Rheological Characterization of Fiber Suspensions Prepared from Vegetable Pulp and Dried Fibers. A Comparative Study.

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ABSTRACT

The effect of the water insoluble solids (WIS) content, the particle size, and the water holding capacity on the rheological properties of fiber suspensions has been studied. The flow behavior of the suspensions was described by a power law model in the shear rate range between 1 and 100 s^{-1}.

INTRODUCTION

The rheological properties of food products are important to control, both during processing and storage, as they affect the quality of the final product. Moreover, reliable rheological data allows a better design of the process and the processing equipment. Vegetable foods consist to a large extent of cell wall material. When this type of foods are mashed into purees and pastes they form a dispersion of fibers, whole cells, cell fragments and proteins (i.e. the pulp) in a continuous phase, usually an aqueous solution of sugars (i.e. the serum).

Literature on the rheology of fluid foods is wide and often contradictory, and has been rather focused on describing the effect of both the concentration and temperature on viscosity[1, 2, 3]. The role of the pulp content on the rheological properties of fluid foods such as tomato puree[4] or tomato juice[5] has previously been studied. The structure of the cell wall material and how it is disintegrated and swollen in the continuous phase is of key importance to control the rheological behavior of fibrous suspensions under flow conditions.

We have therefore chosen to generally characterize and study the rheological behavior of cell wall materials as dried fibers and vegetable pulps (i.e. different swelling capacities) and from different origins (i.e. different composition) in suspensions of similar fiber content.

MATERIAL AND METHODS

Dry fiber suspensions. Three different types of commercial dried fibers with similar particle size (30-35 µm) were used: potato fiber (Lyckeby Culinar), apple fiber (Vitacel AF 400-30) and cellulose fibers (Vitacel L 600-30). Fibers were suspended at different concentrations (0.5, 1, 3, 5 and 7 % w/w) in an aqueous sucrose solution (20ºBrix) with different amounts of pectins HM-200 (CPKelco). The pectin content was chosen to be 1.4 % for both potato and apple fibers and 1.8 % for cellulose fibers, in order to avoid precipitation of the fibers.

Pulp dilutions. Three different types of pulp were chosen: mechanically pressed potato pulp obtained from the process of extraction of potato starch, commercial mashed apples, obtained from mechanically pressed apples and separated through a sieve and two tomato pastes obtained by hot break with ~23 and ~29ºBrix, respectively. Potato pulp was diluted with water to 25 and 20 % w/w. Mashed apples were diluted (80, 70, 60, 50, 40, 30, 20, 10 % w/w) in an aqueous suspending medium (12 % sugar, 0.8 % pectins HM-200). Finally, tomato pastes were diluted to 80, 60, 50, 40, and 20 % w/w in a suspending medium (20% sugar and 0.8% pectins HM-200).

General characterization. Particle size and shape was studied by light microscopy (Olympus BX50) and a laser diffraction method (Coulter LS 130) applying the Fraunhofer optical model. Water insoluble solids (WIS) were calculated from the difference between the dry matter and the water soluble solids content, Eq. (1), and it is assumed to be the insoluble fiber content.

$$WIS = \frac{TS - SS}{100 - SS} \qquad (1)$$

Dry matter (TS) was measured in a vacuum oven for 16 h at 70ºC. Water soluble solids (SS) was measured with a manual refractometer as ºBrix.

Rheological characterization. A rotational controlled-stress rheometer was used to study the suspensions under steady-state conditions at 21ºC. The viscosity of the fiber suspensions and of the mashed apple dilutions was measured in a concentric cylinder rheometer (1mm gap, smooth surface). The viscosity of both tomato pastes was measured in a serrated-concentric cylinder rheometer (1 mm gap) in order to avoid slippage at the wall. The viscosity of potato pulp was measured in a tube viscometer (L=3 m, d_i=14 mm), in order to avoid disturbances due to the large particles of this sample. Power law model, Eq. (2) was applied to the data, and both, K and n parameters were determined in the range of shear rates between 1 and 100 s^{-1}.

$$\tau = K \cdot \dot{\gamma}^n \qquad (2)$$

Flow properties were determined at 21ºC because this is a relevant temperature during pumping. The dependence on the temperature was studied in a range of 20 to 30ºC. Tomato and potato pulp showed no dependence within the studied range. The mashed apple suspensions were sensitive to temperature. The effect of temperature on the dried fibers was studied in a separate work and the viscosity slightly decreased with increasing temperature. However, the effect of the pulp content and structure seems to be much greater than the possible effect of temperature[2]. Thus, the temperature effect on the dried fiber and pulp suspensions will not be considered further.

RESULTS

Particle size. The dried fibers were a mixture of heterogeneous particles with an aspect ratio ranging between 1.5 and 7 and an equivalent volume based diameter of 30-35µm (Fig. 1a, 1b). Pulps were a mixture of whole cells, cell fragments, skins and free fibers (Fig. 1c, 1d), with an equivalent volume diameter of ~280, ~420 and ~470 µm for tomato, potato and apple, respectively (Table 1). It has to be emphasized that the volume-based particle size distribution was unimodal but wide.

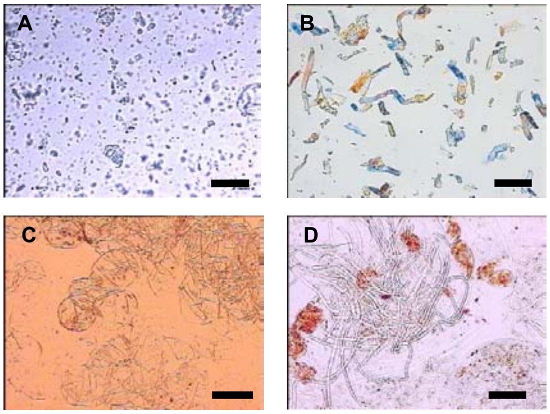

Figure 1. Typical photomicrographs of both dried fibers and pulp suspensions: (a) potato fibers, bar 100µm, (b) cellulose fibers, bar 100µm, (c) mashed apples, bar 200µm, (d) detail of the fiber aggregation in tomato paste ~29 ºBrix, bar 50µm.

Table 1. Compositional characteristics of both the dried fibers and the pulp suspensions.

	Content %	Particle size µm	pH -	SS ºBrix	WIS %	moisture %	separation of water by
Potato fibers	7.0	33,6 ± 66,8	4.44	22.7	5.5	73,0	gravity
Apple fibers	7.0	<30[1]	3.49	24.3	5.4	71,6	gravity
Cellulose fibers	7.0	33,1 ± 63,4	3.28	23.9	6.8	70,9	gravity
Potato pulp	100.0	419,0 ± 461	-	~1	21.5	78.5	non-separation
Mashed apples	100.0	463,0 ± 545	3.64	11.0	~1.5	87.7	gravity
Tomato paste~23	100.0	281,2 ± 364	4.36	17,5[2]	7.0	76.7	centrifugation
Tomato paste~29	100.0	272,9 ± 293	4.23	27,3[2]	4.2	69.6	centrifugation

[1]According to the supplier [2] Soluble solids measured on tomato serum

Water holding capacity. The content of water in 23 and 29ºBrix tomato paste is 76.7 and 69.6 %, respectively; in the apple pulp it is 87.7 % and in potato pulp it is 78.5 %. For the 7% fiber suspensions the water content was around 72 %, independently of the type of fiber (Table 1). Water is held inside the capillaries between the fibers. For the non diluted potato pulps it was impossible to release water by centrifugation at 30 000 g for 20 min, even if the water content of those pulps was high. For tomato paste, only about 9.9 % of the serum was separated by centrifugation under the same conditions. However, the water contained in the apple pulp was easily separated by gravity. Water was easily separated by centrifugation in the potato pulp dilutions, but it was more difficult to separate by gravity.

Rheological characterization. The suspensions of the fibers and the pulps presented a very different viscosity behavior. Figure 2 shows the dependency of the power-law parameters, the consistency coefficient (K) and the flow behavior index

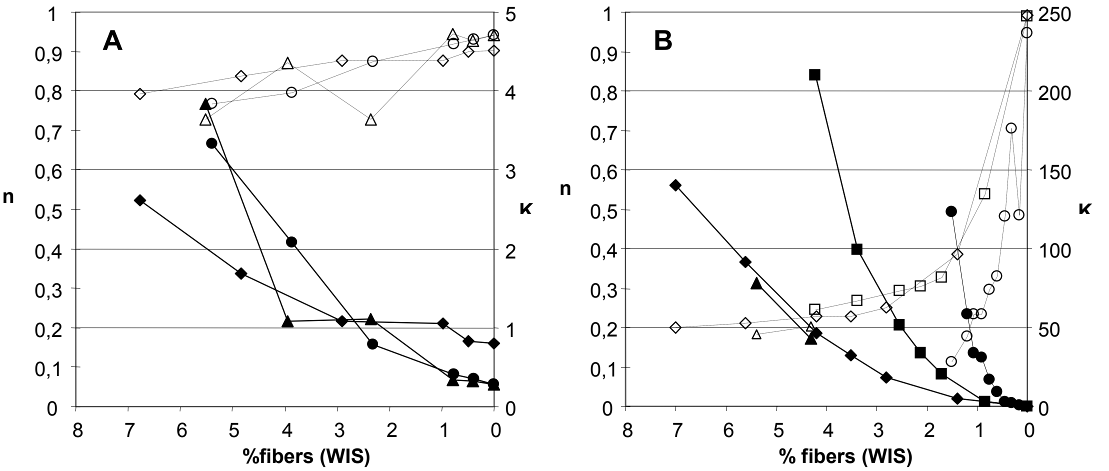

Figure 2. K and n parameters as a function of the fiber concentration, determined in a shear range of 1 and 100 s^{-1} applying a power law model (Eq. 1), to the viscosity curve. A) Fibers: potato (▲), apple (●) and cellulose (♦) and B) Pulps: tomato paste 23 and 29ºBrix (♦ and ■, respectively), mashed apples (●) and potato pulp (▲). Filled symbols are K-values and empty symbols are n-values.

(n), on the fiber concentration, for both dried fibers (Fig. 2A) and pulp suspensions (Fig. 2B). From Fig. 2A, it is observed that n-values increase slightly with decreasing concentration and are significantly higher than those in pulps (Fig. 2B). In addition, K-values were much lower (<5 Pa s^n) in the suspended fibers, whereas in the pulps they ranged between 250 and 0.05 Pa s^n. For the pulps, there is a drastic increase of the n-value below 2 % fiber concentration and a more or less exponential decrease of K with decreasing fiber concentration (Fig. 2B). Note that the calculated K and n parameters are only valid in the studied range of shear rates (1-100 s^{-1}).

DISCUSSION

The reason for this large difference in rheological behavior between dried fibers and pulps of similar fiber content might be due to the fact that the original physical structure of dried fibers have been destroyed during extraction and drying. There was no swelling of these fibers, as no change of the fiber diameter was observed after 2 days in an aqueous solution.

Earlier, Harper and El Sahrigi[6] showed that the viscosity of reconstituted tomato concentrate was only about one third of that of the corresponding original sample. In our study, moreover, the smaller particle size of the dried fibers along with their narrower particle size distribution gave rise to a better packing of the fiber particles and hence, the volume that those fibers occupied in the suspensions was probably very small compared to that of the pulps, at the same fiber content.

In pulps, fibers and cells are in a swollen state, which increases their volume fraction and hence, the number of contacts between the particles, resulting in a higher viscosity. Figure 3 clearly shows the enormous difference in viscosity between two tomato pastes and some of the dried fiber suspensions, at similar fiber (or WIS) content.

The origin of the material gave rise to large differences in the rheological behavior of pulps (Fig. 2B), whereas smaller or no differences were noted for the dried fibers (Fig. 2A).

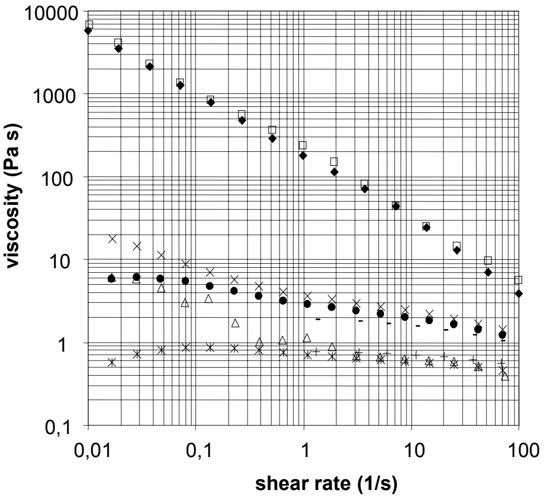

Figure 3. Viscosity as a function of shear rate: (♦) tomato paste ~23 ºBrix, (□) tomato paste ~29 ºBrix, (x) potato fibers at 7 %, (Δ) potato fibers at 3 %, (●) apple fibers at 7 %, (*) apple fibers at 3 %, (-) cellulose fibers at 7%, (+) cellulose fibers at 3%.

Indeed, tomato pastes of similar particle size showed different flow properties, and potato pulp (~420 μm) behaved closer to the tomato paste of 23°Brix (~280 μm) than to the mashed apple suspension (~470 μm). This suggests that not only the particle size is important, but also how these particles interact and form a network plays an important role on the flow behavior of the suspensions. It is speculated that the mashed apple includes more water in its network than the potato pulp does.

Interestingly, the apple pulp gave rise to the largest viscosity per gram of fiber (or WIS). In fact, this sample was the most mildly processed pulp compared to the others, where the latter were concentrated to high solid level by more severe mechanical treatment. It is also noted that the 29°Brix tomato paste was processed to a lesser extent than the 23°Brix paste. The mechanical history of a tomato juice has earlier been found to greatly affect its viscosity[5].

Below a specific level of fiber content (about 2 %), the pulp suspensions behave in a different fashion, denoted by a drastic change in the slope of the n-value (Fig. 2B). This could be an indication of a change in the flow regime from plug to poiseuille, i.e. from a yield stress fluid to a non-yielding one.

CONCLUSIONS

The flow behavior of both dried fibers and pulp suspensions is pseudoplastic and the rheological data is adequately described by the power law model, within the covered range of shear rates (1-100 s-1). Large differences in the rheological behavior between dried fibers and pulps are found. For pulp suspensions, the flow behavior index (n) is nearly independent of the concentration of fiber up to a specific fiber content (about 2 %), whereas the consistency coefficient (K) decreases exponentially with decreasing WIS in the concentration range studied (1-7 % WIS).

The structure of the fibers and the extent to which they were previously processed seem to be the key parameters determining the rheological properties of these suspensions.

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REFERENCES

1. B. Abu-Jdayil, F. Banat, R. Jumah, S. Al-Asheh and S. Hammad, A comparative study of rheological characteristics of tomato paste and tomato powder solutions. *Int. J. Food Prop.*, vol. 7, pp. 483-497, 2004.
2. N. Grigelmo-Miguel, A. Ibarz-Ribas and O. Martín-Belloso, Rheology of peach dietary fiber suspensions. *J. Food Engineering*, vol. 39, pp. 91-99, 1999.
3. M.K. Krokida, Z.B. Maroulis and G.D. Saravacos, Rheological properties of fluid fruit and vegetable puree products: compilation of literature data. *Int. J. Food Prop.,* vol. 4, pp. 179-200, 2001.
4. B.Yoo and M.A.Rao, Effect of unimodal particle size and pulp content on rheological properties of tomato puree. *J. Texture Studies*, vol. 25, pp. 421-436, 1994.
5. N. Beresovsky, I.J. Kopelman and S. Mizrahi, The role of pulp interparticle interaction in determining tomato juice viscosity. *J. Food Processing Preservation*, vol. 19, pp.133-146, 1995.
6. J.C. Harper and A.F. El Sahrigi, Viscometric behavior of tomato concentrates. *J. Food Sci.*, vol. 30, pp. 470-475, 1965