ANNUAL TRANSACTIONS OF THE NORDIC RHEOLOGY SOCIETY, VOL. 17, 2009

Rheological Characterisation of Plant Food Dispersions

Patricia Lopez Sanchez[1], Stephan Schumm[1], Maud Langton[2], and Lucy Bialek[1]

[1] Unilever R&D, Vlaardingen, The Netherlands
[2] SIK, Swedish institute for food and biotechnology, Gothemburg, Sweden

ABSTRACT

The objective of this study is to assess the effect of different temperature and shear treatments during vegetable puree production on the product rheology. The vane tool was selected as the best measurement system to characterise the viscoelastic properties of the plant food dispersions. The rheological behaviour of fresh and rehydrated fibres was compared.

INTRODUCTION

Plant fibres are used in the food industry as a way to produce more natural products due to their structural and nutritional properties. Their physicochemical properties and swelling behaviour make them very suitable as thickening agents and stabilisers. They are also used as fat replacers. Their rheological properties can be used to create textures for a range of applications from solid to liquid like food products.

The properties of cell wall materials depend on the kind of raw material used and on the processing parameters applied during their preparation. During the processing steps structural, physicochemical and nutritional changes can occur.

Plant cell wall dispersions are mixed systems formed of a continuous phase (serum) and a dispersed phase (pulp). The serum is a liquid phase containing different pectic materials, sugars, salts and organic acids. The pulp is formed by cell wall materials and other parts of the plant such as skin and seeds[1].

They usually possess shear thinning properties with a yield stress, however due to the heterogeneity in chemical composition and particle size and shape it is difficult to measure and analyse this rheology.

MATERIALS AND METHODS

Sample preparation

Carrots and tomato were washed, chopped and mixed with 50% and 10% deionised water respectively. The skin of the carrots and core of tomatoes were removed. They were mechanically disrupted with the help of a kitchen blender and thermally treated (90°C for 40 min). A high pressure homogenisation device (Niro Soavi) was used to further disrupt the material. A pressure of 600 bar was used for this. Samples were measured before and after this homogenisation step.

Dehydrated orange fibres (CitriFi 100M40, Fiberstar) were dispersed in water by gentle stirring.

Rheological measurements

The rheological measurements were carried out on a stress controlled rheometer TA ARG2 from Stable Microsystems. Smooth plates (diameter 4 cm, gap 1000 μm), a couette geometry (gap 1000 μm), and two vane tools (4 blades, gap 1000 μm and 8700 μm) were assessed with respect to the reproducibility of the rheological measurements. The cup used had rough surfaces. To prevent drying of the samples a solvent trap was used.

Prior to the measurements the samples were degassed in a vacuum chamber under slow stirring. The samples were loaded in the rheometer and the measurement tool was lowered into the sample. All measurements were performed at 20°C. A total of 3 replicates on fresh samples were performed.

To have some control over the history of the samples a pre-shear at 100 s^{-1} for 60 s was applied followed by a resting step of 5 min after which the small amplitude oscillatory shear measurements were carried out. To determine the viscoelastic moduli (G' and G'') a strain sweep from 0.01 to 100% was applied at 1Hz. Steady shear experiments were conducted by increasing the shear rate from 0.01 to 1000 s^{-1} and back during a total time of 4 minutes. A total of 50 points were collected.

In order to evaluate the most suitable geometry we used "CitriFi" as a control material with well defined chemical properties and particle size.

RESULTS AND DISCUSSION

Selection of the best geometry

A comparison between different geometries was carried out in order to select the best method to obtain reproducible results. The main issues with these plant dispersions are the large particle size, polidispersity and non homogeneity. Fig. 1 shows a comparison between smooth plates, serrated concentric cylinders and the vane. Wall slip occurs when using smooth surfaces. The vane reduced the slip and gave very reproducible results. The vane method is based on the measurement under almost static conditions because the sample within the blades is assumed to behave like a solid body. A vane consisting of a small number of thin blades is introduced into the sample until it is fully immersed[2]. Barnes and Carnali[3] compared the vane in cup geometry with the bob and cup geometry. Besides reducing the wall slip the introduction of the vane in the sample has less impact than a solid bob[4]. Large particles present less problems when a vane is used instead of a couette geometry. The former should give accurate results, as long as the gap is at least 10 times the particle size.

Therefore a vane geometry was selected for measuring the rheological properties of the plant dispersions.

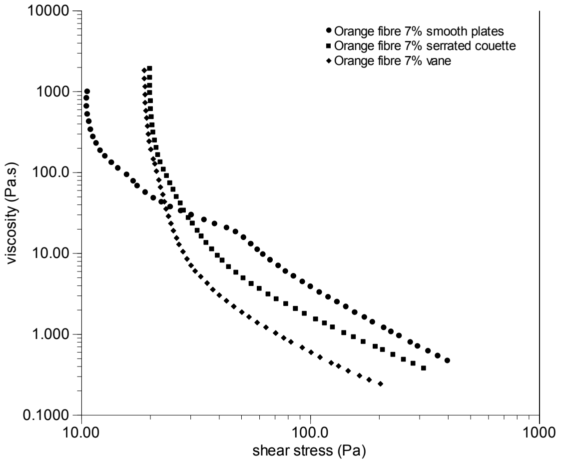

Figure 1. Flow curves of 7% orange fibre dispersions. The vane and the serrated cylinders were found to reduce wall-slip.

A comparison between a small vane (gap 8700 μm) and a large vane (1000 μm) was carried out on a diluted (50% water) and a concentrated (no water added) tomato dispersion. In Fig. 2 it is shown that for both systems the couette and the vane, with the same gap size, showed a very good agreement. The small vane showed lower values of the yield stress than the large vane. This effect was more pronounced for the concentrated system. A possible explanation is that the gap, at 1000 μm, of the large vane and the couette is too small compared to the size of the tomato particles ~300 μm and so particles can be trapped leading to higher yield stress values. This is not the case when a small vane with a wider gap, 8700 μm, is used.

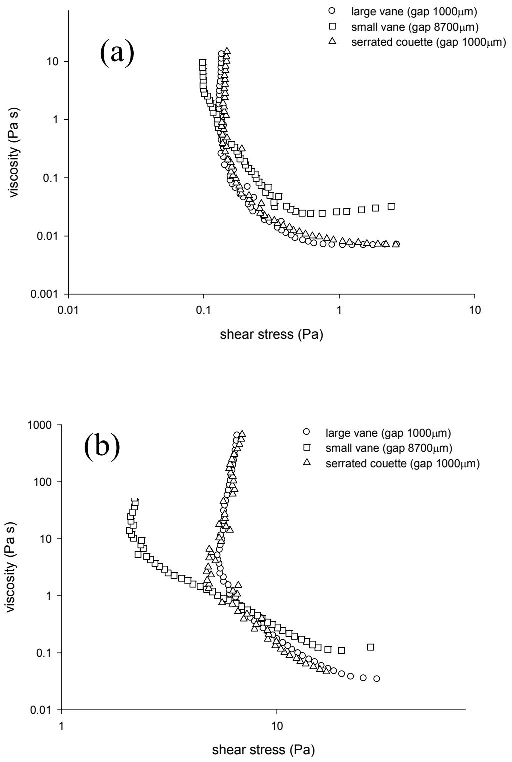

Figure 2. Comparison flow curves with different geometries of (a) diluted (50% water) tomato dispersion and (b) a concentrated tomato dispersion.

A disadvantage of the small vane is that inertia effects are dominant at high shear rate. Furthermore the shear rate varies through the gap. However this geometry was found to be the most suitable for these types of systems with large particle size (~300 μm).

Comparison fresh and rehydrated fibres

Figs. 3 and 4 show a comparison between the rheological behaviour of fresh tomato dispersions and rehydrated CitriFi fibres. Both systems showed a solid like behaviour with G' above G''. They are shear thinning materials with a yield stress. The viscosity curves for the CitriFi fibres and the concentrated tomato dispersion could be fitted to the Hershel-Bulkley model, while for the diluted tomato dispersion best results were obtained using the Sisko model[4].

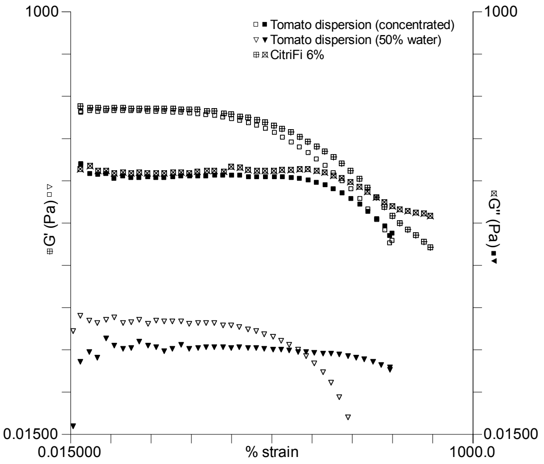

Figure 3. Viscoelastic moduli of fresh tomato fibres and rehydrated orange fibres.

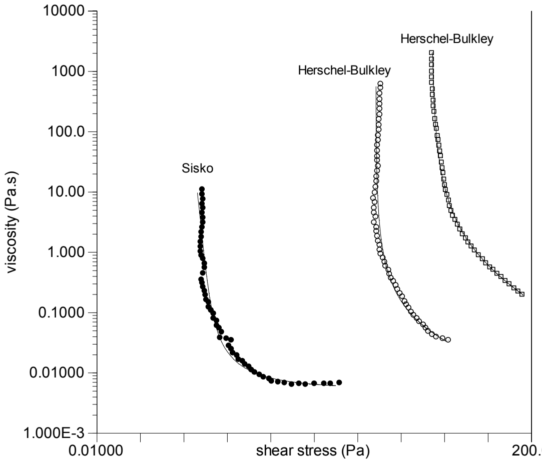

Figure 4. Typical viscosity vs shear stress curves for a concentrated tomato dispersion (open circles), diluted tomato dispersion (close circles) and a 6% CitriFi dispersion (open squares).

Effect of processing on rheology

The high pressure homogenisation step (HPH) led to a decrease in the viscoelastic moduli, G' and G'', of the carrot dispersions whereas a slight increase in the viscosity of the tomato dispersion was found (Fig. 5a and 5b).

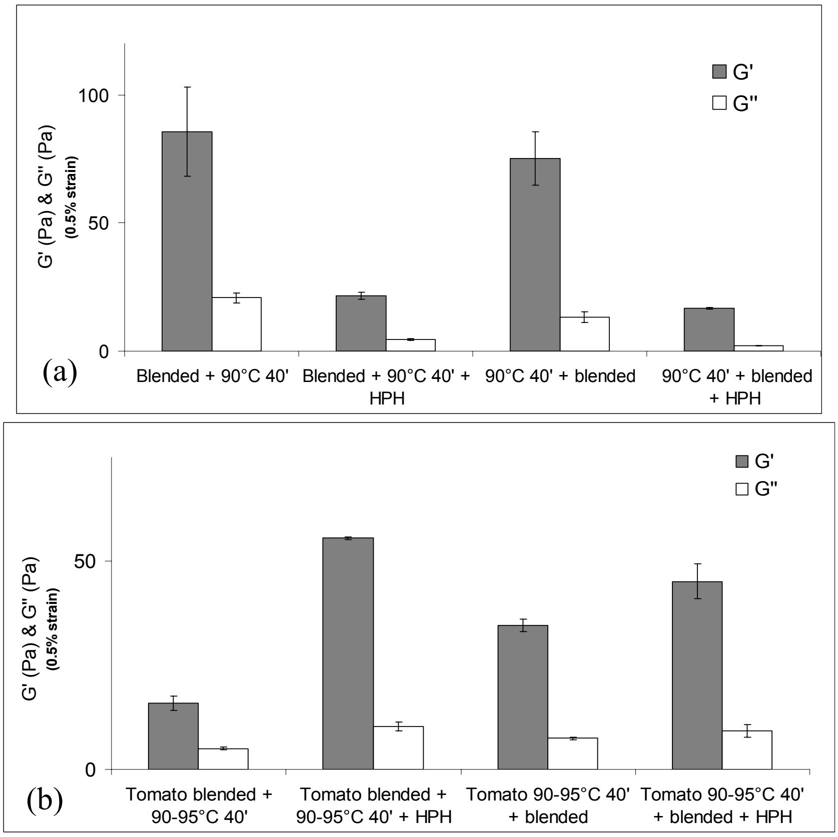

Figure 5. Effect of processing on G' and G'' at 0.5% strain of (a) carrot, and (b) tomato dispersions.

The particle size of all the homogenised samples was less than half that of the non homogenised. This might explain the decrease in viscosity of the carrot dispersions (through a reduction in the aspect ratio of the fragments). However for the tomato dispersion this was not the case. Scanning electron microscopy images (cryo-SEM) showed a change in the cell walls of the tomato particles after the high pressure homgenisation. A combination of size, morphology and hardness of the particles might explain their different rheological behaviour.

CONCLUSIONS

Despite problems with the inertia effect at high shear rates the vane tool was found to be the most suitable geometry for the types of plant fibre dispersions investigated.

Surprisingly, high shear processing led to opposite effects with respect to the measured viscoelastic properties for tomato and carrot purees, indicating important differences in the reaction of cell wall material from different botanical sources to processing conditions.

Fresh and rehydrated fibres showed overall similar rheological behaviour with the elastic modulus G' above the viscous modulus G".

ACKNOWLEDGMENT

The authors would like to thank Fiberstar for supplying Citrifi 100M40, Peter Versluis and Robert Farr for helpful discussions. The authors gratefully acknowledge financial support from the European Commission FOOD-2004-T5.4.1.3: Project 023115-Healthy Structuring.

REFERENCES

1. Rao, M.A. and Qiu, C.G. (1989), "Rheological properties of plant food dispersions" *ACS Symposium Series American Chemical Society*, pp.149-171.

2. Nguyen, Q.D. (1983), "Yield stress measurements for concentrated suspensions", *J. Rheol.,* **27** (4), 321-349.

3. Barnes, H.A. and Carnali, J.O. (1990), "The vane-in-cup as a novel rheometer geometry for shear thinning and thixotropic materials", *J. Rheol.*, **34** (6), 841-866.

4. Macosko, C.W. (1993), "Rheology: principles measurements and applications" VCH publishers New York, pp. 223-224.