

**THE INFLUENCES OF TEMPERATURE AND SOLUBLE SOLID CONCENTRATION
OF CLARIFIED FRUIT JUICES ON THE PHYSICAL PROPERTIES**

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Abstract

The effects of temperature and soluble solid concentration on physical properties of clarified fruit juices were investigated. Density and viscosity of the clarified fruit juices increased with increasing soluble solid content and decreased with decreasing temperature. The favorable effect of temperature on the heat capacities was observed; on the other hand the soluble solid content caused a decrease in it. Experimental data were fitted as functions of temperature and soluble solid content. Models being valid for all clarified fruit juices were achieved for density and viscosity with the correlation coefficients (R^2) being higher than 0.90.

Key words: Clarified fruit juice; density; viscosity; heat capacity; soluble solid concentration; temperature

1. INTRODUCTION

Consumer demands, official and unofficial regulations, and economic trends are the major influences managing and leading world trade of food industry. Factors mentioned above are so changeable that requirements of food industry varies from past to present and obviously will change in future. Food industry presents enormous number of types of products into market, one of which is beverage industry. Clarified fruit juices' occupying one of the biggest portions of this market also indicates fast improvement depending on above factors. Thus, new requirements arise based on product and/or process. The requirements of this market lead researchers to investigate for development of new processes and technologies. The modeling and design of equipments for the fluid flow and heat transfer operations involved in clarified fruit juice processing require data on several engineering properties at different conditions. Clarified fruit juices and their physical properties have been received considerable attention due in part to their significance on modeling and design of processes. Temperature and soluble solid content of products, generally varying in the process units, affects the physical and thermo-physical properties such as density, viscosity, and heat capacity (Gratao, Junior, Polizelli & Telis-Romero 2005). A knowledge of these properties is of particular significance for effective design of food processing equipment, such as evaporators, pumps, heat exchangers, filters and mixers (de Moura Germer, Jardim & Sadahira 1998; Holdsworth, 1993; Nindo Tang, Powers & Bolland 2004; Nindo Tang, Powers & Singh 2005; Ramos & Ibarz 1998; Shamsudin Mohamed &

Yaman 2005; Telis-Romero Telis, Gabas & Yamashita 1998; Zainal Abdul Rahman, Ariff, Saari & Asbi 2000; Zuritz et al., 2005). In addition, the knowledge of the physical and thermophysical properties varying with temperature and soluble solid content is very important in the food process control. Unfortunately, only a few process variables are available for online measurement because of the lack of suitable sensors. Thus, mathematical models that express the dependence of thermal properties on temperature and soluble solid content are a very interesting alternative to experimentation and a useful tool for the implementation of computer-aided routines for equipment design and process automation. In addition, these properties are characteristic parameters in the optimization of productivity and quality of products.

Thermo-physical properties of the different juices have been found to exhibit a close relationship with temperature and soluble solid content and mathematical models have been reported (Ali Ramaswamy & Awuah 2002; Cepeda & Villar  n 1999; Lau 1991; Magerramov Abdulagatov, Azizov & Abdulagatov, 2007; Nindo et al. 2004; Nindo et al. 2005; Ramos & Ibarz 1998; Telis-Romero et al. 1998; Zainal et al. 2000; Zuritz et al. 2005). The soluble solid content is under control of proposed product and handled raw material, including seasonal effects, harvesting time, and fruit species etc. (Poyrazo  lu Vural & Art  k 2002), whereas temperature level is directly related to the process steps and storage conditions.

Studies have indicated that the change of the physical properties of the clarified fruit juices pursue parallel trends under same conditions in terms of soluble solid content and temperature (Azoubel Cipriani, El-Aouar, Antonio & Murr 2005; Cepeda & Villar  n 1999; Constenla Lozano & Crapiste 1989; Zuritz et al. 2005). These facts encourage finding single model being specific for one of the thermo-physical properties, which is valid for all clarified fruit juices. The aim of this study was to investigate the influences of temperature and soluble solid concentration of three different clarified fruit juices, including apple, grape and sourcherry, on their density, viscosity, and heat capacity values, and to get single models for each physical properties being valid for studied fruit juices.

2. MATERIALS & METHODS

Clarified fruit juices including apple juice, sour cherry juice and grape juice, were concentrated in a rotary evaporator under vacuum (Rotavapor-R, B  chi Swiss). Fruit juice samples at the specified   Brix values were made by reconstituting the main concentrates with distilled water. Refractometer (Cole-Parmer Inst. Co., USA) was used to measure the soluble solid content of sample in unit of Brix (  Bx) at constant temperature.

2.1. Density

Fruit juice density, ρ (g/ml) was measured with gravimetric method. The sample contained in a standard volumetric pycnometer (25 mL and 50 mL, Isolab, Turkey) was weighed in an analytical balance (UFO-3000, UFOTECH, Turkey). Temperature of sample was adjusted by equilibration in the thermostatic water bath (ST 402, N  VE, Turkey). Temperature values ranged from 25   C up to 60   C with 5   C increments. Soluble solid content of samples were adjusted from 10   Bx to 60   Bx by 10   Bx increments.

2.2. Viscosity

Viscosity measurements were carried out using a capillary viscometer (Canon-Fhensky Viscometer, Cannon Instrument Co., State College, PA) under atmospheric pressure, assuming that fruit juice samples are Newtonian in the range of proposed   Brix values. The temperature was maintained constant by submerging the capillary viscometer in a water bath, controlled by a submerged heater with centrifugal circulation. Before the measurement, sample was waited to reach temperature

equilibrium for 10 min. Experimental variables, temperature and soluble solid content, were identical to those specified for density measurements. Time required for certain volume of fruit juice to pass through the certain length of capillary tube was recorded and kinematic viscosity, ν (cPs) of sample was determined by multiplying time data with specified capillary viscometer constant. The apparent viscosity, μ (Pa.s) of sample was estimated from the following equation (Eq. 1):

$$\nu = \frac{\mu}{\rho} \quad (1)$$

Once apparent viscosity values (μ) were established at different temperatures. The empirical equation of Arrhenius (Eq. 2) is valid for temperature dependence of viscosity (Altan & Maskan 2005; Alvarado & Romero 1989; Bayındırlı 1992 and 1993; Constenla et al. 1989; Ibarz & Pagan 1987; Magerramov et al. 2007).

$$\mu = \mu_{\infty} * \exp(Ea/R \cdot T) \quad (2)$$

μ_{∞} and Ea from Equation 2 were determined by correlating natural logarithm of apparent viscosity values (μ) with the inverse of absolute temperature ($1/T$) using linear regression. Finally, to derive a predictive equation for viscosity as functions of soluble solids concentration and temperature, μ_{∞} and Ea were correlated with soluble solids concentration of fruit juice ($^{\circ}\text{Bx}$).

2.3. Heat Capacity

Differential scanning calorimeter (DSC) (DSC Q10, TA Instruments, USA) was used to determine the heat capacity of fruit juice sample. Heat transfer rate was scanned in the temperature range of 35°C – 55°C for fruit juices. Soluble solid contents varied from 10°Bx to 60°Bx with 10°Bx increments. Distilled water was used as a reference material. The weight of samples and reference material in aluminum pans were recorded in an analytical balance with 0.00001 g precision (APX-200, Denver Instrument, USA). Heating rate was specified as 10 °C/min. Heat capacities of samples were calculated according to Eq. 3. To analyze the DSC results, DSC software (Universal Analysis 2000, TA Instrument. USA) was used.

$$Cp = \frac{E \cdot (dQ/dt)}{(dT/dt) \cdot m} \quad (3)$$

E in Equation 3 was determined by correlating its values with temperature. E values were obtained by measuring the heat capacity of reference material (distilled water) and comparing with its literature values.

2.4. Statistical analysis

Statistical analysis was performed using Minitab Statistical Software. The suitability of the fitted equations was evaluated by the correlation coefficient (R^2), and mean square error (MSE).

3. RESULTS AND DISCUSSION

The results demonstrate that the temperature and soluble solid content of fruit juices are significant variables to estimate their physical properties; density, viscosity and heat capacity.

3.1. Effect of soluble solid content and temperature on density of clarified fruit juices

Densities of clarified fruit juices exhibited very strong dependencies of temperature and soluble solid content ($p \leq 0.05$) (Table 1). As can be seen from Figure 1, increasing soluble solid content of studied fruit juices caused increases in density values, whereas higher temperature lowered density values. Similar trends have been reported in the previous studies (Alvarado & Romero 1989; Cepeda & Villarán 1999; Constenla et al. 1989; Gratao, Junior, Polizelli & Telis-Romero 2005; Ramos & Ibarz 1998; Shamsudin et al. 2005; Telis-Romero et al. 1998; Zainal et al. 2000). The following equation (Eq. 4) as the best fit for the experimental values was a polynomial type with a correlation coefficient of 0.996 and a MSE of $3 \cdot 10^{-5}$ (Table 1).

$$\rho = 1.156 + 3.469 \times 10^{-3} \cdot B + 2.503 \times 10^{-5} \cdot B^2 - 4.404 \times 10^{-4} \cdot T \quad (R^2: 0.996) \quad (4)$$

, where ρ is a density of studied clarified fruit juices ($\text{g} \cdot \text{cm}^{-3}$) and temperature and soluble solid content units of sample were K and °Brix, respectively.

The data predicted using the equations reported by Ramos and Ibarz (1998) and Gratao et al (2005) were nearly coincident with the experimental results of clarified fruit juices, whereas the calculated data from the equation of Constenla et al (1989) differed from data in the present study (Figure 2). Constenla et al (1989) have reported the effect of sugar content and type on the thermophysical properties of clarified apple juice, accounting for more than 90% of soluble solids. Sugar concentrations of apple, sourcherry and grape juices were similar to each others and corresponded higher than 90% of their soluble solid contents according to the published study by Muramatsu Tagawa and Kasai (2005). Thus, the fitted model can be used to predict the densities of clarified apple, grape and sour cherry juices in the studied temperature and soluble solid content ranges of 25°C to 60°C and of 10°Brix to 60°Brix, respectively.

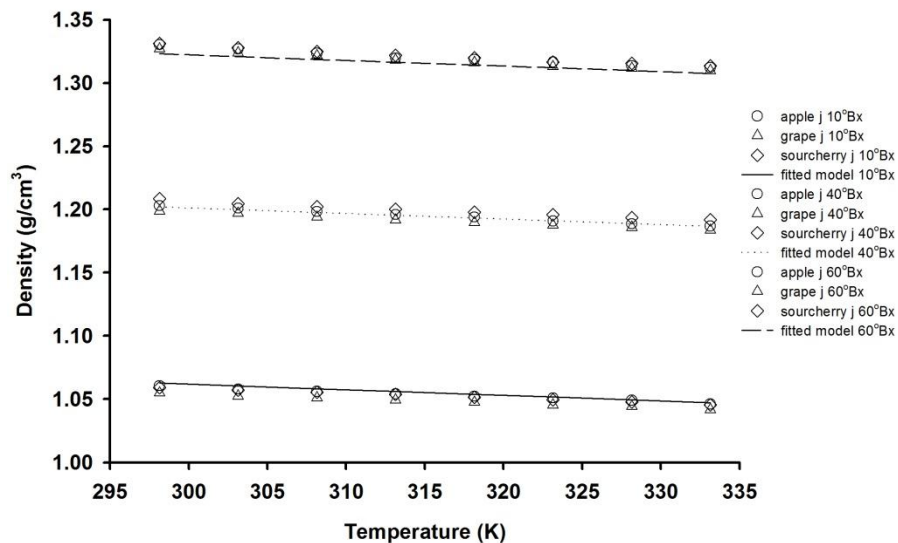


Figure 1 Density change of clear fruit juices with temperature at different soluble solid concentrations

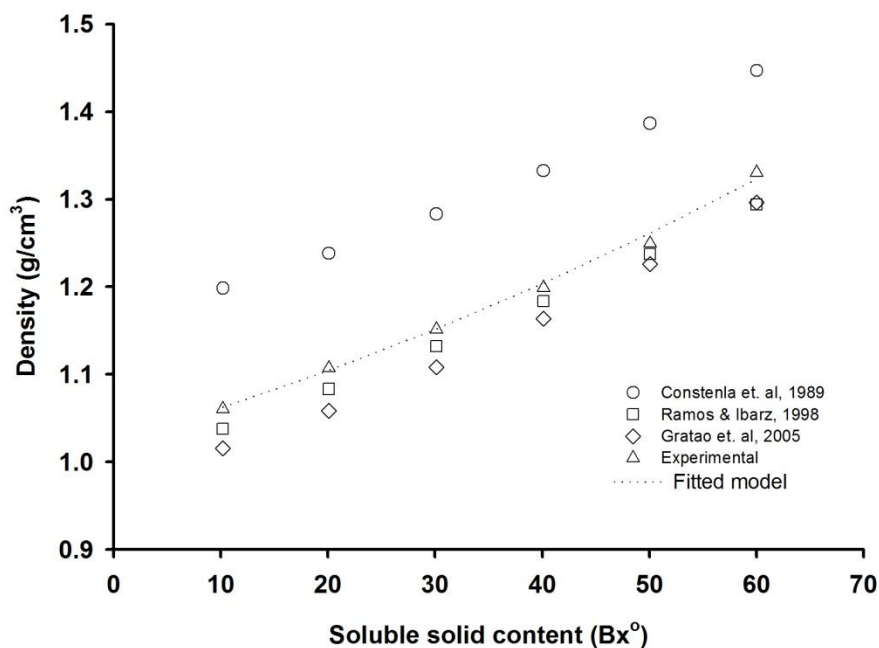


Figure 2 Comparison of fitted model and literature ones of density with change of soluble solid content

Table 1. Regression coefficients of fitted models for studied thermophysical properties of clarified fruit juices and independent effects of factors

Model	Density, (ρ)	Viscosity, (μ) ^a		Heat capacity
		Flow Activation Energy, (E_a)	Arrhenius Equation Constant, (μ_∞)	
R^2	0.996	>0.999	>0.999	0.747
MSE	$3 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-5}$	$<1 \cdot 10^{-1}$
independent effects of factors				
soluble solid content	*	*		ns
temperature	*	*		*

^a, Temperature dependence of viscosity was represented by Arrhenius type equation $\mu = \mu_\infty \cdot \exp(E_a/R \cdot T)$ and soluble solid effect on viscosity was included by correlating E_a and μ_∞ with soluble solid content.

*; significant at $p \leq 0.05$

^{ns}; not significant ($p > 0.05$).

3.2. Effect of temperature and soluble solid content on viscosity of clarified fruit juices

Temperature and soluble solid content of fruit juices were found to be highly significant factors to predict the viscosities of studied clarified fruit juices ($p \leq 0.05$) (Table 1). The viscosities of clarified fruit juices were considerably reduced by temperature. As can be seen from Figure 3, viscosity change with temperature was relatively high at higher soluble solid contents (above 30°Bx), however, the weak temperature influence was observed at lower concentration (below 30°Bx). The changes of viscosities of clarified fruit juices at the soluble solid content range of 10°Bx to 30°Bx followed parallel trends with increasing temperature, while at the higher levels of soluble solid contents, the measured viscosity values of sourcherry juice were higher than other two fruit juices at the lower temperature levels (Figure 2). Bayındırlı (1992, 1993) has reported the effect of temperature on the viscosity due to intermolecular distances increasing as a result of thermal expansion. The positive influence of soluble solid concentration on the magnitude of the viscosity has reported by Rao (1999). The increasing soluble solid content enhanced the viscosity due to the increase in hydrogen bonding with hydroxyl groups and the distortion in the velocity pattern of the liquid by hydrated solute molecules (Azoubel et al. 2005; Constenla et al. 1989). The Arrhenius type relation can be used to describe the effects of temperature and soluble solid content on viscosity (Krokida, Maroulis & Saravacos 2001; Nindo et al. 2004). The calculated flow activation energy values of the clarified fruit juices were correlated with their soluble solid contents. A polynomial model (Eq. 5) with a correlation coefficient ($R^2 > 0.999$) and satisfying MSE less than $1 \cdot 10^{-5}$ presented the influence of soluble solid content on the flow activation energy of fruit juices. The natural logarithm of another calculated parameter (μ_∞) of Arrhenius equation from experimental data was also correlated with soluble solid concentrations of fruit juices with a satisfying correlation coefficient ($R^2 > 0.999$) and MSE (Eq. 6). These models were integrated into Arrhenius type equation and the change of viscosity of the clarified fruit juices with respect to temperature and soluble solid content was described by Equation 7.

$$Ea = 15583.32 + 4.32 \cdot B^2 \quad (R^2 > 0.999) \quad (5)$$

$$\ln \mu_{\infty} = -13.07 - 8.90 \times 10^{-4} \cdot B^2 \quad (R^2 > 0.999) \quad (6)$$

$$\mu = 2.11 \times 10^{-6} \exp \left(\left(\frac{15583.32 + 4.32 \cdot B^2}{R \cdot T} \right) - 8.90 \times 10^{-4} \cdot B^2 \right) \quad (7)$$

, where μ was viscosity in the unit of Pa.s, B and T were soluble solid content and temperature in the units of °Bx and K, respectively.

Flow activation energy data calculated from experimental results of this study varied from 16.3 kJ/mol upto 30.7 kJ/mol. Krokida et al (2001) have reported that the flow activation energy (Ea) in Newtonian fluid foods increases from 14.4kJ/mol for water to more than 60kJ/mol for concentrated clarified juices and sugar solutions. The flow activation energy range in the present study were coincident with data reported by Krokida et al (2001). These equations would be suitable for predicting the viscosity of studied clarified juices over a studied ranges of solids content and temperature.

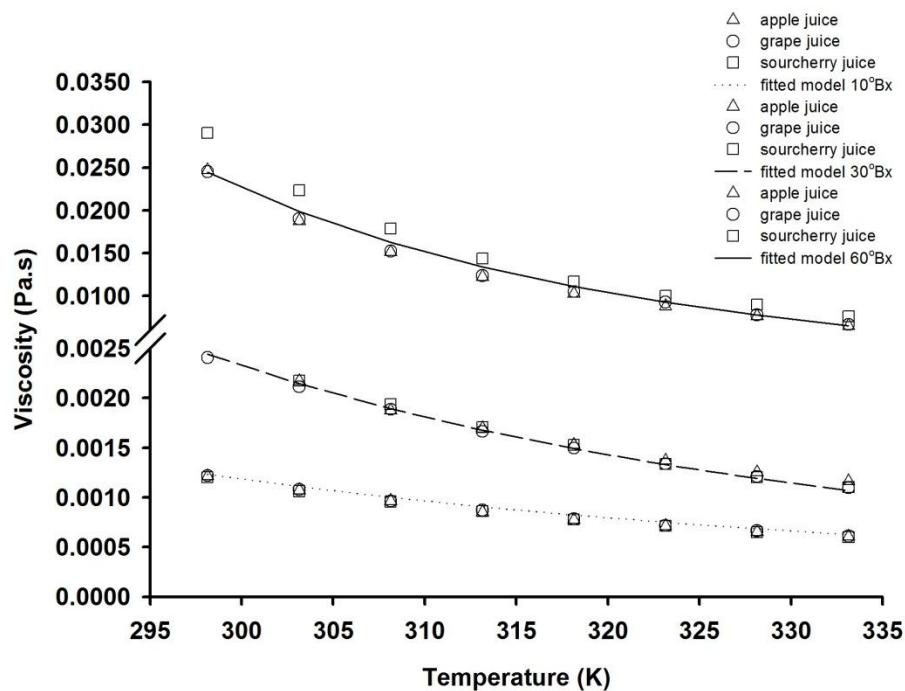


Figure 3 Viscosity change of clear fruit juices with temperature at different soluble solid concentrations

3.3. Effect of temperature and soluble solid content on heat capacity of clarified fruit juices

Soluble solid content were found to significantly influence heat capacities of clarified fruit juices ($p \leq 0.05$), whereas variation in heat capacities with temperature was insignificant ($p > 0.05$) (Table 1). Soluble solid contents of clarified fruit juices caused reduction of heat capacity, whereas increasing temperature enhanced the heat capacity of fruit juices (Figure 4). The influence of soluble solid content can be attributed to the decrease in water content of fruit juices. The heat capacity of water is the highest value in the group of food constituents. Similar dependences on both variables have been shown in previous studies (Constenla et al. 1989; Shamsudin et al. 2005; Telis-Romero et al. 1998; Zainal et al. 2000). The achieved model that fitted best the experimental heat capacity values for clarified fruit juices were far away from expectation of one model being valid for clarified fruit juices. Linear model (Eq. 8) obtained by regression analysis has been proposed; however, the results were fitted to models with correlation coefficient less than 0.90 which is not sufficient for representation (Table 1). The model describing the relationship between heat capacities of the clarified fruit juices and both variables, temperature and soluble solid content can be given as:

$$C_p = 3.9193 - 1.7039 \times 10^{-2} \cdot B + 3.2437 \times 10^{-3} T \quad R^2: 0.747 \quad (8)$$

As can be seen from Equation 8 and Figure 4, the magnitude of the effect of soluble solid content was higher than that one due to temperature. The achieved model with relatively low level of correlation coefficient is associated with the effects of compositional differences of the clarified fruit juices. Sweat (1995) has also mentioned the effect of foodstuff composition on heat capacity.

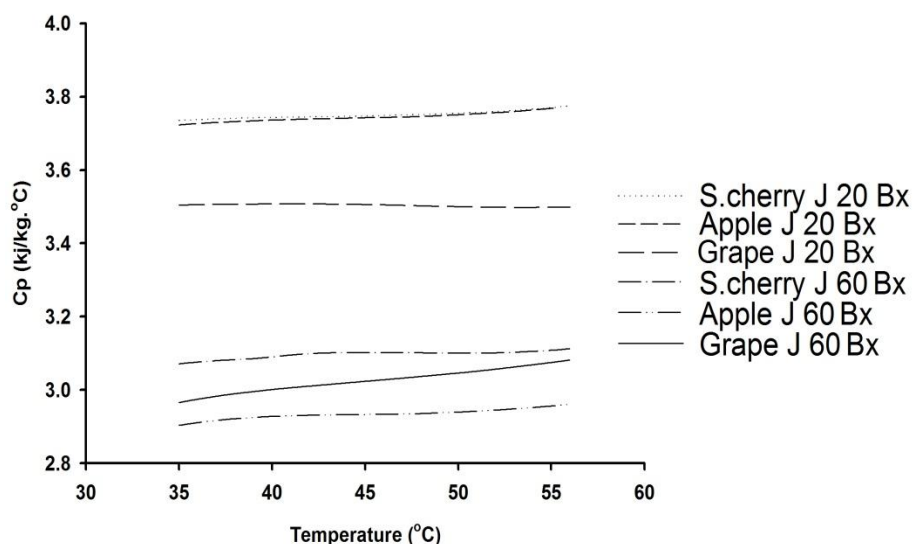


Figure 4. Heat capacity change of clear fruit juices with temperature at different soluble solid concentrations

4. CONCLUSION

This study indicated that temperature and soluble solid content of the clarified fruit juices were effective on their density, viscosity, and heat capacity. The common equations or models representing physical properties were valid and they can be used to estimate them for any clarified fruit juices being considered in this study with high correlation coefficients, except model for heat capacity.

Nomenclature

ρ	; density, g.cm ⁻³ ,
ν	; kinematic viscosity, cPs,
μ	; apparent viscosity, Pa.s,
μ_{∞}	; constant, Pa.s,
Ea	; the flow activation energy, kj.kmol ⁻¹ ,
T	; absolute temperature, K or °C,
B	; soluble solid content of sample, °Bx,
R	; gas constant, kj.kmol ⁻¹ .K ⁻¹ ,
Cp	; heat capacity, kj.kg ⁻¹ .°C ⁻¹
E	; correction factor,
dQ/dt	; heat transfer rate; kj.s ⁻¹ ,
dT/dt	; heating rate, °C.s ⁻¹ ,
m	; weight of sample, kg.

Acknowledgement

Karacabey thanks to Prof. Dr. Şebnem Harsa (Food Engineering Department), Assoc. Prof. Dr. Metin Tanoğlu (Mechanical Engineering Department), and Research Assist. Elçin Kaya (Mechanical Engineering Department) in Faculty of Engineering, Izmir Institute of Technology, Izmir, Turkey for their valuable supports. Support from the T.R. Prime Ministry State Planning Organization (BAP-08-11-DPT2002K120510-GT-4) is gratefully acknowledged.

REFERENCES

- Ali, SD Ramaswamy, HS & Awuah, GB 2002, 'Thermo-physical properties of selected vegetables as influenced by temperature and moisture content', *Journal of Food Process Engineering*, 25, 417-433.
- Altan, A & Maskan, M 2005, 'Rheological behavior of pomegranate (*Punica granatum* L.) juice and concentrate', *Journal of Texture Studies*, 36, 68-77.
- Alvarado, JD & Romero, CH 1989, 'Physical properties of fruits I. density and viscosity of juices as functions of soluble solids content and temperature', *Latin American Applied Research*, 19, 15-21.
- Azoubel, PM Cipriani, DC El-Aouar, AA Antonio, GC & Murr, FEX 2005, 'Effect of concentration on the physical properties of cashew juice', *Journal of Food Engineering*, 66, 413-417.

- Bayındırlı, L 1992, 'Mathematical Analysis of Variation of Density and Viscosity of Apple Juice With Temperature and Concentration', *J. of Food Proc. and Pres.*, 16, 23-28.
- Bayındırlı, L 1993, 'Density and viscosity of grape juice as a function of concentration and temperature', *Journal of Food Processing Preservation*, 17, 147-151.
- Cepeda, E & Villarán, MC 1999, 'Density and viscosity of Malus floribunda juice as a function of concentration and temperature', *Journal of Food Engineering*, 41, 103-107.
- Constenla, DT Lozano, JE & Crapiste, GH 1989, 'Thermophysical properties of clarified apple juice as a function of concentration and temperature' *Journal of Food Science*, 4, 3, 663-668.
- de Moura, SCSR Germer, SPM Jardim, DCP & Sadahira, MS 1998, 'Thermophysical properties of tropical fruit juices', *Brazilian Journal of Food Technology*, 1, 1-2, 70-76.
- Gratao, ACA Junior, VS Polizelli, MA & Telis-Romero, J 2005, 'Thermal properties of passion fruit juice as affected by temperature and water content', *Journal of Food Process Engineering*, 27, 413-431.
- Holdsworth, SD 1993, 'Rheological models used for the prediction of the flow properties of food products: a literature review', *Transactions of Institute of Chemical Engineering, Part C, Food and Bioproducts Processing*, 71c, 139-179.
- Ibarz, A & Pagan, J 1987, 'Rheology of raspberry juices', *Journal of Food Engineering*, 6, 269-289.
- Krokida, MK Maroulis, ZB & Saravacos, GD 2001, 'Rheological properties of fluid fruit and vegetable puree products: compilation of literature data', *International Journal of Food Properties*, 4, 2, 179-200.
- Lau, AK 1991, 'Evaporators', in *Encyclopedia of foodscience and technology*, Hui, YH (ed), Wiley and Sons Press, New York, USA, pp 751-765.
- Magerramov, MA Abdulagatov, AI Azizov, ND & Abdulagatov, IM 2007 'Effect of temperature, concentration, and pressure on the viscosity of pomegranate and pear juice concentrates', *Journal of Food Engineering*, 80, 476-489.
- Muramatsu, Y Tagawa, A & Kasai, T 2005, 'Thermal conductivity of several liquid foods'. *Food Sci. Technol. Res.*, 11, 3, 288-294.
- Nindo, CI Tang, J Powers, JR & Bolland, K 2004, 'Energy consumption during Refractance Window evaporation of selected berry juices', *International Journal of Energy Research*, 28, 12, 1089-1100.
- Nindo, CI Tang, J Powers, JR & Singh, P 2005, 'Viscosity of blueberry and raspberry juices for processing applications', *Journal of Food Engineering*, 69, 343-350.
- Poyrazoğlu, E Vural, G & Artık, N 2002, 'Organic acids and phenolic compounds in pomegranates', *Journal of Food Composition and Analysis*, 15, 567-575.
- Ramos, AM & Ibarz, A 1998, 'Density of juice and fruit puree as a function of soluble solids content and temperature', *Journal of Food Engineering*, 35, 57-63.
- Rao, MA 1999, 'Rheological behavior of processed fluid and semisolid foods', in *Rheology of fluid and semisolid foods: principles and applications*, Rao, MA (ed), Aspen Pub. Inc. Press, Gaithersburg, Maryland, USA, pp 219-255.
- Sweat, VE 1995, 'Thermal properties of foods', in *Engineering properties of foods* (2nd edn), Rao, MA & Rizvi, SSH (eds), Marcel Dekker, Inc., New York, USA, pp 99-138.

Shamsudin, R Mohamed, IO & Yaman NKM 2005, 'Thermophysical properties of Thai seedless guava juice as affected by temperature and concentration', *Journal of Food Engineering*, 66, 395–399.

Telis-Romero, J Telis, VRN Gabas AL & Yamashita, F 1998, 'Thermophysical properties of brazilian orange juice as affected by temperature and water content', *Journal of Food Engineering*, 38, 27-40.

Zainal, BS Abdul Rahman, R Ariff, AB Saari, BN & Asbi, BA 2000, 'Effects of temperature on the physical properties of pink guava juice at two different concentrations', *Journal of Food Engineering*, 43, 55-59.

Zuritz, CA Muñoz Puentes, E Mathey, HH Pérez, EH Gascón, A Rubio, LA Carullo, CA Chernikoff, RE & Cabeza, MS 2005, 'Density, viscosity and coefficient of thermal expansion of clarified grape juice at different soluble solid concentrations and temperatures', *Journal of Food Engineering*, 71, 143–149.