Clean label starches as thickeners in white sauces. Shearing, heating and freeze/thaw stability

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Abstract

The linear viscoelastic properties and syneresis of freshly prepared and freeze/thawed white sauces prepared with different native starches (corn, waxy corn, potato and rice) at different shearing speeds were studied. Viscosity changes during processing were also measured using a starch pasting cell attached to a rheometer. The freeze/thaw cycle produced a significant increase in the viscous and elastic modulus and the appearance of syneresis in the corn and potato starch sauces, while the waxy corn and rice starch sauces were only slightly affected. Syneresis was significantly reduced upon subsequent heating. Greater shearing speed produced a significant decrease in viscoelasticity. Viscosity profiles revealed that the increase in shearing speed decreased the starch gelatinization temperature and swelling capacity and increased starch breakdown.

1. Introduction

Starch is the most widely used thickening and gelling agent in the food industry because of the wide variety of texture and mouthful sensations it provides. Starch is a typical ingredient of foodstuffs such as sauces, soups, and many other processed foods. Starch properties depend on the botanical source of the starch, the presence or otherwise of chemical modifications (modified or native starch), the starch concentration, the cooking procedure (temperature, pH, heating time, shearing time and intensity, among others) and the presence of other ingredients or additives.

Native starches have limitations in industrial applications due to their high thermal and shearing instability and their tendency to retrograde during cooling or/and freezing, causing a decrease in food product quality. Despite these limitations, the current greater tendency towards natural, clean-label food has promoted the use of native starches. Native starch properties vary considerably according to their botanical source. Corn and wheat starches have much higher amylose contents (about 28%) than potato and tapioca starches (which only contain about 20% amylose) and than rice starch (which contains about 17%). The fat and protein contents also vary among the different botanical sources of starch. Cereal starches (wheat, corn, barley, or rice) contain more lipids (0.6–1% w/w) than tuber (potato, 0.05%), root (tapioca, 0.1%) and waxy mutant cereal starches. The same trend is found in the protein content: 0.25–0.6% for cereal starches compared with 0.06% for potato and 0.1% for tapioca. The lipid/protein content of starch has been correlated with swelling behaviour and shear sensitivity. Starches that swell rapidly on heating tend to be more shear sensitive and contain less protein and lipid than starches displaying a more controlled swelling (Debet & Cidley, 2006).

Starches from different botanical sources also differ in granule size and shape. Potato starch is characterized by oval and spherical shapes measuring 5–100 μm, corn starch granules are smaller (3–26 μm) and polygonal and rice starch granules have polygonal and angular shapes and are 3–8 μm in size (Swinkels, 1985).

During their manufacturing process, starch-containing foods are submitted to considerable shear forces (high-speed mixers, pumps, homogenizers), which have an important influence on the final quality of the food product. The effect of shearing on the gelatinization process of isolated starches has mainly been studied by a research group from south China and Australia. Xie et al. (2006) reviewed different techniques (differential scanning calorimetry (DSC), X-ray diffraction, nuclear magnetic resonance spectroscopy, microscopy with a hot stage and rheometry together with microscopy) which are employed to study the starch gelatinization process under shear and shearless conditions. Under shearless conditions more water was necessary for complete starch gelatinization than under shear, since the shearing tension heightens the gelatinization process. Chen, Yu, Kealy, Chen, and Li (2007) evaluated the gelatinization process of corn starches with different amylose/amylpectin.
contents under shearless and shear conditions, using a microscope with a hot stage and a rheometer joined to a microscope respectively. Xie, Yu, Chen, and Li (2008) studied the gelatinization process of rice starch under shear stress using dynamic mechanical analysis (DMA). The DMA results were compared with those obtained with DSC. Xue, Yu, Xie, Chen, and Li (2008) investigated the starch gelatinization process under shear stress conditions using a rheometer with a twin-roll mixer. Phase transition was also studied by microscopy and DSC in samples collected from the mixer at different times and temperatures. Research on the influence of shearing type and speed on the quality properties of semi-solid starch-based products is scarce.

The objectives of the present work were to evaluate a) the effect of shearing speed during processing and b) the effect of native starches from four different botanical sources (corn, waxy corn, potato and rice) on the freeze/thaw and thermal stability of white sauces. For these purposes, the linear viscoelastic properties, pasting properties and syneresis of the white sauces were studied. The main final aim was to establish the extent to which native starch can be employed without significant changes in white sauce quality.

2. Materials and methods

2.1. Starches

Native starches from four different botanical sources were employed: waxy corn starch (WC) (Cgel 04 201), corn starch (C) (Gel 03 401), potato starch (P) (C Gel 30 000), all from Cargill, Barcelona, Spain, and rice starch (R) (Remy DR) from Ferrer Alimentación S.A, Barcelona.

2.2. Preparation and frozen storage of the white sauces

White sauces were prepared with powdered skimmed milk (9.30% w/w) (Central Lechera Asturiana, Asturias, Spain), sunflower oil (2.55% w/w) (Cosool), starch (6.00% w/w), salt (0.23% w/w) and water up to 100% w/w. All the ingredients were placed in a food processor (Thermomix TM 31, Wuppertal, Germany), heated to 90 °C (17 °C/min) and kept at 90 °C for 5 min. Shearing was performed with a propeller. Three different shearing speeds were employed: 200 rpm, 1100 rpm and 3100 rpm. The prepared sauces were placed in glass containers, covered with plastic film and cooled to 30 °C in an ice-water bath.

For the study of the freshly prepared white sauces, the measurements were performed on the day of preparation. To study the effect of one freeze/thaw cycle, the white sauces were cooled to 20 °C, placed in plastic containers and frozen at −18 °C. After four days the sauces were thawed at room temperature, reheated to 30 °C in a hot water bath and measured the same day.

2.3. Rheological behaviour

2.3.1. Starch pasting properties in the white sauces

The pasting properties were studied using a starch pasting cell (SPC) attached to a controlled stress rheometer (AR-G2, TA Instruments, Crawley, England). The SPC consists of an impeller and a cylindrical cup (3.6 cm wide and 6.4 cm high). The impeller is designed to fit closely into the cylindrical cup containing the sample. The top of the mixing element shaft is gradually extended to provide a non-contact, conically-shaped cover which significantly prevents solvent evaporation. Heating is accomplished through electrical elements placed concentrically to the cup and cooling through water recirculation in a helical conduit placed in close proximity to the outer walls of the cup. The cooling water flow is controlled through the cooling control unit, which is located upstream of the cup.

25 g of the unmixed white sauce ingredients (9.30% powdered skimmed milk, 2.55% sunflower oil, 6.00% starch, 0.23% salt and water up to 100%) were placed in the cylindrical cup of the SPC. To evaluate the effect of shearing speed, three different shearing speeds were used: 30, 60 and 90 s⁻¹. The sample was stirred strongly (100 s⁻¹) for 10 s at 30 °C before switching the shear rate to the corresponding speed, which was maintained until the end of the test. The samples were heated from 30 °C to 90 °C at 15 °C/min and the temperature was held at 90 °C for 5 min. Subsequently, the samples were cooled to 30 °C at 15 °C/min and held at 30 °C for 5 min. Viscosity data were recorded over time by the TA data analysis software provided by the instrument's manufacturer.

To compare the behaviour of the different sauce formulations objectively, specific parameters were extracted from the viscosity-temperature versus time curves obtained. The parameters extracted were: gelatinization temperature (GT), taken as the temperature at which viscosity begins to rise; peak viscosity (PV), taken as the highest viscosity achieved during heating; hot paste viscosity (HPV), taken as the viscosity value at the end of the isothermal period at 90 °C; cold paste viscosity (CPV), taken as the viscosity value at the end of the isothermal period at 30 °C; breakdown (PV-HPV)/PV; relative breakdown (PV-HPV)/PV; total setback (CPV-HPV); and relative total setback, (CPV-HPV)/CPV.

2.3.2. Linear viscoelastic properties of white sauces

Linear viscoelastic properties were studied in the freshly prepared sauces and after one freeze/thaw cycle. A controlled stress rheometer (AR-G2, TA Instruments, Crawley, England) with a 45 mm diameter serrated plate-plate geometry and a gap of 1 mm was employed. Before measurement, the sample was kept between the plates for a 10 min equilibration time. The exposed edges of the samples were covered with silicon oil to avoid their drying during measurements.

To simulate the effect of heating in the white sauce structure, temperature sweeps were performed from 30 °C to 80 °C at a heating rate of 1.5 °C/min. The applied strain was selected to guarantee the linearity of the viscoelastic response according to preliminary stress sweeps carried out at 30 °C and at 80 °C. The temperature sweep was stopped at the corresponding temperature and, after a 10 min temperature-equilibration time, the stress sweep was performed. Additionally, mechanical spectra in the linear region from 10 to 0.01 Hz at 30 °C and at 80 °C (after the equilibration time and temperature sweep) were also recorded in separate tests. The storage modulus (G'), loss modulus (G''), complex modulus (G*) and loss tangent (tangent (G'')/G') values were recorded.

2.4. Syneresis of white sauces

Syneresis was quantified after extrusion of the different white sauces at 30 °C and 80 °C, as explained elsewhere (Arocas, Sanz, & Fiszman, 2009). Two minutes after extrusion, the sauce was recovered, quantitatively transferred to a funnel and filtered through a paper filter (DF 420 110) for 15 min. Syneresis was expressed as the amount of water released per 100 g white sauce.

2.5. Data treatment

Two replicates of each test were performed with samples prepared on different days. Each of the replicates was measured in duplicate. An analysis of variance (ANOVA) was performed to evaluate the effect of shearing speed on the different white sauces. Least significant differences were calculated by the Tukey test. These analyses were performed using the SPSS for Windows Version 12 (SPSS Inc., USA).

For the study of the freshly prepared white sauces, the measurements were performed on the day of preparation. To study the effect of one freeze/thaw cycle, the white sauces were cooled to 20 °C, placed in plastic containers and frozen at −18 °C. After four days the sauces were thawed at room temperature, reheated to 30 °C in a hot water bath and measured the same day.
3. Results and discussion

3.1. Starch pasting properties in the white sauces

The influence of native starch source and shearing speed on the structural changes occurring in the white sauces during the cooking process was evaluated using a starch pasting cell, which allowed viscosity to be monitored while mixing during heating and cooling. Fig. 1(A–D) shows the viscosity and temperature profiles over time for the different source starch sauces at the three different shearing speeds.

All the curves revealed increasing viscosity during the heating period, up to a maximum value, reflecting the starch-swelling process. From this maximum value, the viscosity decreased more or less noticeably (starch breakdown) depending on the starch type. Finally, viscosity increased again during the cooling period.

In order to compare the influence of the starch source and shearing speed objectively, the gelatinization temperature, peak viscosity, hot peak viscosity, cold peak viscosity, breakdown, relative breakdown, total setback and relative total setback parameters were determined. The values obtained are shown in Table 1.

3.1.1. Starch source

The GT values ranged from 63 to 75 °C. The highest GT value was found for the corn sauces and the lowest for the potato sauces. GT was related to the speed of the starch-swelling process. Potato starch granules swelled very quickly and at the lowest temperature, while swelling in the corn starch granules was delayed until higher temperatures were reached. The high swelling capacity of potato starch was also associated with the higher PV achieved in the potato sauces in comparison with the corn sauces. Similar results were found by Swinkels (1985) in native starches.

Table 1

<table>
<thead>
<tr>
<th>Starch/Shearing speed</th>
<th>GT (°C)</th>
<th>PV (Pas)</th>
<th>HPV (Pas)</th>
<th>CPV (Pas)</th>
<th>Breakdown (Pas)</th>
<th>Relative breakdown</th>
<th>Total setback (Pas)</th>
<th>Relative total setback</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>74.9</td>
<td>0.59</td>
<td>0.55</td>
<td>1.24</td>
<td>0.04</td>
<td>0.07</td>
<td>0.69</td>
<td>0.55</td>
</tr>
<tr>
<td>60</td>
<td>74.6</td>
<td>0.39</td>
<td>0.32</td>
<td>0.67</td>
<td>0.07</td>
<td>0.19</td>
<td>0.35</td>
<td>0.52</td>
</tr>
<tr>
<td>90</td>
<td>71.6</td>
<td>0.26</td>
<td>0.22</td>
<td>0.46</td>
<td>0.04</td>
<td>0.17</td>
<td>0.24</td>
<td>0.53</td>
</tr>
<tr>
<td>WC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>71.4</td>
<td>0.99</td>
<td>0.60</td>
<td>0.98</td>
<td>0.39</td>
<td>0.39</td>
<td>0.38</td>
<td>0.38</td>
</tr>
<tr>
<td>60</td>
<td>69.7</td>
<td>0.58</td>
<td>0.35</td>
<td>0.60</td>
<td>0.23</td>
<td>0.40</td>
<td>0.25</td>
<td>0.42</td>
</tr>
<tr>
<td>90</td>
<td>68.2</td>
<td>0.44</td>
<td>0.25</td>
<td>0.39</td>
<td>0.20</td>
<td>0.45</td>
<td>0.15</td>
<td>0.38</td>
</tr>
<tr>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>65.0</td>
<td>1.29</td>
<td>0.81</td>
<td>1.58</td>
<td>0.48</td>
<td>0.37</td>
<td>0.76</td>
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<tr>
<td>60</td>
<td>63.7</td>
<td>0.72</td>
<td>0.42</td>
<td>0.93</td>
<td>0.30</td>
<td>0.41</td>
<td>0.50</td>
<td>0.54</td>
</tr>
<tr>
<td>90</td>
<td>63.7</td>
<td>0.48</td>
<td>0.27</td>
<td>0.77</td>
<td>0.21</td>
<td>0.43</td>
<td>0.49</td>
<td>0.64</td>
</tr>
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<td></td>
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</tr>
<tr>
<td>30</td>
<td>68.3</td>
<td>0.69</td>
<td>0.66</td>
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<td>0.05</td>
<td>0.75</td>
<td>0.53</td>
</tr>
<tr>
<td>60</td>
<td>68.0</td>
<td>0.48</td>
<td>0.42</td>
<td>0.80</td>
<td>0.05</td>
<td>0.11</td>
<td>0.38</td>
<td>0.47</td>
</tr>
<tr>
<td>90</td>
<td>68.1</td>
<td>0.34</td>
<td>0.26</td>
<td>0.50</td>
<td>0.08</td>
<td>0.25</td>
<td>0.25</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Fig. 1. Viscosity-temperature profiles of white sauce dispersions. A: C sauce, B: WC sauce, C: P sauce, D: R sauce. Shearing speeds: 30 s⁻¹ (●), 60 s⁻¹ (■), 90 s⁻¹ (▲). Continuous line: temperature.
potato was explained by the presence of negatively charged phosphate groups. In the corn sauces, the low PV was partly due to the presence of amylose–lipid complexes.

To quantify the degree of the starch structure breakdown during cooking, the parameter ‘relative breakdown’ is proposed here instead of the traditionally employed ‘breakdown’. In comparison with ‘breakdown’, ‘relative breakdown’ possesses the advantage of eliminating the differences attributed to different initial PV values, allowing correct comparison among different samples.

The highest relative breakdown values were found in the potato and waxy corn sauces and the lowest in the corn and rice sauces. These differences in starch breakdown properties can be seen in Fig. 1. In both the potato (Fig. 1C) and waxy corn sauces (Fig. 1B), a clear decrease in viscosity is observed during the heating period, while only a slight decrease is observed in the rice and corn starches. These results agree with the general idea that starches that swell rapidly on heating tend to be more shear sensitive (Debet & Gidley, 2006).

Traditionally, the ‘total setback’ parameter has been considered an indicator of the starch retrogradation process (Karim, Norziah, & Seow, 2000; Ravi, Manohar, & Rao, 1999). However, as in the case of the evaluation of the starch breakdown process, here the ‘relative total setback’ is considered instead, as it is a more convenient option for eliminating the influence of the absolute values and allowing correct comparison among different systems.

As expected, the waxy corn sauce showed lower relative total setback than the corn sauce, indicating its well known reduced tendency to retrogradation due to its lower amylose content. The potato and rice sauces showed a very similar relative total setback to the corn sauce.

3.1.2. Shearing speed

In all the starches, increased shearing speed reduced GT, indicating that granule swelling started at a lower temperature. However, a decrease in PV was found, reflecting a more difficult starch-swelling process with lower viscosity development. In addition, a slight increase in the ‘relative breakdown’ parameter was found with increased shearing speed, reflecting higher structural breakdown of the starch granules upon heating. Relative total setback was practically unaffected by the shearing speed.

In conclusion, for all the starches, greater shearing speed during processing reduced the initial starch-swelling temperature but also reduced the starch swelling and, consequently, the development of viscosity, as well as increasing structural breakdown increasing the phenomenon of breakdown during heating.

Previous research on pasting properties has mainly focused on isolated starch systems. The results obtained have been related to physicochemical, morphological and thermal properties. Singh, Kaur, Sandhu, Kaur, and Nishinari (2006) studied the pasting properties of...
isolated rice starch from 19 different cultivars using the Rapid Viscoanalyzer (RVA). Amylose content was positively correlated with peak viscosity, final viscosity and setback, being the correlation stronger with setback. The correlation of amylose with peak viscosity was attributed to the remission of water from the exuded amylose by the granules as they swell. The correlation with final viscosity and setback was expected to be due to degradation of amylose molecules during cooling, which increased viscosity. This suggested that amylose association is mainly responsible for setback.

Sandhu and Singh (2007) characterized the corn varieties grown in India on the basis of physicochemical, thermal, pasting, and gel texture properties. Valuable information on the mechanisms contributing to the functional properties of the starches was obtained. The onset gelatinization temperature was negatively correlated to peak, breakdown, final and setback viscosities and positively correlated to pasting temperature. The enthalpy of gelatinization was negatively correlated to peak and breakdown viscosities.

The pasting properties of waxy corn and waxy rice have been compared by Lu, Duh, Lin, and Chang (2008). Waxy corn starches showed lower pasto viscosity and higher breakdown viscosity than waxy rice starches, which indicated that under heating and shearing, the granular rigidity of waxy corn starches was weaker than that of waxy rice starches.

3.2. Linear viscoelastic properties

3.2.1. Freshly prepared sauces

The influence of shearing speed and native starch source on the linear viscoelastic properties (mechanical spectra) of the white sauces is shown in Fig. 2 (A–D).

In the corn starch sauce (Fig. 2A), at all shearing speeds, the mechanical spectra reflected the existence of soft gels with G’ values higher than G” values and with very mild frequency dependence in the frequency range measured. Increased shearing speed caused a significant decrease in the values of both moduli and in viscoelasticity (tg’ values increased from 0.1 to 0.5), denoting structural weakening.

The mechanical spectra of the waxy corn starch sauces (Fig. 2B) showed lower viscoelastic characteristics than for the corn sauces. At the lower speed, G’ values were higher than G” values, with a tg’ of 0.5. Higher shearing speeds again led to a significant decrease in viscoelasticity; in this case, G” values became higher than G’ values; the distance between them was highest at the highest speed.

The behaviour of the potato starch sauce (Fig. 2C) at the lowest speed was intermediate between that of corn and of waxy corn, with a tg’ of 0.3. Increased shearing speed brought a significant decrease in the values of both G’ and G” and a crossover between G’ and G” was observed, with G” values higher than G’ at the higher frequencies.

Finally, the rice starch sauce (Fig. 2D) showed similar behaviour to that of the potato starch sauce. At the highest shearing speed (3100 rpm) a crossover between G’ and G” was found. Considering the above pasting results, the decrease in viscoelasticity found in all the white sauces with increased shearing speed would seem to be a consequence of the decrease in starch granule swelling and the increase in starch granule breakdown.

To evaluate the effect of increasing temperature (white sauces are consumed hot) on the viscoelastic properties of the white sauces, the evolution of G’ and G” at 1 Hz from 30 to 80 °C was studied. Fig. 3 shows the curves obtained at the lowest preparation speed as a representative example.

The viscoelastic properties of all the different starch sauces were practically unaffected by the increase in temperature up to 80 °C, as only a slight decrease in both viscoelastic functions was observed. This behaviour was also observed for the intermediate and highest speeds employed.

Table 2 shows the G’, G” and tg’ values at 1 Hz at 30 °C and 80 °C. For all the starches, the G’ and G” values were lower at 80 °C than at 30 °C but the tg’ values were practically unaffected, which indicates that the increase in temperature had no effect on viscoelasticity.

As in the mechanical spectra discussed above, the highest G’ and G” values were those of the corn sauce, followed in decreasing order by the potato, rice and waxy corn sauces.

3.2.2. Freeze/thaw stability of sauces

The mechanical spectra of the different white sauces after the freeze/thaw cycle are shown in Fig. 4 (A–D). In addition, Table 3 shows the G’, G” and G” values of the freeze/thaw cycle sauces measured at 30 °C and after heating to 80 °C.

In all the sauces the freeze/thaw cycle led to an increase in the moduli values and a decrease in tg’ in comparison with the fresh sauces. However, the effect of the freeze/thaw cycle was clearly dependent on the type of starch. In the corn and potato starch sauces it had a significant effect on the viscoelastic properties, with an increase of G’ and G” in excess of one decade, whereas only a slight increase in the viscoelastic functions was observed in the waxy corn and rice starch sauces.

The greater effect of the freeze/thaw cycle on the corn and potato sauces compared to the rice and waxy corn sauces was also observed visually. After thawing, the corn and potato sauces showed a gel-like texture, spongy, stratified and flaky, as observed in other studies (Arocas et al., 2009; Ferrero & Zaritzky, 2000; Navarro, Martino, & Zaritzky, 1997), while the appearance of the freeze/thawed rice and waxy corn sauces was very similar to that of the fresh sauces.

Cereal starches (corn and rice) are known to retrograde faster than tuber starches (potato). Waxy starches show the lowest retrogradation, due to the absence of amylose (Swinkels, 1985). The
decreased the highest speed, where a crossover between from 0.1 to 0.4).

Table 3
Mean values of $G'$, $G''$ and $\tan \delta$ at 1 Hz at 30 °C and 80 °C for the different sauces and shearing speeds. Freeze/thawed sauces.

<table>
<thead>
<tr>
<th>Starch type</th>
<th>30 °C</th>
<th>80 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200 rpm</td>
<td>1100 rpm</td>
</tr>
<tr>
<td></td>
<td>$G'$</td>
<td>$G''$</td>
</tr>
<tr>
<td>C</td>
<td>5227 A</td>
<td>5262 A</td>
</tr>
<tr>
<td>(1040)</td>
<td>(1020)</td>
<td>(0.04)</td>
</tr>
<tr>
<td>WC</td>
<td>44.7 A</td>
<td>46.5 A</td>
</tr>
<tr>
<td>(4.9)</td>
<td>(4.8)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>P</td>
<td>2026 A</td>
<td>2028 A</td>
</tr>
<tr>
<td>(619)</td>
<td>(623)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>R</td>
<td>138.3 A</td>
<td>139.7 A</td>
</tr>
<tr>
<td>(0.4)</td>
<td>(0.4)</td>
<td>(0.0)</td>
</tr>
</tbody>
</table>

Values between parentheses are the standard deviations. Within each row, values with different letters for the same temperature and parameter are significantly different ($P < 0.05$) according to Tukey's test.

Fig. 4. Influence of shearing speed on the mechanical spectra of the freeze/thawed sauces at 30 °C. A: C sauce, B: WC sauce, C: P sauce, D: R sauce. Shearing speeds: 200 rpm ($G'$; C, $G''$: C), 1100 rpm ($G'$; B, $G''$: B), 3100 rpm ($G'$; A, $G''$: A).

appearance and viscoelastic properties of the freeze/thawed rice sauces revealed that the retrogradation of the rice starch did not noticeably affect the quality properties of the sauce.

In general, the effect of shearing speed on the viscoelastic properties was less noticeable after the freeze/thaw cycle than in the freshly prepared sauces. The freeze/thawed corn sauces were the least affected by shearing speed (Fig. 4A). The increase in shearing speed only produced a slight, non-significant decrease in $G'$ and $G''$ (Table 3).

In the waxy corn sauces, higher shearing speeds significantly decreased the $G'$, $G''$ and viscoelasticity values, especially at the highest speed, where a crossover between $G'$ and $G''$ was observed in the mechanical spectra. At the lower speeds (200 and 1100 rpm), $G'$ values were higher than $G''$, with $\tan \delta$ values of 0.3 and 0.4 respectively.

Like the corn sauce, the freeze/thawed potato sauce was less affected by shearing speed than the fresh sauces. For all the speeds, $G'$ values were higher than $G''$ values throughout the frequency range measured. However, a significant decrease in viscoelastic functions and in viscoelasticity was observed ($\tan \delta$ values increased from 0.1 to 0.4).

Finally, in the rice sauce the increase in shearing speed resulted in an increase in $\tan \delta$ from 0.1 to 0.8 at the highest speed.

The influence of heating on the freeze/thaw cycle sauces is shown in Fig. 5. Contrary to the results in the fresh sauces, raising the temperature from 55 to 60 °C led to a decrease in the viscoelastic functions in the corn, potato and waxy corn sauces. This decrease has previously been observed in normal and waxy corn-based white sauces and attributed to a possible breaking of the linkages formed during retrogradation (Arocas et al., 2009).

In the rice sauces, raising the temperature only led to a small decrease in the viscoelastic functions. This could indicate that in the rice sauces the possible linkages formed during retrogradation are less susceptible to breakdown during heating or that their breakdown does not significantly affect the viscoelastic properties of the white sauce.

3.3. Sauce syneresis

One of the consequences of the freeze/thaw process, as a consequence of the structural changes associated with the retrogradation process, is the possibility of syneresis, the appearance of water
The employment of native starches to prepare an industrial clean-label white sauce is not incompatible with a good quality product, even if a freezing step is part of the manufacturing process. However, the starch source has a big impact on quality.

The viscoelastic properties and appearance of waxy corn and rice starch sauces were only slightly affected by a freeze/thaw cycle, while corn and potato sauces showed an increase in viscoelasticity and the appearance of syneresis. Nevertheless, it should be noted that heating after thawing eliminated the syneresis almost completely and reduced the viscoelastic functions significantly, implying a partial recovery of the structure of a freshly prepared sauce. Higher shearing speeds during processing reduced the viscoelasticity of the sauces significantly in all the sauces studied; this could be associated with a decrease in starch swelling and an increase in the starch breakdown process.

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References


4. Conclusion

expelled from the sauce structure. The appearance of syneresis in a white sauce is a very negative quality factor.

Syneresis was not observed in any of the freshly prepared sauces. Syneresis values after the freeze/thaw cycle are shown in Table 4. Syneresis was only observed in the corn and potato starch sauces. The different patterns of behaviour of corn and potato starches in comparison with waxy corn and rice starch sauces were in accordance with the differences in their viscoelastic properties and appearance. Thus, the viscoelastic properties of the corn and potato starch sauces were the most affected by the freeze/thaw cycle, which may explain their higher tendency to syneresis as a consequence of these structural changes.

The effect of increased temperature on syneresis can also be related to viscoelastic properties. Heating to 80 °C reduced corn and potato starch sauce syneresis to almost zero. Equally, the viscoelastic functions were clearly reduced by the increase in temperature. Hanson, Campbell, and Lineweaver (1951) also observed reduced syneresis with an increase in temperature in thawed sauces; the effect was more noticeable in waxy cereals than in common cereals. They attributed the reduction in syneresis to the effect of temperature in breaking the linkages formed during retrogradation, allowing reassociation with water, and the disappearance of the free water molecules.

No clear effect of shearing speed on syneresis was observed.

Table 4

<table>
<thead>
<tr>
<th>Starch type</th>
<th>30 °C</th>
<th>80 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200 rpm</td>
<td>1100 rpm</td>
</tr>
<tr>
<td>C</td>
<td>37.13</td>
<td>13.59</td>
</tr>
<tr>
<td>WC</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>P</td>
<td>31.08</td>
<td>29.14</td>
</tr>
<tr>
<td>R</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Fig. 5. \( G' \) and \( G'' \) as a function of increasing temperature in the freeze/thawed sauces prepared at a shearing speed of 200 rpm. C sauce (G\( G' \bullet \), G\( G'' \bullet \)), WC sauce (G\( G' \bullet \), G\( G'' \bullet \)), P sauce (G\( G' \bullet \), G\( G'' \square \)), R sauce (G\( G' \triangle \), G\( G'' \triangle \)). Frequency: 1 Hz; \( \gamma \): 0.001. Heating rate: 1.5 °C/min.