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STRUCTURE, MELTABILITY, AND FIRMNESS
OF PROCESS CHEESE CONTAINING WHITE CHEESE

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Abstract

White cheese made by coagulating heated milk (90°C) with a 2.5% citric acid solution to pH 5.5 consists of casein particles having a characteristic core-and-shell ultrastructure. The presence of this White cheese in process cheese can be detected by transmission electron microscopy on the basis of the core-and-shell ultrastructure which is stable during cheese processing. White cheese additions may be detected at levels equal to or higher than 8%.

White cheese, which does not melt alone when heated, increases meltability of the process cheese in which it is present as an ingredient. Meltability increases at all White cheese concentrations examined (8, 16, and 33%) with trisodium phosphate used as the melting salt. With sodium citrate, there is a 14% increase in meltability at 8% White cheese. Meltability of process cheese containing 16% White cheese is about the same as the control process cheese, and meltability of process cheese containing 33% White cheese is decreased by 20%.

Firmness of process cheese made with sodium citrate increases as the proportion of White cheese is increased from 8 to 33% but decreases in process cheese made with trisodium phosphate except at the highest White cheese concentration.

Introduction

Process cheese is made by heating and stirring blends of various natural cheeses and other ingredients in the presence of melting salts. Ripened cheeses form the major part of the cheese blend [3] but a cultured ultrafiltered whole milk retentate was used as a major ingredient by Ernstrom et al. in 1980 [7]. Since then, experimental results have been reported by many authors. For example, Savello et al. [21] found good melting properties of process cheese made with acid casein as well as rennet casein using appropriate melting salts. Recently, Tamime et al. [22] processed cheese blends containing large proportions of a cheese base prepared from a retentate obtained by ultrafiltration and diafiltration of reconstituted skim milk. One part of the cheese base was used as obtained by coagulating the milk with a bacterial starter culture and calf rennet and the other part was treated after coagulation by adding a protease to increase proteolysis. Anhydrous milk fat was added to the cheese blends to provide the desired fat content in the finished product. Process cheese made from these blends was of acceptable quality.

Unripened cheeses such as White or Ricotta cheeses made by coagulating hot milk with an acid [16] may also be used as ingredients in the process cheese blends. The use of these products in process cheese would be economically advantageous because (a) unripened cheese may be used directly from the manufacture without aging, (b) the yield is higher due to the recovery of both casein and whey proteins, and (c) unripened cheeses have very low bacterial counts at the time of manufacture.

Unripened cheese used in the process cheese blend may affect the texture and structure of the finished product. Being unable to melt on heating, White cheese is expected to decrease meltability of the process cheese in which it is used. However, it would be difficult to detect unripened cheese by chemical analysis because there are only very small differences in qualitative chemical composition between process cheeses made from ripened cheese and process cheeses in which White cheese has been used as an ingredient. One difference is the presence of κ-casein in the form of a complex with β-lactoglobulin in White cheese, where it develops as a result of heating milk to 90°C before coagulation. A possibility of detecting White cheese by electron microscopy has arisen from a finding that unripened White cheese made by acid coagulation of hot milk contains a characteristic ultrastructure. This ultrastructure,
initially called the core-and-lining ultrastructure by Harwalkar and Kalab [8] who studied it in milk gels obtained from heated milk coagulated with glucono-δ-lactone, is characterized by casein particles having solid cores surrounded by proteinaceous shells. There is a void space of 50 to 80 nm in width, between the cores and the shells. The presence of the milk salt system and β-lactoglobulin was found to be essential for the full development of this ultrastructure. The ultrastructure is found in several dairy products, e.g., Queso Blanco [13] and Paneer cheeses [12]. Recently renamed [11], the core-and-shell ultrastructure has been found very stable when exposed to various treatments such as frying in oil. An earlier finding of the core-and-shell structure in commercial process cheese [4] suggested that White cheese was probably used as an ingredient in the manufacture of the process cheese. The objective of this study was to examine effects of White cheese on the ultrastructure in commercial process cheese [4] suggested by other researchers [11].

Materials and Methods

White cheese

White cheese was prepared in two different dairy establishments on laboratory and pilot plant scales. In both instances, the preparation consisted of heating commercial milk, having a 3% fat content, at 90°C for 10 min and coagulating the proteins using a 2.5% citric acid solution (45 mL/L of milk). In one preparation, the citric acid solution was dispersed in the milk through a spray nozzle [16] during the continuous production of White cheese and in the other preparation it was added in a thin stream from a can while the milk was mechanically stirred. The final pH of the coagulum was 5.5 in each case. The curd, consisting of casein and whey proteins, was drained overnight in perforated trays lined with cheese cloth. The White cheese used in this study contained 18.2% protein, 17.3% fat, and 58.6% moisture.

Process cheese

Process cheese was made from blends of natural cheeses and three levels of White cheese: 8%, 16%, and 33%. One series of blends consisted of a 1:1 ratio of mild and medium ripened Cheddar cheese diced in the form of 1.5 cm cubes, and other ingredients such as White cheese, butter, sodium chloride, and sorbic acid used as a preservative. The blends were processed using 2.5% sodium citrate or trisodium phosphate (TSP) as melting salts. Spray-dried whey powder was used as an ingredient in two experimental sets of process cheese (Table 1) but was not used in another set. The mass of each individual batch was 4.7 kg.

Processing was carried out in a kettle heated with indirect steam, which was equipped with a stirrer operated at 80 rpm. The cheese blends were heated to 85°C and maintained at this temperature for 10 min, and then were homogenized for 3 min in an Ultra-Turrax homogenizer (type T65 DPX 5115). The homogenized blends were hot-packed in plastic 450-mL tubs, cooled at 20°C, and stored at 4°C.

Analyses

Moisture was determined by drying the process cheese samples at 100±2°C to constant mass and fat was determined by extraction according to the Roese-Gottlieb method [1].

Meltability of the process cheeses under study was determined according to the method designed by Olson and Price [17] and slightly modified by Savello et al. [21]. Process cheese columns, 25 mm in diameter and 25 mm high, weighing 15.0±0.1 g, were placed at rubber-stopped ends of 250 mm long Pyrex glass tubes having 25 mm inner diameter, and the opposite ends were closed with rubber stoppers, each having a 3-mm hole. The tubes were heated in horizontal position for 50 min at 110°C. As the process cheese samples melted, the distance to which they spread, was measured in millimetres (mm) and was used as a criterion of meltability.

Firmness was measured using the Ottawa Texture Meter [6] equipped with a cylindrical cell, 48 mm in diameter. Three wires, 0.4 mm in diameter, 139 mm total length, were driven at 177 mm/min through the cheese placed in the cell and the resistance in grams was recorded on a chart; the data were converted into newtons (N). The mean resistance was accepted as the firmness of that particular sample. All firmness measurements were carried out in duplicate at 25°C.

The search for the core-and-shell structure in the White cheese and processed cheese samples was carried out using transmission electron microscopy (TEM). Process cheese samples were taken for TEM at 3 stages: (1) when the temperature of the blends reached 70°C, (2) after heating at 85°C for 10 min, and (3) after homogenization. The samples were cooled to 6°C, cut into ~1 mm3 cubes, and fixed with a 2.8% glutaraldehyde solution for 24 h and postfixed with a 2% osmium tetroxide in a 0.05 M veronal-acetate buffer, pH 6.85, for 4 h. The fixed samples were dehydrated in a graded ethanol series, embedded in a Spurr's low-viscosity medium (J. B. EM Service, Pointe Claire, Dorval, Quebec, Canada), and sectioned. Thin sections (90 nm) were stained with uranyl acetate and lead citrate solutions [20] and examined in a Philips EM 300 electron microscope operated at 60 kV. Micrographs were taken on 35-mm film.

Table 1. Ingredient composition of process cheese blends containing 8 and 33% White cheese

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Na citrate (%)</th>
<th>TSP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheddar mild</td>
<td>34.8</td>
<td>34.2</td>
</tr>
<tr>
<td>Cheddar medium</td>
<td>34.8</td>
<td>34.2</td>
</tr>
<tr>
<td>White cheese</td>
<td>7.9</td>
<td>7.8</td>
</tr>
<tr>
<td>Water**</td>
<td>10.5</td>
<td>12.8</td>
</tr>
<tr>
<td>Whey powder</td>
<td>6.6</td>
<td>6.5</td>
</tr>
<tr>
<td>Butter</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Sorbic acid</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Cheese colour</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Na citrate</td>
<td>2.9</td>
<td>--</td>
</tr>
<tr>
<td>Trisodium phosphate</td>
<td>--</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Total 99.93 99.93 100.03 100.03

* Percentage of White cheese present in the blend.
** Including crystal water in the melting salts.
Results and Discussion

White cheese

Coagulation of hot milk by acidification produces a fine curd which contains both casein and whey proteins. The whey consists mostly of lactose.

The structure of the resulting curd (White cheese) depends on the conditions under which it has been made. A uniform distribution of the acid in the hot milk achieved by the use of a spray nozzle produces a well-developed core-and-shell ultrastructure (Fig. 1). Distribution of the citric acid solution through a nozzle having numerous fine openings resulted in the production of White cheese consisting almost exclusively of casein particle clusters having the characteristic core-and-shell ultrastructure.

In commercial processes which do not distribute the acid evenly, the conditions are not as favourable to the development of the ultrastructure. Mixing of the milk and the acid on a large scale results in the formation of areas, where local pH may temporarily deviate from the value of 5.5 because in the vicinity of the acid outlet the milk may be overacidified, as was mentioned in the study on the structure of Paneer cheese [12]. Consequently, areas of the casein particle clusters resemble those found in Cottage cheese, may also be found. These findings are in agreement with the studies of the conditions necessary for the development of the core-and-shell structure [8-10]; different structures were found in the curd, if the pH value deviated from 5.5 by as little as one half of a unit.

Process cheese

There were two control samples of process cheese made: (a) process cheese made solely from a blend of natural cheeses, and (b) process cheese made from a blend of Cheddar cheese to which spray-dried whey powder had been added.

Ingredient composition of process cheese blends is listed in Table 1 only for samples made with the addition of whey powder. With the 3 levels of White cheese present in the process cheese samples, the total solids fluctuated between 59 and 63%, protein was 19.8-22.0%, and fat ranged from 25.8 to 28.5%. The only significant difference was in the pH value: process cheese samples made with sodium citrate had pH of 5.8-5.9 whereas with TSP, pH was 6.6-6.7 (Table 2).

![Image of the core-and-shell structure](https://example.com/core-shell.jpg)

**Fig. 1. The core-and-shell structure (C for "core" and arrow for "shell") was well developed in casein particles of White cheese made by acidulating hot (90°C) milk with citric acid using a spray nozzle; coagulated casein particles, in which this structure was not developed (P), were also present. F: Fat particles.**

<table>
<thead>
<tr>
<th>Table 2. Composition (%), pH, firmness, and meltability of process cheeses which contained 8 to 33% of White cheese</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese:</td>
</tr>
<tr>
<td>(melt, salt)</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>(Citrate)</td>
</tr>
<tr>
<td>Control</td>
</tr>
<tr>
<td>8% WC</td>
</tr>
<tr>
<td>16% WC</td>
</tr>
<tr>
<td>33% WC</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>(TSP)**</td>
</tr>
<tr>
<td>Control</td>
</tr>
<tr>
<td>8% WC</td>
</tr>
<tr>
<td>16% WC</td>
</tr>
<tr>
<td>33% WC</td>
</tr>
</tbody>
</table>

* White cheese
** Trisodium phosphate

Structurally, the control process cheese (a) had a uniform protein matrix, in which only fat globules and individual bacteria could be seen. In contrast, electron-dense areas having apparently no organized structure (Figs. 2A and B) were observed in the control process cheese (b) made with the addition of spray-dried whey powder. The use of whey proteins in the form of a dry whey powder apparently prevented their uniform dispersion and dissolution in the aqueous phase of the process cheese. The undissolved whey protein particles were found as compact inclusions in the product.

White cheese was added to the cheese blends at 3 different concentrations: 8, 16, or 33%. Areas having the core-and-shell structure were clearly noticeable at all levels of White cheese in the process cheese samples irrespective of the presence of the spray-dried whey powder. The core-and-shell structure found in the process cheese samples was easy to distinguish from the whey powder particles and resembled the structures present in the initial White cheese (Figs. 3A and B and 4A and B). The characteristic features of the structure were particularly well preserved in process cheese made with trisodium phosphate (Figs. 3A and B). Degradation of the structure consisted of widening the annular space between the shells and the cores and granulation of the cores. In process cheese made with sodium citrate, the characteristic features consisted of the shell material whereas the cores were degraded to a greater extent (Fig. 4A) than in process cheese made with TSP and were frequently reduced to minute inclusions in areas surrounded by the shells (Fig. 4A).
Fig. 2. Spray-dried whey powder added to the cheese blend appeared as dark compact areas (W) in the protein matrix (P) of process cheese made with trisodium phosphate (Fig. 2A) and also in process cheese made with sodium citrate (Fig. 2B). F: Fat particles.

Fig. 3. The core-and-shell structure was relatively well preserved in process cheese which contained White cheese when trisodium phosphate was used as the melting salt. Short and long arrows point to cores and shells, respectively. A: 16% White cheese; B: 8% White cheese. F: Fat particles.

Fig. 4. Process cheese made with White cheese using sodium citrate as the melting salt showed considerable degradation of the core-and-shell structure. Short and long arrows point to cores and shells, respectively. A: 16% White cheese; B: 8% White cheese. F: Fat particles.

Fig. 5. The core-and-shell structure (C for "core" and arrow for "shell") remained intact in White cheese heated at 50°C for 12 h. F: Fat particles.

Fig. 6. The core-and-shell structure of White cheese retained its characteristic features in process cheese heated at 50°C for 12 h. A and B: Two different samples of process cheese made with trisodium phosphate; C: Process cheese made with sodium citrate. Short and long arrows point to cores and shells, respectively. F: Fat particles.
The core-and-shell structure was stable in White cheese heated at 50°C for 12 h (Fig. 5). The characteristic features of White cheese present in process cheese also remained preserved after additional heating of the process cheese samples in sealed glass vials at 50°C for 12 h. The differences between process cheeses made using TSP (Figs. 6A and 6B) and sodium citrate (Fig. 6C) were noticeable also after heating. In the former process cheese, both the shells and the cores were clearly visible, but in process cheese made using sodium citrate (Fig. 6C), the shells were better preserved than the cores. Heating at 60°C for 24 h resulted in the disintegration of the process cheese into aqueous, lipid, and protein phases. The protein phase turned dark and was not further examined.

Meltability

In the original procedure designed by Olson and Price [17] to measure meltability of process cheese, the sample was heated at 110°C for 6 min. This heating was extended firstly to 30 min by Rayan et al. [19] and later to 60 min by Savello et al. [21]. The latter procedure was followed in our tests.

Meltability of the control cheese samples containing whey protein powder but no White cheese made with TSP or sodium citrate was similar (Table 2) in spite of the difference in pH. However, the addition of White cheese affected the meltability in different ways depending whether the process cheeses were made with TSP or sodium citrate. Addition of 8% of White cheese to the blends significantly increased their meltability. The increase was greater with TSP than with sodium citrate. Doubling the amount of White cheese in the blends to 16% slightly increased the meltability of the process cheese made with TSP but markedly decreased it in the cheese made with sodium citrate. Replacing one third of the total amount of cheese with White cheese reduced the meltability of both types of process cheese. With TSP, however, the cheese still melted easier than the control process cheese whereas meltability of the cheese made with sodium citrate was decreased by about 20% (Fig. 7).

These results may seem to contradict the work by Ernstrom et al. [7] who found that the addition of a cheese base made from an ultrafiltration retentate to a process cheese blend decreased meltability of the resulting product. However, there is an important difference between our results and those reported by Ernstrom et al. The interaction of β-lactoglobulin and κ-casein occurred during the production of White cheese before it was mixed with Cheddar cheese whereas in the other work, the whey proteins were denatured by heating in a mixture with Cheddar cheese which means that this interaction was taking place in the process cheese blend. Addition of rework, consisting of excessively heated process cheese which does not melt alone, also decreased meltability of process cheese [14] but the compact structure of this type of rework is considerably different from the structure of White cheese.

Firmness

Firmness of the control process cheeses under study (Table 2) reflected their pH, which was 5.8-5.9 in the citrate-containing samples and 6.6-6.7 in the TSP-containing samples. Having other parameters such as the total solids and fat contents similar to each other, the process cheese samples made with sodium citrate were considerably firmer (23.0 mN) than those made using TSP (18.6 mN). The increasing concentration of White cheese in process cheese made with sodium citrate increased the firmness of the samples. This contrasted with samples made with TSP, where the additions of 8 and 16% White cheese decreased the firmness and only the 33% proportion of White cheese in the process cheese increased its firmness by slightly over 10% (Fig. 8).
Electron microscopy showed that in both cases the White cheese was well dispersed in the process cheese protein matrix. However, this technique cannot be used to provide any base for speculation on possible interactions between White cheese and Cheddar cheese proteins. A different set of experiments would be required to establish mutual correlations between the structure of process cheese on one hand and the nature of melting salts, pH, meltability, and firmness on the other hand. The initial objective of this study was to detect the presence of White cheese in process cheese using electron microscopy and this objective has been achieved.

Conclusions

The easy and rapid manufacture of White cheese makes it a suitable ingredient in process cheese. Even at a 33% concentration, the White cheese blended well with mild and medium ripened Cheddar cheese and resulted in the manufacture of an acceptable product. The core-and-shell structure of casein particles, which characterizes milk products made by acid coagulation of hot milk, persisted in the process cheese blends. Processing and homogenization evenly distributed the curd but left the core-and-shell structures mostly undisturbed. It was thus possible to detect them by transmission electron microscopy as a proof that White cheese was used as an ingredient in the manufacture of that particular process cheese. Disruption of the core-and-shell structure, which to some extent occurred in the process cheeses under study, was less noticeable in products made with trisodium phosphate than with products made with sodium citrate. It was possible to easily detect 8% of White cheese in the finished product; the limit of detection is probably lower. In general, White cheese has a similar qualitative chemical composition as natural cheese and other milk protein-based ingredients used to produce process cheese. Its presence in process cheese, therefore, may not be easily detected by chemical analytical methods. The most significant difference between White cheese and the other ingredients is structural, with the core-and-shell structure being of submicroscopical dimensions. For this reason, the detection of White cheese in process cheese may be accomplished primarily by transmission electron microscopy.

Acknowledgments

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References


Discussion with Reviewers

D. N. Holcomb: Proteolysis is known to affect cheese meltability; does increased proteolysis lead to increased meltability? Did the authors determine proteolysis in their cheeses? Was it the same in the White and Cheddar melts?
Authors: We did not study the relationship between proteolysis and meltability. One could speculate that extensive proteolysis in regular renneted cheese would lead to decreased meltability and increased separation of the fat from the protein matrix due to weakening of the protein structures which hold the moisture and fat components in an intricate balance.

D. N. Holcomb: Firmness of cheese has often been assessed by measuring the compression forces when the cheese is compressed between stainless steel platens with an Instron tester or a related instrument. Campanella et al. [2], Casiraghi et al. [5], and others have argued convincingly that such results are more meaningful if the specimens are lubricated with silicone oil. With unlubricated specimens, we measure a composite friction/firmness parameter, and it is difficult to separate the two factors. Might the same concerns apply to the Ottawa Texture Meter? That is, couldn't the wire-cheese friction be significant, just as the platen-cheese friction was significant enough to concern the cited authors? A sticky cheese, with a high coefficient of friction, would appear to be firmer than a comparable non-sticky cheese.
Authors: Had the wires in the Ottawa Texture Meter been lubricated with silicone oil, questions would arise as to whether the silicone oil lubricated the wires with equal efficiency throughout the entire path of measurement, whether there was no interference with the fat in the process cheese, etc. We recognize that all such measurements are arbitrary.

Nadia Carrell: In process cheese, 1% difference in moisture or fat can have significant impact on firmness and perhaps also meltability. It is difficult to evaluate with certainty the effect of increased White cheese content when the solids, protein, and fat are so different amongst the samples. In the samples made with TSP, there are differences of 2% in fat content. This difference alone could account for the difference in meltability and firmness. Firm conclusions can only be drawn regarding the 0% and 33% samples, which are close in composition.
Authors: We agree with the reviewer.

D. N. Holcomb: Park et al. [18] compared four procedures for cheese meltability evaluation and found a marked lack of correlation. The authors of the present paper concluded that the TEM technique allows one to detect the presence of White cheese in a process cheese. Did they find any correlation between meltability and other physical properties? Can the authors speculate as to why there is such a complicated variation of meltability (an increase, then a decrease) with increasing White cheese content? Would the presence (or absence) of the proposed core-and-shell structure be expected to affect meltability?
S. Taneya: Could you explain why meltability increased and then decreased depending on the amount of White cheese?
Authors: We assume that at a low concentration such as 8%, White cheese does not contribute structurally to the integrity of the cheese matrix; in fact, it may disrupt the cheese structure and cause it to flow more easily. At higher concentrations, White cheese may reduce meltability because it reduces the proportion of the highly meltable ripened Cheddar cheese.
We are unable to answer the question as to whether the core-and-shell structure would affect meltability of process cheese, because this structure cannot be separated from the White cheese. By coagulating hot milk to pH other than 5.5, no core-and-shell structure would develop but one might argue that the difference in pH might be more important than the presence of the core-and-shell structure.

D. N. Holcomb: Sometimes a particular batch of process cheese does not melt normally and more or less time in the blender may be required; this seems to be related to the lot of natural cheese being used in the blend. Did the White cheese-containing blends behave the same as those without White cheese? Different times of working in the blender could lead to differences in meltability and/or texture. This may be analogous to the rework phenomenon with which the authors have previously investigated [14].
Authors: No differences were observed in the various treatments with respect to the behaviour of the blends during either the melting or homogenizing steps.

D. N. Holcomb: Could the authors state what were the protein contents of their White and Cheddar cheeses? Is it only coincidental that the blend protein contents were constant, or was some adjustment made to keep that level the same?
Authors: The protein content of the White cheese used in this study was 18.2% but was not determined in the Cheddar cheese; however, this product consistently contained 25.0% protein (±0.2%) based upon previous experience in this laboratory.

D. N. Holcomb: If only duplicate measurements were made and those values were used to calculate standard deviations, one might argue that a standard deviation so calculated cannot have much significance and that only ranges
should be reported.

**Authors:** Approximate ranges may be obtained in this case by multiplying the standard deviations by a factor of 0.7. Thus, an expression of 25.7 ± 1.4 may be converted into a range of 24.7 to 26.7 (1.4 x 0.7 = 0.98, i.e., approx. 1.0; 25.7 - 1.0 = 24.7 and 25.7 + 1.0 = 26.7).

**Nadia Carrell:** Why were the cheeses homogenized? How does this homogenization step affect the microstructure? Can you comment on differences in the cheese structure observed before and after homogenization?

**Authors:** Homogenization was necessary to disintegrate the White cheese and distribute it uniformly through the process cheese product. One must remember that the White cheese does not melt; therefore, it must be distributed by mechanical means.

As indicated, samples were taken at various stages of processing. In addition to uniformly distributing the White cheese in the product, homogenization reduced the dimensions of the fat particles. There were local high and low concentrations of the core-and-shell structure in samples taken before homogenization but the structure itself was not destroyed by homogenization.

**Nadia Carrell:** Why were the cheeses heated to 50°C? Please comment and explain.

**Authors:** The cheeses were exposed to heat (50°C and 60°C) in order to examine the stability of the core-and-shell structure. Heating at 60°C led to the disintegration of the process cheese but heating at 50°C did no affect it; the core-and-shell structure was altered by the latter temperature neither in White cheese nor in process cheese.

**Nadia Carrell:** Can you provide a reference to the statement that the compact structure of rework is considerably different?

**Authors:** Klostermeyer and Buchheim [15] found areas of compacted protein in replicas of freeze-fractured samples of process cheese that had been heated at 140°C. It is probable that these areas are related to osmiophilic areas found in process cheese that had been heated at 82°C for 5 h and subsequently fixed with osmium tetroxide and examined by electron microscopy in the form of thin sections [14].

**Nadia Carrell:** In your micrographs of the White cheese (Fig. 1), the fat appears to be excluded from the core-and-shell structure. However, in the process cheeses made with White cheese, particularly in Figs. 3B, 4A, and 4B, there is fat within the core-and-shell structure. Do you ever find fat in the core-and-shell structure of the White cheese? Will you comment on the structures in the process cheese containing fat?

**Authors:** We have not found core-and-shell structures in the White cheese which would contain fat. This is probably because these structures originate from the casein micelles [8-11]. However, when the White cheese is mixed with Cheddar cheese and the blend is melted and homogenized, it is probable that emulsified fat particles become incorporated in the mass of the White cheese as it is dispersed during processing. This process may also explain partial separation of the shells from the cores.

**Nadia Carrell:** Since the White cheese used in this study was made by acidifying milk with citric acid, the process cheeses made with White cheese had higher levels of emulsifier, citrate, than those without White cheese. In addition, the higher the level of White cheese, the more emulsifier in the process cheese. If the White cheese had been produced with lactic acid, for example, there would be no difference in emulsifier level. Please comment on how your results are influenced by the varying levels of citrate.

**Authors:** It is true that the White cheese contributed some citrate to the system, but the amount is rather small (0.05-0.22 g of citric acid/kg of process cheese) when compared with the 25.0 g of sodium citrate added per kg of the blend by means of formulation. The above values take into account consideration of the following factors: 45 mL of a 2.5% citric acid solution were added per L of cheese milk; cheese yield was 14.8%; White cheese contained approximately 60% moisture and 0.08 g citrate-citric acid/kg of the product; 8%, 16%, or 33% of White cheese was present in the finished process cheese.

**Nadia Carrell:** Sodium citrate is widely used and quite appropriate for this study. Trisodium phosphate (TSP) is not. TSP is not used alone as an emulsifying salt but in combination with other salts to adjust the pH of process cheeses. Why was this used and not disodium phosphate? Use of TSP has resulted in a cheese of pH 6.6-6.7. (At this pH, it cannot really even be called cheese). It is no wonder that the firmness and meltability of the cheeses made with TSP were different from those made with sodium citrate. Therefore I find the conclusions of the effect of emulsifying salt greatly overstated. A discussion of the effects of pH on texture, and on microstructure, is needed.

**Authors:** The objective of this study was to test the possibility of detecting White cheese in process cheese and not to prepare a new variety of process cheese. In contrast to sodium citrate, TSP provided an extreme pH value, yet the core-and-shell structure was not changed by this condition. Meltability and firmness measurements were merely used to characterize the samples under study and to complement the electron microscopic analysis.

**Nadia Carrell:** Process cheeses can undergo changes in meltability, firmness, and structure with time. How old were the cheeses when they were assayed? Did you follow any of the products for structural changes over time?

**Authors:** The cheeses were analyzed immediately after preparation. Homogenization, extreme pH value (6.7), and heating at 50°C were used to test the stability of the core-and-shell structure but the effects of storage were not examined.