Effect of pH on technological parameters and physicochemical and texture characteristics of the pasta filata cheese Telita

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ABSTRACT

The objective of this study was to determine the effect of stretching pH on technological parameters and physicochemical and texture characteristics of the pasta filata cheese Telita. A no-brine cheese-making method was used to control both melting and stretching temperatures. Six vats of cheese, each with a different stretching pH (5.2, 5.3, 5.4, 5.5, 5.6, and 5.7), were made in 2 h. Cheese-making was replicated using 2 different lots of milk. Differences in stretching pH significantly affected all variables evaluated; stretching temperature and pH were positively correlated. Technological parameters showed an inverse relationship between pH and acidity and a direct relationship between melting and stretching temperature. The yield was highest as the pH increased and ranged from 11.4 to 12.9 kg of cheese/100 kg of milk. Physicochemical characteristics showed the following: moisture 48.1 to 53.5% (soft and semi-hard cheese), fat 46.3 to 54.9% (dry basis, full-fat cheese), minerals 2.8 to 3.5% (dry basis), calcium content 0.5 to 1.0% (dry basis), sodium 0.38 to 0.78% (dry basis), and whiteness index 77.2 to 84.5. Texture parameters showed that as the stretching pH increased, hardness increased, adhesiveness decreased, cohesiveness decreased, springiness increased, and chewiness increased. Samples were grouped based on principal component analysis. Group 1 contained cheeses at pH 5.2 and 5.3 and were better in terms of retention of components. Group 2 contained cheeses at pH 5.6 and 5.7. These cheeses attained the highest yields, were whitest, and presented the highest values for texture parameters except for adhesiveness and cohesiveness. The third group of cheeses at pH 5.4 and 5.5 were considered the best because they showed a good balance among all variables evaluated.

Key words: pasta filata cheese Telita, stretching pH, physicochemical, texture

INTRODUCTION

In Venezuela, Telita cheese is classified as a “pasta filata” cheese, which is made by preacidification of milk to reach the melting point in the curd as an initial step for the stretching process when subjected to temperatures over 40°C. This type of cheese is soft (72% moisture on free-fat basis), white, unripened, and medium fat (40%; Sangronis and García, 2007). Telita cheese is very popular in Venezuela because it has a unique structure characterized by forming string similar to that of mozzarella cheese but with a softer texture. However, Telita cheese is made in an artisanal form (made manually from unpasteurized milk), and limited information exists on the effects of melting and stretching temperature during the manufacturing process, and how acidification affects the physicochemical composition, texture characteristics, and yields. Traditional Telita cheese made from raw milk is not made using starter cultures. If the cheese is made using pasteurized milk, it is recommended (but not required) that a starter culture be used.

In Venezuela, daily milk production during 2012 was 8 million liters, of which 80% was destined for cheese manufacturing (46% for industrial cheese and 34% for artisanal cheese). Data indicate the great importance of cheeses in the milk processing industry in Venezuela (FEGAVEN, 2012).

Many factors can influence texture, melting, and stretching properties of cheese. These include cheese composition, pH, and interactions between casein and serum proteins, proteolysis, Ca content, ionic strength, salt content, and manufacturing protocols (McMahon et al., 1993; Rowney et al., 1999; Guinee et al., 2002).

A well-known pasta filata cheese is Mozzarella cheese, whose acidification is performed in the curd via fermentation. A study by Kiely et al. (1992) proved that the optimum condition for curd melting and stretching of
the string in this type of cheese was a pH ranging from 5.2 to 5.4. The total amount of Ca in cheeses has also been shown to influence cheese texture (Solorza and Bell, 1995; Yun et al., 1995) and can be controlled with a variety of manufacturing parameters, including pre-acidification, pH at whey draining, cooking rate, and final cooling temperature (Metzger et al., 2001). Likewise, Lucey et al. (2003) indicated that cheese pH and mineral content have a major influence on the structure and texture of cheese. In fact, it has been suggested that the texture of Mozzarella cheese may be more dependent on pH than on any other factor (Lawrence and Gilles, 1982). It is more likely that the proportion of Ca phosphate, in an undissolved form, varied in these types of cheeses, depending on the pH value, which may have contributed to the reported differences in texture.

Cheese yield is defined as the weight of cheese obtained from a given weight of milk with defined contents of casein and fat. This is affected by many factors, including milk composition, milk pretreatment, coagulant type, curd firmness at cutting, cutting program, vat design, and curd handling system (Fenelon and Guinee, 1999). In this regard, the purpose of this work was to study the effect of pH on melting and stretching temperature, as well as physicochemical and texture characteristics of Telita cheese from pasteurized milk when using lactic acid as the acidifying agent.

**MATERIALS AND METHODS**

**Materials and Preparation of Lactic Acid Solution**

The milk used for manufacturing Telita cheese was provided by the Louisiana State University Agricultural Center dairy farm (Baton Rouge). The herd was composed of mechanically milked Holstein cows. Calcium chloride at 32% (food grade, Nelson Jameson, Marshfield, WI) was added to the milk at a rate of 16 g of CaCl₂/100 L of milk. Lactic acid solution (LAS; Aldrich Chemical Co., St. Louis, MO) at 4% (450°Dornic, 1°Dornic = 1 mg of lactic acid per 10 mL of solution) was used for reducing the pH of the milk. Chymosin (Chy-Max Extra, Chr. Hansen, Milwaukee, WI) was used at a rate of 10 mL of chymosin/100 L of milk for clotting.

**Telita Cheese-Making Procedure**

Ten liters of 3% fat milk was filtered and pasteurized at 63°C for 30 min and cooled to 5°C. Five milliliters of CaCl₂ (16 g of CaCl₂/100 L of milk) was added to the milk. Then, milk was acidified (demineralized) at the same temperature using LAS at 4% with required quantities to reach the different stretching pH (5.2, 5.3, 5.4, 5.5, 5.6, and 5.7) and obtain demineralized milk (Figure 1). Milk was then heated at 20°C for clotting by addition of 1 mL of chymosin to form paracasein calcium phosphate gel. The mixture was then allowed to rest for 40 min (these steps represent the first stage of the process).

The gel was then cut using a stainless steel lyre (1 cm²) to form both whey and acidified curd, which was heated to 40°C and gently stirred with a stainless steel paddle until the curd (size of a chickpea) emerged from the whey, and was allowed to settle for 5 min. The whey was then drained off to separate it from the curd before direct salting was applied in the vat with 10 g of salt (100 g of salt per 100 L of milk). Salt was mixed for 1 min (second stage of the process). The acidified and salted curd was poured into a stainless steel container and heated before melting and stretching.

The melting and stretching temperatures are pH dependent and were measured during the process. After the stretching process, the stretched curd was kneaded and pressed to obtain a bright and homogeneous cheese. In this step, the weight of the cheese was measured to calculate the yield as kilograms of cheese per 100 kg of milk. Next, the cheese was molded in small, round plastic containers, cooled to 5°C, and vacuum packaged. Finally, the packaged cheeses were stored at 5°C for analysis (third stage).

**Experimental Design and Statistical Analysis**

The purpose of this paper was to study whether stretching pH had a significant effect on the technological parameters during the cheese-making process as well as on the physicochemical and texture characteristics of the Telita cheese. Six different stretching pH values (5.2, 5.3, 5.4, 5.5, 5.6, and 5.7) represent the treatments and cover the range of stretching in this type of cheese. Cheese-making was replicated in 2 different lots of milk (repetitions). A completely randomized design was carried out in accordance with the treatment proposed, and the data generated from the experiments were analyzed by one-way ANOVA. When the treatments were significant, the means were compared using the post hoc multiple comparison Tukey’s studentized ranged test (honestly significant difference test, α = 0.05), resulting in statistical groupings. All data analysis was performed using SAS software version 9.3 (SAS Institute Inc., Cary, NC).

**Measurement of pH and Titratable Acidity**

The pH in the milk and LAS (4%) was measured with an Orion 520 pH meter (Orion Labs, Tucson, AZ) and determined by official method 947.05 of AOAC In-
Sodium hydroxide (0.1 \(N\)) was used to determine acidity of milk in terms of lactic acid and converted to °Dornic by using the following equivalence: 

\[1^{\circ}\text{Dornic} = 1 \text{ mg of lactic acid/10 mL of milk.}\]

For the most part, the milk contained 0.17% lactic acid, which is equivalent to 17°Dornic.

**Melting and Stretching Temperatures**

Melting temperature is defined as the temperature at which each piece of the curd starts to melt and lose its form. Stretching temperature is when the melted curd starts to strand easily upon stretching when it is
subjected to 2 opposing forces by using 2 stainless steel paddles. The acidified curd was put into a 2-L stainless steel vessel. The vessel was immersed in warm water until the melting and stretching temperatures were reached. The temperature difference between the water bath and the vessel used for the experiments was kept at 10°C, meaning if the stretching temperature was 50°C, the water bath was 60°C. The melting temperature was determined at the moment when the small pieces of curd started to melt. At that point, the temperature was checked in the center of the curd using a digital thermometer. When the melted curd started to form strands, the temperature was also checked. The stretch time was 1 min per 100 g of acidified curd. The analyses were done 24 h after cheesemaking.

Yields

Yield attained in the Telita cheese-making process was calculated as the weight of cheese obtained (kg of cheese/100 kg of milk).

Physicochemical Analysis

AOAC International (1995) methods were used to quantify moisture (method 926.08), protein (method 976.06), ash (method 935.42), and Ca content (method 985.01). Fat content was measured in duplicate using a modified Babcock test (Richardson, 1985). Color of cheeses was measured with a Minolta handheld spectrophotometer model CM-508d (Minolta Co. Ltd., Osaka, Japan) with illuminant D65 and 2° observer. Whiteness index (WI) was calculated as 100 − [(100 − L*)2 + a*2 + b*2]1/2, where L* (lightness), a* [redness (+)–greenness (−)], and b* [yellowness (+)–blueness (−)] were also recorded.

Texture Analysis

Three representative samples were picked randomly from each of the 6 treatments and cut into 13 mm × 17 mm pieces for analysis using an automatic texture analyzer TA-XT2 PLUS (Stable Micro Systems, Godalming, UK; Exponent 32 V 1.0.0.13 software), fitted with a 5.08-cm compression platen probe (TA-25). Hardness, cohesiveness, adhesiveness, and chewiness were calculated as described by Bourne (1968).

RESULTS AND DISCUSSION

Cheese-Making Process and Technological Parameters

Table 1 describes the results of analyses of acidity (°Dornic), melting and stretching temperatures (°C), and yields (expressed as kg of cheese/100 kg of acidified curd or kg of cheese/100 kg of milk) for each pH (5.2 through 5.7), which were identified as technological parameters in this research.

Acidity in the Milk

The statistical analysis of the acidity showed significant differences (P < 0.05) among evaluated treatments. Cheese with pH of 5.2 obtained the highest acidity value (47.5°Dornic) and cheese with pH of 5.7 had the lowest value (32.5°Dornic). This indicates that to reduce the pH of the milk to the lowest value requires at least 32% more LAS. No significant differences were found between samples stretched at pH 5.3 and 5.4 or between samples stretched at pH 5.5 and 5.6. Cheeses manufactured at the artisanal level characteristically have pH values between 5.6 and 5.8 (Sangronis and García, 2007).

The acidity of the milk used in the manufacturing of Telita cheese is required to achieve the melting and stretching temperatures when the acidified curd is subjected to heating. In this study, lactic acid in pure form was added directly into the milk. The acidity reached in the curd and not in the milk, starters are used at the beginning of the process to attain the stretching pH. In the case of Telita cheese, stretching

Table 1. Technological parameters of pasta filata cheese type Telita at different stretching pH1

<table>
<thead>
<tr>
<th>Variable</th>
<th>5.2</th>
<th>5.3</th>
<th>5.4</th>
<th>5.5</th>
<th>5.6</th>
<th>5.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidity (°Dornic)</td>
<td>47.50 ± 3.53a</td>
<td>46.00 ± 1.41ab</td>
<td>43.90 ± 2.82ab</td>
<td>40.50 ± 0.70b</td>
<td>36.50 ± 2.12cd</td>
<td>32.50 ± 2.12d</td>
</tr>
<tr>
<td>Melting temperature (°C)</td>
<td>38.75 ± 0.35</td>
<td>35.15 ± 1.20c</td>
<td>40.36 ± 2.77</td>
<td>48.30 ± 3.81b</td>
<td>49.45 ± 3.32ab</td>
<td>55.00 ± 1.41c</td>
</tr>
<tr>
<td>Stretching temperature (°C)</td>
<td>46.60 ± 0.01b</td>
<td>44.45 ± 1.90d</td>
<td>49.60 ± 0.56c</td>
<td>54.50 ± 0.70c</td>
<td>58.60 ± 2.26ab</td>
<td>64.30 ± 0.42c</td>
</tr>
<tr>
<td>Yield2</td>
<td>12.12 ± 0.31 b</td>
<td>11.45 ± 0.20a</td>
<td>12.76 ± 1.03a</td>
<td>12.73 ± 0.06ab</td>
<td>12.53 ± 0.52ab</td>
<td>12.99 ± 0.10a</td>
</tr>
</tbody>
</table>

1For each variable, means with different superscripts within a row indicate significant differences (P < 0.05).
2Means ± SEM of 2 repetitions.
3Yield = kg of cheese/100 kg of milk.
Melting Temperature

Melting temperature significantly increased \((P < 0.05)\) from pH 5.4 to pH 5.7 at 40.3 and 55.0°C, respectively; the lowest melting temperature (35.1°C) was obtained at pH 5.3. This means that it required much more heat to melt the acidified curd as the pH increased, especially from pH 5.4. Melting (as it applies to cheese) is the ability of the cheese to flow and spread as well as the loss of (visual) integrity of the individual cheese shreds (Lucey et al., 2003). The same authors pointed out that, from a physical point of view, a substance melts when it transforms from a solid-like to liquid-like state. Cheese curd in the current study started to melt around 38°C. These melting values are lower than reported by Lucey et al. (2003), whose reported values were around 40°C. This was probably because the strength of the casein–casein interaction decreased because the temperature to melt the curd was lower. Therefore, lower stretching temperature and less energy are required for stretching at pH between 5.2 and 5.4; this is advantageous in terms of energy savings. Park et al. (1984) suggested that melting of the cheese is primarily determined by the number and strength of the casein–casein interactions. Hydrophobic interactions, which tend to increase in strength with temperature (Bryant and McClements, 1998), can also influence melting. A balance exists between hydrophobic interaction and electrostatic repulsion. At the start of the acidification process, hydrophobic interactions are higher than electrostatic repulsion so the formed curd is hard because the protein strands are separated and neutralized by the calcium bridges. However, if the acidity in the milk continues to decrease, the Ca comes out from the protein interaction as ionic Ca and the protein strands in the formed curd are closer, electrostatic repulsion increases, the curd is weaker, and the stretching temperature decreases.

Stretching Temperature

Significant differences \((P < 0.05)\) were detected for the different stretching pH values evaluated (Table 1). The minimum (44.5°C) and maximum (64.3°C) stretching temperatures were found at minimum and maximum pH values evaluated (5.2 and 5.7, respectively). The post hoc multiple comparison Tukey’s studentized range test (HSD) showed that the stretching temperatures were separated into 5 groups. The lowest pH values (5.2 and 5.3) formed 1 group with lower values of stretching temperature (44.4 and 46.0°C), respectively. Other pH values (5.4–5.7) formed the remaining 4 groups, with higher values obtained. As the pH increased in these groups, the stretching temperature also increased from 49.60 to 64.30°C.

The temperature of stretching in the directly acidified cheeses provides an indirect measure of the strength of the casein network in the curd before the stretching process: because the paracasein network is stronger, a higher curd stretching temperature is required to get the cheese to stretch. Traditionally, pasta filata type cheese curd is stretched in hot water (70°C) and kneaded until the proper texture is achieved. This process imparts unique characteristics to this type of cheese (Renda et al., 1997; Lucey et al., 2003). Because the casein network is strongest at higher pH, more heat is necessary and more energy is required. According to Renda et al. (1997), the temperature of stretching can range from about 50 to 65°C. This range of temperature is in agreement with findings in this research.

Regression Analysis

Because the cheese-maker subjectively deciding when the curd is suitable for stretching, it is important to know, especially in an industrial process, the acidity and melting and stretching temperatures required for cheese-making at different stretching pH. The acidity data were fitted to a simple linear regression model with respect to the pH of the milk (Figure 2, top panel). The regression analysis indicated that 89% of the variability is explained by the model, and, as the pH increased, the acidity decreased. Through this equation
[acidity = −30.3 × (pH) + 206.1], it was possible to predict significantly ($P < 0.05$) the required acidity in the milk to reach stretching pH. The difference (11%) may explain the effect of the buffer capacity occurring in the milk.

For melting temperature, the regression analysis indicated that 82% of the variability was explained by the model. As the pH increased, the melting temperature also increased (Figure 2; middle panel). Through this equation [melting temperature = −37.7 × (pH) – 161.2], it was possible to predict significantly ($P < 0.05$) the value of melting temperature at a given pH. The difference (18%) may explain the effect of casein–casein interaction type present in the paracasein network.

Stretching temperature data were fitted to a simple linear regression model with respect to the pH of the milk (Figure 2; bottom panel). The regression analysis indicated that 92% of the variability was explained by the model, and as the pH increased, the stretching temperature increased. Through this equation (stretching temperature = 39.7 × (pH) – 163.3), it was possible to predict significantly ($P < 0.05$) the value of stretching temperature at a given pH. The difference (8%) may explain the effect of other factors such as Ca content and casein–casein interaction type present in the paracasein network.

Yield

The quantity of cheese produced from a known quantity of milk is of great economic importance for the cheese industry. Cheese yield is defined as the kilograms of cheese produced from 100 kg of milk with a defined protein and fat content (Lucey and Kelly, 1994). The statistical analysis showed significant differences ($P < 0.05$) in the stretching pH values evaluated for yield variables expressed as kilograms of cheese per 100 kg of milk (Table 1). The highest yield reached was at stretching pH 5.7 with 12.9 kg of cheese/100 kg of milk. Cheeses stretched at pH 5.4, 5.5, and 5.6 showed no significant differences among them, and neither did those with stretching pH at 5.7. The lowest yield values were at stretching pH 5.2 and 5.3, with 12.12 and 11.45 kg of cheese/100 kg of milk, respectively. Depending on the milk composition, cheese recipe, and manufacturing technology, 75 to 78% of milk protein and 85 to 95% of milk fat are entrapped in the cheese curd, leading to a typical total cheese yield of 9 to 15% on a weight basis. In the production of pasta filata Mozzarella cheese, fat retention rarely exceeds 90% because of the additional losses encountered in the hot stretching step (Farkye, 2004; Nielsen, 2004). The data reported by these authors are within ranges indicated by our research. The differences found in yields can be attributed to greater loss of protein and fat in the serum and more retained moisture with lower pH, as demonstrated by Fenelon and Guinee (1999).

Thus, stretching pH affected the technological parameters of the Telita cheese-making process by decreasing stretching pH (by increasing the acidity in the milk). Both melting and stretching temperatures decreased as the stretching pH was reduced. This is favorable from an energy point of view because it requires less heat to reach the melting and stretching temperature but not

Figure 2. Acidification process of pasteurized milk (top), melting (middle), and stretching (bottom) temperature during the Telita manufacturing process.
The results of physicochemical analysis of Telita at different stretching pH values are shown in Table 2. Significant differences \((P < 0.05)\) were found among treatment (stretching pH values) for all evaluated variables.

### Moisture

Mean moisture content of Telita cheeses ranged from 48.1\% (pH 5.7) to 53.55\% (pH 5.4). The statistical trend showed that as the stretching pH increased, the moisture content was lower. A similar result (53.5\% moisture) was observed in Mozzarella cheese stretched at pH 5.2 (Rudan et al., 1998). Owni and Osman (2009) reported values between 45.4 and 48.5\% for Mozzarella cheese. Therefore, the moisture content of Telita cheeses in the current study was within the reported ranges for Mozzarella cheese. A high stretching temperature at higher pH may explain the lower moisture content in these cheeses because more whey loss occurred during the stretching process due to the higher temperature used.

### Fat

The average fat content of Telita cheeses at different stretching pH ranged from 46.3\% (pH 5.2) to 54.9\% (pH 5.6). Significant \((P < 0.05)\) differences were observed among treatments. According to the fat content in dry basis, the Telita cheeses were classed as full fat (45–60\% fat on a dry basis). These results were approximately in accordance with Sangronis and García (2007), who reported values in Telita cheeses ranging from 39.7 to 53.0\% fat on a dry basis. Lower fat content in cheeses stretched at pH 5.5 and 5.7 may be attributed to small amounts of this component being lost in the whey during stretching.

### Protein

Mean protein content obtained in Telita cheese ranged from 37.4\% (pH 5.7) to 43.0\% (pH 5.2). Significant differences \((P < 0.05)\) were found among pH evaluated for this variable. Two stretching pH treatments (5.2 and 5.5) resulted in the highest values of protein content: 43.0 and 42.9\%, respectively. The second highest values (40.5–41.0\%) were obtained below stretching pH 5.5. The rest of the pH measurements (5.6 and 5.7) had the lowest values (37.6 and 37.4\%, respectively). These results are within the range obtained in our previous study (unpublished data) where protein values in Telita cheese obtained from raw milk ranged from 40.5 to 47.6\%. Upon acidification, many of the physicochemical properties of the casein micelle go through significant changes, especially in the pH range of 5.0 to 5.5, which includes voluminosity, solvation, and dissociation of the caseins (Phadungath, 2005). Our results showed that the highest values for protein content were observed in the cheeses stretched at pH 5.2 and 5.5. These results may be explained by significant \((P < 0.05)\) reductions of the fat content occurring at these pH values. This highlights the importance of protein content and fat content with respect to the yield attained at this range of stretching pH.

### Minerals

A significant \((P < 0.05)\) decrease in mineral content occurred in cheeses stretched at pH 5.4 and 5.6, with 2.9 and 2.8\% reductions in mineral content (dry basis), respectively. These values were higher than those re-

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**Table 2. Physicochemical characteristics of pasta filata cheese type Telita at different stretching pH**

<table>
<thead>
<tr>
<th>Variable</th>
<th>5.2</th>
<th>5.3</th>
<th>5.4</th>
<th>5.5</th>
<th>5.6</th>
<th>5.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>53.31 ± 3.15</td>
<td>52.12 ± 0.50</td>
<td>53.55 ± 0.50</td>
<td>52.58 ± 0.07</td>
<td>48.56 ± 2.21</td>
<td>48.12 ± 1.08</td>
</tr>
<tr>
<td>MFFB (%)</td>
<td>69.21 ± 3.46</td>
<td>68.85 ± 1.05</td>
<td>70.46 ± 0.36</td>
<td>68.68 ± 0.40</td>
<td>67.67 ± 2.48</td>
<td>65.77 ± 0.40</td>
</tr>
<tr>
<td>Fat (%, db)</td>
<td>49.32 ± 1.81</td>
<td>50.75 ± 1.42</td>
<td>51.67 ± 0.69</td>
<td>49.45 ± 0.81</td>
<td>54.94 ± 1.12</td>
<td>51.74 ± 1.23</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>43.62 ± 1.94</td>
<td>40.53 ± 0.89</td>
<td>41.07 ± 0.99</td>
<td>42.94 ± 0.76</td>
<td>37.61 ± 3.21</td>
<td>37.49 ± 2.42</td>
</tr>
<tr>
<td>Minerals (%, db)</td>
<td>3.20 ± 0.14</td>
<td>3.51 ± 0.03</td>
<td>2.93 ± 0.38</td>
<td>3.23 ± 0.07</td>
<td>2.82 ± 0.22</td>
<td>3.28 ± 0.05</td>
</tr>
<tr>
<td>Calcium (%, db)</td>
<td>0.56 ± 0.10</td>
<td>0.52 ± 0.05</td>
<td>0.84 ± 0.07</td>
<td>0.81 ± 0.05</td>
<td>0.88 ± 0.05</td>
<td>1.03 ± 0.04</td>
</tr>
<tr>
<td>Sodium (%, db)</td>
<td>0.78 ± 0.13</td>
<td>0.73 ± 0.01</td>
<td>0.68 ± 0.13</td>
<td>0.52 ± 0.16</td>
<td>0.49 ± 0.07</td>
<td>0.38 ± 0.05</td>
</tr>
<tr>
<td>Whiteness index</td>
<td>77.25 ± 2.64</td>
<td>77.66 ± 0.75</td>
<td>78.78 ± 0.70</td>
<td>83.97 ± 1.82</td>
<td>83.19 ± 1.29</td>
<td>84.59 ± 0.82</td>
</tr>
</tbody>
</table>

\(^{a-d}\)Means within a row with different superscripts indicate significant differences \((P < 0.05)\).

\(^1\)Means ± SEM of 2 repetitions.

\(^2\)MFFB = moisture on fat-free basis; db = dry basis.
ported by Owni and Osman (2009), who reported values ranging from 2.25 to 2.38%. The differences found in their experiment were explained by greater demineralization caused by the higher acidity (developed in these cheeses as the stretching pH decreased). In this study, the reduction of mineral content could be explained by the demineralization caused by the addition of LAS to reach the stretching pH. Nevertheless, the demineralization at high pH could be explained by the high amount of whey loss during the stretching-cooking, which caused an increase in the mineral content.

**Calcium**

Milk Ca can exist as free ionic Ca or calcium caseinate (bound to casein) or it can be complexed with phosphate in the form of calcium phosphate ion clusters or microgranules. Additionally, the complexed calcium phosphate may also be bound to casein (micellar calcium phosphate) or in the serum phase (colloidal calcium phosphate; Holt, 1992). As a result of this crosslinking function, colloidal calcium phosphate and calcium caseinate would play a role in the structural characteristics of the casein matrix in cheese, hence its importance in cheese (Metzger et al., 2000).

The trend observed in this research was that as stretching pH decreased, the calcium content decreased significantly ($P < 0.05$). Cheese at pH 5.7 retained the higher percentage of calcium (1.0%), whereas in cheeses at pH 5.4, 5.5, and 5.6, the retention was 0.84, 0.81, and 0.88%, respectively. The lowest values were at stretching pH 5.2 and 5.3, with 0.56 and 0.52%, respectively.

For the most part, a Mozzarella cheese made from milk without preacidification has a calcium content of 1.40% (dry basis, db), whereas a Mozzarella cheese made from preacidified milk using citric acid plus acetic acid to pH 5.6 has a calcium content of 0.75% db (Joshi et al., 2004). The values reached in this research for the same stretching pH (5.6) were 17% greater compared with those attained by Joshi et al. (2004), probably because of the type of organic acid used.

The observed decrease in cheese calcium content with preacidification using LAS was expected because, according to Joshi et al. (2004), the addition of weak acids (phosphoric, citric, acetic, and lactic) to milk before rennet coagulation will induce a loss of colloidal Ca associated with the casein micelle being solubilized, lowering the calcium content of cheese (Metzger et al., 2000). Reducing the pH and preacidifying the milk before cheese-making has 3 important benefits. First, as the total calcium content is reduced, the amount of cross-linking between casein polymers is reduced and these cheeses become softer. Second, a cheese at a given pH with lower amounts of bound Ca will melt and flow faster and will do so at lower heating temperature (Metzger et al., 2000). Third, with direct acid addition, the curd will stretch, melt, and flow at a higher pH than in cheeses made with starter culture (Lucey et al., 2003). All the reasons mentioned above were observed in this research using LAS. In Venezuela, the stretching and melting process is done in the traditional way (according to the cheese-maker’s experience without any control during the cheese-making process); therefore, our findings relating stretching pH and its effects on the technological and physicochemical parameters of Telita cheese highlight the importance of this paper. The regression analysis (Figure 3) indicated that 80% of the variability is explained by the model. As the pH increased, the calcium content increased. Through this equation [$\%Ca = 0.97 \times (pH) - 4.5$], it was possible to significantly ($P < 0.05$) predict the percentage of calcium at a given stretching pH. The difference (20%) could be explained by the effect of variability presented in the chemical composition, especially in the acidity and sodium content, because these variables had negative correlations ($r$-values) of 0.84 and 0.9, respectively.

**Sodium**

Sodium exists in the body as the ion $\text{Na}^{+}$ and is acquired through diet, mainly in the form of salt ($\text{NaCl}$). This is a commonly used food ingredient that provides many technological functions such as cheese flavor enhancement, preservation, and texture modification (Hutton, 2002). From a biological point of view, in humans, sodium performs several vital roles in the body, including maintaining the volume of extracellular fluid, osmotic pressure, acid-base balance, and transmission of nerve impulses (Geerling and Loewy, 2008).

![Figure 3. Calcium content of the pasta filata cheese type Telita through stretching pH. db = dry basis.](image-url)
The results attained for Na in this research indicated that the addition of 1% NaCl to the curd produced cheeses with a total Na content ranging from 0.38% (0.96% NaCl) to 0.78% (1.98% NaCl) (db). To be considered low in sodium, cheese cannot contain more than 280 mg of Na/100 g, equivalent to 0.7% salt (US Food and Drug Administration, 2008). Higher-salt cheeses (2.5–3.5% salt) such as blue cheese, Romano, Parmesan, and feta are expected to be salty (Johnson et al., 2009). Johnson et al. (2009) reported that Mozzarella cheese made from whole milk had a sodium content of 628 mg per 100-g sample, equivalent to 1.6% NaCl. This latter percentage is within the range obtained in this research (0.9–1.9% NaCl).

The results for Na content in this study were consistent with that of the World Health Organization (2003). Based on a 2,000 calorie intake for adults and children ≥4 yr, an adequate sodium intake is <87 mmol/d (<5,000 mg/d). Our findings indicated that as the stretching pH decreased, Na values increased significantly (P < 0.05, except at stretching pH 5.4). At pH 5.5 and 5.6, the highest values of sodium (1.98 and 1.85% NaCl), respectively, were observed. At stretching pH 5.7, the lowest value of sodium (0.38%) was observed. The differences found can be explained by the fact that during the stretching process, the acid curd failed to release whey between pH 5.2 and 5.3 and consequently salt was better retained.

**Whiteness Index**

Appearance and color of the cheese is an important factor in consumer acceptance and is directly related to product quality (Kaya, 2002). Cheese WI was significantly affected (P < 0.05) by stretching pH treatments (Table 2). The WI values of the pH 5.2, 5.3, and 5.4 cheeses were lower than those of the other pH treatments evaluated (5.5, 5.6, and 5.7). The higher value for WI may be attributable to higher fat content, especially at pH 5.5 and 5.6, because fat content increases light-scattering and cheeses become whiter and less opaque (Johnson et al., 2009).

In general, the highest retention of the components, highest level of demineralization, and lowest WI values were found at low pH values (5.2 and 5.3).

**Textural Properties**

The mean values of the texture profile analysis parameters are given in Table 3. All of the texture parameters were affected significantly (P < 0.05) by the pH treatments evaluated.

**Hardness**

Hardness is defined as the maximum peak force during the first compression cycle (first bite; Van Hekken et al., 2007). The results indicated that Telita cheese presented 3 degrees of hardness. Cheeses between the stretching pH 5.6 and 5.7 had the hardest texture (see Table 3). Cheeses at stretching pH 5.4 and 5.3 had intermediate values of hardness. Finally, cheeses at pH 5.2 and 5.3 had the softest texture (Table 3).

Comparing the cheese of pH 5.7 with that at pH 5.2, we found a 66% reduction in hardness. The moisture content of cheeses in the pH 5.4 and 5.5 treatments and cheeses in the pH 5.2 and 5.3 treatments would both be classified as typical of soft cheese. However, regarding calcium content, more studies are needed to demonstrate that the classification based on moisture seems inconsistent with pasta filata cheeses, because according to the correlation analysis, calcium content in this study was more related to hardness than to moisture.

On the other hand, hardness was positively correlated with pH (r = 0.82) and calcium content (r = 0.99). This is consistent with Lawrence and Gilles (1982), who suggested that the texture of Cheddar and Mozzarella cheeses may be more dependent on pH than on other factors, although it is more likely that the proportion of Ca phosphate in an undissolved form varied in this type of cheese, depending on the pH value, which may have contributed to the reported differences in texture.

### Table 3. Texture characteristics of the pasta filata cheese type Telita at different stretching pH

<table>
<thead>
<tr>
<th>Variable</th>
<th>Stretching pH</th>
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<tbody>
<tr>
<td></td>
<td></td>
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<tr>
<td>Hardness (N)</td>
<td>20.44 ± 0.50&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Adhesiveness (N·s)</td>
<td>−0.66 ± 0.08&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cohesiveness (−)</td>
<td>0.60 ± 0.07&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Springiness (%)</td>
<td>62.32 ± 4.63&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Chewiness (N)</td>
<td>8.11 ± 0.04&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a–d</sup>Means within a row with different superscripts indicate significant differences (P < 0.05).

<sup>1</sup>Means ± SEM of 2 repetitions.
Springiness is related to the height that the food recovers during the time that elapses between the end of the first bite and the start of the second bite; that is, the ability of the cheese to return to its original height after the first compression (Van Hekken et al., 2007). Our results indicated that cheeses stretched at pH 5.6 and 5.7 had the highest values of springiness (Table 3) and almost recovered to their original height. These springiness values can be compared with those attained by Imm et al. (2003), who reported springiness of 89% in Mozzarella cheese. The lowest attained values were in cheeses stretched at pH 5.2 and 5.3. These values were higher than those reported by Rudan et al. (1999), who found 52% springiness in Mozzarella cheese with 25% fat. Intermediate values were attained at pH measurements 5.4 and 5.5. The values of springiness (at highest pH) in the cheeses were higher as the hardness was higher and the cohesiveness was lower.

**Chewiness**

Chewiness is defined as the product of the hardness $\times$ cohesiveness $\times$ springiness and is therefore influenced by changes in any one of these parameters. Chewiness also is known as the mechanical work before the cheese is swallowed (Van Hekken et al., 2007). Chewiness for cheeses with pH 5.6 and 5.7 obtained the highest values among evaluated cheeses (Table 3). Cheeses with pH 5.4 and 5.5 showed medium values, while cheeses with pH 5.2 and 5.3 showed lower values. Hardness is linked to Ca content in the cheese and Ca content is linked to chewiness. The 50% reduction in Ca reached through the decrease in pH from 5.7 to 5.2 led to a 72% reduction in chewiness.

**Adhesiveness**

Adhesiveness is defined as the negative force area for the first bite and represents the work required to overcome the attractive force between the surface of a food and the surface of other materials with which the food comes into contact (Pavia et al., 1999). At pH 5.2 and 5.3, adhesiveness values were highest (Table 3). Adhesiveness values of cheeses stretched at pH 5.4 and 5.5 were intermediate, and the lowest adhesiveness values were obtained at higher pH (5.6 and 5.7; Table 3). The main features for the first group (pH 5.2 and 5.3) were lowest for both hardness and chewiness degrees and highest for cohesiveness degree. Keller et al. (1974) stated that cheese can become very tacky and viscous if too much Ca is removed, as in the cheeses stretched at pH 5.2 and 5.3, through demineralization of the milk with lactic acid. This can become a problem in the molding and packing stage, because these cheeses are harder to remove from the container surface. In addition, during the melting and stretching processes in this study, a lot of the curd stuck on the hot plate surface, making it much more difficult to carry out the process. However, this problem could be overcome if the acidified curd is melted, stretched, and immersed in water at 60°C with 4% salt solution (our unpublished data). This allows the curd to hydrate and spread more easily on the hot plate and improve the yield.

The cheeses stretched at pH 5.6 and 5.7 had the lowest degrees of adhesiveness and cohesiveness and higher springiness and chewiness. At these both stretching pH
values, cheeses were easier to handle during the melting and stretching steps. Separation of these cheeses on the hot plate surface was also easier. The cheeses stretched at pH 5.4 and 5.5 presented intermediate values between both extreme groups, presenting a good balance among the degree of adhesiveness, cohesiveness, springiness, and chewiness, making processing easier. In general, the values for cohesiveness and adhesiveness increased 30 and 83%, respectively, as the pH decreased from 5.7 to 5.2. Therefore, cheeses stretched at pH 5.2 and 5.3 are characterized by having high cohesiveness, and being sticky, not springy, and easily chewable. On the other hand, values for hardness, springiness, and chewiness increased 66, 35, and 72%, respectively, as the pH increased from 5.2 to 5.7. Therefore, cheeses stretched at pH 5.6 and 5.7 are characterized for being firm, springy, and probably difficult to chew. Cheese with pH between 5.4 and 5.5 presented balanced values for all texture parameters.

**Principal Component Analysis**

Principal component analysis was carried out using loading from technological parameters, physicochemical analysis, and texture characteristics from the texture profile analysis. Figure 4 shows the biplot of the first 2 principal components, which explained 78.1% of the variation. The analysis showed that the cheeses stretched at pH 5.2 and 5.3 were more related to moisture, protein, acidity, Na, and ash; those cheeses are linked to texture parameters such as cohesiveness and adhesiveness. In cheeses stretched at pH 5.6 and 5.7, the related variables were pH, Ca, and WI. Texture parameters were hardness, chewiness, and springiness. In technological parameters, the variables linked were melting and stretching temperature and yield. Cheeses stretched at pH 5.4 and 5.5 presented intermediate relationships among all variables studied. Lawrence et al. (1987) reported that the pH of Cheddar cheese

![Figure 4. Principal component analysis (PCA) score for 2 first principal components from 17 variables obtained from technological parameters and physicochemical and texture characteristics of pasta filata cheese type Telita showing factor loading for variables and factor scoring for group of cheeses with different pH. WI = whiteness index; MT = melting temperature; ST = stretching temperature.](image-url)
had a large effect on textural properties. Ionic species covalently bound to the casein strands become protonated during curd formation as pH decreases toward 5.4, causing the curd to become firm and more elastic. Further reduction of pH to below 5.2 reverses this effect because of the dissociation of calcium phosphate bridges between casein molecules in Cheddar cheese (Everett and Olson, 2003).

CONCLUSIONS

Cheeses made at a lower stretching pH reached lower melting and stretching temperatures and had lower yields but showed higher retention of nutrients and were darker. As stretching pH increased, yield increased and the cheeses were much whiter, with higher melting and stretching temperatures. These cheeses had lower retention of nutrients because of higher whey drainage during the stretching process. Cheeses stretched at pH 5.2 and 5.3 were characterized by being sticky and easily chewable, not springy, and having low disintegration. Cheeses stretched at pH 5.6 and 5.7 were characterized by being firm, springy, and probably difficult to chew. Cheese stretched at pH 5.4 and 5.5 presented balanced values for all variables studied between the formed statistical groups; therefore, they were considered the best in terms of technological, physicochemical, and texture properties.

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