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Effect of processing on rheological, structural and sensory properties of apple puree

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Abstract

The relation between rheological, structural and sensory properties of apple purees was studied taking into account the effect of processing. For this reason, a grinding - separation strategy was established in order to vary pulp content and particle size. By grinding, three different particle size distributions were obtained. A second heat treatment was applied to purees to see the impact on its rheological and structural properties. An experimental design was constructed, with two factors (pulp content and particle size) and 4 levels (25, 31, 42, 60 \%) for pulp content and 3 levels (200, 500, 1100 \(\mu m\)) for particle size. The rheological properties of purees were characterized using a controlled stress rheometer by the flow curves obtained from 2.14 to 214 \(s^{-1}\) shear rate range; frequency sweeps measurements were performed within the linear viscoelastic region, in the range of 0.1-40 \(rad/s\). Purees behaved as shear-thinning fluids presenting a yield stress. Apparent viscosity and yield stress increased as pulp content increased, and they decreased as particle size decreased. The least shear thinning behaviour was observed in purees with low pulp content and small particles. A second heat treatment affected cell wall structure inducing a decrease of the rheological properties of the puree. The most important attributes to explain the texture of apple purees are consistency and graininess, parameters that can be manipulated by controlling processing conditions.

Keywords: Malus x domestica Borkh; particle size; serum; viscosity; consistency

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1. Introduction

Texture is a major quality attribute of plant-based foods; texture is defined as the sensory and functional manifestation of the structural, mechanical and surface properties of foods detected through the senses of vision, hearing, touch and kinesthetics [1]. Recently, there has been a great interest in the development of methods to predict and control the texture of plant-based foods, particularly in relation to processing and/or post harvest treatments [2]. Apple purees are concentrated plant food dispersions where soft insoluble particles (pulp) composed of cell or cell wall clusters from parenchyma are dispersed into an aqueous solution (serum) of sugars, organic acids and pectic substances [3]. In general purees of fruits and vegetables are shear-thinning (pseudoplastic) fluids and exhibit a yield stress, defined as the stress that must be exceeded for flow to occur [4]. The consistency index, apparent viscosity, yield stress are important product properties. Thus the rheological parameters are a useful tool in understanding changes in food structure during processing and to control the quality of the product. Solids content, particle size distribution of solids and serum viscosity play important roles in the rheological behaviour of plant food dispersions [3]. Structural and rheological properties of fruit purees depend also on variety and ripeness stage of the fruits. Another important parameter influencing the products properties is related to the processing conditions (heating and mechanical treatments). Schijvens et al [5] observed that cooking time seemed to influence serum viscosity in relation to pectin degradation and pulp content. At the refining stage, varying the screen opening will change the particle size and pulp content [6] and hence modify the flow properties. The mechanical properties of apple purees thus seem to be very specific to the processing parameters involved. Moreover, the processing induced changes in various mechanical attributes of these products are likely to influence their sensory perception [7]. The aim of this study is to better understand the relationship between the structural, rheological, and sensory parameters of apple puree, taking into account the impact of manufacturing process on these parameters, mainly the texture. For that reason reconstituted purees were made with defined pulp content and particle size. A second heat treatment was applied to some purees to simulate some steps of industrial processing and to understand their impact on the final product.

Nomenclature

\[
\begin{align*}
\dot{\gamma} & \quad \text{Shear rate (s}^{-1}\text{)} \\
\sigma & \quad \text{Shear stress (Pa)} \\
\sigma_o & \quad \text{Yield stress (Pa)} \\
k & \quad \text{Consistency index (Pa-s}^n\text{)} \\
n & \quad \text{Flow behaviour index}
\end{align*}
\]

2. Materials & Methods

The studied apple puree was industrially processed by a French manufacturer using a cold-break method with a single batch of Golden Delicious. Apples were selected, washed and roughly cut, followed by the addition of ascorbic acid (500 ppm) to prevent oxidation. Then the apple pieces were refined (sieve opening of 1.2 mm) and cooked (98°C, 4 min). Puree was kept in a flow regulating tank before being sterilised. Finally purees were conditioned in hermetically sealed bags. This sample is called Native puree (N).
2.1. Preparation of products with varied structure

Puree was ground, so as to obtain samples with different particle size distribution. Thus N was ground in a Grindomix GM 200 (Retsch GmbH, Germany) for 5000 rpm/15 sec, to obtain sample denoted MB and for 10000 rpm/3min, to obtain sample called TB.

For all three purees (N, MB and TB), the pulp and the serum were separated from the purees (N, MB and TB) by centrifugation at 5000 x g for 2 hours at 20°C in a 3.18 K centrifuge (Sigma GmbH, Germany). Samples with a wide range of pulp content were obtained by reconstitution, by mixing the pulp and serum in different ratios.

The reconstitution was carried out following an experimental design so as to study the relationship between structural, rheological and sensory properties, with two factors (pulp content and particle size) and 4 levels (25, 31, 42, 60 %) for pulp content and 3 levels (200, 500, 1100 μm) for particle size (Table 1). A total of 12 products resulted from this experimental design; one product was removed (25%, 200μm) as its texture (more liquid) did not belong to a puree.

Table 1. Experimental Design; * Native puree (N); Ground purees a: MB, b: TB

<table>
<thead>
<tr>
<th>d(0.9) μm</th>
<th>Pulp percentage (%w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 (N)</td>
<td>25 31* 42 60</td>
</tr>
<tr>
<td>500 (MB)</td>
<td>22 28a 39 57</td>
</tr>
<tr>
<td>232 (TB)</td>
<td>- 27b 38 56</td>
</tr>
</tbody>
</table>

2.2. Effect of heat treatment

N and TB purees were subjected to a heating program of 105°C for 15 min in a rotatory autoclave.

2.3. Particle size distribution

The particle size distribution (PSD) was measured using a laser diffraction analyser (Master Sizer, Malvern Instruments Ltd UK), applying the Fraunhofer optical model. The \(d(0.9)\) represents the diameter above which there is only 10 % (in volume) of bigger particles. Analysis was done on the diluted samples in distilled water; each sample was run in triplicate.

2.4. Pulp Content

The pulp content of the samples was determined in triplicate by centrifugation at 5000 x g for 2 hours at 20°C. The pulp percentage was expressed as the relation between the pulp weight and the initial sample weight [8].

2.5. Rheological measurements

Rheological measurements were carried out using an MCR-301 controlled stress rheometer (Anton Paar, Germany) at 20°C in triplicate. Steady state measurements of apple purees were characterized using a concentric cylinder geometry consisting of a rotating inner cylinder with an inner radius of 14.46 and 40 mm immersed height. The outer stationary cup had an outer radius of 14.46 giving a gap of 5.0 mm. A pre-shear rate of 43 s\(^{-1}\) was applied to the puree for 1 min, and the apparent viscosity was obtained from
this step. Then shear rate was increased from 2.14 to 214 s\(^{-1}\) for 5 min and decreased from 214 to 2.14 s\(^{-1}\) for 5 min.

The rheological properties were described by the Herschel-Bulkley model: 
\[
\sigma = \sigma_0 + k \gamma^n
\]
where \(\sigma\) is shear stress (Pa), \(\sigma_0\) is yield stress (Pa), \(k\) is consistency index (Pa.s\(^n\)), \(\gamma\) is shear rate (s\(^{-1}\)), and \(n\) is a dimensionless flow behaviour index.

Oscillatory tests of apple purees were carried out using a six blade vane geometry, with an outer radius of 11 and 16 mm height. The outer stationary cup had an outer radius of 14.46 giving a gap of 3.46 mm. Oscillatory stress sweep tests were performed at an angular frequency of 10 rad/s in order to determine the range of linear viscoelastic response (limit of linearity) under oscillatory shear conditions. The frequency sweep measurements were performed within the linear viscoelastic region, in the range of 0.1 - 40 rad/s.

The viscosity of the serum obtained by centrifugation was measured using double gap cylinder geometry with an internal gap of 0.422 mm, an external gap of 0.473 mm and 40 mm height. Serum was previously filtered using a filter paper (Filter papers No 41, Whatman International, Ltd.). Shear rate was increased from 10 to 1000 s\(^{-1}\) for 4 min and decreased from 1000 to 10 s\(^{-1}\) for 4 min; viscosity of the serum was obtained in the Newtonian range at low shear rate.

2.6. Sensory analysis

The sensory analysis was performed by a trained panel consisting of eleven panellists. Each puree was subjected to evaluation of its textural properties, as previously studied by Colin-Henrion et al [7] on industrially processed applesauces. Sensory attributes (data to be published) were evaluated in an unstructured scale anchored with the terms ‘very weak’ and ‘very intense’.

3. Results & Discussion

3.1. Particle size distribution

Laser scattering analysis indicated a bimodal particle size distribution in the native sample N (the first peak at 1000 \(\mu\)m and the second at 200 \(\mu\)m). Nevertheless, by grinding, the peak of the bigger particles disappeared and the characteristic size of the first peak decreased (Figure 1a), reaching 200 \(\mu\)m with TB. Probably the smaller particles consisted of individual cells from parenchyma tissue, while larger particles consisted of aggregates of cells, as it has been observed for other fruit purees [9]. The \(d(0.9)\) is 1000, 500 and 230 \(\mu\)m for N, MB and TB purees respectively (Figure 1b). The different grinding parameters were sufficient to create different particle size distributions, thus resulting in different products and properties.

![Graphs showing particle size distribution and cumulative volume](image-url)
3.2. Pulp Content

According to the centrifugal protocol, N puree has a pulp content of 31%, MB puree of 28% and TB puree of 27%. As Rao [10] stated, the level of the pulp content in plant dispersion depends on the centrifugal force employed in the separation of the phases, so its determination is difficult. The pulp content measured after reconstitution of the purees differed from what we expected (Figure 2). The height sedimentation might vary depending on the shape, size and amount of the particles in the sample. Concerning the diluted products, the pulp percentage was higher than expected, but never exceeding 31%. For the concentrated samples, values were lower than expected. The quantity of cell wall was higher so the mass of sediment was higher, resulting in lower apparent pulp content values than expected.

![Pulp Content Graph](image1)

**Fig. 2.** Pulp content measured and expected of the products

3.3. Effect of processing on rheological properties of apple puree and serum.

All apple purees showed a shear thinning behaviour as observed in other fruit purees [11]. By grinding, that is to say by changing the particle size, apparent viscosity (43s⁻¹ shear rate) of purees decreased from 1600 (N) to 1180 (MB) and 620 mPa-s (TB). As stated by Tanglerpaibul and Rao [12] large particles contribute to higher viscosity. Apparent viscosity increased as pulp content increased, and it decreased as particle size decreased (Figure 3a).

![Rheological Properties Graph](image2)

**Fig. 3.** (a) Apparent viscosity (43s⁻¹) and (b) Flow index (n) as a function of pulp content (% w/w)
The rheological properties were described by the Herschel-Bulkley model. The highest values of indices were shown by purees with high pulp content, and the consistency index decreased as the particle size of the puree decreased. The flow index \( n \) varied between 0.27 and 0.49, which showed that purees behaved as shear-thinning fluid. It depended on the particle size and on the pulp content, for a pulp concentration of 25% and 31%, when the particle size decreases the consistency index increases Ahmed et al [13] reported similar results for green chilli puree. The opposite was observed for the higher concentrations (42-60%), where the index behaviour decreased as particle size decreased (Figure 3b).

Yield stress of purees increased as pulp content increased. In fact, even a small change in pulp content strongly affected the yield stress values. Yield stress values decreased as particle size decreased, and yield stress values for N and MB were closer to each other than those of TB values; as it can be observed in Figure 1 PSD of TB is almost concentrated in one peak (200 \( \mu \text{m} \)) whereas MB and N have bigger particles. Comparing the yield stress obtained by the different methods such as Herschel–Bulkley (HB) and limit of linearity (LOL), it can be observed (Figure 4) that \( \sigma_{\text{HB}} \) is higher than \( \sigma_{\text{LOL}} \). However \( \sigma_{\text{HB}} \) is obtained by extrapolation of the flow curve and \( \sigma_{\text{LOL}} \) is obtained by oscillatory tests; the same phenomena was observed in jaboticaba pulp [9].

![Figure 4](image4.png)

*Fig. 4. Yield stress obtained from the Herschel-Bulkley model (\( \sigma_{\text{HB}} \) full symbols) and limit of linearity (\( \sigma_{\text{LOL}} \) empty symbols)*

The linear viscoelastic region for purees with lower pulp content occurred in a stress range of 0.01 to 2 Pa and for those with high pulp content between 0.1 and 13 Pa. The mechanical spectra of samples were typical spectra of a concentrated suspension (Figure 5). For all samples \( G' \) values are greater than \( G'' \) corresponding to a structured viscoelastic product with soft solid-like behaviour. By grinding, \( G' \) and \( G'' \) values decreased. As it was expected, higher pulp content purees showed a higher \( G' \) and \( G'' \) values than those with a lower pulp concentration.

![Figure 5](image5.png)

*Fig. 5. Elastic modulus \( G' \) (filled symbols) and loss modulus \( G'' \) (empty symbols) as a function of the frequency \( \omega \) in three apple purees N, MB and TB (● ▲ respectively)*
The serum obtained by centrifugation of the purees presented a Newtonian behaviour between 10-200s\(^{-1}\), and a shear-thinning behaviour in higher shear rates, these flow properties were likely due to the soluble pectins present in serum. Serum viscosity values of the purees varied between 11 and 13.9 mPa.s. The viscosity of the serum did not change between N and MB, and it increased slightly in the case of TB purees.

The second part of our study was conducted on N and TB purees with a second heat treatment. Particle size distribution was not affected. Pulp content was observed to decrease (Table 2) which could be attributed to the softening of particles and thus better compression during centrifugation.

Table 2. Effects of a second heat treatment on pulp content serum and puree viscosity

<table>
<thead>
<tr>
<th>Sample</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\eta) app 43s(^{-1}) (mPa-s)</td>
<td>(\eta) serum (mPa-s)</td>
</tr>
<tr>
<td>N</td>
<td>1440 ± 60</td>
<td>12.2 ± 0.1</td>
</tr>
<tr>
<td>TB</td>
<td>630 ± 70</td>
<td>12.8 ± 0.6</td>
</tr>
</tbody>
</table>

The effect of cooking on serum and puree viscosities is summarized in Table 2. After heat treatment, viscosities of the puree and serum decreased for both samples. As heating promotes the degradation of cell walls, resulting in the degradation and solubilization of pectins, it changes the rigidity of the particles. Redgwell et al [14] observed that solubilization of the pectic polysaccharides did not greatly affect the viscosity on suspensions of apple cell wall material; otherwise they observed a significant decrease on the viscosity due to a loss of cellulose/xyloglucan network. Thus the decrease in puree and serum viscosities can be explained by the modification of the cell wall structure and some pectin depolymerisation.

Results obtained from the sensory analyses will soon be published elsewhere: the textural properties of apple purees were dissociated by the panellists in two principal dimensions, the first one describing consistency and viscosity (firmness and fluidity) and the second related to graininess.

4. Conclusions

Pulp concentration and particle size may be identified as the key structural parameters having a large effect on the rheological properties of apple puree and then on their sensory properties. These parameters can be modified by the processing operations, i.e. the size opening of the finisher screen.

Apple purees showed a shear thinning behaviour, presenting a yield stress. Increasing pulp content increased shear thinning behaviour and consistency index. Apparent viscosity and yield stress decreased with decreasing particle size and pulp content, which was in accordance with the results found in literature [5,8]. The second heat treatment affected cell wall structure inducing a decrease of the viscosity of the puree and the serum. Therefore controlling the heat treatment parameters is important as they can affect the structural and rheological properties of the final product. Consistency and graininess are the most important attributes to explain the texture of apple purees.

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References


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