The aim of this work was to examine the effect of a different dry matter (DM) contents (35 and 45% wt/wt) and fat in DM contents (40 and 50% wt/wt) on the textural and viscoelastic properties and microstructure of model processed cheeses made from real ingredients regularly used in the dairy industry. A constant DM content and constant fat in DM content were kept throughout the whole study. Apart from the basic chemical parameters, textural and viscoelastic properties of the model samples were measured and scanning electron microscopy was carried out. With increasing DM content, the rigidity of the products increased and the size of the fat globules in the model samples of the processed cheeses decreased. With increasing fat in DM content, the rigidity of the processed cheeses decreased and the size of the fat globules increased.

Key words: processed cheese, texture, rheology, scanning electron microscopy

INTRODUCTION

Spreadable processed cheese is defined by Codex Alimentarius (1978) as a product made by grinding, mixing, melting, and emulsifying with the aid of heat and emulsifying salts, one or more varieties of cheese with or without the addition of milk components or other foodstuffs in accordance with this standard. The rules for the relationship between the DM content and the fat in DM (FDM) content are also presented (Codex Alimentarius, 1978). In the region of Middle Europe, we could also find products in which the DM content is lower than the amount stated in the standard but that is still named “processed cheese.”

Processed cheeses are traditionally manufactured from a mixture of natural cheeses and many other dairy (e.g., anhydrous butterfat, butter, cream, milk powder, whey, buttermilk) and nondairy (e.g., stabilizers, preservatives, flavor enhancers) ingredients. Important food additives during the production of processed cheeses are emulsifying salts (usually the sodium salts of phosphates, polyphosphates, and citrates or their mixtures), which help the casein proteins emulsify the fat present, hydrate the free water, and participate in developing the final matrix of the product. Processed cheeses are directly consumed and are used as raw material for further processing in the industry and catering (Lee et al., 2003; Kapoor and Metzger, 2008; Nagyová et al., 2014).

One of the most important and very critically evaluated parameters of processed cheeses is their consistency, which can be, according to the actual parameters, in the form of blocks, slices, spreads, or sauces (Kapoor and Metzger, 2008). The particular consistency of the product is affected by many factors, which can be divided into 4 main groups: (1) the final parameters of the processed cheese (especially DM, protein, fat and fat-free DM content, and pH value); (2) the composition of the raw material mixture (e.g., the type and degree of maturity of the natural cheese, the concentration and composition of the emulsifying salts, and the concentration and composition of the stabilizers), which to some extent determines the final parameters of the product quoted in (1); (3) processing parameters during production (especially the agitation speed, melting temperature, stirring time, and rate of cooling the melt); and (4) the storage conditions of processed cheeses (e.g., impermeability of the packaging, storage temperature, and length of the storage period; Lee and Klostermeyer, 2001; Dimitrelli and Thomareis, 2004, 2007, 2008; Kapoor and Metzger, 2008; Bayarri et al., 2012; Buňka et al., 2013, 2014; Nagyová et al., 2014; Shirashoji et al., 2016). During the storage period, especially within the first 14 d of cold storage, a further change in consistency, along with an increase in the rigidity of the processed cheeses, is to be expected (Buňka et al., 2013; Nagyová et al., 2014).
In the industry, the consistency of processed cheeses regularly is assessed sensorially. However, the instrumental evaluation using small (e.g., dynamic oscillation rheometry) or large (e.g., texture profile analysis) deformations or their combinations is increasing (Lee et al., 2003; Kapoor and Metzger, 2008; Buňka et al., 2013, 2014; Nagyová et al., 2014). Rheological parameters measured in the area of small or large deformations are given mainly by the microstructure of processed cheeses and mutual bonds between the individual components (especially the properties of the protein network and its interactions with other components; Hosseini-Parvar et al., 2015; da Silva et al., 2016). To explain the nature of the current state of consistency, it is therefore useful to have the data about the mechanical properties of the processed cheese and also its microstructure. The microstructure of processed cheeses may be studied by several methods, the most common of which are optical microscopy (Hladká et al., 2014; da Silva et al., 2016), scanning electron microscopy (Kaláb and Modler, 1985; Noronha et al., 2008; Cunha et al., 2010), transmission electron microscopy (Lee et al., 2003; Zhang et al., 2011; Hoffmann and Schrader, 2015), and confocal laser scanning microscopy (Hosseini-Parvar et al., 2015; Lee et al., 2015).

Although the final parameters of processed cheeses (especially DM, FDM, and fat-free DM content) affect their consistency to a large extent, they have not been given sufficient attention in the literature over the past 10 yr. One of the few studies, by Lee et al. (2015), dealt with the effect of protein content (10–20% wt/wt) and fat content (0–40% wt/wt) on the viscoelastic properties of model samples of processed cheeses made from rennet casein (melting temperature = 85°C) and stored for 24 h. With the increasing protein content and decreasing fat content (constant protein-to-water content, variable DM content), the rigidity of the processed cheeses increased. A more significant effect of the protein content was observed compared with the fat content. The conclusions of the study were supported by the results of confocal laser scanning microscopy.

Guinee and O’Callaghan (2013) used processed cheeses made from cheddar and skim milk cheese (melting temperature = 80°C) with a fat content of 14 to 33% (wt/wt), protein content of 12 to 25% (wt/wt), and constant DM content of 46 to 47% (wt/wt) stored for a maximum of 4 d. With the increasing fat content (and decreasing protein-to-fat ratio), the rigidity of the samples declined. Dimitreli and Thomareis (2004, 2007, 2008) studied the viscosity and the textural and viscoelastic properties of processed cheeses made from Gouda (melting temperature = 80°C) with a different fat content (12–23% wt/wt) content stored for 24 h. With the decreasing DM and protein content and the increasing fat content, the rigidity of the model samples declined. Some of the other few studies dealing with the effect of the content components on the consistency of processed cheeses were published by Bayarri et al. (2012) and Chatziantoniou et al. (2015). In both of the studies (specific processed cheeses made from whey Myzithra-type cheese and the samples obtained from the retail network), the rigidity of the samples increased with the decreasing FDM content. None of the studies mentioned in this paragraph used any of the microscopic methods to explain the changes in consistency.

The aim of this work was to examine the effect of a different DM content (35 and 45% wt/wt) and FDM content (40 and 50% wt/wt) on the textural and viscoelastic properties and microstructure of model processed cheeses made from real ingredients regularly used in the dairy industry. A similar objective was already fulfilled in some of the previously mentioned studies. However, none of the published works took advantage of the rheological methods, using both large and small deformations in combination with scanning electron microscopy (which helps to explain the processes going on during the manufacture and storage of processed cheese), to describe the properties of the samples. A constant DM content and constant FDM content were kept throughout the whole study. These 2 parameters were variable in most previously published works. Most of the studies published in this area used model samples stored for only 24 h or for a maximum of 4 d at a cold storage temperature. This work uses processed cheeses stored for 14 d at 6 ± 2°C. Within this time, the most intensive changes in consistency occur during the storage period. In most producers, processed cheeses are dispatched after 10 to 14 d when the almost-final consistency of the product is already known. The samples with 40 and 50% (wt/wt) FDM content and 45% (wt/wt) DM content are “spreadable processed cheese” according to the standards of Codex Alimentarius (1978). The samples with lower DM content (35% wt/wt) and both FDM contents (40 and 50% wt/wt) correspond to products that are available in the region of Middle Europe.

**MATERIALS AND METHODS**

**Preparation of the Samples**

Dutch-type cheese (50% wt/wt DM content and 30% wt/wt FDM content), butter (84% wt/wt DM content and 82% wt/wt fat content), water, and emulsifying salts (the total concentration was 2.9% wt/wt of the total weight of the melt; the composition of the emulsifying salt mixture was 35% relative NaH₂PO₄, 20% rela-
Effective Na$_2$HPO$_4$, 25% relative Na$_4$P$_2$O$_7$, and 20% relative sodium salt of polyphosphate; total weight = 100% were used for manufacturing 4 model processed cheeses with 35 and 45% (wt/wt) DM content and 40 and 50% (wt/wt) FDM content, respectively. The formulations for manufacturing the model samples are shown in Table 1. A Stephan UMC-5 (Stephan Machinery GmbH, Hameln, Germany; indirect heating tool) was used for the manufacture of the samples. A target temperature of 86°C was held for 1 min (agitation speed = 3,000 rpm). The hot melt was poured into polystyrene cups and closed with aluminum lids. For the analysis of the textural properties, polypropylene doses of cylindrical shape (52 mm in diameter and 50 mm high) were used. The processed cheeses were cooled and stored at 6 ± 2°C for 14 d. Each of the 4 model samples was produced 3 times.

**Basic Chemical Analysis of the Model Processed Cheeses**

The DM content, fat content, and protein content of the processed cheeses were determined according to methods 5534 (ISO, 2004b), 1735 (ISO, 2004a), and 8968–1 (ISO, 2014), respectively. The FDM content of the samples was calculated as fat content divided by DM. The ash content was obtained according to Černá and Mergl (1971): The sample was incinerated at 550 ± 5°C and the residue was weighed. Each method was applied 3 times on 2 samples from every batch (3 repetitions × 3 batches × 2 samples; n = 18). The pH values were measured at ambient temperature using a glass-tip electrode of a pH meter (pH Spear, Eutech Instruments, Oakton, Malaysia) by directly inserting the spear into the processed cheese (n = 18).

**Textural and Viscoelastic Properties of the Model Processed Cheeses**

The textural properties of the samples were evaluated using a TA.XTplus texture analyzer (Stable Micro Systems Ltd., Godalming, UK). Before measurement, the samples were tempered at 20°C. The textural analyses were carried out by 2 sequential penetration events (penetration depth = 10 mm, probe speed = 2 mm/s, trigger force = 5 g) using a 20-mm (diameter) P20 stainless steel cylinder probe. The following textural parameters were determined: hardness (the force needed to attain a given deformation minus the maximum force during the first penetration cycle; N), cohesiveness (the strength of the internal bonds of the cheese minus the ratio of the positive force area of the second peak to that of the first peak; unitless), and relative adhesiveness (the relative strength of adhesiveness between the cheese and the probe surface minus the ratio of the absolute value of the negative force area to the positive force area of the first peak; unitless; Fiszman and Damásio, 2000; Breuil and Meullenet, 2001; Weiserson et al., 2011). Each batch was analyzed 3 times (3 repetitions × 3 batches; n = 9; each dose was used for the textural analysis only once).

The viscoelastic properties of the model processed cheeses were analyzed using a dynamic oscillatory shear rheometer (RheoStress 1, Haake, Bremen, Germany) with a plate-plate geometry (diameter = 35 mm, gap = 1 mm) at a temperature of 20.0 ± 0.1°C. All samples were measured in the control shear stress mode at a frequency ranging from 0.01 to 100.00 Hz. The amplitude of shear stress (20 Pa) was chosen in the region of linear viscoelasticity. The exposed edge of the parallel-plates geometry was covered with a thin layer of silicone oil to prevent the samples from dehydrating. The selected monitored parameters (determined as a function of frequency) included the storage modulus (G') and loss modulus (G'″; n = 9; 3 repetitions × 3 batches). The loss tangent (tan δ) was calculated as tan δ = G''/G'. The complex modulus (G*) was obtained using the formula

\[ G^* = \sqrt{(G')^2 + (G'″)^2}. \]  

The frequency of 1 Hz was chosen as the reference for the presentation of tan δ and G*.

**Table 1. Formulation of the processed cheese samples with different DM content (% wt/wt) and fat in DM (FDM) content (% wt/wt)**

<table>
<thead>
<tr>
<th>Raw material</th>
<th>35% DM (40% FDM)</th>
<th>35% DM (50% FDM)</th>
<th>45% DM (40% FDM)</th>
<th>45% DM (50% FDM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dutch-type cheese (g)</td>
<td>785</td>
<td>636</td>
<td>1,050</td>
<td>847</td>
</tr>
<tr>
<td>Butter (g)</td>
<td>110</td>
<td>208</td>
<td>135</td>
<td>260</td>
</tr>
<tr>
<td>Emulsifying salts (g)</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Water (g)</td>
<td>600</td>
<td>665</td>
<td>315</td>
<td>398</td>
</tr>
<tr>
<td>Total (g)</td>
<td>1,540</td>
<td>1,554</td>
<td>1,545</td>
<td>1,550</td>
</tr>
</tbody>
</table>
theory was also implemented using the following equation (Gabriele et al., 2001):

\[ G^* (\omega) = A_F \cdot \omega^{1/z} , \]

where \( A_F \) is the gel strength (Pa s^{1/2}), \( \omega \) (Hz) is the frequency, and \( z \) is the interaction factor (defined as the number of structure units interacting with one another in a 3-dimensional network; unitless). The higher the interaction factor, the more interactions that occur in the matrix of the sample (Gabriele et al., 2001).

**Scanning Electron Microscopy of the Model Processed Cheeses**

A Jeol JSM-7401F scanning electron microscope (Jeol, Tokyo, Japan) was used to study the microstructure of the model processed cheeses. The preparation of the model processed cheese samples was as follows. Part of the processed cheese sample (size = approximately 5 \( \times \) 2 \( \times \) 2 mm) was put in a 3\% (vol/vol) glutaraldehyde solution in 0.2 mol/L cacodylate buffer for 24 h. The samples were washed in cacodylate buffer 3 times for 15 min. The postfixation was performed for 48 h in 2\% (wt/vol) OsO4. The samples were washed again in cacodylate buffer 3 times for 15 min. The samples were dehydrated by solutions with an increased concentration of ethanol from 30 to 100\%. Then the samples were frozen and fractured in liquid nitrogen and defatted by chloroform. The fragments of model processed cheeses were critical point dried using carbon dioxide (Leica EM CPD300, Leica Microsystems, Vienna, Austria). The samples were mounted on an aluminum stem and holder and sputter coated (Sputter Coater SCD 050, Bal-tec, Balzers, Liechtenstein) for 98 s (20-nm layer of gold; Kaláb and Modler, 1985). The samples were critical point dried using carbon dioxide (Leica EM CPD300, Leica Microsystems, Vienna, Austria). A Jeol JSM-7401F scanning electron microscope (Jeol, Tokyo, Japan) was used to study the microstructure of the model processed cheeses. Each image was analyzed using ImageJ software (National Institutes of Health, Bethesda, MD). The photograph of each model sample was analyzed to determine the fat globule diameter (\( \mu \)m). Each sample was analyzed twice (2 repetitions \( \times \) 2 samples \( \times \) 3 batches; \( n = 12 \)), and the results were expressed as median \( \pm \) standard error.

**Statistical Analysis**

Kruskal–Wallis and Wilcoxon tests were used to evaluate the results obtained (the significance level was 0.05) with the exception of the results of fat globule diameter. For this parameter, the Pearson test was applied. For the estimation of \( A_F \) and \( z \), nonlinear regression analysis (the Marquardt–Levenberg method; \( A_F > 0 \) and \( z \geq 0 \)) was used. Unistat 6.5 software (Unistat, London, UK) was applied for the statistical analysis.

**RESULTS AND DISCUSSION**

The results of the chemical, rheological, and microscopic analyses are summarized in Table 2. We managed to produce model processed cheeses with minimal deviations (\( P \geq 0.05 \)) from the target values of DM (35 and 45\% wt/wt) and FDM (40 and 50\% wt/wt). As expected, the protein and ash content increased (\( P < 0.05 \)) with the increasing DM. On the contrary, with the increasing FDM (at constant DM), the protein content decreased (\( P < 0.05 \)). In the samples with the same FDM, a similar value of the ratio of protein to fat (~1:0.85 and ~1:1.30, respectively) was maintained (Table 2). In the samples with the same FDM, the ash content did not change significantly (\( P \geq 0.05 \)). The pH value was higher in the samples with the higher FDM (\( P < 0.05 \)), whereas it was similar in the samples with the same DM (\( P \geq 0.05 \)). The higher relative fat content and lower relative protein content may have led to the change in the acid dissociation constant (\( pK_a \)) of the chemicals present (Lu et al., 2008; Guinee and O’Callaghan, 2013), and thus to a slight increase (~0.3 unit) in pH level. According to Lee and Klostermeyer (2001) and Lu et al. (2008), a slight increase in the pH value leads to higher rigidity of processed cheeses. However, this shift (~0.3 unit) could be evaluated as not so significant.

The textural analysis of the samples using the area of large deformations of the material showed (Table 2) that with the increasing DM and decreasing FDM, hardness of the samples increases (\( P < 0.05 \)) and the relative adhesiveness of the processed cheeses decreases (\( P < 0.05 \)). The cohesiveness of the samples was not significantly affected by the DM and FDM levels used (\( P \geq 0.05 \)).

The course of the storage (\( G' \)) and loss (\( G'' \)) moduli depending on the frequency (0.01–100.00 Hz) is plotted in Figure 1. The \( G' \) and \( G'' \) curves of the processed cheeses are, within the range of frequency observed, higher (\( P < 0.05 \); at constant FDM) in the products with higher DM (Figure 1, parts C and D) compared with the samples with a lower DM content (Figure 1, parts A and B). Furthermore, the \( G' \) and \( G'' \) curves in processed cheeses with higher FDM (Figure 1, parts B and D) were significantly lower (\( P < 0.05 \); at constant DM) compared with the products with lower FDM (Figure 1, parts A and C). The storage modulus (\( G' \)) reached higher values (\( P < 0.05 \)) than the loss modulus within the whole range of frequency tested in the samples with higher DM (regardless of FDM). This implies a significantly higher proportion of the storage
component \( G' \) compared with the loss component \( G'' \), which is very typical of densely interlinked weak gels (Lee and Klostermeyer, 2001; Cunha et al., 2013; Lee et al., 2015). On the other hand, in the processed cheeses with a lower DM content, higher values at a lower frequency were reached by the loss modulus \( G'' \) (\( P < 0.05 \)). It is assumed that if \( G'' > G' \) (within a certain range of lower applied frequency), the intermolecular bonds in the protein matrix observed have sufficient time to weaken during the oscillation cycle. However, at higher frequency the system does not have sufficient time to weaken the intermolecular bonds and it starts to behave more like a solid (\( G'' < G' \)), which is typical of concentrated solutions and dispersions (Lee and Klostermeyer, 2001; Lee et al., 2015).

With the increasing frequency, intersection of both curves was observed in the samples with lower DM, and the values of \( G' \) exceeded those of \( G'' \) (Figure 1, part A and B). The intersection point of the 2 curves (\( G' \) and \( G'' \)) was observed at higher frequency in the processed cheese with higher FDM. Within the range of frequency observed, the intersection of the storage and loss moduli curves did not occur in the samples with higher DM (Figure 1, part C and D). The intersection of \( G' \) and \( G'' \) may have been expected at much lower frequency than observed in our case. The results of the development of \( G' \) and \( G'' \) depending on frequency can be supported by the obtained values of the complex modulus (\( G^* \)) and the tangent of the phase shift angle (\( \tan \delta \)) for the reference frequency \( f = 1 \) Hz (Table 2). With the increasing DM (at constant FDM) and decreasing FDM (at constant DM), \( G^* \) was increasing and \( \tan \delta \) was decreasing (\( P < 0.05 \)).

As it follows from these findings, a higher DM content and lower FDM content resulted in obtaining a stronger gel and thus a product with a tougher and less spreadable consistency. The stated information can also be supported by the calculated values of the 4 parameters (Table 2). With the increasing DM (at constant FDM) and the decreasing FDM (at constant DM), the gel strength (\( A_F; P < 0.05 \)) of the model processed cheeses increased significantly (\( P < 0.05 \)) along with the interaction factor (\( z; P < 0.05 \)), which refers to the number of structural units mutually interacting in the protein network or the number of intermolecular bonds between proteins. The increasing gel strength was likely attributable to the increasing number of interactions in the 3-dimensional system studied (Cunha et al., 2013; Guinee and O’Callaghan, 2013; Lee et al., 2015). Apart from the values of the gel strength \( A_F \) and \( z \) factors, the results of dynamic oscillation rheometry can also be supported by the microstructure study of the model processed cheeses. The microstructure of the individual types of the model processed cheeses is presented in Figure 2, and the results of the calculation of the median diameter of the fat globules are shown in Table 2.

As it follows from the microphotographs (Figure 2) and the numerical calculation in Table 2, with the increasing FDM (at constant DM), the diameter of the fat globules increases (\( P < 0.05 \)) and the ratio of protein to fat decreases. In the model processed cheeses studied, the ratio of proteins to fat was approximately 1:0.85 in the products with 40% (wt/wt) FDM and approximately 1:1.30 in the products with 50% (wt/wt) FDM. Proteins (caseins) are the main emulsifier in this

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**Table 2. Results of the analysis of the processed cheese samples with different DM content and fat in DM (FDM) content (% wt/wt)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>35% DM</th>
<th>40% FDM</th>
<th>45% DM</th>
<th>50% FDM</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM content (% wt/wt)</td>
<td>35.18 ± 0.13a</td>
<td>35.09 ± 0.22a</td>
<td>45.16 ± 0.27b</td>
<td>45.21 ± 0.21b</td>
</tr>
<tr>
<td>Fat content (% wt/wt)</td>
<td>14.2 ± 0.4a</td>
<td>17.5 ± 0.2b</td>
<td>18.3 ± 0.5c</td>
<td>22.5 ± 0.4d</td>
</tr>
<tr>
<td>FDM content, calculated (% wt/wt)</td>
<td>40.3</td>
<td>49.9</td>
<td>40.5</td>
<td>49.8</td>
</tr>
<tr>
<td>Protein content (% wt/wt)</td>
<td>16.4 ± 0.5b</td>
<td>13.6 ± 0.2a</td>
<td>22.1 ± 0.6d</td>
<td>17.6 ± 0.3c</td>
</tr>
<tr>
<td>Ash content (% wt/wt)</td>
<td>3.99 ± 0.15b</td>
<td>3.83 ± 0.26a</td>
<td>5.17 ± 0.21b</td>
<td>4.99 ± 0.19b</td>
</tr>
<tr>
<td>pH value (% wt/wt)</td>
<td>5.77 ± 0.04b</td>
<td>6.05 ± 0.03b</td>
<td>5.74 ± 0.02b</td>
<td>5.97 ± 0.03b</td>
</tr>
<tr>
<td>Protein-to-fat ratio, calculated</td>
<td>1.087</td>
<td>1.129</td>
<td>1.082</td>
<td>1.128</td>
</tr>
<tr>
<td>Protein-to-moisture ratio, calculated</td>
<td>1.395</td>
<td>1.477</td>
<td>1.348</td>
<td>1.311</td>
</tr>
<tr>
<td>Cohesiveness (% wt/wt)</td>
<td>0.60 ± 0.02a</td>
<td>0.61 ± 0.04b</td>
<td>0.62 ± 0.06b</td>
<td>0.60 ± 0.03c</td>
</tr>
<tr>
<td>Relative adhesiveness (% wt/wt)</td>
<td>0.42 ± 0.01c</td>
<td>0.54 ± 0.02d</td>
<td>0.01 ± 0.00b</td>
<td>0.07 ± 0.01b</td>
</tr>
<tr>
<td>Fat globule diameter (% wt/wt)</td>
<td>1.53 ± 0.13c</td>
<td>2.16 ± 0.27d</td>
<td>0.44 ± 0.03c</td>
<td>0.65 ± 0.02b</td>
</tr>
<tr>
<td>Complex modulus in 1 Hz (kPa)</td>
<td>4.8 ± 0.3e</td>
<td>1.2 ± 0.1c</td>
<td>55.9 ± 2.2a</td>
<td>27.8 ± 1.3c</td>
</tr>
<tr>
<td>Loss tangent in 1 Hz (unitless)</td>
<td>0.66 ± 0.04d</td>
<td>1.14 ± 0.07c</td>
<td>0.29 ± 0.02a</td>
<td>0.37 ± 0.01b</td>
</tr>
<tr>
<td>Gel strength (kPa·s(^{-1/2}))</td>
<td>4.7 ± 0.2b</td>
<td>1.3 ± 0.0c</td>
<td>55.6 ± 3.4a</td>
<td>26.9 ± 0.8e</td>
</tr>
<tr>
<td>Interaction factor (unitless)</td>
<td>3.01 ± 0.16b</td>
<td>2.26 ± 0.06b</td>
<td>5.14 ± 0.22d</td>
<td>4.39 ± 0.19c</td>
</tr>
</tbody>
</table>

*Means within a row with different superscripts differ (\( P < 0.05 \)).

1Mean ± standard deviation.

2Mean ± standard error.
network. Their lower relative amount causes a lower degree of emulsification, manifested as an increased diameter of the fat globules. The larger fat globules are then able to break the continuity of the protein matrix much more intensively (softer, more spreadable processed cheese) compared with a larger number of smaller fat globules (tougher, less spreadable processed cheese; Lee et al., 2003; Kapoor and Metzger, 2008; Noronha et al., 2008). At constant FDM and increasing DM (in this case, without the addition of ingredients other than the natural cheeses), the amount of the proteins that enhance the emulsifying ability of the system increases, which was manifested as a decreased diameter of the fat globules ($P < 0.05$; Table 2; Figure 2, parts C and D in comparison with parts A and B). Similarly, Lee et al. (2015) demonstrated the effect of the increasing concentration of protein on the decreasing size of the fat globules in processed cheeses. The higher relative protein content is able to cover a larger area of the fat globules, thus allowing the formation of smaller fat globules and vice versa (Dalgleish, 1997). As it follows from Figure 2B, the samples with the lowest protein content (and with the smallest ratio of protein to moisture at the same time; Table 2) showed partial coalescence of fat, which is evident in the formation of larger fat globules with a less regular spherical shape. Similar conclusions in the samples with the highest relative fat content were also reached in the study by Lee et al. (2015). Moreover, it can be assumed that a higher number of structural units of caseins will also form a denser protein network and that the number of interactions between the individual protein chains will increase (Lee et al., 2003). The latter is supported by a more compact network (which is particularly apparent in Figure 2C). This assumption is strongly supported by the values of the gel strength $A_F$ and the interaction factor $z$ observed in the processed cheeses studied. Additionally, higher viscosity of hot melt (in cheese with higher DM and protein content) could result in more shear (during manufacturing) and contribute to changes

Figure 1. Dependence of the storage ($G'$; Pa; solid symbols) and loss ($G''$; Pa; open symbols) moduli of the model processed cheese on frequency ($f$; Hz). (A) Samples with 35% (wt/wt) DM content and 40% (wt/wt) fat in DM content. (B) Samples with 35% (wt/wt) DM content and 50% (wt/wt) fat in DM content. (C) Samples with 45% (wt/wt) DM content and 40% (wt/wt) fat in DM content. (D) Samples with 45% (wt/wt) DM content and 50% (wt/wt) fat in DM content.
in textural and viscoelastic properties of products and decreasing of fat droplets (Yoon and McCarthy, 2003; Zhu et al., 2015).

CONCLUSIONS

This work examined the effect of different DM contents (35 and 45% wt/wt) and FDM contents (40 and 50% wt/wt) on the textural and viscoelastic properties and microstructure of model processed cheeses made from real ingredients regularly used in the dairy industry. Apart from the basic chemical parameters, textural and viscoelastic properties of the model samples were measured and scanning electron microscopy was carried out. With increasing DM content, the rigidity of the products increased and thus the size of the fat globules in the model samples of the processed cheeses decreased. With increasing FDM content, the rigidity of the processed cheeses decreased and the size of the fat globules increased. Further studies will be necessary to obtain better insight into the effect of the protein content on the properties of processed cheeses.

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