Influence of Emulsifying Salts on the Textural Properties of Nonfat Process Cheese Made from Direct Acid Cheese Bases

C. A. Brickley,* S. Govindasamy-Lucey,† J. J. Jaeggi,† M. E. Johnson,† P. L. H. McSweeney,* and J. A. Lucey‡¹

*University College Cork, Cork, Ireland

†Wisconsin Center for Dairy Research, and

‡Department of Food Science, University of Wisconsin-Madison, 53706

ABSTRACT

The objective of this study was to investigate the influence of several types of emulsifying salts (ES) on the texture of nonfat process cheese (NFPC). Improperly produced nonfat cheese tends to exhibit several problems upon baking including stickiness, insufficient or excessive melt, pale color upon cooling, formation of a dry skin (skinning) often leading to dark blistering, and chewy texture. These attributes are due to the strength and number of interactions between and among casein molecules. We propose to disrupt these interactions by using suitable emulsifying salts (ES). These ES chelate Ca and disperse caseins. Stirred curd cheese bases were made from skim milk using direct acidification with lactic acid to pH values 5.0, 5.2, and 5.4, and ripened for 1 d. Various levels of trisodium citrate (TSC; 0.5, 1, 1.5, 2, 2.5, 3, and 5%), disodium phosphate (DSP; 1, 2, 3, and 4%), or trisodium phosphate (TSP; 1, 2, 3, and 4%) were blended with the nonfat cheese base. Cheese, ES, and water were weighed into a steel container, which was placed in a waterbath at 98°C and then stirred using an overhead stirrer for 9 min. Molten cheese was poured into plastic containers, sealed, and stored at 4°C for 7 d before analysis. Texture and melting properties were determined using texture profile analysis and the UW-Melt-profiler. The pH 5.2 and 5.4 cheese bases were sticky during manufacture and had a pale straw-like color, whereas the pH 5.0 curd was white. Total calcium contents were approximately 400, 185, and 139 mg/100 g for pH 5.4, 5.2, and 5.0 cheeses, respectively. Addition of DSP resulted in NFPC with the lowest extent of flow, and crystal formation was apparent at DSP levels above 2%. The NFPC manufactured from the pH 5.0 base and using TSP had reduced melt and increased stickiness, whereas melt was significantly increased and stickiness

was reduced in NFPC made with pH 5.4 base and TSP. However, for NFPC made from the pH 5.4 cheese and with 1% TSP, the pH value was >6.20 and crystals were observed within a few days. Use of TSC increased extent of flow up to a maximum with the addition of 2% ES for all 3 types of cheese bases. Addition of high levels of TSC to the pH 5.2 and 5.4 cheese bases resulted in increased stickiness. Similar pH trends for attributes such as extent of flow, hardness, and adhesiveness were observed for both phosphate ES but no consistent pH trends were observed for the NFPC made with TSC. These initial trials suggest that the pH 5.0 cheese base was promising for further research and scale-up to pilot-scale process cheese making, because cheeses had a creamy color, reasonable melt, and did not have high adhesiveness when TSC was used as the ES. However, the acid whey produced from the pH 5.0 curd could be a concern.

Key words: process cheese, cheese texture, emulsifying salt, nonfat cheese

INTRODUCTION

Consumers are becoming more conscious of their health and of the nutritional benefits of foods. To some consumers cheese may be seen as an undesirable food product due to its relatively high fat content. There continues to be an emphasis on the development of nonfat cheese that retains the desirable flavor and textural attributes associated with full-fat cheeses.

However, problems have been associated with nonfat cheeses, such as undesirable color, texture, poor melt, and scorching or browning (Tunick et al., 1991). In the past, several attempts have been made to alleviate these problems by increasing the moisture content of cheese, which results in a decrease in the protein density of the matrix, thereby facilitating better flowability. Increasing the moisture content has been achieved by a number of modifications to the manufacturing procedure, such as increasing the pH at milling (Kosikowski and Mistry, 1997), the addition of exopolysaccharide-

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¹Corresponding author: jaluacey@facstaff.wisc.edu

producing starter cultures (Perry et al., 1997), or the addition of whey proteins (Mistry, 2001). Denatured whey proteins (heat-treated to temperatures $>80^{\circ}\text{C}$) have an increased ability to bind water and they have been added during the manufacture of several varieties of low-fat cheeses such as Havarti-type cheeses (Lo and Bastian, 1998) and Edam (Schreiber et al., 1998). However, Guinee et al. (1998) observed that high levels of denatured whey protein due to high pasteurization temperatures might disrupt curd fusion during cheese manufacture resulting in a cheese of poor quality. Both protein- and carbohydrate-based fat replacers have also been used in an effort to increase the moisture content and to improve the functionality of low fat cheese (McMahon et al., 1996). Although high moisture contents result in improved meltability in low and nonfat cheeses, there is also a reduction in the shelf life of these cheeses. In addition, high moisture cheeses are often sticky, which can cause serious problems in the vat during cheese manufacture, and stickiness is an undesirable attribute in the final cheese (e.g., poor shreddability).

The concentration of Ca in cheese is one of the main factors contributing to its meltability (Lucey and Fox, 1993). Cheeses with a high Ca content are less meltable compared with cheeses with lower Ca levels. This is because much of the Ca in cheese is in an insoluble form, which forms crosslinks involving phosphoserine groups on caseins. These crosslinks help to strengthen the overall casein network and provide a rigid and less meltable cheese texture when cheese is heated. In this study the cheese bases were manufactured using direct acidification, which is a well-known method used to reduce the total Ca content in cheese (Keller et al., 1974). These authors also found that when the final pH of Mozzarella cheese was lowered, an increase in cheese meltability was achieved.

In this study nonfat process cheeses (NFPC) were made on a small scale, and several types of emulsifying salts (ES) were investigated. Emulsifying salts act by solubilizing the colloidal calcium phosphate and hydrating caseins during process cheese (PC) manufacture, which leads to a more shelf-stable cheese with specific functional characteristics. Various types of ES were tested to alter the characteristics of the initial cheese base to improve the functional properties in the NFPC, such as meltability and stickiness. Manufacturing NFPC on a small scale had many advantages in this study, primarily that we were able to study the effects of several ES at a number of levels without major time and cost constraints, which would have been incurred for such an extensive study on a larger scale. However, because this project was carried out on a small scale, sample sizes were small and only a re-

stricted number and type of analyses could be carried out.

In this study, we tried to overcome the problems associated with nonfat cheeses by making NFPC from cheese bases that were manufactured to have specific textural characteristics and with the use of different types of ES during process cheese making. The ultimate goal of this study was to develop a NFPC with improved textural and functional properties.

MATERIALS AND METHODS

Cheese Base Manufacture

Stirred curd cheese bases were made from skim milk by direct acidification of cold (approximately 4°C) milk using lactic acid to pH values 5.0, 5.2, and 5.4. Acid was added in several increments and once the target pH of the milk had been reached and maintained for approximately 30 min, CaCl_2 (18 mL/100 kg of milk) was added to improve rennet coagulation properties. Milk was then heated to 33°C at which point rennet (Chymax Extra Double Strength, Chr. Hansen, Milwaukee, WI) was added at a level of 2 g/100 kg of milk. When the coagulum was sufficiently firm, it was cut using 12.7-mm knives. The curd-whey mixture was then stirred as the temperature in the vat was increased from 33 to 37°C over a 20-min period. Once the cooking temperature (37°C) was reached, the whey was completely drained from the vat. The curd was then dry-salted at a level of 49 g/100 kg of milk before being filled into 9-kg Wilson-style hoops and pressed for 60 min at 275.8 kPa. Cheese bases were then packed and stored at 4°C for 1 d before being used for the manufacture of small-scale NFPC. Two 9-kg blocks of cheese were obtained from each vat. Cheese bases were manufactured at each of the desired pH values at least 3 times.

Small-Scale NFPC Manufacture

Cheese base (90 g) that had been aged for 1 d, trisodium citrate (TSC) at 0.5, 1, 1.5, 2, 2.5, 3, or 5%, disodium phosphate (DSP) at 1, 2, 3, or 4%, and trisodium phosphate (TSP) at 1, 2, 3, or 4%, and water (added to adjust the final moisture content to a constant level of 57 to 58%) were weighed into a steel container. This steel container was placed in a waterbath that was preheated to 98°C and the contents were stirred using a Maxima digital overhead stirrer (Fisher Scientific International Inc., Hampton, NH) fitted with a paddle stirrer at 20 rpm for 1 min, followed by 200 rpm for 30 s, and finally 400 rpm for 7.5 min. Loss of moisture through evaporation during stirring was minimized by placing a plastic cover over the top of the steel container.

Once the mixing was complete, the molten cheese (~74°C) was poured into plastic containers that had diameters of 30 mm (for UW-Meltprofler and compositional analysis) or 16 mm (for texture profile analysis). These containers were then sealed with a plastic film and stored at 4°C for 7 d before analysis. All NFPC treatments were manufactured in triplicate.

Compositional Analysis

Both the cheese bases and the NFPC were analyzed for moisture (IDF, 1982) and pH by direct insertion of the probe into the cheese samples (pH meter 420A, Orion Research, Beverly, MA). The cheese bases were also analyzed for protein using the Kjeldahl method (IDF, 1986), fat (Marshall, 1992), total calcium using the method described by Mizuno and Lucey (2005), and insoluble calcium using the acid-base buffering method (Hassan et al., 2004). Cheese bases were analyzed after 1 d of storage, whereas process cheese samples were analyzed after 7 d of storage. All analyses were carried out in triplicate.

Texture Profile Analysis

Cylindrical samples (16 mm diameter, 17.5 mm height) of NFPC were taken, placed in a sealed plastic bag, and stored overnight at 4°C. The NFPC sample was then compressed twice between 2 flat surfaces to 80% of its original height at a rate of 1 mm/s using a Texture Analyzer TA-XT2 (Stable Micro Systems, Godalming, Surrey, UK). Hardness and adhesiveness were calculated as described by Bourne (1978). At least 6 replicates were performed for each treatment.

Meltability

A cylindrical sample (30 mm diameter, 7 mm height) was taken from the NFPC, placed in a sealed plastic bag, and stored overnight at 4°C. The extent of flow (EOF); that is, cheese height as a percentage of initial cheese height when cheese was heated to 60°C in an oven set at 72°C, was measured using the UW-Meltprofler that was designed by Muthukumarappan et al. (1999). At least 3 replicates were performed for each treatment.

Statistical Analysis

Analysis of variance was carried out using the SAS software (SAS Institute, 1999). The level of significant difference was determined at $P < 0.05$. The correlation coefficient (R^2) between responses was calculated using Sigmaplot software (Systat Software Inc., Richmond, CA).

RESULTS AND DISCUSSION

Cheese Base Manufacture and Color

One of the major problems associated with nonfat cheese is its behavior in the vat during manufacture, including excessive stickiness to equipment (e.g., walls). During manufacture of the cheese bases in this study, both the milks acidified to pH 5.2 and 5.4 produced curds that were extremely sticky and stringy in the vat making them very difficult to work with. However, the curd from milk acidified to pH 5.0 was not sticky, making it easier to handle during manufacture.

Following manufacture, the pH 5.2 and 5.4 cheeses were straw-like or translucent in color, whereas the pH 5.0 cheese was white. The white color of the pH 5.0 cheese was attributed to the fact that the cheese pH was approaching the isoelectric point of caseins, which caused the casein molecules to aggregate and exhibit this white color (Lee et al., 2005). Low pH (<5) cheeses such as Feta tend to be white. In this study color differences were due to changes in the type of protein interactions in the cheese bases, because all 3 cheeses had the same fat content (Table 1). The white color or opacity of the pH 5.0 base was due to increased casein interactions in the system resulting in a highly aggregated structure that had greater light-scattering properties. The translucency of the pH 5.2 and 5.4 cheeses in turn may have been due to the formation of a fine-stranded matrix, which allowed light to pass through the protein matrix (a similar phenomenon occurs in whey protein gels; Foegeding and Bowland, 1995).

Cheese Base Composition

The composition of the pH 5.0, 5.2, and 5.4 cheese bases are shown in Table 1. Fat levels were low and ranged from 1.2 to 1.5%, which, according to the Food and Drug Administration guidelines for the labeling of low and nonfat cheese (FDA, 2004), would classify the cheese bases as nonfat (i.e., <1.6% fat, or 0.5 g of fat for a 28-g serving). The moisture contents of the cheese bases increased as the pH values and total calcium contents in the cheese system decreased, as was previously reported by O'Mahony et al. (2006). The use of lactic acid to preacidify the cheesemilk was successful in reducing total (Table 1) and insoluble Ca (Figure 1) concentrations in the cheese bases, in agreement with previous preacidification studies involving Mozzarella cheese manufacture (Keller et al., 1974). In the acid-base buffering curves of the cheese bases (Figure 1), the buffering peak at pH ~4.8 is caused by the solubilization of colloidal calcium phosphate (Lucey and Fox, 1993). This peak can still be clearly identified in the pH 5.4 cheese curd; however, it does not appear to be

Table 1. Compositional data (means $\pm$ SD) for the nonfat cheese bases used in process cheese manufacture

Base	pH	Moisture, %	Protein, %	Fat, %	Calcium, mg/100 g
pH 5.0 base	5.04 $\pm$ 0.01 ^a	58.4 $\pm$ 1.5 ^a	31.5 $\pm$ 0.4 ^a	1.2 $\pm$ 0.1 ^a	137 $\pm$ 2 ^a
pH 5.2 base	5.21 $\pm$ 0.04 ^b	55.6 $\pm$ 2.5 ^b	37.8 $\pm$ 2.3 ^{bc}	1.5 $\pm$ 0.1 ^b	185 $\pm$ 8 ^b
pH 5.4 base	5.41 $\pm$ 0.04 ^c	54.1 $\pm$ 1.1 ^{bc}	35.6 $\pm$ 0.4 ^b	1.2 $\pm$ 0.1 ^a	352 $\pm$ 8 ^c

^{a-c}Means with different superscript letters within the same column are significantly different ($P < 0.05$).

present in either the pH 5.0 or pH 5.2 curds, because the total Ca levels were extremely low in these cheeses. We concluded from these buffering curves that the Ca present in the pH 5.0 and 5.2 cheeses was likely to be mostly in the soluble form.

Cheese Base Meltability

The melt profiles for the cheese bases during heating are shown in Figure 2. Because these cheeses contain very low levels of fat, it can be assumed that the flow is due to the relaxation of, or changes in, protein-protein interactions in the cheese system (Lucey et al., 2003). The pH 5.2 and 5.4 cheese bases both display good melting properties with EOF values of 71 and 72%, respectively. This could be due to the significant reduction in the Ca levels in the cheeses, greatly reduced casein crosslinks, and increased protein hydration facilitating greater protein mobility during heating (Joshi et al., 2004). The pH 5.0 cheese base also had very low levels of both total Ca and insoluble Ca; however, there was a clear reduction in meltability (EOF = 53%) compared with the bases with higher pH values. This was attributed to the fact that at this low pH value the cheese was approaching the isoelectric point of the ca-

seins, and so extensive casein aggregation (electrostatic and hydrophobic) resulted in a cheese with a much firmer texture and reduced melt. The pH 5.0 cheese base also started to flow (i.e., initial reduction in cheese height) at a much higher temperature than the pH 5.2 and 5.4 cheeses, indicating that more thermal energy was required to initiate flow, signifying a difference in the protein interactions present in the pH 5.0 cheese base. The pH 5.0 base had much greater moisture content (3 to 4%) compared with the other bases and yet had inferior melt. This result agrees with studies that have shown that very low pH (e.g., ≤ 5.0) curds have reduced melt (e.g., Lee et al., 2005).

Process Cheese Composition

In all cases, as the ES concentration in the NFPC increased there was a concomitant increase in the pH of the NFPC due to the buffering abilities of these ES (Table 2). All 3 ES are alkaline in nature (pH values for 1% solutions of TSC, DSP, and TSP are 8.3, 9.8, and 13.0, respectively; Fox et al., 2000) and their addition to NFPC mixtures results in an increase in pH. The

Figure 1. Acid-base buffering curves of nonfat cheese bases at pH 5.0 (Δ), pH 5.2 ($\bullet$), and pH 5.4 ($\square$) used in process cheese manufacture. Titrated from initial curd pH to pH 3.0 with 0.5 N HCl and titrated from pH 3.0 to pH 9.0 with 0.5 N NaOH. Arrow indicates location of pH $\sim$ 4.8 buffering peak during acidification. Data points are means of 3 replicates.

Figure 2. Cheese height (as a percentage of initial cheese height) as a function of heating temperature for nonfat cheese bases, pH 5.0 (Δ), pH 5.2 ($\bullet$) and pH 5.4 ($\square$) tested using the UW-Meltprofiler. Cheese bases were heated from 10 to 65°C over a 15-min period. Data points are means of 3 replicates.

Table 2. pH values (means $\pm$ SD) for nonfat process cheeses made from different pH cheese bases and different emulsifying salts

Emulsifying salt ¹	Cheese base		
	pH 5.0	pH 5.2	pH 5.4
TSC, %			
Control	5.11 $\pm$ 0.02 ^a	5.26 $\pm$ 0.03 ^b	5.44 $\pm$ 0.07 ^c
0.5	5.18 $\pm$ 0.04 ^a	5.38 $\pm$ 0.01 ^b	5.52 $\pm$ 0.10 ^c
1.0	5.26 $\pm$ 0.03 ^a	5.43 $\pm$ 0.01 ^b	5.64 $\pm$ 0.13 ^c
1.5	5.28 $\pm$ 0.03 ^a	5.46 $\pm$ 0.02 ^b	5.69 $\pm$ 0.14 ^c
2.0	5.30 $\pm$ 0.01 ^a	5.54 $\pm$ 0.04 ^b	5.74 $\pm$ 0.13 ^c
2.5	5.34 $\pm$ 0.01 ^a	5.61 $\pm$ 0.07 ^b	5.77 $\pm$ 0.13 ^c
3.0	5.39 $\pm$ 0.01 ^a	5.67 $\pm$ 0.13 ^b	5.81 $\pm$ 0.12 ^c
5.0	5.54 $\pm$ 0.04 ^a	5.83 $\pm$ 0.09 ^b	5.94 $\pm$ 0.09 ^c
DSP, %			
Control	5.11 $\pm$ 0.02 ^a	5.26 $\pm$ 0.03 ^b	5.44 $\pm$ 0.07 ^c
1	5.52 $\pm$ 0.01 ^a	5.60 $\pm$ 0.11 ^b	5.74 $\pm$ 0.05 ^c
2	5.73 $\pm$ 0.03 ^a	5.78 $\pm$ 0.06 ^b	5.89 $\pm$ 0.09 ^c
3	6.06 $\pm$ 0.07 ^a	6.07 $\pm$ 0.04 ^b	6.14 $\pm$ 0.04 ^c
4	6.21 $\pm$ 0.02 ^a	6.29 $\pm$ 0.02 ^b	6.39 $\pm$ 0.04 ^c
TSP, %			
Control	5.11 $\pm$ 0.02 ^a	5.26 $\pm$ 0.03 ^b	5.44 $\pm$ 0.07 ^c
1	5.69 $\pm$ 0.03 ^a	5.90 $\pm$ 0.09 ^b	6.09 $\pm$ 0.11 ^c
2	6.30 $\pm$ 0.07 ^a	6.55 $\pm$ 0.12 ^b	6.69 $\pm$ 0.02 ^c
3	6.93 $\pm$ 0.06 ^a	7.23 $\pm$ 0.06 ^b	7.41 $\pm$ 0.07 ^c
4	7.61 $\pm$ 0.04 ^a	8.05 $\pm$ 0.04 ^b	8.84 $\pm$ 0.10 ^c

^{a-c}Means with different superscript letters within the same row are significantly different ($P < 0.05$).

¹TSC = trisodium citrate; DSP = disodium phosphate; TSP = trisodium phosphate.

phosphate salts increased the pH of the NFPC more than the use of similar concentrations (by weight) of TSC, with TSP exhibiting the greatest increase in pH. During NFPC manufacture, all cheeses were adjusted to a final moisture content of ~58% by the addition of water. This was done to ensure that variations in moisture were not responsible for any of the observed changes in NFPC functionality.

Process Cheese Meltability

The EOF for the different NFPC samples as a function of ES concentration for the different types of ES are shown in Figure 3. Increasing the TSC levels up to 2% tended to increase meltability slightly for NFPC made using all 3 cheese bases (Figure 3a); however, these increases in melt were not significantly different for all NFPC. This improved melt was probably due to an increase in the pH value of NFPC resulting in increased electrostatic repulsion and a weakening of casein interactions present in the system. The EOF of NFPC was plotted as a function of pH for the different cheese bases (Figure 4). An increase in EOF was observed with a small increase in pH of the 3 types of cheese bases, but overall pH did not appear to be the dominant influence here because various EOF values were observed at the same pH value for NFPC made from different bases. Swenson et al. (2000) also found

Figure 3. The extent of flow for nonfat process cheese made with (a) trisodium citrate, (b) disodium phosphate, and (c) trisodium phosphate and using the pH 5.0 (○), pH 5.2 (●) and pH 5.4 (□) cheese bases. Data points are means of 3 replicates and error bars are the standard deviations. Extent of flow was measured using the UW-Meltprofiler.

Figure 4. Extent of flow, hardness, and adhesiveness values for the nonfat process cheeses made with trisodium citrate, disodium phosphate, or trisodium phosphate and using the pH 5.0 (○), pH 5.2 (●), or pH 5.4 (□) cheese bases. Data points are means of 3 replicates.

that increased pH in nonfat process cheese spreads resulted in increased meltability. This increase in melt could be due to the chelation of Ca associated with casein in the cheese system by TSC. The loss of Ca crosslinks would result in reduced casein-casein interactions and increased melt. At TSC levels greater than 2% (Figure 3a), melt decreased for all NFPC treatments. One possible explanation is that high pH values and high TSC levels may have promoted excessive casein dispersion during PC cooking and, upon cooling, a more reinforced network formed due to an increase in the number of possible casein interactions. Shirashoji et al. (2006) have also found in full-fat PC systems that there was a reduction in melt with an increase in TSC levels even when the pH values and moisture content of these cheeses were constant.

For the phosphate salts, very high meltability was observed in the NFPC at 1% ES levels; as the levels of DSP (Figure 3b) and TSP (Figure 3c) increased above 1%, there was a decrease in meltability. There was a

decrease in the EOF with an increase in pH for both phosphate ES (Figure 4). The phosphate salts did an excellent job of casein dispersion when added at the 1% level; however, further increases in the ES concentration in the cheeses caused a large increase in pH values and in turn excessive casein dispersion that could have resulted in a reduction in melt. Some types of phosphate ES also have the ability to act as crosslinking agents between casein molecules, which is another factor that could contribute to reduced melt in the NFPC system. This effect was also reported by Mizuno and Lucey (2005) who observed a large reduction in cheese meltability with the addition of tetrasodium pyrophosphate to nonfat Mozzarella cheese.

Texture Profile Analysis of Process Cheese

The addition of TSC, DSP, and TSP also affected the textural properties of the NFPC. Hardness values for NFPC made from the different pH bases and the differ-

Figure 5. Hardness values determined from texture profile analysis of nonfat process cheese made with (a) trisodium citrate, (b) disodium phosphate, and (c) trisodium phosphate and using the pH 5.0 (○), pH 5.2 (●), and pH 5.4 (□) cheese bases. Data points are means of 3 replicates and error bars are the standard deviations.

ent types of ES are shown in Figure 5. Hardness values as a function of pH are shown in Figure 4. With the addition of TSC up to 2%, there was a reduction in hardness for the NFPC made using the pH 5.0 cheese

base or the pH 5.2 cheese base (Figure 5a), which could be due to the weakening of casein interactions in the system due to the loss of Ca crosslinks. In the case of the NFPC manufactured using the pH 5.4 cheese base and TSC, there was a decrease between 0.5 and 1%; there was little change in hardness in NFPC between 1 and 3% TSC. A large increase in NFPC hardness was observed at TSC levels >3%, which agrees with earlier results in which melt tended to decrease at high TSC levels (Shirashoji et al., 2006). The NFPC made using TSC and the pH 5.0 cheese base were harder than the corresponding cheeses made using the pH 5.2 or 5.4 cheese bases. This result was expected because the pH 5.0 cheese base was significantly firmer (results not shown) and less meltable than both the pH 5.2 and 5.4 cheese bases (Figure 2) because of a large increase in the attractive forces (electrostatic and hydrophobic) between caseins in the pH 5.0 cheese base (due to the approach of the isoelectric point of caseins; Lucey et al., 2003). The addition of TSC to the pH 5.0 cheese base probably weakened these interactions by chelating Ca crosslinks (Shirashoji et al., 2006) and increasing the pH of NFPC; both probably resulted in increased electrostatic repulsion in the NFPC system. The pH 5.4 cheese base had significantly lower hardness values than the pH 5.2 cheese base at nearly all levels of TSC addition (except for 0.5 and 1%, for which there was no difference in hardness). No consistent pH trend for hardness was seen for the NFPC made with TSC (Figure 4).

As the level of DSP (Figure 5b) or TSP (Figure 5c) increased in NFPC, there was an increase in hardness, which agrees with previous results for NFPC spreads reported by Swenson et al. (2000). Hardness increased with increasing pH for the NFPC made with both DSP and TSP (Figure 4). There was no difference in the hardness of the NFPC cheese made with TSP at the 3 and 4% levels. When TSP was used as the ES, the NFPC made from the pH 5.0 cheese base were harder than the other cheese bases at the 1 and 2% ES levels. When DSP was used at low ES levels (1%) the pH 5.0 cheese base was harder than the other cheese bases, but at higher ES levels, the pH 5.4 cheese base had greater hardness values. An inverse relationship existed between NFPC meltability and NFPC hardness (regardless of cheese base or type of ES used).

Adhesiveness for the different NFPC samples as a function of the type and concentration of ES is shown in Figure 6. The greatest adhesiveness values for the pH 5.0 bases were observed at 2.5% TSC and adhesiveness decreased at greater levels of TSC (Figure 6a). For the pH 5.2 cheese bases, the greatest adhesiveness values were observed at 1.5% TSC, and adhesiveness decreased greatly at >2.5% TSC. For the pH 5.4 cheese

Figure 6. Adhesiveness values determined from texture profile analysis of nonfat process cheese made with (a) trisodium citrate, (b) disodium phosphate, and (c) trisodium phosphate and using the pH 5.0 (○), pH 5.2 (●), and pH 5.4 (□) cheese bases. Data points are means of 3 replicates and error bars are the standard deviations.

bases, the greatest adhesiveness values were observed at 2% TSC, and adhesiveness decreased at greater TSC levels. In the case of the phosphate salts, an increased ES content resulted in decreased adhesiveness (Figure 6b, 6c). The NFPC made using the pH 5.0 cheese base at all TSC levels had very low adhesiveness values (i.e.,

Figure 7. Adhesiveness values for nonfat process cheese (NFPC) made from the pH 5.2 cheese base as a function of pH for cheese made with (○) trisodium citrate, (□) disodium phosphate, and (●) trisodium phosphate (TSP); control cheese (■) contained no emulsifying salt. The shaded region indicates the main sticky zone for the NFPC. Data points are means of 3 replicates.

low stickiness) compared with those made using the pH 5.2 or pH 5.4 cheese bases.

Nonfat process cheeses made using DSP and the pH 5.0 base had much lower stickiness values than NFPC made with either the pH 5.2 or 5.4 cheese bases. The NFPC made using 1% TSP and the pH 5.0 cheese base were much stickier than those NFPC made using the pH 5.0 cheese base and the other types of ES. This may be because the addition of 1% TSP to NFPC resulted in a very large decrease in hardness compared with the NFPC made from the pH 5.0 cheese base and using 1% of TSC or DSP. The NFPC system made with the pH 5.0 cheese base and 1% TSP was very fluid, which promoted increased stickiness in the system.

Nonfat process cheeses in the pH range of approximately 5.3 to 5.9 were stickier than NFPC with other pH values regardless of the ES type or cheese base used in its manufacture (Figure 7). However, there were NFPC samples within this pH range that were not sticky and so it was concluded that pH was one important contributory factor to stickiness but not the only determining factor.

A scatter plot for adhesiveness and hardness values for NFPC made with DSP from the pH 5.2 and pH 5.4 cheese bases is shown in Figure 8. Similar trends were observed for the other types of ES studied (results not shown). We observed that harder cheeses tended to be less sticky, which is in agreement with the findings of Dahlquist (1969). That author reported that the storage modulus (index of elasticity and firmness) of an adhesive must be below 10^5 Pa for adhesion to occur. The NFPC made using the pH 5.2 and 5.4 bases were stick-

Figure 8. Adhesiveness values as a function of hardness values for nonfat process cheese made from the pH 5.2 (●) and pH 5.4 (□) cheese bases and using disodium phosphate as the emulsifying salt. Data points are means of 3 replicates.

ier than those made using the pH 5.0 base. The trends for adhesiveness were consistent with those observed for hardness, with an increase in adhesiveness observed when hardness decreased, and vice versa. Comparing the results for the pH 5.0, 5.2, and 5.4 cheese bases showed that a very low correlation ($R^2 = 0.23$) was observed (Figure 8). However, when the data for the NFPC made using the pH 5.2 and 5.4 bases were analyzed, there was a negative correlation ($R^2 = 0.82$) between hardness and adhesiveness (Figure 8). This again indicates that the use of the pH 5.0 cheese base resulted in NFPC with very different characteristics compared with the other pH cheese bases. The pH 5.0 cheese base resulted in harder NFPC due to an increased number of attractive forces in the system, and these NFPC samples were also less sticky.

Crystal Formation

Crystals were usually observed in NFPC containing $\geq 3\%$ DSP or $\geq 1\%$ TSP. These NFPC samples had pH values of approximately 6 (Table 2), which is close to the pH optimum for calcium phosphate precipitation (Scharpf and Kichline, 1968). These authors also reported that the pH of the cheese system and the level of added phosphates were the most important factors that contribute to crystal formation in process cheese. They also found that at pH values >6 , crystals would almost certainly be observed but that at pH values <6 , crystals would only be observed at high levels of added phosphates.

CONCLUSIONS

The pH 5.0 cheese base was not sticky in the vat during manufacture and thus was quite easy to work

with. The pH 5.0 cheese base also had a desirable creamy white color and, when used for NFPC manufacture, resulted in a reduction in stickiness, particularly when TSC or DSP were used as the ES. However, the low pH of the pH 5.0 base is unattractive as an acid whey is produced. Nonfat process cheeses in the pH range of approximately 5.3 to 5.9 were the stickiest; however, pH was not the only determining factor but rather one contributory factor to NFPC stickiness. The increased pH due to the addition of DSP and TSP resulted in the dispersion of caseins during cooking. Excessive casein dispersion resulted in NFPC that exhibited reduced flow during heating and increased hardness after cooling. It is possible that phosphate salts may also crosslink caseins, further contributing to hardness. For the NFPC made using TSC as the ES, melt tended to increase and hardness decreased with the addition of up to 2% ES; this was probably due to a decrease in Ca crosslinks. However, at ES levels $>2\%$, melt decreased and hardness increased, which was probably due to excessive casein dispersion resulting in the formation of a firmer structure on cooling (possibly due to the formation of a finer matrix with more numerous casein interactions). No clear pH trend was observed for NFPC made with TSC for attributes like melt, hardness, or adhesiveness. For the NFPC made with both phosphate salts there was a decrease in melt and adhesiveness and an increase in hardness with an increase in pH. The use of TSC had advantages over the use of the phosphate salts, including reasonable melt that could be obtained with low adhesiveness levels, and there was less risk of crystal formation.

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