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Pedro Esteves Duarte Augusto, *University of Campinas (UNICAMP)*
Marcelo Cristianini, *University of Campinas (UNICAMP)*
Albert Ibarz, *University of Lleida (UdL)*

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Using the Mitschka-Briggs-Steffe Method for Evaluation of Cactus Pear Concentrated Pulps Rheological Behavior

Pedro Esteves Duarte Augusto, Marcelo Cristianini, and Albert Ibarz

Abstract

The rheological characterization of food is important for efficient product and process design. Although its importance in semi-arid regions, there are only a few studies regarding the rheological properties of cactus pear products in the literature. The present work has used the Mitschka-Briggs-Steffe method for evaluation of the rheological behavior of cactus pear concentrated pulps. The pulps have shown pseudoplastic behavior. The flow behavior index (n) shows a constant value in the evaluated conditions, and its average value was considered in the evaluated temperature and concentration range. The consistency index (k) has shown dependency of concentration and temperature, being well modeled by a modified Arrhenius equation. Thus, the rheological parameters of cactus pear concentrated pulps can be obtained using a single equation, related with temperature, concentration and shear rate. The obtained data are potentially useful for future studies on product development, food properties and process design.

KEYWORDS: food properties, rheology, viscosity

Author Notes: Corresponding author: PED Augusto, pedro@cotuca.unicamp.br

1. Introduction

The rheological characterization of food is important for unit operations design, process optimization and high quality products assurance (Ibarz and Barbosa-Cánovas, 2003; Rao, 1999).

Mitschka (1982) has developed a simple technique to determine rheological parameters of power law fluids (i.e., Ostwald-de-Waele model, Equation 1) using a Brookfield viscometer, considered a low cost instrument, common in a large segment of the food industry (Briggs and Steffe, 1997).

$$\sigma = k \cdot \gamma^{n} \qquad \text{(Equation 1)}$$

Briggs and Steffe (1997) have improved the method by modeling the Mitschka data and expand the covered Brookfield models. In the resulted Mitschka-Briggs-Steffe method, the flow behavior index (n) and the consistency index (k) of power law fluids are obtained using the following procedure:

1. Shear stress (σ) is obtained using the spring torque (obtained by reading the instrument dial) and factors related with Brookfield model and spindle;

2. The logarithm of shear stress is plotted versus the logarithm of rotational speed (ω); the flow behavior index (n) is obtained as the slope of the graphic;

3. Average shear rate (γ) is then obtained by Equation 2, empirically determined by authors:

$$\gamma = (0.263 \cdot n^{-0.771}) \cdot \omega \qquad \text{(Equation 2)}$$

4. The fluid rheological parameters (n and k) can then be obtained by regression using the linearized flow curves ($\ln\sigma$ versus $\ln\gamma$), as described by Rao (1999).

The cactus pear (*Opuntia ficus indica*) is an important fruit crop in many semi-arid lands of the world (Grangeiro et al., 2007; Saenz, 2000). The fruit is commonly consumed fresh, or through the production of juices, marmalades, gels, liquid sweeteners, dehydrated foods and other products (Saenz, 2000). However, there are only a few studies regarding the rheological properties of cactus pears products in the literature (Cerezal et al., 2007).

The objective of this work was to use the Mitschka-Briggs-Steffe method for evaluation of the rheological behavior of cactus pear concentrated pulps.

2. Materials and Methods

The present work was carried out using the previously published data provided by Grangeiro et al. (2007). In that work, authors have used cactus pear pulp obtained in the northeast Brazilian semi-arid region. Fruits were harvest at the commercial maturity, hygienized, manual peeled and depulped using a 2.5 mm pore sieve. The obtained pulp was then concentrated at 60ºC under vacuum until the concentrations of 16, 19, 22, 25 and 28 °Brix.

The apparent viscosities (η_a) were obtained using a Brookfield RVT viscometer (Brookfield Engineering Laboratories, USA), in the rotational speeds (ω) of 0.5, 1.0, 2.5, 5.0, 10, 20, 50 and 100 rpm and temperatures of 10, 20, 30, 40, 50 and 60°C. Each experiment was carried out in six replicates; the average values were then used in the present work.

The flow behavior index (n) and the consistency index (k) of the products were obtained using the Mitschka-Briggs-Steffe method, and modeled as function of product concentration (C, in ºBrix) and temperature (T, in K). Power law parameters were modeled using the well known modified Arrhenius equation (Equation 3, where R is the constant of the ideal gases; Rao, 1999; Steffe, 1996), where each parameter P (i.e., k and n) is modeled by a pre-exponential factor (A_P), the activation energy (Ea_P) and a factor related with concentration (B_P).

$$P = A_P \cdot \exp\left(\frac{Ea_P}{R \cdot T} + B_P \cdot C \right) \qquad \text{(Equation 3)}$$

The parameters of each model were obtained by regression using the software Statistica 5.5 (StatiSoft, Inc., Tulsa, Okla., U.S.A.) with a significant probability level of 95%.

The accuracy of the model was evaluated by plotting the values of shear stress obtained by models (σ_{model}) as function of the experimental values ($\sigma_{experimental}$). The regression of those data to a linear function (Equation 4) results in three parameters that can be used to evaluated the description of the experimental values by the models, i.e., the linear function slope (α that must be as close as possible to the unit), the intercept (β that must be as close as possible to zero), and the coefficient of determination (R^2 that must be as close as possible to the unit).

$$\sigma_{model} = \alpha \cdot \sigma_{experimental} + \beta \qquad \text{(Equation 4)}$$

3. Results and Discussion

As expected, the cactus pear pulps have shown pseudoplastic behavior, with rheological properties well described by the power law model (Equation1). Figure 1 shows the cactus pear pulp flow behavior index (*n*) and consistency index (*k*) as function of concentration (C) and temperature (T).

The general approach used in literature consists of modeling the viscosity or apparent viscosity as a function of temperature and soluble solids or pulp contents (Yilmaz et al., 2011; Ibarz et al., 2009; Shamsudin et al., 2009; Altan et al., 2005; Ibarz et al., 1996; Giner et al., 1996; Ibarz et al., 1992; Vitali and Rao, 1984a, Vitali and Rao, 1984b). A few publications have evaluated rheological properties by modeling each of the power law model parameters (*k, n*) separately, although this approach is more important in the evaluation of non-Newtonian fluids. In the present work, the power law parameters were modeled using the modified Arrhenius equation (Equation 3).

Observing Figure 1 it is clear that the consistency index (*k*) shows a rising tendency in relation with concentration, and a falling behavior in relation with temperature. Moreover, it is expected that those relationships can be modeled using the exponential function. Applying the experimental data to the modified Arrhenius equation (Equation 3), the obtained parameters A_k (0.0317 Pa·s^n), Ea_k (6542.10 J·mol^{-1}) and B_k (0.141 °Brix^{-1}) are shown in Equation 5 (where k is expressed in Pa·s^n, C in ºBrix, T in K, and R = 8.314 Pa·m^3·mol^{-1}·K^{-1}). The obtained model describes well the experimental data, as can be seen by plotting the experimental data versus those obtained by the model (Figure 2). The regression for Equation 4 results in values of α and R^2 higher than 0.98, while the value of β was lower than 0.03.

$$k = 0.0317 \cdot \exp\left(\frac{6542.10}{R \cdot T} + 0.141 \cdot C \right) \quad \text{(Equation 5)}$$

The values for the activation energy (Ea_k) and the concentration parameter (B_k) are closed to those reported for other fruit products as tomato products, *Juniperus drupacea* fruit juice, jabuticaba pulp, *Malus floribunda* juice and concentrated orange juice (Table 1).

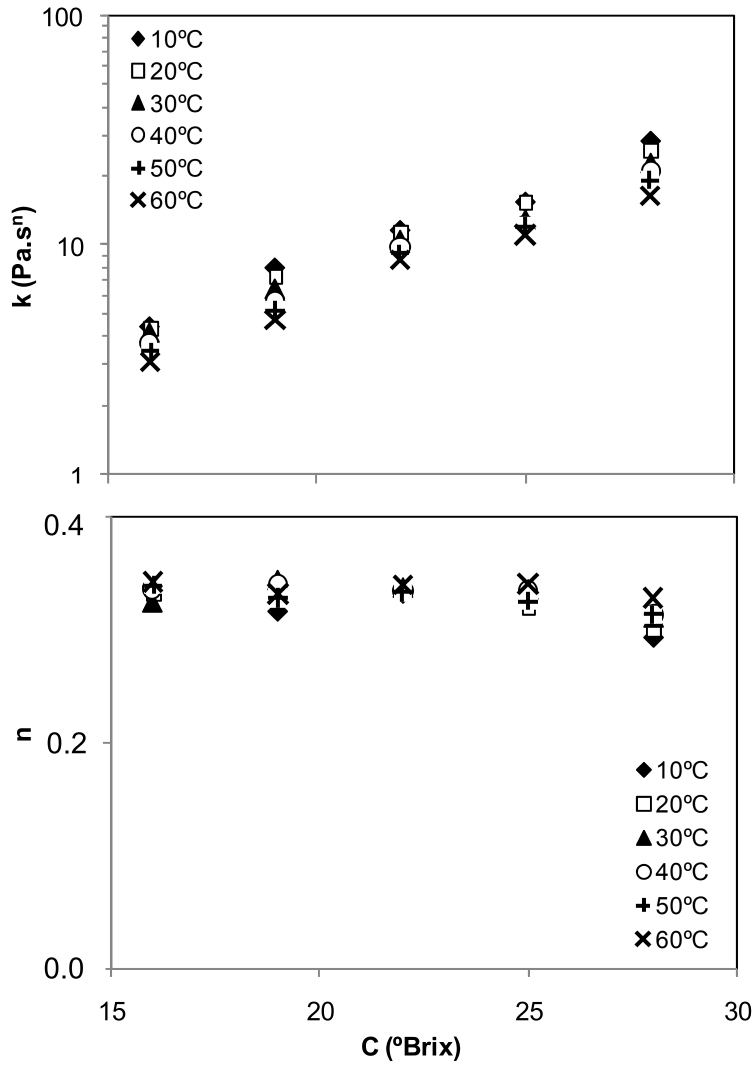

Figure 1. Cactus pear pulp flow behavior index (*n*) and consistency index (*k*) as function of concentration (C) and temperature (T)

Table 1. Activation energy (Ea) and concentration parameter (B) of the Arrhenius model (Equation 3) for the consistency index (k) in some fruit products

Product	Ea_k (kJ·mol^{-1})	B_k (°Brix^{-1})	Reference
Cactus pear pulp	6.54	0.141	Present work
Tomato juice	7.35	-	Augusto et al. (2010)
Reconstituted tomato concentrates	3.63 – 7.36	-	Barbana and El-Omri (2010)
Pineapple juice	4.85	0.356	Dak et al. (2008)
Juniperus drupacea fruit juice	35.38	0.288	Akbulut et al. (2008)
Dragon fruit *(Hylocereus sp.)* juice	-	0.313 – 0.337	Chuah et al. (2008)
Jabuticaba pulp	13.0	-	Sato and Cunha (2007)
Malus floribunda juice	13.1 – 17.1	0.17 – 0.21	Cepeda et al. (1999)
Concentrated orange juice	38.0 – 38.5	0.165 – 0.170	Vitali and Rao (1984b)

On the other hand, the flow behavior index (n) shows a constant value in regarding to concentration and temperature (Figure 1). In fact, the flow behavior index (n) is assumed to be relatively constant with temperature and concentration (Rao 1999). It enables the utilization of a constant value equal to the average value in the evaluated temperature and concentration range ($\overline{n}$ = 0.329).

The rheological behavior of the cactus pear pulp can be described by the power law model (Equation 1), with the consistency index (k) as function of temperature and concentration (Equation 6). Thus, the rheological parameters of cactus pear concentrated pulps can be obtained using a single equation, related with temperature, concentration and shear rate.

$$\sigma = \left[0.0317 \cdot \exp\left(\frac{6542.10}{R \cdot T} + 0.141 \cdot C\right)\right] \gamma^{0.3285} \qquad \text{(Equation 6)}$$

The obtained model describes well the experimental data, as can be seen by the regression for Equation 4 (Figure 2). The value of α was lower than 1.04; β close to -0.86 and R^2 higher than 0.98. The obtained results can contribute to the development of efficacious food processing protocols, helping the design and optimization of cactus pear pulps processing.

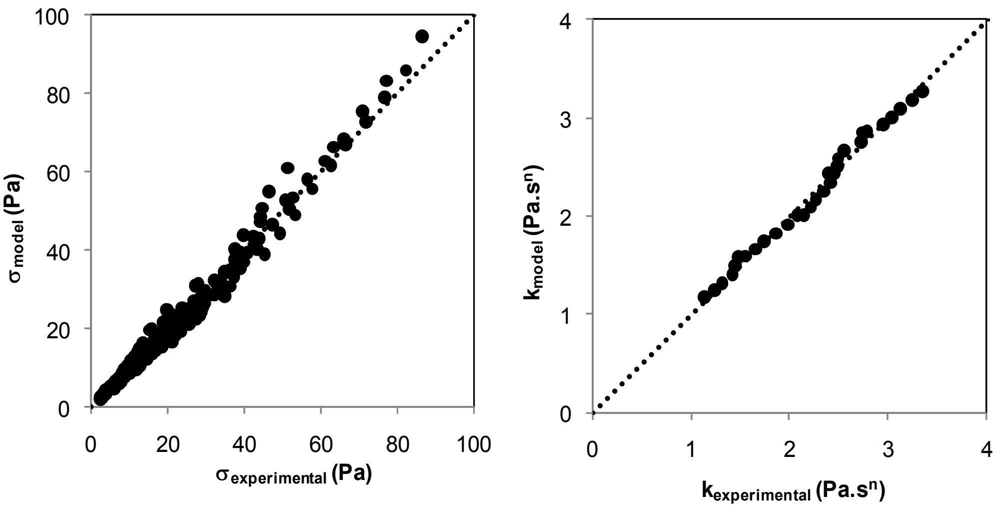

Figure 2. Cactus pear pulp stress (left) and consistency index (right): experimental values versus those predicted by the models. The dashed line represents a regression with $\alpha = 1$, $\beta = 0$ and $R^2 = 1$.

4. Conclusions

The present work has evaluated the rheological behavior of cactus pear concentrated pulps in the range of 10-60ºC and 16-28ºBrix using the Mitschka-Briggs-Steffe method. The pulp has shown a pseudoplastic behavior, whose flow properties could be well described by the following modified Arrhenius equation (where *T* is the temperature in K, *R* is the constant of the ideal gases, and *C* is the concentration in ºBrix):

$$\sigma = \left[0.0317 \cdot \exp\left(\frac{6542.10}{R \cdot T} + 0.141 \cdot C \right) \right] \gamma^{0.3285}$$

The obtained data are potentially useful for future studies on product development, food properties and process design.

5. References

Akbulut,M.; Çoklar, H. C.; Özen, G. O. 2008. Rheological characteristics of *Juniperus drupacea* fruit juice (pekmez) concentrated by boiling. *Food Science and Technology International*, 14, 321-328.

Altan, A.; Kus, S.; Kaya, A. 2005. Rheological behaviour and time dependent characterization of gilaboru juice (*Viburnum opulus L.)*. *Food Science and Technology International*, 11(2), 129-137.

Augusto, P. E. D.; Falguera, V.; Cristianini, M.; Ibarz, A. 2010. Rheological behavior of tomato juice: steady-state shear and time-dependent modeling. *Food and Bioprocess Technology*, *in press (DOI: 10.1007/s11947-010-0472-8)*.

Barbana, C.; El-Omri, A. 2010. Viscometric behavior of reconstituted tomato concentrate. *Food and Bioprocess Technology*, *in press (DOI: 10.1007/s11947-009-0270-3)*.

Briggs, J. L.; Steffe, J. F. 1997. Using Brookfield data and the Mitschka method to evaluate power law foods. *Journal of Texture Studies*, 28, 517-522.

Cepeda, E.; Villarán, M. C.; Ibarz, A. 1999. Rheological properties of cloudy and clarified juice of *Malus fluribunda* as a function of concentration and temperature. *Journal of Texture Studies*, 30, 481-491.

Cerezal, P., Castro, E.; Duarte, G. 2007. A research note on rheological behavior of some processed products from cactus pear (*Opuntia ficus-indica* [L.] Mill.). *Journal of Texture Studies*, 38, 738–754.

Chuah, T. G.; Ling, H. L.; Chin, N. L.; Choong, T. S. Y.; Fakhru'l-Razi, A. 2008. Effects of temperatures on rheological behavior of dragon fruit (*Hylocereus* sp.) juice. *International Journal of Food Engineering*, 4(7), Article 4.

Dak, M.; Verma, R. C.; Jain, M. K. 2008. Mathematical models for prediction of rheological parameters of pineapple juice. *International Journal of Food Engineering*, 4(3), Article 3.

Grangeiro, A. A.; Queiroz, A. J. M.; Figueirêdo, R. M. F.; Mata, M. E. R. M. C. 2007. Viscosities of cactus pear concentrated pulps *(in Portuguese). Revista Brasileira de Agrociência*, 13(2), 219-224.

Giner, J.; Ibarz, A.; Garza, S.; Xhian-Quan, S. 1996. Rheology of clarified cherry juices. *Journal of Food Engineering*, 30, 147-154.

Ibarz, A.; Barbosa-Cánovas, G. V. 2003. *Unit Operations in Food Engineering*. Boca Raton: CRC Press.

Ibarz, R.; Falguera, V.; Garvín, A.; Garza, S.; Pagán, J.; Ibarz, A. 2009. Flow behaviour of clarified orange juice at low temperatures. *Journal of Texture Studies,* 40, 445–456.

Ibarz, A.; Garvin, A.; Costa, J. 1996. Rheological behaviour of Sloe (*Prunus spinosa*) fruit juices. *Journal of Food Engineering*, 27, 423-430.

Ibarz, A.; Gonzalez, C.; Esplugas, S.; Vicente, M. 1992. Rheology of clarified fruit juices. I: peach juices. *Journal of Food Engineering,* 15, 49-61.

Mitschka, P. 1982. Simple conversion of Brookfield R.V.T. readings into viscosity functions. *Rheologica Acta*, 12, 207-209.

Rao, M.A. 1999. Flow and functional models for rheological properties of fluid foods. In: RAO, M.A. (Ed.). *Rheology of Fluid and Semisolid Foods: Principles and Applications*, Gaithersburg: Aspen Publishers.

Saenz, C. 2000. Processing technologies: an alternative for cactus pear (*Opuntia* spp.) fruits and cladodes. *Journal of Arid Environments*, 46, 209–225.

Sato, A. C. K.; Cunha, R. L. 2009. Effect of particle size on rheological properties of jaboticaba pulp. *Journal of Food Engineering*, 91, 566-570.

Shamsudin, R.; Daud, W. R. W.; Takrif, M. S.; Hassan, O.; Ilicali, C. 2009. Rheological properties of Josapine pineapple juice at different stages of maturity. *International Journal of Food Science & Technology*, 44, 757-762.

Steffe, J. F. 1996. *Rheological Methods in Food Process Engineering*, 2nd ed. East Lansing: Freeman Press.

Vitali, A. A.; Rao, M. A. 1984a. Flow properties of low-pulp concentrated orange juice: serum viscosity and effect of pulp content. *Journal of Food Science*, 49, 3, 876-881.

Vitali, A. A.; Rao, M. A. 1984b. Flow properties of low-pulp concentrated orange juice: effect of temperature and concentration. *Journal of Food Science*, 49, 3, 882-888.

Yilmaz, M. T.; Karaman, S.; Cankurt, H.; Kayacier, A.; Sagdic, O. 2011. Steady and dynamic oscillatory shear rheological properties of ketchup-processed cheese mixtures: effect of temperature and concentration. *Journal of Food Engineering*, 130, 197-210.