

Effect of strawberry concentrate on applesauce rheology

H.S. RAMASWAMY, S. BASAK and F.R. van de VOORT

Department of Food Science and Agricultural Chemistry, Macdonald Campus of McGill University, Box 187, Ste Anne de Bellevue, PQ, Canada H9X 3V9. Received 19 May 1993; accepted 21 February 1994.

Ramaswamy, H.S., Basak, S. and van de Voort, F.R. 1994. **Effect of strawberry concentrate on applesauce rheology.** *Can. Agric. Eng.* 36:109-115. Rheological properties of applesauce were evaluated using a rotational viscometer. Applesauce was mixed with various amounts of strawberry concentrate (68° Brix) to yield product mixtures with soluble solids ranging between 10 and 65° Brix. Applesauce and applesauce-concentrate mixtures showed pseudoplastic, shear-thinning flow behavior while the strawberry concentrate (68, 60, 40, and 20° Brix) alone exhibited Newtonian flow. The power-law model well described the flow curves of applesauce with or without added concentrate. Stress decay behavior of applesauce followed a logarithmic time model. Apparent viscosity of the mixture was modeled based on individual apparent viscosity contributions of the concentrate and applesauce.

Les caractéristiques rhéologiques de la sauce aux pommes ont été évaluées en utilisant un viscosimètre rotatif. La sauce aux pommes a été mélangée avec différentes concentrations de concentré aux fraises (68° Brix) pour obtenir des mélanges comprenant de solides solubles entre 10 et 65° Brix. Les mélanges: sauce aux pommes et sauce aux pommes concentrée on montre un comportement pseudoplastique et une dégradation progressive de la structure. Le concentré de fraise (68, 60, 40, and 20° Brix) seul a montré un comportement Newtonien. L'étude de la variation du taux de cisaillement pour la sauce aux pommes montre des courbes qui suivent globalement le modèle power law avec ou sans l'ajout de concentré. La viscosité de la sauce aux pommes suivant un modèle logarithmique. La viscosité apparente du mélange a été modélisée à partir des contributions individuelles de la viscosité apparente du concentré et de la sauce aux pommes.

INTRODUCTION

Natural fruit products such as "fruit leathers" prepared from dried fruit purée are becoming popular in North America. Fruit leathers are prepared from a purée base, the type depending on its geographical abundance and a second purée or concentrate added as a flavoring agent. In North America, the most popular purée base is apple, with strawberry, raspberry, grape, and apricot concentrates added as flavor ingredients. The dried fruit product gives a chewy product constituting a good source of dietary fiber and natural sugars. They have relatively high shelf-stability due to low moisture (15-18%) and high carbohydrate contents. The drying characteristics of these products are dependent on several factors with the consistency of purée base representing an important parameter.

The quality of the dried fruit product and drying rate depend on several characteristics of the purée base: type of fruit and concentrate used, soluble solids content, consistency of the product, presence of viscosity modifiers, etc.

Some studies on drying rates of these products have been reported by Moyles (1981, 1986) and Bains et al. (1989).

The rheological characteristics of these products are important with respect to standardization of the feed formulation used for drying and product quality control. These properties are largely dependent on the chemical composition, fruit, and concentrate contents. Fruit concentrates and juices exhibit Newtonian behavior (Saravacos 1970; Ibarz and Pegan 1987), while a purée base constituting dispersions of insoluble matter in a liquid medium generally displays a non-Newtonian behavior (Harper and El-Sharigi 1965; Holdsworth 1971; Rao 1977; Barbosa-Canovas and Peleg 1983). Due to the biphasic nature of dispersed food products, their rheological behavior depends on their pulp content, particle size, and serum (Rao et al. 1981; Duran and Costell 1982; Rao et al. 1986; Tanglertpaibul and Rao 1987; Qui and Rao 1988). These studies have shown that the contribution of particle size and serum in determining viscosity was much less than that of pulp content. Rheological properties of applesauce with special reference to its yield stress, pulp content, particle size, and serum content have been reported (Rao et al. 1986; Qui and Rao 1988; Missaire et al. 1990). Despite the many studies on the flow properties of individual concentrates and fruit purées, data on the rheological properties of purée-concentrate mixtures as used by the fruit-leather industry are scarce. This prompted us to examine the rheological behavior of feed-mixtures consisting of the purée from the most commonly used fruit, apples, and flavored with strawberry concentrate.

The objectives of this study were to first evaluate individually the rheological behavior of applesauce and strawberry concentrates and then to evaluate the rheology of their mixtures.

MATERIAL AND METHODS

Applesauce and strawberry concentrate

Glass jars of unsweetened applesauce (IGA Brand) were obtained from a local grocery store. The sauce showed a homogeneous appearance with a soluble solid content of 10.4° Brix. The contents of several jars were carefully mixed to obtain a uniform sample. The chemical composition of applesauce was (manufacturer supplied): carbohydrate - 12%, protein - 0.15%, fat - 0.15%, and dietary fiber - 2.8%. Strawberry concentrate (68° Brix) was also obtained from a commercial source (Kerr Inc., Toronto, ON). Strawberry

concentrates of 20, 40, and 60° Brix were prepared by diluting the 68° Brix concentrate with appropriate amounts of distilled water.

Applesauce-concentrate mixtures

Applesauce-strawberry concentrate mixtures with various soluble solid contents (15, 20, 25, 30, 40, 50, 60, and 65° Brix) were prepared by mixing appropriate amounts of applesauce and strawberry concentrate (68° Brix). The proportions used are summarized in Table I and were obtained by using the Pearson Rule or as commonly called "rule of squares" (Lal et al. 1986). The soluble solid content was determined by means of Abbe-Zeiss refractometer.

Rheological measurements

Rheological tests were carried out using a Haake RV20 rotational viscometer (Haake Mess-Technik Co., Karlsruhe, Germany) equipped with an M5 OSC measuring head and MV1 rotor ($R_o = 20.04$ mm; $h = 60$ mm) in a concentric cylindrical cup ($R_i = 21$ mm) and interfaced to a microcomputer for control and data acquisition. All samples were equilibrated to room temperature (23°C) before testing and all experiments were replicated three times.

Test samples were subjected to a dynamic shear at a programmed shear rate linearly increasing from 0 to 500 s^{-1} in 5 min and back to 0 s^{-1} in the next 5 min. To study the structural breakdown, the upward and downward cycles were repeated three times continuously. Test samples of applesauce were also subjected to continuous shearing at a fixed rate (300 s^{-1}) for evaluating the stress decay behavior.

The flow curve (σ , shear stress, vs $\dot{\gamma}$, shear rate) was evaluated by using various rheological models detailed elsewhere (Ramaswamy and Basak 1991, 1992):

Newtonian model:

$$\sigma = \eta \dot{\gamma} \quad (1)$$

Power-law model:

$$\sigma = m \dot{\gamma}^n \quad (2)$$

Herschel-Bulkley model:

$$\sigma - \sigma_o = m \dot{\gamma}^n \quad (3)$$

Casson model:

$$\sigma^{0.5} = \sigma_o^{0.5} + \eta_c^{0.5} \dot{\gamma}^{0.5} \quad (4)$$

Weltman model (stress decay):

$$\sigma = A - B \log(t); t > 0 \quad (5)$$

where:

A, B = constants,

m = consistency coefficient ($Pa \cdot s^n$),

n = flow behavior index,

t = time (s),

$\dot{\gamma}$ = shear rate (s^{-1}),

η = viscosity ($Pa \cdot s$),

η_c = Casson viscosity ($Pa \cdot s$),

σ = shear stress (Pa), and

σ_o = yield stress (Pa).

Table I. Proportions of applesauce and strawberry concentrate used to prepare the mixtures of various soluble solids contents

| Sample # | Strawberry concentrate fraction | Applesauce fraction | Soluble solids (° Brix) | Apparent* viscosity (Pa·s) |
|----------|---------------------------------|---------------------|-------------------------|----------------------------|
| 1 | 0.000 | 1.000 | 10 | 0.270 |
| 2 | 0.086 | 0.914 | 15 | 0.242 |
| 3 | 0.172 | 0.828 | 20 | 0.226 |
| 4 | 0.259 | 0.741 | 25 | 0.199 |
| 5 | 0.345 | 0.655 | 30 | 0.211 |
| 6 | 0.517 | 0.483 | 40 | 0.157 |
| 7 | 0.690 | 0.310 | 50 | 0.114 |
| 8 | 0.862 | 0.138 | 60 | 0.112 |
| 9 | 0.948 | 0.052 | 65 | 0.154 |
| 10 | 1.000 | 0.000 | 68 | 0.226 |

* at a shear rate of 300 s^{-1}

The structural integrity of the applesauce following shearing was expressed as the ratio of areas (computed using a numerical integration technique) under the second and first upward flow curves, with the first upward curve representing the rheogram for the fresh sample (without a previous shear history) and the second one that of a shear degraded sample. A stability index was expressed as the ratio of areas under the third and second upward flow curves, the two curves representing successive rheograms of shear degraded samples.

An apparent viscosity value, η , was calculated from Eq. 1 at an arbitrary shear rate ($\dot{\gamma} = 300 s^{-1}$) for applesauce and applesauce-concentrate mixtures for developing a predictive model for the mixture apparent viscosity based on individual apparent viscosity contributions. Such a model would be useful in quality control applications.

RESULTS AND DISCUSSION

Applesauce rheology

Typical rheograms of applesauce during the 3-cycle upward and downward programmed shearing are shown in Fig. 1. They demonstrate typical pseudoplastic flow behavior of applesauce. The upward and downward flow curves did not entirely overlap, thereby indicating some hysteresis or loss of structure between the upward and downward shearing. In addition, the first, second, and third cycle flow curves were distinct and indicated some progressive loss in shear resistance between the shearing cycles. The structural integrity, as calculated by the ratio of areas under the second and first upward flow curves of applesauce (Fig. 2, U2/U1, or alternately D2/D1), varied from 0.90 to 0.92 (Table II) indicating about 8 to 10% loss in structure. Stability index (Fig. 2, ratio of areas under the third and second upward flow curves, U3/U2 or alternately D3/D2) remained higher than 0.96 indicating that the loss in structure of the applesauce following the first shearing cycle is somewhat smaller, although continuing.

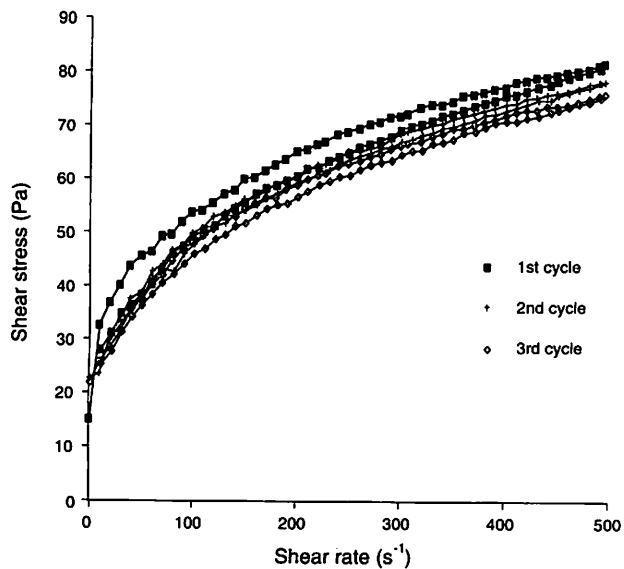


Fig. 1. Flow curves for applesauce in a 3-cycle linearly programmed upward and downward shearing sequence.

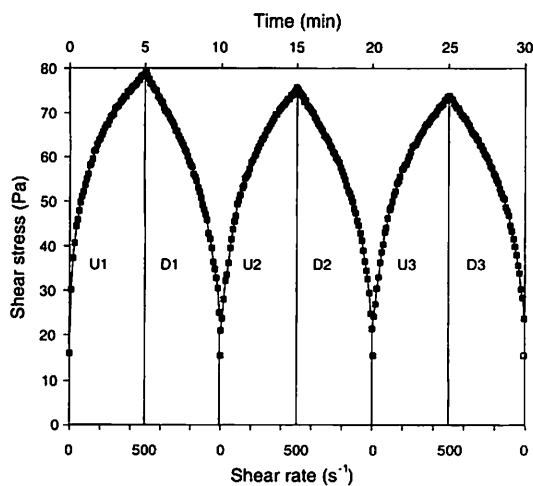


Fig. 2. Representation of structural integrity (U2/U1 or D2/D1) and stability index (U3/U2 or D3/D2) for applesauce rheology.

Rheological models

The coefficient of determination for describing the flow behavior of applesauce by different models (Eqs. 2-4) are compared in Table III. In general, the flow behavior was well described by all three models; however, the power-law model which gave a slightly better R^2 as well as visual fit over the other models was adopted for the remaining discussion. A second reason for opting for the power-law model was its wide acceptance in most engineering applications describing non-Newtonian flow behavior. Figure 3 compares the power-law fitted data for applesauce under the 3-cycle programmed shearing test. Power-law flow parameters for various fruit purées from early studies were compiled by Holdsworth (1971). Several recent studies also evaluated the behavior of

Table II. Typical values for structural integrity and stability of applesauce under dynamic three cycle shearing

| Replicate | Upcurve | |
|-----------|---------|-----------|
| | Loss | Stability |
| #1 | 0.918 | 0.969 |
| #2 | 0.928 | 0.964 |
| #3 | 0.903 | 0.978 |
| #4 | 0.909 | 0.971 |
| #5 | 0.929 | 0.967 |
| #6 | 0.908 | 0.972 |

several fruit juices and purées containing pulpy materials (Rao et al. 1981, 1986; Manohar et al. 1990; Duran and Costell 1982; Jimenez et al. 1989). The flow behavior index and consistency coefficient found in the present studies for applesauce are within the range reported for applesauce and other fruit purées.

Stress decay

Stress decay tests employing continual shearing at a steady shear rate indicated the gradual destruction of applesauce structure (thixotropicity) following a larger initial loss. The logarithmic-time model (Weltman 1943), Eq. 5, well described the stress decay behavior ($R^2 = 0.96$), showing a continual decay of stress even on prolonged shearing (Fig. 3). Several other models reported in Basak (1991) were not used because an equilibrium shear stress was rarely reached over a 30 min shearing test. Stress decay behavior has not been widely studied with fruit products (Holdsworth 1971).

Rheology of strawberry concentrate

Flow curves of strawberry concentrate at four different $^{\circ}$ Brix levels are shown in Fig. 5 indicating essentially a Newtonian flow behavior. Similar results have been observed with several concentrated clarified juices (Saravacos 1970; Rao et al.

Table III. Coefficients of determination for three rheological models for applesauce

| Sample | Flow Model | Upcurve | Downcurve |
|--------|------------------------|---------|-----------|
| | | R^2 | R^2 |
| #1 | Power-law model | 0.99 | 1.00 |
| | Herschel-Bulkley model | 1.00 | 0.98 |
| | Casson model | 0.92 | 0.98 |
| #2 | Power-law model | 1.00 | 1.00 |
| | Herschel-Bulkley model | 0.99 | 0.97 |
| | Casson model | 0.96 | 0.98 |
| #3 | Power-law model | 0.99 | 1.00 |
| | Herschel-Bulkley model | 0.97 | 0.96 |
| | Casson model | 0.96 | 0.98 |

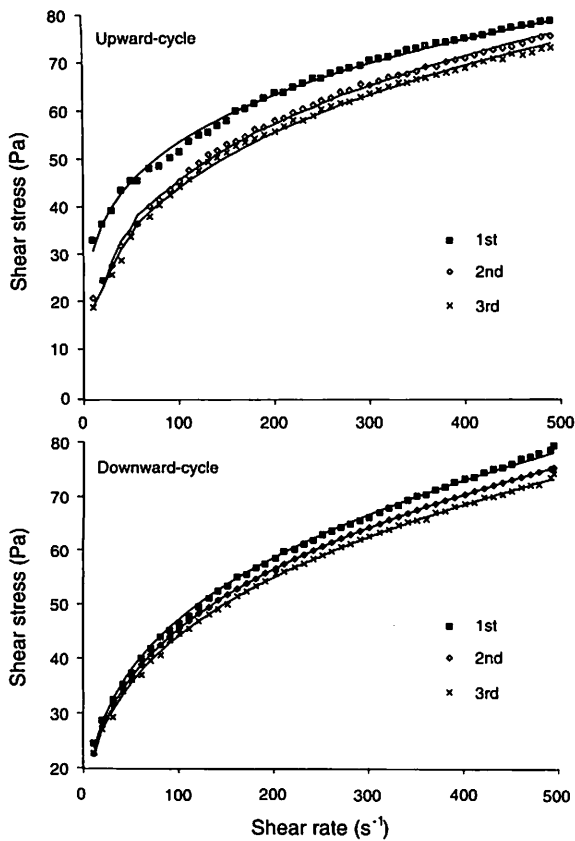


Fig. 3. Power-law model (solid lines, Eq.2) describing the 3-cycle upward and downward flow curves of applesauce.

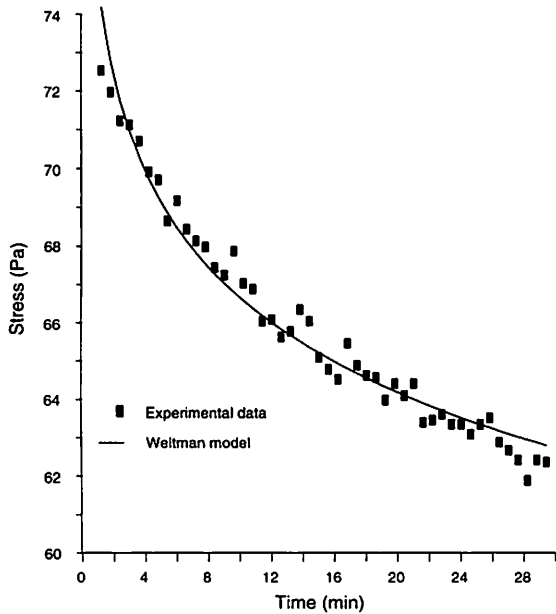


Fig. 4. Weltman logarithmic-time model (Eq.5) describing the time dependent stress decay of applesauce.

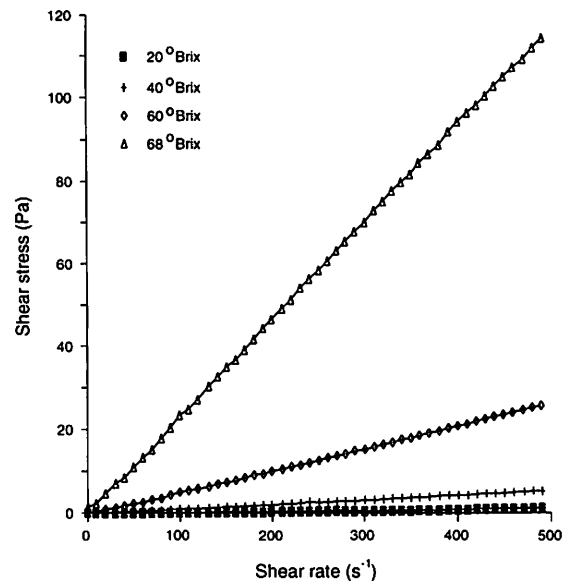


Fig. 5. Flow curves of strawberry concentrates (20-68 °Brix) demonstrating a Newtonian flow behavior.

1984; Ibarz and Pegan 1987; Ibarz et al. 1987, 1989; Khalil et al. 1989). The slopes of these linear flow curves give the test sample viscosity which, as expected, increased with the soluble solids content (as indicated by steeper slopes). The relationship between viscosity and soluble solids content was clearly nonlinear (Fig. 6).

Several empirical correlations have been reported to relate the viscosity of concentrates to their soluble solids content (Harper and El-Sharigi 1965; Rao 1977; Rao et al. 1981; Rao et al. 1984):

$$\eta = a C^b \quad (6)$$

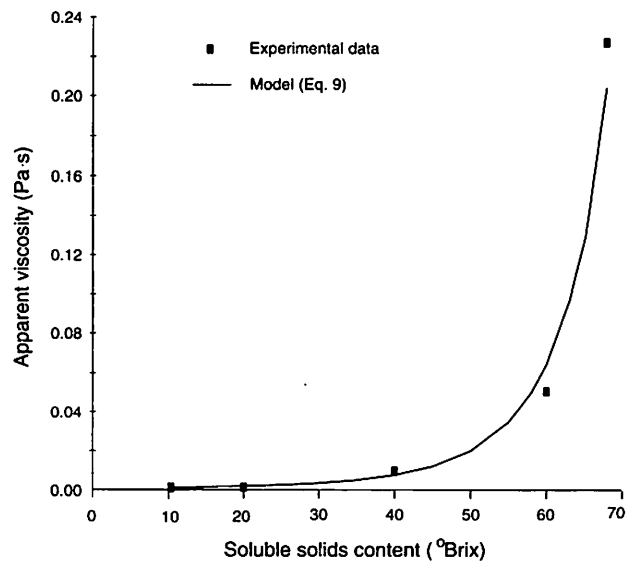


Fig. 6. Apparent viscosity of strawberry concentrate as a function of soluble solids content.

$$\eta = a \exp(bC) \quad (7)$$

$$\eta = a \exp(bC + dC^2) \quad (8)$$

where:

$a, b, d = \text{constants, and}$

$C = \text{soluble solids content (}^\circ\text{Brix).}$

However, the one that gave a good fit for the data (Fig. 6) involved the logarithm of viscosity versus exponential of the concentration fraction ($R^2 = 0.98$):

$$\log_e \eta = -8.422 + 1.428 e^{(2.303C)} \quad (9)$$

Rheology of applesauce-strawberry concentrate mixtures

All applesauce-concentrate mixtures (Table I) with soluble solids content ranging from 15-65 $^\circ$ Brix exhibited non-Newtonian viscosity (Fig. 7). The evaluated power-law parameters (consistency coefficient and flow behavior index) are shown as a function of $^\circ$ Brix in Fig. 8. The consistency coefficient progressively decreased as $^\circ$ Brix increased, somewhat contrary to the common notion that viscosity increases with solids content. The flow behavior index also showed an increasing trend, especially beyond 20 $^\circ$ Brix indicating a trend toward decreasing pseudoplasticity. Even the small addition (~5%) of applesauce to concentrate (Sample #9, Table I) resulted in a steep change from the Newtonian flow behavior (value lowered from 1 to below 0.4).

The seemingly contradictory behavior of applesauce-concentrate mixtures can be more clearly illustrated by comparing their apparent viscosities (calculated at the shear rate of 300 s $^{-1}$). The apparent viscosity of the applesauce decreased with the addition of concentrate up to 50 $^\circ$ Brix although the soluble solid content increased (Fig. 9). However, at soluble solids content of 60 $^\circ$ Brix and above, the

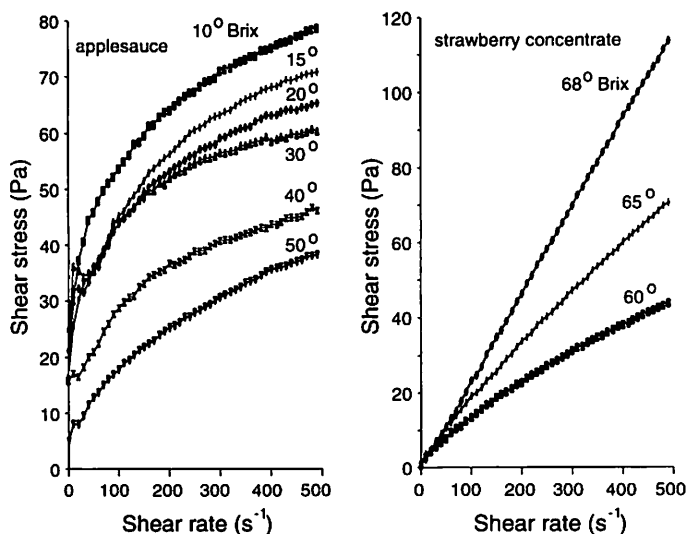


Fig. 7. Flow curves of applesauce - concentrate mixtures prepared from applesauce (10 $^\circ$ Brix) and strawberry concentrate (68 $^\circ$ Brix) demonstrating power-law flow behavior.

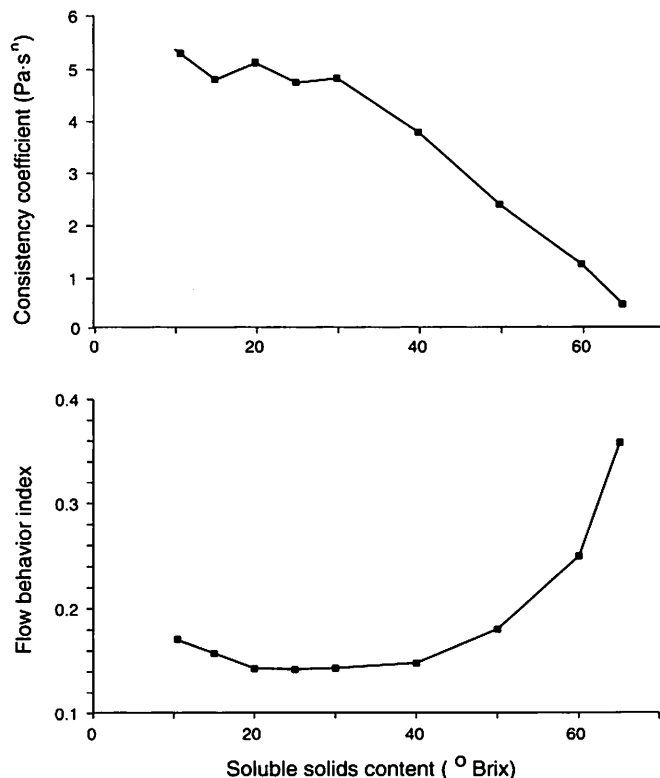


Fig. 8. Consistency coefficient and flow behavior index of applesauce - concentrate mixtures (10-65 $^\circ$ Brix) as a function of soluble solids content.

product viscosity showed an increasing trend. This behavior can probably be explained by the fact that the applesauce rheology is dependent not only on the soluble solids content, but also on its other constituents especially starch, pectin, and other viscosity modifiers, which are naturally present. Addition of concentrate not only results in increased soluble solids content but also reduces the concentration of these active components. This dilution effect was possibly the reason for the decrease in the apparent viscosity up to a point (soluble solids content build up of 50 $^\circ$ Brix), beyond which the role of concentrate became more dominant. This is consistent with the findings of Rao et al. (1986) who found a strong positive correlation between apparent viscosity and the pulp content of applesauce.

Based on individual apparent viscosity contributions of concentrate and applesauce, a relationship ($R^2 = 0.95$) was developed for the apparent viscosity of their mixture at 300 s $^{-1}$, η_{MX} (Pa·s):

$$\eta_{MX} = 0.027 + 0.9036 (\eta_{AS} + \eta_C) \quad (10)$$

Figure 9 demonstrates good agreement between Eq. 10 and experimental data.

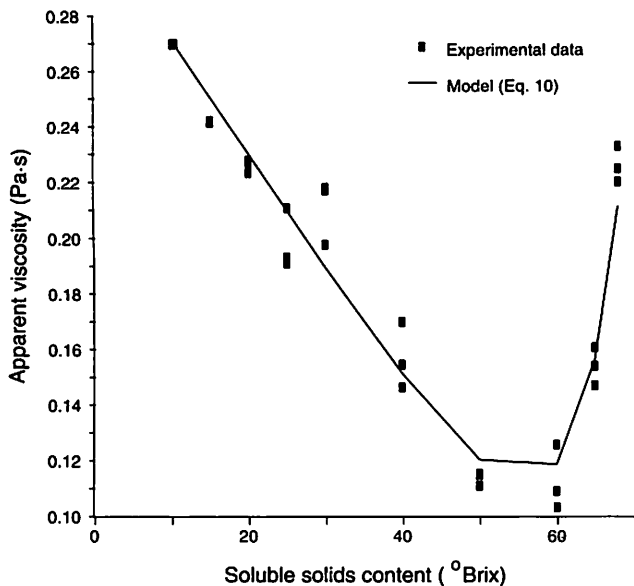


Fig. 9. Apparent viscosity of applesauce - concentrate mixtures as a function of soluble solids content: experimental data (points) vs. a predictive model (solid line, Eq. 10) based on apparent viscosities of individual components.

CONCLUSIONS

Applesauce and applesauce-concentrate mixtures demonstrated typical shear-thinning, irreversible thixotropic flow behavior while the strawberry concentrate alone exhibited a Newtonian flow. The power law model well described the flow curves of applesauce with or without added concentrate. Stress decay behavior of applesauce followed a logarithmic time model. Apparent viscosity of the mixture could be modeled based on individual viscosity contributions of the concentrate and applesauce.

Although the present studies were carried out with primary reference to rheology of fruit purées employed in fruit leather industry, they may have relevance to other applications, for example, in pie fillings in baked foods.

ACKNOWLEDGEMENT

The authors acknowledge the financial support for the research from the Natural Sciences and Engineering Research Council of Canada Operating Grants Program.

NOMENCLATURE

- A, B = constants
- a, b, d = constants
- C = soluble solids concentration ($^{\circ}$ Brix)
- h = height of the concentric cylindrical rotor (mm)
- m = consistency coefficient ($\text{Pa}\cdot\text{s}^n$)
- n = flow behavior index
- R_i = inside radius of the concentric cylindrical cup (mm)
- R_o = outside radius of the concentric cylindrical rotor (mm)
- t = time (s)
- $\dot{\gamma}$ = shear rate (s^{-1})

- η = viscosity ($\text{Pa}\cdot\text{s}$)
- η_{AS} = apparent viscosity ($\sigma/\dot{\gamma}$) of applesauce at 300 s^{-1} ($\text{Pa}\cdot\text{s}$) x mass fraction of applesauce
- η_C = Casson viscosity ($\text{Pa}\cdot\text{s}$)
- η_{CN} = viscosity of strawberry concentrate ($\text{Pa}\cdot\text{s}$)
- η_{MX} = apparent viscosity ($\sigma/\dot{\gamma}$) of applesauce-concentrate mix at 300 s^{-1} ($\text{Pa}\cdot\text{s}$)
- σ = shear stress (Pa)
- σ_o = yield stress (Pa)

REFERENCES

- Bains, M.S., H.S. Ramaswamy and K.V. Lo. 1989. Tray drying of apple purée. *Journal of Food Engineering* 9:195-201.
- Barbosa-Canovas, G.V. and M. Peleg. 1983. Flow parameters of selected commercial semi-liquid flow food products. *Journal of Texture Studies* 14:213-234.
- Basak, S. 1991. Rheology of stirred yogurt. Unpublished M.Sc. thesis, Department of Food Science and Agricultural Chemistry, McGill University, Montreal, PQ.
- Duran, L. and E. Costell. 1982. Rheology of apricot purée: characterization of flow. *Journal of Texture Studies* 13:43-58.
- Harper, J.C. and A.F. El-Sahrigi. 1965. Viscometric behavior of tomato concentrates. *Journal of Food Science* 30:470-476.
- Holdsworth, S.D. 1971. Applicability of rheological models to the interpretation of flow and processing behavior of fluid food products. *Journal of Texture Studies* 2:393.
- Ibarz, A. and J. Pegan. 1987. Rheology of raspberry juices. *Journal of Food Engineering* 6:269-289.
- Ibarz, A., J. Pegan and J. Graell. 1987. Rheological behavior of apple and pear juices and their concentrates. *Journal of Food Engineering* 6:257-267.
- Ibarz, A., J. Pegan, J. Gutierrez and M. Vicente. 1989. Rheological properties of clarified pear juice concentrates. *Journal of Food Engineering* 10:57-63.
- Jimenez, L., J.L. Ferrer and L.M. Paniego. 1989. Rheology, composition and sensory properties of pulped tomatoes. *Journal of Food Engineering* 9:119-128.
- Khalil, K.E., P. Ramakrishna, A.M. Nanjundaswamy and M.V. Patwardhan. 1989. Rheological behavior of clarified banana juice: Effect of temperature and concentration. *Journal of Food Engineering* 10:231-240.
- Lal, G., G.S. Siddappa and G.L. Tandon. 1986. *Preservation of Fruits and Vegetables*, revised edition. Indian Council of Agricultural Research, New Delhi, India.
- Manohar, B., P. Ramakrishna and R.S. Ramteke. 1990. Effect of pectin content on flow properties of mango pulp concentrates. *Journal of Texture Studies* 21:179-190.
- Missaire, F., C.G. Qui and M.A. Rao. 1990. Yield stress of structured and unstructured food suspensions. *Journal of Texture Studies* 21:479-490.

- Moyles, A.L. 1981. Drying of apple purées. *Journal of Food Science* 46:939-942.
- Moyles, A.L. 1986. A case study on modification and operation of two commercial fruit leather dryers. *Canadian Agricultural Engineering* 28: 61-70.
- Qui, C.G. and M.A. Rao. 1988. Role of pulp content and particle size in yield stress of applesauce. *Journal of Food Science* 53:1165-1170.
- Ramaswamy, H.S. and S. Basak. 1991. Rheology of stirred yogurts. *Journal of Texture Studies* 22:231-241.
- Ramaswamy, H.S. and S. Basak. 1992. Time dependent stress decay rheology of stirred yogurt. *International Dairy Journal* 2:17-31.
- Rao, M.A. 1977. Rheology of liquid foods - a review. *Journal of Texture Studies* 8:135-168.
- Rao, M.A., M.C. Bourne and H.J. Cooley. 1981. Flow properties of tomato concentrates. *Journal of Texture Studies* 12:521-538.
- Rao, M.A., H.J. Cooley, J.N. Nogueira and M.R. McLellan. 1986. Rheology of applesauce: Effect of cultivar, firmness, and processing parameters. *Journal of Food Science* 51:176-179.
- Rao, M.A., H.J. Cooley and A.A. Vitali. 1984. Flow properties of concentrated juices at low temperatures. *Food Technology* 38(3):113-119.
- Saravacos, G.D. 1970. Effect of temperature on viscosity of fruit juices and purées. *Journal of Food Science* 35:122-125.
- Tanglerpaibul, T. and M.S. Rao. 1987. Flow properties of tomato concentrates: Effect of serum viscosity and pulp content. *Journal of Food Science* 52:318-321.
- Weltman, R.N. 1943. Breakdown of thixotropic structure as a function of time. *Journal of Applied Physics* 14:343-350.