations for 2 trials (n = 4), smaller values equal greater spreadability.

cook temperature was increased. Observations in our study indicate that, in the absence of fat, protein-structural interactions and modifications, and not the fat-emulsifying capability of proteins, govern the textural properties of fat-free process cheese.

pH

The effect of pH on cheese texture was evaluated using additions of glacial acetic acid or powdered sodium bicarbonate to adjust the pH of the fat-free process-cheese spread formulations. Physical properties of cheese spreads were examined over the range of pH 5.26 to 6.88, and results are reported in Table 5. As pH values increased, a corresponding increase in cheese firmness resulted, with significant increases above 6.0. In the case of meltability, cheese spreads produced with higher pH values melted more readily than those produced with lower pH values. Results of experimental process-cheese spreads showed those produced at lower pH values were more spreadable than those produced at higher pH values. Steady decreases in spreadability were noticed as pH values increased from 5.26 to 6.88. These observations may indicate the isoelectric point of cheese proteins plays a large role in resulting textures of process cheeses. At higher pH values, cheese proteins are further from their normal isoelectric point of about 5 and tend to exist in a more open conformation (Shimp 1985). This would facilitate protein-protein interactions resulting in increased firmness and decreased spreadability. However, the increased meltability of fat-free process-cheese spreads at higher pH values would not be explained by this theory, indicating that other factors also must beinvolved.

Changes in pH, relative to the isoelectric point of cheese proteins, additionally would be expected to affect the water-binding capacity of fat-free process-cheese spreads. Presumably, cheese proteins function to bind greater amounts of free water at increased pH values (Zehren and Nusbaum 1992). Such changes in the ability to absorb water have been shown to play a major role in the textural performance of various foods (Fennema 1985) and may have influences on the texture of fat-free process cheeses. Overall, the influence of pH on cheese texture may function through a number of mechanisms, and further investigation is needed to clarify its effects.

Conclusions

Emulsifying salts, hydrocolloids, cook time, cook temperature, and pH all affected the final texture of fat-free process-cheese spreads to some degree. Results from this study can be used to identify potential combinations of added ingredients and processing conditions that should produce fat-free process-cheese spreads with improved functionality.

Materials and Methods

Cheese and ingredients

Young hard skim-milk cheese was obtained from local cheese plants and stored at 2 °C, to limit proteolysis, until needed. Ages of cheeses used were closely monitored so that all trials utilized skim-milk cheese 8 wk or younger. Emulsifying salts studied included trisodium citrate (ADM Corp., Decatur, Ill., U.S.A.); disodium phosphate duohydrate (FMC Corp., Philadelphia, Pa., U.S.A.); and Joha S9, Joha SE, and Joha C New (BK Ladenburg Corp., Simi Valley, Calif., U.S.A.). Hydrocolloids studied included gelatin (Rousselot® 175 B 40), carrageenan (Satiagel® RPT 8/60), locust-bean gum (Viscogum® FA), and guar gum (Xwo-112), all from Systems Bio-Industries (Waukesha, Wis., U.S.A.). Dried sweet whey (Davisco Co., Le Sueur, Minn., U.S.A.) and nonfat dried milk (Dairy America™, Fresno, Calif., U.S.A.) were commercially obtained and stored in closed containers at 8 °C until needed.

Manufacture of process-cheese spreads

Pasteurized process-cheese spreads were manufactured in a twin-screw pilot cooker (Blentech Corp., Rohnert Park, Calif., U.S.A.) equipped with variable agitation and indirect steam heating capabilities. Batches of cheese spread were produced from 4700 g freshly ground, hard skim-milk cheese; 2100 g water; 420 g dried sweet whey; 320 g nonfat dried milk; 240 g emulsifying salt; and 80 g salt (Table 6). Disodium phosphate duohydrate was used as the emulsifying salt except where indicated.

Table 6—Fat-free process-cheese spread formulation

Ingredient	%
Hard skim-milk cheese	59.8
Water	26.8
Dried sweet whey	5.3
Nonfat dry milk	4.1
Salt	1.0
Emulsifier	3.0
Hydrocolloid	0
Total	100.0

All dry ingredients were premixed in the cooker for 1 min on high agitation followed by addition of water and cooking up to 75 °C. Indirect steam was used for cooking to control moisture content. Once the desired temperature was reached, steam was turned off, and agitation continued for 5 min for a total cook time of approximately 9½ min. Following the cook procedure, pasteurized process-cheese spreads were filled and sealed in 2-pound high-density polyethylene tubs. Samples then wereplaced at 8 °C in a walk-in cooler for chilling and subsequent storage. A full-fat reference was produced according to the formulation in Table 1, using 2- to 6-wk-old full-fat cheddar cheese instead of skim-milk cheese. The full-fat reference contained 3% disodium phosphate duohydrate as the emulsifying salt. In trials evaluating hydrocolloids, the hydrocolloids were added with the other dry ingredients at a level of 2%, based on the final weight of the fat-free process-cheese spread. In trials evaluating cook time, cheese spreads were held in the cooker for 0, 5, 10, 15, or 20 min after the spread had reached the final temperature of 75 °C. For trials evaluating cook temperature, cheese spreads were heated to final temperatures of 60, 70, 80, or 90 °C and held for 5 min before the spreads were packaged and cooled.

Firmness

Process-cheese spread firmness measurements were made in triplicate using a TA-XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, N.Y., U.S.A.). Two-pound tubs of cheese spread were tempered to 8 °C and penetrated at a rate of 3 mm/s by a 60° stainless-steel cone to a depth of 25 mm. Peak force over the duration of the test was converted into Newtons, and these values were used as a measure of firmness.

Meltability

Meltability of experimental process-cheeses was determined in duplicate by the method described by Olson and Price (1958). Processed-cheese spread samples weighing 15 ± 0.2 g were placed in the glass melt tube and tempered at 8 °C for 1/2-hour before analysis. A waterbath held at 95 ± 1 °C was employed instead of an oven to thermally equilibrate cheese samples during the test. Meltability was indicated by the total cheese flow distance at 8 min in the waterbath.

Spreadability

Spreadability was measured in duplicate using a TA-XT2 Texture Analyzer with a spreadability attachment (Texture Technologies Corp.). Process-cheese spread samples were filled into a female cone with minimal physical structural disruption, and then they were tempered at 8 °C for 1 h. After tempering, samples were displaced to within 2 mm of the base of the female cone using a corresponding male cone attachment for the texture analyzer. Force in Newtons was measured for the duration of the test, and spreadability was equated to the area under the curve. As more easily spread samples required smaller forces to be displaced from the female cone, smaller values reflected easier spreadability. Cheeses requiring forces in excess of the texture analyzer capacity were recorded as not spreadable under test conditions (NSTC) and thus were considered not practically spreadable.

Fat

Fat contents were monitored by the Mojonnier method as outlined by Marshall (1992). Acid hydrolysis with concentrated HCl was carried out directly in the extraction flask following addition of NH_4OH. Flasks were then placed in a gently boiling water bath for approximately 20 min to allow for complete digestion. The remainder of the extraction was executed according to the procedure discussed by Marshall (1992).

Moisture

Moisture contents of all cheese spreads were monitored by the vacuum-oven method outlined by Marshall (1992).

pH

The pH values were monitored throughout the duration of the study using the quinhydrone method described by Van Slyke and Price (1979).

Statistical analysis

Statistical analyses were conducted using Minitab Release 11 (Minitab Inc., State College, Pa., U.S.A.). Differences between treatments were established using 1-way analysis of variance (ANOVA) and the post hoc Tukey's HSD pairwise test ($P < 0.05$).

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References

Anonymous. 1991. Pectin: nature's own fat replacer. Prepared Foods 160(12):57.

Brummel SE, Lee K. 1990. Soluble hydrocolloids enable fat reduction in process cheese spreads. J Food Sci 55:1290-1292, 1307.

Chiu KM. 1991. Addition of soluble hydrocolloids to develop a fat-reduced process cheese spread [MSci thesis]. Madison, Wis.: University of Wisconsin-Madison. 67 p. Available from: University of Wisconsin-Madison, Madison, Wis.

Davidson BC, Schwimmer WH, Prostko LJ, Hamann AC, Buliga GS, Heth AA, Jackson LK, Kerwin PJ, Miller MS, Pechak DG, Smith GF, 1993. Kraft General Foods Inc., assignee. Date issued [1991 Sep 6] Low-fat processed cheese product having fat-mimetic properties and method of making same. U.S. patent 5,215,778.

Fennema OR. 1985. Food Chemistry. 2nd ed. New York: Marcel Dekker, Inc. 991 p.

Fukushima M, DeMan JM. 1970. Effect of processing salts on some rheological properties of process cheese. 18th Int. Dairy Congr.; 18th Intl. Dairy Congr. Oct 12-16. Sydney, Australia. Brussels, Belgium: Int. Dairy Fed. 1E:315.

Gupta SK, Karahadian C, Lindsay RC. 1984. Effect of emulsifier salts on textural and flavor properties of processed cheeses. J Dairy Sci 67:764-778.

Hayter TC, Olson NF, Price WV. 1969. Low-fat pasteurized process cheese product made from Dariworld cheese. J Dairy Sci 52:900.

Hsieh YL, Yun JJ, Rao MA. 1993. Rheological properties of Mozzarella cheese filled with dairy, egg, soy proteins, and gelatin. J Food Sci 58:1001-1004.

Hwang SY, Lindsay RC. 1993. Performance of JOHA condensed phosphate emulsifiers in low-fat processed cheese products. Low-Fat Processed Cheese Products and Ingredients Technology Seminar; 1993 May 11; Madison, Wis. Madison: Center for Dairy Research, University of Wisconsin. p 1-8.

Lazaridis HN, Rosenau JR. 1980. Effects of emulsifying salts and carrageenan onrheological properties of cheese-like products prepared by direct acidification. J Food Sci 45:595-597.

Marshall RT. 1992. Standard Methods for the Examination of Dairy Products. 16th ed. Washington, D.C.: American Public Health Association. 546 p.

Mehnert DW, Prince S. Kraft Foods Inc., assignee. Date issued: 1996 Dec 17. Methods and compositions for fat-free process cheese. Effect of different parameters. U.S. patent 5,585,132.

Mitchell HL. 1993. Novel milk protein concentrate for low-fat foods. Intl Food Ingredients 5:25-28.

Olson NF, Price WV. 1958. A melting test for pasteurized processed cheese spreads. J Dairy Sci 41:999-1000.

Rayan AA, Kalab M, Ernstrom CA. 1980. Microstructure and rheology of processed cheese. Scanning Electron Microscopy 3:635-643.

Rybinski BE, Dawson LE, Bixby DG, Woodford LE. 1993. Kraft General Foods, Inc., assignee. Date issued: 1992 Apr 28. Product and process of producing a no-fat cheese analog containing rennet casein. U.S. patent 5,244,687.

Shimp LA. 1985. Process cheese principles. Food Tech 39(5):63, 64, 66, 68, 70.

Swaitek A. 1964. The effect of type and quantity of emulsifying salts on the consistency of processed cheese. Milchwissenschaft 19:409-403.

Templeton HL, Sommer HH. 1930. Some observations on processed cheese. J Dairy Sci 13:203-221.

Van Slyke LL, Price WV. 1979. Cheese. Atascadero, Calif.: Ridgeview Publishing Co. 522 p.

Zehren VL, Nusbaum DD. 1992. Process Cheese. Madison, Wis.: Cheese Reporter Publishing Co. 364 p.

MS 19991043 received 10/15/99; revised 2/11/00; accepted 4/10/00.

We thank the FMC Corporation (Philadelphia, Pa., U.S.A.) and BK Ladenburg (Simi Valley, Calif., U.S.A.) for supplying emulsifying salts for this study and Systems Bio-Industries, Inc. (Waukesha, Wis., U.S.A.) for providing the hydrocolloids. Appreciation is also extended the Wisconsin Center for Dairy Research for use of equipment and facilities. This research was supported in part by the College of Agriculture and Life Sciences and the Wisconsin Milk Marketing Board.

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