Viscoelastic properties of orange fiber enriched yogurt as a function of fiber dose, size and thermal treatment

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ABSTRACT

The effect of orange fiber addition on yogurt viscoelastic properties was studied, the following factors were evaluated: (i) fiber doses (0, 0.2, 0.4, 0.6, 0.8 and 1 g/100 ml) (ii) fiber particle size (0.417–0.7 and 0.701–0.991 mm) (iii) fiber addition prior or after pasteurization. (i) In yogurts with pasteurized fiber C’ and G’ and complex viscosity increased with fiber dose, whereas in non-pasteurized fiber yogurts smaller fiber particles (<0.4 g/100 ml) rheological parameters decreased due to the disruptive effect of the fiber, and over 0.6 g/100 ml rheological parameters increased. The presence of particles alters yogurt structure but when the fiber dose is high enough the water absorption compensates the weakening effect of the fiber. (ii) C’, G’ and viscosity were higher in yogurts with large particles than in yogurts with fiber of smaller size. The higher the number of fiber particles, the higher the disrupting effect. (iii) Fiber pasteurization in the mix enhances its integration in the gel matrix.

1. Introduction

Fermented milk products already have a positive health image due to the beneficial action of its viable bacteria. Dietary fibers have beneficial effects for human health. The recommended daily intake of fiber is about 38 g for men and 25 g for women (Trumbo, 2009). Slow acid development favours formation of beneficial bacteria in yogurt. Hydrophobic, are progressively established between the proteins (pH 5.2), and casein (pH 4.6) are reached, low-energy bonds, mainly hydrophobic, are progressively established between the proteins (Lucey & Singh, 1998). Slow acid development favours formation of grains in yogurt, a coarse microstructure and low viscosity may be due to short gelation time with a lower degree of casein aggregation and a looser network (Sodini, Lucas, Tisier, & Corrieu, 2005). Rheometry is a useful technique for measuring shelf life and texture, as many consumers evaluate the sensory texture to assess the freshness and quality of a product. In a previous study at Universidad Miguel Hernández (García-Pérez et al., 2006) the rheology of fiber enriched yogurts was assessed by means of viscosity, texture and syneresis determinations. Set and stirred yogurts were manufactured: set yogurt textural characteristics were evaluated by a penetration test and stirred yogurts’ characteristics were evaluated by means of back extrusion tests and viscosity. All the applied methods were destructive and no information was obtained on the viscoelastic behaviour of yogurt. Viscoelastic properties are useful in the food industry for observing the onset of gelation, measuring the extent and strength of internal structures, such as those present in yogurt. Clearly, measurements in the linear viscoelastic region involve probing the structure of the sample in a non-destructive manner. In the mouth, as in the texture analyzer, this is not the case, and irreversible deformation takes place. However, it is hypothesized that viscoelastic properties can give an indication of the initial experience of a consumer (Kealy, 2006).

A controlled stress rheometer allows the shear stress on the sample to be controlled; and it is possible to gradually increase the shear stress on the material and measure the deformation. When a small load is applied, the material stretches and a small deformation resisted by the internal structure of the sample may be measured. The...
internal structural strength is overcome when the yield stress is exceeded. As the load is increased beyond the yield stress the material structure ceases to be stretched, and deforms irreversibly (flows).

Commercial yogurts are typically either set or stirred. In set style yogurts the milk is fermented in the retail containers, resulting in a continuous gelled structure in the final product. A stirred product is the result of fermentation commonly in large tanks, followed by the disruption of the acid gel by stirring and sieving to give a more fluid product which is often used as a base for inclusion of fruit before packaging.

The rheological properties of stirred yogurt have been well studied; their flow properties are characteristic of a non-Newtonian and weakly viscoelastic fluid (Lubbers, Decourcelle, Vallet, & Guichard, 2004). The rheological characteristics of yogurt are governed by milk composition, temperature and time of milk heat pretreatment, type and quantity of starter culture employed to inoculate the milk, fermentation temperature and storage conditions of the final product. Several authors have studied the correlation among yogurt rheology and structure, evaluating the effect of milk heat treatment, type of starter culture, incubation temperature, storage time, etc. (Girard & Schaffer-Lequart, 2007; Ozer, Robinson, Grandison, & Bell, 1997; Remeuf, Mohammed, Sodin, & Tissier, 2003; Renan et al., 2009; Sodini et al., 2005). Scanning electron microscopy (SEM) (Ozer et al., 1997; Remeuf et al., 2003; Sodini et al., 2005) and Confocal Laser Scanning Microscopy (CLSM) (Girard & Schaffer-Lequart, 2007; Guggisberg, Cuthbert-Steven, Piccinali, Bütikofer, & Eberhard, 2009; Renan et al., 2009) are the most widely used techniques. Results from rheology studies usually show good correlation with the observations of the microstructural analysis, although several times uneven results may be obtained. As an example, Guggisberg et al. (2009) studied the rheology and microstructure of inulin fortified low fat yogurts and reported minimal microstructural differences as observed by CLSM, although inulin addition provided high consistency as assessed by rheological and sensory evaluation. May be inulin formed a non-CLSM visible network. Oscillatory tests are widely accepted for the evaluation of rheological characteristics of yogurt (Ozer et al., 1997; Remeuf et al., 2003; Sodini et al., 2005).

Keogh and O’Kennedy (1998) studied the role of milk fat, protein, gelatin and hydrocolloids (starch, locust bean gum/xantan mixture) on the rheology of stirred yogurt, reporting that the consistency index and syneresis were more frequently influenced by the composition than the behaviour index (n) and the critical strain. Hess, Roberts, and Ziegler (1997) concluded that polymer (starch, pectin and guar gum) association with the casein network prevents disruption of a portion of the network. Thickeners are generally incorporated in yogurts as a part of a fruit preparation, and then a decrease in the viscosity of yogurt with fruit preparation in comparison to control was observed (Kratz & Dengler, 1995; Celik & Bakirci, 2003). Conflicting results have been reported by different authors regarding the effect of milk supplements in yogurt rheology, probably due to the different methodology and equipment used for the rheological analysis (Sodini et al., 2005).

The addition of novel fibers to milk products such as yogurt is seldomly reported: oat, rice, soy and maize fibers (Fernández-García & McGregor, 1997), apple, wheat, bamboo and inulin (Dello Staffolo, Bertola, Martino, & Bevilacqua, 2004), inulin in yogurt ice cream (El-Nagar, Clowes, Tudorica, Kuri, & Brennan, 2002), β-glucan in yoghurt (Tudorica, Jones, Kuri, & Brennan, 2004).

Concerning citrus fiber in dairy products, Dervosigiu and Vazici (2006) reported that citrus fiber as a single stabiliser could not improve the viscosity, overrun and sensory properties of ice cream but had a positive effect on the melting resistance. The addition of citrus fiber had a negative effect on the viscosity values of ice cream mixes. Dello Staffolo et al. (2004) observed that the type of fiber significantly affected the rheological properties of the yogurts. Apple fiber fortification decreased yogurt compression values, probably due to the formation of fiber aggregates that interfered with yogurt structure. Wheat and bamboo fiber fortification increased yogurt compression force and texture sensory scores, Consumer’s preferred firmer yogurts, probably, resulting from the insoluble nature of these fibers. Tudorica, Jones, Kuri, and Brennan (2004) observed that, when added to milk, β-glucan seems to promote shelf association of caseins. Caseins appear to promote the association of β-glucans as well, which at high concentrations could result in the formation of a gel network, probably reinforcing the casein network. The inclusion of β-glucan in milk affected the viscoelastic properties of the resulting coagulum, at higher levels of glucan, higher values for G′ and G″ were obtained. Full fat milk curds have significantly lower G′ than their low fat counterpart samples. Fat in solid state increases the flexibility of the casein matrix due to the decrease in tan δ and so increases its gel like behaviour.

The addition of inulin at more than 1 g/100 ml increased whey separation, inulin addition caused a decrease in organoleptic scores (Guven, Yasar, Karaka, & Hayaloglu, 2005). Pectin hindered the formation of the casein matrix in rennet-induced gels (Fagan, O’Donnell, Cullen, & Brennan, 2006).

Gelatine interacted with the network of milk proteins as a connection between the clusters formed and so gelatine was found suitable to improve the texture in milk products (Fiszman, Lluch, & Salvador, 1999).

In our previous study on the rheology of orange fiber enriched yogurt (García-Pérez et al., 2006) measured by destructive methods, it was observed that fiber concentration modified yogurt rheology but not the fiber particle size. The addition of 1 g/100 ml orange fiber reduced syneresis and improved the creaminess sensory scores, together with: increased gel firmness, stickiness and average force measured by back extrusion. Unexpectedly, lower fiber doses increased syneresis and decreased textural parameters when compared to control samples. The present study aimed to complement previous knowledge of the rheology of orange fiber enriched yogurts. The impact of milk heating on yogurt structure when citrus fiber is added prior to pasteurization has not been yet evaluated. The following factors were included on the design: fiber dose, fiber particle size and, fiber heat treatment.

2. Materials and methods

2.1. Materials

Fiber was obtained from orange fiber by-products by a procedure described by Fernández-López, Fernández-Ginés, Alesón-Carbosc, Sendra, Sayas-Barberá, & Pérez-Alvarez (2004). Powders with two different particle sizes (0.417–0.701 and 0.701–0.991 mm) were obtained. The citrus fiber product used has a total dietary fiber content of 53.65 g/100 g (determined by method 985.29, AOAC, 1995), 80.1 g/100 g crude fiber (determined by Weende method 962-09, AOAC, 1995), 4.19 g/100 g ash, 7.34 g/100 g moisture, 11.3 g/100 g water holding capacity (WHC), pH 3.92, 30 CFU/g aerobic mesophilic bacteria and 25 CFU/g moulds and yeasts. For all the tests the same batch of skim milk powder was used (34 g/100 g protein, 52 g/100 g lactose, 1 g/100 g fat, 6.8 g/100 g ash, 5.2 g/100 g moisture; Central Lechera Asturiana, CAPSA, Granda-Siero, Spain). Skim milk powder was reconstituted with deionised water at 15 g/100 ml total solids. Commercial starter cultures of Streptococcus thermophilus and Lactobacillus delbrueckii subsp. bulgaricus (Ezal MV900, Rhodia Food-Danisco A/S, Sassenage, France) were used at the concentrations prescribed by the suppliers, but instead of direct vat use, a poach for 20 L milk was pre-suspended in 20 mL of sterile peptone water (1.5 g/ml) from which a corresponding aliquot was added to the milk and gently shaken.
2.2. Experimental design and statistical analysis

A total of 21 experimental groups were obtained: 5 fiber concentrations (0.2, 0.4, 0.6, 0.8 and 1 g/100 ml), 2 fiber particle sizes (0.417–0.701 and 0.701–0.991 mm), 2 fibre heating procedures (pasteurized and non-pasteurized fiber) (5 × 2 × 2) plus a control group without fiber. Overall composition and pH were determined in duplicate on each group; rheological measurements were made in triplicate on set and stirred yogurt of each group. Statistical analysis was run on SPSS 14.0 (Chicago, IL, USA) for Windows. General Linear Model procedures and pairwise comparison (Tukey’s test) for means was used. The whole experiment was run in triplicate.

2.3. Sample preparation

2.3.1. Procedure to prepare yogurt

For treatment samples that required fiber heat treatment, orange fiber powder was dispensed into 50 ml Pyrex® flasks according to the fiber doses corresponding to each treatment. Milk was poured into the flasks to obtain the final mix. The flasks were closed and immersed into a water bath for heat treatment at 80 °C for 30 min, followed by immersion in ice-water baths to cool down to 43 °C at this point the starter culture was added and gently shaken. For those treatments not requiring fiber heating, the fiber was added to the pasteurized milk at this point. The inoculated mix was poured into the cylindrical containers and incubated at 43 °C to reach pH 4.7, and then cooled down to 4 °C.

2.3.2. Preparation of cylindrical samples for rheometry

The cylindrical containers in which yogurts’ fermentation took place were prepared by cutting the narrow end of 60 ml graduated syringes (150 mm height, 25 mm diameter). After fermentation, gel cylinders of 1.2 ± 0.2 mm thickness were carefully sliced with a sharp blade while pushing the plunger very slowly to avoid breakages. All samples were handled similarly, and no evidence of early breakages was apparent from rheological measurements.

Stirred yogurt samples were obtained similarly, but fermentation took place in sterile 100 mL plastic cups. After fermentation, samples were stirred with a spoon 10 times clockwise and 10 anti-clockwise. In order to create a creamy texture and remove hydrated fiber particles, an aliquot of yogurt was sieved by gravity through a screen (1.65 mm).

2.4. Rheological measurements

An oscillatory test was applied to determine the rheological behaviour of the set yogurt slices and sieved stirred yogurt samples prepared as described before, using a rheometer (Rheostress 600, with Rheowin 3.21 Haake, Karlsruhe, Germany). Measurements from all samples were within the range of linear viscosity. The geometry used was plate and plate with serrated platens (35 mm diameter, 1 mm gap) to prevent slippage, and it was set at 7 °C. Haque et al. (2001) suggested that when the yogurt network is very weak, sedimentation of casein aggregates occur, and that the syneresis triggered by this agglomeration leads to the formation of a depleted layer at the upper surface of the sample. When oscillatory measures are to be taken in a horizontal geometry, this layer causes slippage of the moving element, thus giving rise to an apparent reduction in modulus. In the present work, serrated plates were used to overcome this possibility.

Two types of test were run: (i) stress sweep from 0.015 to 1.5 Pa at a constant frequency of 1 Hz and (ii) frequency sweep from 0.01 to 10 Hz at a constant stress of 0.4 Pa with three cycles of measurements in both tests. The measurements were conducted in triplicate.

2.5. Overall composition and pH

Protein, fat, ash and water content were determined following standard methods (AOAC, 1995) on 24 h old yogurt preparations. The pH was determined with a pH meter GPL 21 Crison (Alella, Spain).

3. Results and discussion

The mean fermentation time was 5 h and 30 min. The total solid content of yogurts ranged from 14.35 to 14.85 g/100 g, the fat content was less than 0.1 g/100 g, protein from 4.89 to 5.12 g/100 g and ash from 0.68 to 0.81 g/100 g. The pH values ranged from 4.58 to 4.71. Increasing citrus fiber concentration from 0.2 to 1 g/100 g did not significantly affect the pH, total solids, and fat, ash and protein contents of yogurts.

Dello Staffolo et al. (2004) recommended the addition of fruit fibers to yogurt at levels up to 1.3 g/100 ml, in the present study doses up to 1 g/100 ml were tested following evidences from previous studies, indicating that higher doses produced low sensory scores. Previous studies on fiber addition to yogurts reported the use of fiber of less than 85 μm, a distinctive feature of this study is that bigger fiber sizes were used (dry particles were from 417 to 991 μm and the size increased due to water absorption). Smaller sizes were reported to be inappropriate because they were linked to sandiness perception (García-Pérez, 2002). Orange fiber particles have an uneven composition, they may include both albedo and flavedo. Additionally, it should be noted that the fibre preparations are diverse both in composition and structure. Upon microscopical examination of the bigger particle sizes, it is evident that the structure of the orange tissues is to some degree intact (results not shown).

Considering that the structure of the protein network in yogurt is not well established in the first days of ageing, no rheological measurement was made right after manufacture (Lubbers et al., 2004). In young gels (shortly after formation) the elastic or storage modulus (G′) is low and the pH is still at high levels (>5.0), where the electrostatic attraction between casein particles is not yet as high as it would be in aged gels (Lucey, 2001). However, the fracture properties of young gels may be relevant as an indicator of possible rearrangements.

In the potential interactions between proteins and polysaccharides in aqueous solutions three equilibrium situations could be possible: miscibility, thermodynamic incompatibility (protein polysaccharide repulsion) and complex coacervation (attraction of protein and polysaccharide) (Tudorica et al., 2004). Incompatibility consequently leads to the separation of the mixture into liquid phases, with a corresponding increase of their relative concentration in the different phases.

3.1. Rheology of set style yogurt

The data obtained through oscillatory measurements are the contributions to the internal structure of the sample from the elastic and viscous portions of flow, G′ and G″ (Pa), respectively, the complex viscosity η* (Pa s), the tan (δ) which is equal to G″/G′ and the deformation (γ). G′ is the energy stored per deformation cycle during an oscillatory test. It is related to the stiffness of the network (Lucey, 2001). It was hypothesized that the elastic contribution to flow, G′, would relate to the elastic nature, measured by the texture analyzer, and the complex viscosity to the cohesiveness (estimation of the amount of deformation before rupture) measured by the panel and the texture analyzer (Kealy, 2006). G″ is the viscous contribution to flow and tan (δ) reflects the viscoelastic behaviour.
3.1.1. Results of the stress sweep test

The studied yogurts remained in the linear viscoelastic region over a short range of applied stress (0.1–0.4 Pa). $G$, $G'$, $\eta^*$, tan ($\delta$) and $\gamma$ at 0.363 Pa were selected to run statistical analysis of the data (Table 1). The statistical analysis output in the table includes univariate comparisons (type of yogurt). Steffe (1996) reported values of 129 Pa, 153 Pa, 20 Pa s and 1.19 for $G$, $G'$, $\eta^*$ and tan ($\delta$), respectively, in concentrated solution whereas values of 518 Pa, 363 Pa, 520 Pa s and 0.0699 were typical for gels. Data from the set yogurts of the present study would suggest a more concentrated solution behaviour.

All the studied factors significantly affected rheological properties of yogurt. However, the best indicator of viscoelasticity, tan ($\delta$) was not significantly affected. The values of $G$, $G'$ and $\eta^*$ increased with fiber dose in pasteurized fiber yogurts; whereas in non-pasteurized fiber only slight changes, not significant for all groups were observed. Actually low doses of 0.2 and 0.4 g/100 ml resulted in lower values for these parameters, coinciding with the observations of García-Pérez et al. (2006). Possibly, at fiber dose lower than 0.4 g/100 ml, rheological parameters decreased due to a disruptive effect of the fiber, and when fiber dose was higher than 0.6 g/100 ml rheological parameters increased. It is suggested that although the presence of fiber particles always alters yogurt structure, when the fiber dose is high enough the water absorption compensates the weakening effect of the fiber and strengthens gel structure. Yogurt deformation ($\gamma$) decreased with increased fiber levels.

Regarding particle fiber size, $G$, $G'$ and $\eta^*$ increased with fiber size and deformation was lower for the largest fiber size. For a given dose, the total number of fiber particles is higher when the small fiber size is used, and consequently the disrupting effect is higher.

Regarding fiber pasteurization, $G$, $G'$ and $\eta^*$ were higher in pasteurized fiber yogurts and deformation tended to decrease although no significant differences were observed in all cases. It seems that fiber pasteurization would solubilise some components of the orange fiber powder which lead to an enhanced yogurt structure whereas if it is not pasteurized fiber is mainly insoluble and only reinforces yogurt structure in the measure that it absorbs water. It is suggested that orange fiber will present thermodynamic incompatibility with milk proteins and only when the fiber is pasteurized with the milk some solubilization and miscibility of compounds will occur.

3.1.2. Results of the frequency sweep test

The yogurts showed a predominantly elastic behaviour ($G' > G''$) over the whole range of frequencies tested (Fig. 1), which corresponds closely to that of a true gel. When analyzing the results from frequency sweeps, moduli ($G'$ and $G''$) are a strong function of frequency in dilute and concentrated solutions, but practically constant in gels (Steffe, 1996). In the present study moduli increased with increased frequency. The tangent of the phase shift of phase angle is also a function of frequency: tan ($\delta$) = $G'/G''$. Steffe (1996) suggested the following numerical ranges for tan ($\delta$) of polymer systems: very high for dilute solutions, 0.2–0.3 for amorphous polymers, low (near 0.01) for glassy crystalline polymers and gels. The obtained results (tan ($\delta$) from 0.250 to 0.330) point to a concentrated amorphous polymer rather than a gel.

The delta value for a gel is practically constant, indicating consistent solid like behaviour over the entire frequency range (Steffe, 1996). In the present study the set yogurt behaves more than a concentrated solution. Materials usually exhibit more solid like characteristics at higher frequencies (Steffe, 1996) as in the present study where a decrease in tan ($\delta$) with increased frequency has been observed. The linear decrease of the complex viscosity corresponds to a typical shear thinning profile. The obtained set yogurt seems to behave as a very weak gel, much closer to a concentrated solution than to a true gel.

3.2. Rheology of stirred yogurt

3.2.1. Results of the stress sweep tests

No significant differences within stirred yogurt samples were observed for the studied rheological parameters (data not shown). Values for the following parameters were between: $G'$ from 64.99 to 115.97 Pa; $G''$ from 14.00 to 29.82 Pa; $\eta^*$ from 8.43 to 18.53 Pa s; $\gamma$ from 6.43 to 15.85 s⁻¹; tan ($\delta$) from 0.36 to 1.19.

### Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Control</th>
<th>Pasteurized fiber</th>
<th>Non-pasteurized fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>$G'$ (Pa)</td>
<td>58.03±4</td>
<td>79.51±7</td>
<td>50.55±4</td>
</tr>
<tr>
<td>$G''$ (Pa)</td>
<td>18.91±4</td>
<td>26.28±4</td>
<td>16.36±4</td>
</tr>
<tr>
<td>$\eta^*$ (Pa s)</td>
<td>1.26</td>
<td>3.05</td>
<td>4.14</td>
</tr>
<tr>
<td>$\gamma$ (°)</td>
<td>9.72±4</td>
<td>13.31±4</td>
<td>8.43±4</td>
</tr>
<tr>
<td>$\tan (\delta)$</td>
<td>0.81</td>
<td>1.48</td>
<td>2.42</td>
</tr>
<tr>
<td>$\gamma$ (°)</td>
<td>0.24</td>
<td>0.327</td>
<td>0.327</td>
</tr>
<tr>
<td>$\gamma$ (°)</td>
<td>0.012</td>
<td>0.0071±1</td>
<td>0.0017</td>
</tr>
</tbody>
</table>

Fiber addition levels: 0.2, 0.4, 0.6, 0.8, 1 g/100 ml; fiber size M (0.417–0.701 mm); G (0.701–0.991 mm). Values with different superscript letters within the same column significantly differ (*P < 0.05).
tan (δ) from 0.290 to 0.335; and deformation (γ) from 0.002 to 0.003. A single significant difference was observed, the tan (δ) of yogurts with 1 g/100 ml pasteurized fiber (0.401–0.711 mm) was significantly higher than that of all the other groups, meaning a decreased solid behaviour of this type of yogurts. A decrease in tan δ in a viscoelastic material is generally associated with more pronounced solid like behaviour (Tudorica et al., 2004).

Once lost the original structure of the yogurts, the rheological properties will depend mainly on the total solids, particularly the amount and type of protein (Oliveira et al., 2001). Although no significant differences on composition were detected between samples, the fact that fiber has an important water holding capacity could have modified the rheological behaviour of the yogurt which has been previously described in the case of inulin addition to yogurt (El-Nagar et al., 2002). A non-significant tendency to increase G', G″ and tan (δ) and to decrease deformation due to fiber presence was observed, but it was not always dose dependent.

Rheology assessment in particulate foods such as fiber enriched yogurts is difficult. The selected procedure did not yield the expected results and so it does not seem suitable for the study of the rheology of stirred yogurts.

### 3.2.2. Results of the frequency sweep tests

G', G″ increased with frequency increases whereas complex viscosity dramatically decreased showing a clear shear thinning profile, tan (δ) remained almost constant during the frequency sweep (Fig 2). Stirring the yogurts hindered differences among different samples. When the fiber had been pasteurized differences between samples with different fiber concentrations almost disappeared. The fiber with small particles resulted in a weaker gel structure (lower G', G″ and γ decreased).

Although some types of non-pasteurized fiber yogurts with doses lower than 0.4 showed weaker network structure than the control, as described by García-Pérez et al. (2006), it has to be pointed out that in the cited work only pasteurized fiber was tested.
The fact that this effect has not been observed in pasteurized fiber yogurts in the present study may be due to the nature of the measurements: García-Peñalver et al. (2006) only used destructive tests with large deformations instead of the non-destructive methods with small deformations of the present study (Table 1). Related to sensory properties, Kealy (2006) observed a good correlation between the sensory cohesiveness and complex viscosity measurements. As $\eta^*$ is a function of both viscous and elastic contributions to flow, they would be expected to correlate with the human sensory experience. Hardness (the force required to evenly deform the sample) assessed by a taste panel and a texture analyzer showed a strong correlation. Probably due to the difference in techniques (destructive vs. non-destructive), texture analyzer and rheometer ranked samples in opposite order in their study. This neatly illustrates the differences between the extensional properties (which dominate in large deformations in destructive assays) and elastic modulus (small deformation, non-destructive measurement). The combination of these techniques could provide practitioners with an effective tool for predicting the properties of a product.

4. Conclusions

Citrus fiber from orange by-products is a novel ingredient that can be successfully used in yogurt production. Yogurts behave as shear thinning fluids and very weak gels. Orange fiber addition modifies yogurt rheology; when the fiber is with the pasteurized mix $G'$, $G''$, and complex viscosity increase with fiber dose, whereas in non-pasteurized fiber yogurts, rheological parameters remain low at low fiber doses due to the disruptive effect of the fiber, while at higher fiber dose over 0.6 g/100 ml rheological parameters increased. Although the presence of fiber particles always alters yogurt structure, when the fiber dose is high enough the water absorption may compensate the weakening effect of the fiber and strengthens the gel structure. $G'$, $G''$ and viscosity are higher in yogurts with large fiber particle size than in yogurts with smaller fiber particles. For a given dose, the total number of fiber particles is higher when fiber size is small, and consequently the disrupting effect is higher. Fiber pasteurization in the mix enhances its integration in the gel matrix decreasing the differences in rheological behaviour between yogurts with different fiber levels.
experiments on the set gel provided more detailed information than those on the stirred gel.

References