Rheology of redcurrant juices

Ibarz A., Falguera V., Garza S. and Garvín, A.*
Departament de Tecnologia d'Aliments UP-XaRTA
(Universitat de Lleida) Av. Rovira Roure, 191, CP 25198 Lleida-España

Reología de zumos de grosella

Reologia de sucs de grosella

Recibido: 6 de septiembre de 2010; revisado: 7 de noviembre de 2010; aceptado: 1 de diciembre de 2010

RESUMEN

Se ha estudiado el comportamiento reológico de dos zumos diferentes de grosella. El zumo con contenido en pectinas exhibió comportamiento no newtoniano. El zumo al que se le han extraído las pectinas exhibió comportamiento newtoniano. El modelo de la ley de la potencia describió la relación entre el esfuerzo cortante y el gradiente de velocidad para el primer tipo de zumo y el modelo newtoniano describió el comportamiento del segundo tipo de zumo. El efecto de la temperatura en la viscosidad aparente a 100 s^{-1} queda descrito por la ecuación de Arrhenius.

Palabras clave: Reología, grosella, zumo, viscosidad

ABSTRACT

The rheological behaviour of two different redcurrant juices was studied. Juices containing pectins exhibited non-Newtonian behavior. Juices from which pectins were removed exhibited Newtonian behavior. The power law model described the relationship between shear stress and shear rate for the first type of juice, and the Newtonian model described the second type. The effect of temperature on the apparent viscosity at 100 s^{-1} was described by Arrhenius equation.

Keywords: Rheology, redcurrant, juices, viscosity

RESUM

S'ha estudiat el comportament reològic de dos sucs diferents de grosella. El suc amb contingut en pectines va exhibir comportament no newtonià. El suc al que se li van extreure les pectines va mostrar un comportament newtonià. El model de la llei de la potència va descriure la relació entre el esforç tallant i el gradient de velocitat pel primer tipus de suc i el model newtonià va descriure el comportament del segon tipus de suc. L'efecte de la temperatura en la viscositat aparent a 100 s^{-1} es pot descriure per l'equació d'Arrhenius.

Paraules clau: Reologia, grosella, suc, viscositat

*Corresponding authors: aibarz@tecal.udl.cat,
vfalguera@tecal.udl.cat,
garza@tecal.udl.cat, garvin@tecal.udl.cat*

INTRODUCTION

The redcurrant (*ribes rubrum*) is original of Western Europe. These fruits can be consumed freshly, although its concentrated juice is often used in the elaboration of jams, jellies, liquors, syrups and sauces. It contributes to acidify the products due to its high content in organic acids, and to improve their consistency because of its high content in pectins.

The flow behavior of fruit juices and their fluid derivatives is strongly affected by both juice and fruit characteristics. The presence of pulp solids, as in the dispersed phase of fruit juice, contributes to their non-Newtonian nature (Ramos & Ibarz 2006, Falguera et al 2010). Clarified and depectinated juices usually show a rheological behavior that may be described either by Newton's viscosity equation or by power-law equation. Juices with pectins and pulp in suspension usually show yield stress, and their rheological behavior may be described by Herschel-Bulkley's model.

In non-Newtonian fluids the quotient between shear stress and shear rate is not a constant as it occurs with Newtonian fluids. Therefore, the concept of apparent viscosity (h_a) is used at a given shear rate, which for fluids which follow the power-law equation will be expressed according to the following equation:

$$h_a = K \cdot \dot{\gamma}^{n-1} \quad (1)$$

and fluids which follow the Herschel-Bulkley model will be expressed according to this one:

$$h_a = \frac{s_0}{\gamma} + k \cdot \dot{\gamma}^{n-1} \quad (2)$$

The main purpose of this work has been to analyze the rheological behavior of redcurrant juices studying its flow response as a function of the temperature and soluble solids concentration. Although there are many studies with similar fuits: raspberry, strawberry and blackberry (Alvarez et al 2006, Haminiuk et al 2006, 2007, 2009, Ramaswamy and Basak 1992, Sousa et al 2006) and blackcurrant (Ibarz et al 1992b), the rheology of redcurrant juices has not been studied yet.

MATERIALS AND METHODS

Obtaining Samples

The redcurrant juices were obtained in the laboratory from natural fruits purchased in a local market in Lleida (Spain). The juice was obtained by squeezing the fruits and filtering the liquor obtained. The obtained paste was clarified by centrifugation at 3600 rpm for 20 minutes (Medifriger, Selecta, Abrera, Spain). The clarified juice had no pulp in suspension, but it did have pectins. Approximately half the juice without pulp was subjected to an enzymatic clarification in order to eliminate the pectins, using Pectinex and Ultrazym 100-C (Novo). The enzymes were left to act for two hours at 25ºC, and the juice was then vacuum filtered. Two types of juices were therefore obtained, the first one clarified and depectinated (type I) and the other one clarified with pectins (type II).

From these two types of juices, different samples with different soluble solids contents were obtained by evaporation at approximately 25ºC, temperature that corresponds to a pressure of 24 mm Hg (Labo-rota C-311, Resonatechnics, Buchs, Switzerland).

Samples were extracted during the time of the concentration process, which allowed obtaining juices with different soluble solids contents: 68, 65, 60, 55, 50, 45 and 40ºBrix for type I, and 63, 58, 53, 44 and 38ºBrix for type II.

All experiments and analysis were carried out by triplicate.

Physical and Chemical Analysis

- The physicochemical analysis carried out to the redcurrant juices were:
- Soluble solids. These were determined using a digital refractometer at 20ºC (Atago RX-1000, Tokyo, Japan).
- Density. A picnometer was used at 20ºC (PROTON, Barcelona, Spain).
- Total acidity. This was determined by titrating the juice with NaOH 0.1 N, using phenolphthalein as indicator.
- pH. It was determined by using a pH-meter (MicropH2001, Crison Instruments, Alella, Spain).
- L-malic acid. This was determined by using the enzyme L-malate dehydrogenase. The absorbance was measured at 340 nm (Boehringer Mannheim 1984) using a spectrophotometer (PU 8720 UV/VIS, Philips, Eindhoven, Netherlands).
- Citric acid. This was determined by using the enzymes citrate lyase, malate dehydrogenase and L-malate dehydrogenase. The absorbance was measured at 340 nm (Boehringer Mannheim 1984).
- Ascorbic acid. This was determined by using the enzyme ascorbate oxidase. The absorbance was measured at 578 nm (Boehringer Mannheim 1984).
- Glucose, fructose and sucrose. These were determined by using the enzymes hexokinase and glucose-6-phosphate dehydrogenase. The absorbance was measured at 340 nm.
- Pectins. This content was determined by degradation in sulphuric acid medium. The absorbance was measured at 525 nm (De Giorgi et al 1985) and the result was expressed as g of galacturonic acid (AGA) per kg of juice.

Rheological measurements.

The rheological measurements of the different samples were carried out on a concentric cylinder viscometer (Rotovisco RV 12, Haake, Karlsruhe, Germany), equipped with M-500-type measurement attachment, which can transmit a torque of 4.9 N-cm. A thermostatic bath (Digitherm 30000613, Selecta, Abrera, Spain) controls the working temperature within the range 5-65ºC.

Rotor speeds were variable in the range 0.01-512 rpm. Readings were taken at decreasing rotor speeds until a minimum speed was reached, after which it was gradually increased. In order to eliminate the possible effects of thixotropy, the sample was previously sheared at maximum speed for three minutes.

The rheological behavior of the juices at different temperatures (5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60ºC.) was studied.

Statistical analysis

The experimental results obtained were fitted to mathematical models by using the Statgraphics Plus 5.1 software (STCSC Inc. Rockville, Md, USA) for data processing. All the fittings and the estimates were calculated at a 95% significant level.

RESULTS AND DISCUSSION

First of all, thixotropy was not observed.
The results of the physical and chemical analysis of redcurrant juice are shown in Table 1.

Table 1.- *Characteristics of centrifuged juice*

Density	1.044	g/mL
pH	2.64	
Soluble solids	11.2	ºBrix
Total acidity	0.41	eq/L
L-Malic acid	1.2	g/L
Citric acid	26.8	g/L
Ascorbic acid	60	mg/L
Glucose	10.1	g/L
Fructose	13.6	g/L
Sucrose	0.9	g/L
Pectins (Type I – 68ºBrix)	2.2	g AGA/kg
Pectins (Type II – 63ºBrix)	6.8	g AGA/kg

Rheological behavior of type I juice.
Figure 1 shows the experimental results obtained for the depectinated juice of 68 ºBrix at the different temperatures tested. Similar rheograms were obtained for the other concentrations.

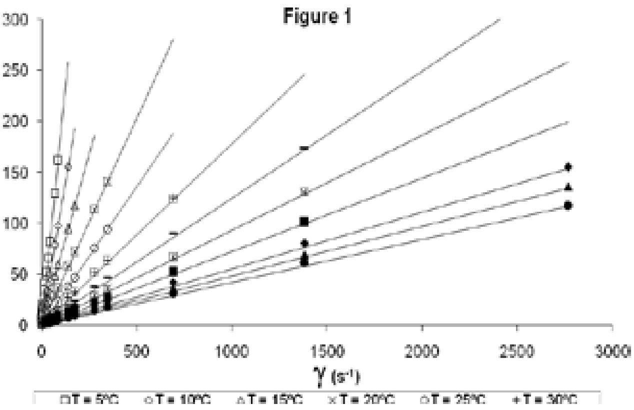
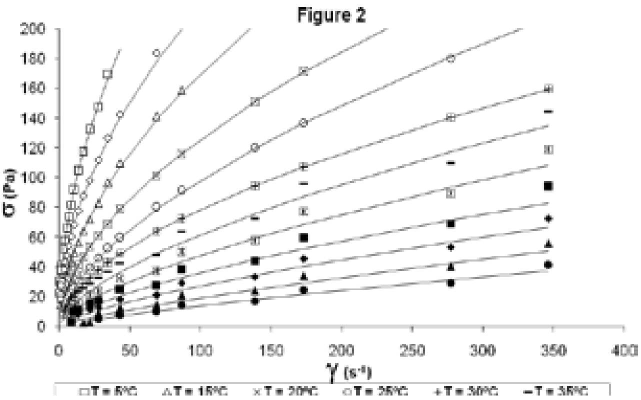


Table 2 shows the parameters obtained with Newton and power-law models. Herschel-Bulkley model was discarded because the yield stress obtained for all the concentrations and temperatures was smaller than 1 Pa (Vitali and Rao 1984).
In all cases, Newton model and power-law model show good fits. The behavior of type I juice can be considered as Newtonian due to its bigger simplicity. Newton model fittings show that the viscosity decreases with temperature and increases with soluble solids content.
Power-law model always shows a flow behavior index smaller than the unit, but near to it. As expected, the consistency index (k) decreases with temperature and increases with soluble solids content. The flow behavior index (n) is relatively constant with temperature for soluble solids content below 60ºBrix, similarly to previous works (Falguera and Ibarz 2010, Falguera et al 2010). For soluble solids content above 65ºBrix, the flow behavior index (n) show a slight decrease with temperature, as it was observed by Ibarz et al. (1993).

Rheological behavior of type II juice.
Figure 2 shows the experimental results obtained for the concentrated sample of 63ºBrix at the different tested temperatures. Similar rheograms were obtained for the other concentrations. The rheogram shows the non-linear fit; therefore, experimental data were fitted to the power-law and Herschel-Bulkley models.
Table 3 shows the parameters obtained with power-law and Herschel-Bulkley models. The values of the apparent viscosity at a shear rate of 100 s^{-1} are included for each model.



In Table 3 it can be observed that rheological behavior of this type of juice fits better to power-law model. The flow behavior index is always clearly smaller than the unit, thus the rheological behavior is pseudoplastic, and it shows an upward trend with decreasing concentration and increasing temperature. The consistency coefficient increases as the concentration increases and temperature decreases. The apparent viscosity increases as the concentration rises up, temperature decreases and the pectins content increases. The obtained values and tendencies are similar to those described in the literature (Falguera and Ibarz 2010, Falguera et al 2010, Ibarz et al 1993, Haminiuk et al 2006, 2007, 2009, Sato and Cunha 2009, Tonon et al 2009, Vandresen et al 2009).

Temperature effect.
The variation in apparent viscosity or viscosity with temperature can be described by an Arrhenius-type equation (Saravacos 1970; Rao et al 1984; Ibarz et al 1992a;1992b;1996; Falguera et al, 2010):

$$h \text{ or } h_a = h_\psi \exp\left[\frac{E_a}{RT}\right] \quad (3)$$

The parameters of the equation are shown in tables 4 and 5. The activation energy increases with the soluble solids content; therefore, temperature had a greater effect on the samples with higher soluble solids. For fixed soluble solids content, the value of activation energy of flow for clarified and depectinized juice is greater than the activation energy for juice containing pulp and pectin.
The activation energy values obtained for the clarified and depectinized juice were very similar to those for the depectinated apple and grape juices (Rao et al 1984), clarified banana juice (Khalil et al 1989), depectinized pear juice (Ibarz et al 1987), depectinized peach juice (Ibarz et al 1992a) and depectinized blackcurrant juice (Ibarz et al 1992b). For the juice containing pulp and pectins, the values obtained were similar to those obtained in tomato

Table 2.- *Clarified and depectinated redcurrant juices parameters*

C	T	Newton Model				Power-law Model						
		h			r	k			n			r
°Brix	°C	mPa·s				Pa·sn						
68	5	1866	±	15	0.9999	2.06	±	0.14	0.98	±	0.02	0.9998
	10	1116	±	10	0.9999	1.43	±	0.11	0.95	±	0.02	0.9999
	15	674	±	8	0.9999	0.92	±	0.07	0.94	±	0.02	0.9997
	20	406	±	6	0.9999	0.56	±	0.03	0.94	±	0.01	0.9998
	25	272	±	3	0.9999	0.35	±	0.02	0.96	±	0.02	0.9975
	30	177.6	±	2.0	0.9999	0.33	±	0.02	0.90	±	0.04	0.9997
	35	124.6	±	1.5	0.9999	0.27	±	0.03	0.89	±	0.02	0.9995
	40	93.2	±	1.0	0.9999	0.22	±	0.02	0.87	±	0.02	0.9997
	45	72.0	±	1.0	0.9999	0.17	±	0.02	0.88	±	0.02	0.9997
	50	57.0	±	0.9	0.9999	0.14	±	0.02	0.88	±	0.03	0.9996
	55	45.1	±	0.7	0.9999	0.13	±	0.01	0.87	±	0.02	0.9999
	60	43.1	±	0.7	0.9999	0.11	±	0.02	0.87	±	0.02	0.9982
65	5	682	±	7	0.9999	0.67	±	0.05	1.00	±	0.02	0.9999
	10	396	±	4	0.9999	0.59	±	0.04	0.93	±	0.01	0.9998
	15	144.4	±	1.3	0.9999	0.51	±	0.03	0.89	±	0.01	0.9996
	20	176.6	±	1.6	0.9999	0.29	±	0.04	0.93	±	0.03	0.9985
	25	120.3	±	1.4	0.9999	0.27	±	0.03	0.88	±	0.09	0.9992
	30	86.9	±	1.0	0.9999	0.21	±	0.02	0.87	±	0.02	0.9996
	35	66.1	±	0.7	0.9999	0.17	±	0.02	0.87	±	0.02	0.9991
	40	52.6	±	0.6	0.9999	0.13	±	0.01	0.88	±	0.02	0.9991
	45	41.2	±	0.5	0.9999	0.11	±	0.01	0.88	±	0.01	0.9998
	50	35.2	±	0.4	0.9999	0.10	±	0.02	0.86	±	0.03	0.9991
	55	29.6	±	0.3	0.9999	0.07	±	0.01	0.89	±	0.02	0.9993
	60	27.1	±	0.3	0.9999	0.06	±	0.01	0.89	±	0.02	0.9996
60	5	194.7	±	2.0	0.9999	0.36	±	0.03	0.90	±	0.02	0.9998
	10	123.2	±	1.4	0.9998	0.33	±	0.03	0.85	±	0.02	0.9995
	15	86.2	±	0.9	0.9997	0.28	±	0.03	0.83	±	0.02	0.9993
	20	63.9	±	0.7	0.9998	0.20	±	0.03	0.84	±	0.03	0.9996
	25	48.2	±	0.5	0.9999	0.16	±	0.02	0.84	±	0.02	0.9997
	30	36.3	±	0.3	0.9999	0.13	±	0.02	0.83	±	0.02	0.9992
	35	29.5	±	0.4	0.9988	0.11	±	0.02	0.83	±	0.02	0.9992
	40	25.5	±	0.3	0.9989	0.10	±	0.01	0.82	±	0.02	0.9996
	45	21.90	±	0.20	0.9974	0.08	±	0.01	0.84	±	0.03	0.9999
	50	19.6	±	0.3	0.9976	0.08	±	0.01	0.82	±	0.02	0.9998
	55	17.2	±	0.3	0.9968	0.06	±	0.02	0.84	±	0.04	0.9998
	60	15.30	±	0.20	0.9967	0.06	±	0.01	0.82	±	0.03	0.9996
55	5	70.6	±	1.0	0.9998	0.17	±	0.02	0.87	±	0.02	0.9993
	10	52.5	±	0.6	0.9997	0.14	±	0.01	0.86	±	0.02	0.9997
	15	38.0	±	0.7	0.9997	0.11	±	0.01	0.86	±	0.02	0.9997
	20	28.5	±	0.5	0.9995	0.08	±	0.01	0.87	±	0.02	0.9991
	25	24.2	±	0.3	0.9993	0.08	±	0.01	0.84	±	0.02	0.9994
	30	18.1	±	0.3	0.9989	0.07	±	0.01	0.83	±	0.02	0.9995
	35	15.10	±	0.20	0.9986	0.05	±	0.01	0.85	±	0.04	0.9999
	40	13.00	±	0.20	0.9985	0.05	±	0.02	0.81	±	0.06	0.9972
	45	11.70	±	0.20	0.9978	0.04	±	0.01	0.84	±	0.02	0.9996
	50	9.40	±	0.20	0.8788	0.03	±	0.03	0.86	±	0.09	0.9991
	55	9.40	±	0.10	0.9975	0.03	±	0.01	0.86	±	0.05	0.9982
	60	8.30	±	0.10	0.9978	0.02	±	0.01	0.88	±	0.06	0.9996
50	5	36.7	±	0.5	0.9998	0.12	±	0.02	0.84	±	0.02	0.9992
	10	27.4	±	0.4	0.9996	0.08	±	0.03	0.86	±	0.03	0.9992
	15	21.9	±	0.3	0.9992	0.07	±	0.02	0.86	±	0.01	0.9993
	20	17.4	±	0.3	0.9975	0.06	±	0.02	0.83	±	0.01	0.9997
	25	14.9	±	0.3	0.9975	0.05	±	0.01	0.84	±	0.02	0.9993
	30	9.00	±	0.20	0.9943	0.04	±	0.01	0.85	±	0.03	0.9999
	35	10.70	±	0.20	0.9962	0.03	±	0.01	0.85	±	0.04	0.9998
	40	9.40	±	0.10	0.9973	0.03	±	0.01	0.86	±	0.04	0.9998
	45	8.30	±	0.10	0.9978	0.02	±	0.01	0.87	±	0.04	0.9992
	50	7.20	±	0.10	0.9998	0.02	±	0.01	0.87	±	0.04	0.9996
	55	7.90	±	0.10	0.9997	0.02	±	0.01	0.90	±	0.06	0.9995
	60	6.80	±	0.10	0.9982	0.02	±	0.01	0.88	±	0.06	0.9995
45	5	21.3	±	0.3	0.9986	0.54	±	0.22	0.71	±	0.06	0.9918
	10	17.00	±	0.20	0.9961	0.08	±	0.12	0.79	±	0.13	0.9992
	15	14.20	±	0.20	0.9942	0.07	±	0.01	0.80	±	0.03	0.9993
	20	12.10	±	0.20	0.9932	0.06	±	0.01	0.79	±	0.03	0.9997
	25	10.40	±	0.20	0.9948	0.05	±	0.01	0.80	±	0.04	0.9996
	30	9.00	±	0.10	0.9948	0.04	±	0.01	0.82	±	0.05	0.9997
	35	8.20	±	0.10	0.9956	0.04	±	0.01	0.81	±	0.05	0.9997
	40	7.00	±	0.10	0.9973	0.03	±	0.01	0.80	±	0.02	0.9994
	45	6.70	±	0.10	0.9972	0.03	±	0.08	0.82	±	0.04	0.9993
	50	6.30	±	0.07	0.9974	0.02	±	0.02	0.82	±	0.08	0.9982
	55	5.60	±	0.07	0.9948	0.02	±	0.02	0.82	±	0.10	0.9996
	60	4.90	±	0.06	0.9923	0.04	±	0.01	0.83	±	0.05	0.9993
40	5	12.90	±	0.15	0.9987	0.04	±	0.01	0.87	±	0.05	0.9994
	10	11.00	±	0.13	0.9962	0.04	±	0.03	0.85	±	0.05	0.9983
	15	9.10	±	0.11	0.9965	0.04	±	0.02	0.83	±	0.05	0.9991

***Table 3**.- Clarified redcurrant juice parameters*

C	T	Power-law Model				Herschel-Bulkley Model				
		k	n	r	ha(100s-1)	s0	k	n	r	ha(100s-1)
ºBrix	ºC	Pa·sn			mPa·s	Pa	Pa·sn			mPa·s
63	5	28.3 ± 0.5	0.50 ± 0.01	0.9998	2808.7	19.4 ± 0.1	12.3 ± 1.4	0.73 ± 0.05	0.9955	3697.0
	10	20.53 ± 0.18	0.51 ± 0.01	0.9996	2161.9	15.2 ± 0.1	8.0 ± 1.0	0.75 ± 0.05	0.9942	2430.7
	15	13.5 ± 0.3	0.55 ± 0.01	0.9994	1695.6	10.6 ± 0.1	5.5 ± 0.9	0.78 ± 0.05	0.9926	3098.0
	20	9.55 ± 0.13	0.56 ± 0.01	0.9997	1252.4	11.0 ± 0.2	3.3 ± 0.9	0.79 ± 0.07	0.9863	2458.9
	25	6.20 ± 0.15	0.60 ± 0.01	0.9992	989.1	8.4 ± 0.1	2.4 ± 0.5	0.80 ± 0.06	0.9911	1631.1
	30	5.69 ± 0.17	0.57 ± 0.01	0.9992	796.5	7.8 ± 0.1	2.6 ± 0.3	0.71 ± 0.03	0.9988	1316.0
	35	3.39 ± 0.12	0.63 ± 0.01	0.9998	629.5	5.8 ± 0.1	2.4 ± 0.3	0.79 ± 0.05	0.9956	1249.3
	40	2.28 ± 0.10	0.66 ± 0.01	0.9997	479.8	5.3 ± 0.1	0.50 ± 0.04	0.94 ± 0.16	0.9636	661.9
	45	1.65 ± 0.02	0.67 ± 0.01	0.9997	367.4	4.0 ± 0.1	2.4 ± 0.2	0.80 ± 0.05	0.9918	468.2
	50	0.99 ± 0.04	0.72 ± 0.01	0.9996	267.4	3.8 ± 0.1	2.62 ± 0.21	0.71 ± 0.02	0.9986	324.9
	55	0.50 ± 0.05	0.79 ± 0.02	0.9989	185.8	1.8 ± 0.1	2.41 ± 0.09	0.79 ± 0.05	0.9951	190.9
	60	0.33 ± 0.04	0.81 ± 0.02	0.9991	137.1	1.9 ± 0.1	0.50 ± 0.10	0.94 ± 0.19	0.9638	91.5
58	5	8.1 ± 0.4	0.59 ± 0.02	0.9997	1237.8	5.8 ± 0.1	3.6 ± 1.1	0.80 ± 0.09	0.9776	1744.2
	10	4.0 ± 0.4	0.68 ± 0.03	0.9963	924.0	3.0 ± 0.1	2.6 ± 0.6	0.77 ± 0.06	0.9883	1002.2
	15	3.11 ± 0.28	0.68 ± 0.03	0.9972	706.1	3.6 ± 0.1	1.6 ± 0.6	0.82 ± 0.09	0.9797	801.8
	20	2.17 ± 0.13	0.68 ± 0.01	0.9995	492.6	2.6 ± 0.2	0.8 ± 0.3	0.86 ± 0.08	0.9805	518.4
	25	2.17 ± 0.11	0.65 ± 0.01	0.9991	432.7	3.3 ± 0.1	0.9 ± 0.3	0.82 ± 0.08	0.9849	492.3
	30	1.24 ± 0.08	0.70 ± 0.02	0.9991	310.7	3.0 ± 0.1	0.56 ± 0.16	0.83 ± 0.06	0.9926	344.3
	35	0.74 ± 0.10	0.75 ± 0.03	0.9976	238.6	1.9 ± 0.1	0.44 ± 0.14	0.84 ± 0.06	0.9936	241.6
	40	0.64 ± 0.07	0.75 ± 0.03	0.9982	198.7	1.6 ± 0.1	0.31 ± 0.11	0.87 ± 0.07	0.9907	193.1
	45	0.38 ± 0.05	0.79 ± 0.03	0.9983	140.3	1.4 ± 0.1	0.18 ± 0.07	0.91 ± 0.07	0.9938	138.1
	50	0.29 ± 0.05	0.80 ± 0.04	0.9977	114.7	1.0 ± 0.1	0.16 ± 0.05	0.89 ± 0.06	0.9949	110.0
	55	0.21 ± 0.02	0.81 ± 0.02	0.9994	90.3	0.9 ± 0.1	0.11 ± 0.04	0.91 ± 0.06	0.9958	84.2
	60	0.14 ± 0.04	0.85 ± 0.05	0.9969	68.8	0.6 ± 0.1	0.08 ± 0.05	0.94 ± 0.10	0.9888	60.1
53	5	2.72 ± 0.18	0.68 ± 0.02	0.9982	619.3	3.5 ± 0.1	1.76 ± 0.21	0.75 ± 0.03	0.9974	685.8
	10	2.30 ± 0.15	0.65 ± 0.02	0.9997	467.5	3.8 ± 0.1	0.9 ± 0.3	0.83 ± 0.07	0.9858	551.0
	15	1.51 ± 0.13	0.69 ± 0.02	0.9986	355.4	2.6 ± 0.1	0.69 ± 0.24	0.83 ± 0.08	0.9863	384.2
	20	3.11 ± 0.07	0.69 ± 0.02	0.9987	753.9	2.4 ± 0.1	0.62 ± 0.15	0.79 ± 0.05	0.9939	296.0
	25	0.88 ± 0.08	0.69 ± 0.02	0.9996	216.1	2.1 ± 0.1	0.43 ± 0.13	0.81 ± 0.06	0.9922	226.4
	30	0.62 ± 0.05	0.72 ± 0.02	0.9991	169.5	2.2 ± 0.1	0.28 ± 0.09	0.84 ± 0.06	0.9928	184.4
	35	0.60 ± 0.03	0.70 ± 0.01	0.9998	148.4	2.1 ± 0.1	0.23 ± 0.07	0.84 ± 0.06	0.9941	159.2
	40	0.38 ± 0.03	0.74 ± 0.02	0.9993	114.2	1.4 ± 0.1	0.19 ± 0.05	0.85 ± 0.05	0.9960	113.3
	45	0.28 ± 0.03	0.75 ± 0.02	0.9994	90.0	1.2 ± 0.1	0.43 ± 0.05	0.81 ± 0.07	0.9928	86.3
	50	0.20 ± 0.02	0.78 ± 0.02	0.9995	72.0	0.9 ± 0.1	0.28 ± 0.04	0.84 ± 0.07	0.9922	67.3
	55	0.15 ± 0.02	0.80 ± 0.02	0.9995	58.5	0.7 ± 0.1	0.23 ± 0.03	0.84 ± 0.06	0.9948	54.3
	60	0.14 ± 0.03	0.79 ± 0.03	0.9994	52.0	0.7 ± 0.1	0.19 ± 0.05	0.85 ± 0.08	0.9960	44.3
44	5	0.54 ± 0.22	0.71 ± 0.06	0.9911	141.7	1.9 ± 0.1	0.24 ± 0.02	0.93 ± 0.06	0.9970	322.9
	10	0.37 ± 0.05	0.74 ± 0.03	0.9982	112.6	1.5 ± 0.1	0.17 ± 0.07	0.93 ± 0.07	0.9928	146.6
	15	0.26 ± 0.05	0.76 ± 0.04	0.9961	87.0	1.0 ± 0.1	0.12 ± 0.06	0.86 ± 0.08	0.9902	73.0
	20	0.25 ± 0.03	0.74 ± 0.02	0.9996	75.1	1.4 ± 0.1	0.09 ± 0.05	0.89 ± 0.09	0.9907	71.9
	25	0.21 ± 0.02	0.74 ± 0.02	0.9992	62.9	1.1 ± 0.1	0.10 ± 0.05	0.85 ± 0.06	0.9953	61.3
	30	0.15 ± 0.03	0.76 ± 0.03	0.9998	49.1	0.6 ± 0.1	0.09 ± 0.04	0.83 ± 0.07	0.9943	45.7
	35	0.10 ± 0.02	0.80 ± 0.03	0.9994	38.3	0.4 ± 0.1	0.05 ± 0.02	0.89 ± 0.08	0.9940	32.9
	40	0.08 ± 0.02	0.81 ± 0.04	0.9994	31.3	0.4 ± 0.1	0.05 ± 0.02	0.87 ± 0.08	0.9969	27.4
	45	0.06 ± 0.03	0.81 ± 0.06	0.9989	26.8	0.4 ± 0.1	0.15 ± 0.15	0.69 ± 0.26	0.8019	34.5
	50	0.06 ± 0.02	0.79 ± 0.05	0.9988	23.8	0.4 ± 0.1	0.04 ± 0.03	0.87 ± 0.11	0.9932	21.6
	55	0.05 ± 0.01	0.81 ± 0.02	0.9997	20.3	0.3 ± 0.1	0.03 ± 0.11	0.88 ± 0.10	0.9988	18.3
	60	0.04 ± 0.01	0.83 ± 0.05	0.9997	17.4	0.3 ± 0.1	0.02 ± 0.02	0.90 ± 0.11	0.9961	14.8
38	5	0.16 ± 0.02	0.85 ± 0.02	0.9973	80.6	0.9 ± 0.1	0.06 ± 0.04	0.95 ± 0.10	0.9917	54.8
	10	0.19 ± 0.02	0.75 ± 0.03	0.9999	61.7	1.5 ± 0.2	0.12 ± 0.01	0.81 ± 0.02	0.9990	72.3
	15	0.17 ± 0.01	0.75 ± 0.03	0.9998	52.7	1.0 ± 0.1	0.07 ± 0.04	0.88 ± 0.06	0.9963	50.3
	20	0.11 ± 0.01	0.78 ± 0.01	0.9996	40.1	0.6 ± 0.1	0.06 ± 0.02	0.88 ± 0.07	0.9955	36.7
	25	0.08 ± 0.01	0.81 ± 0.01	0.9984	32.2	0.4 ± 0.1	0.04 ± 0.02	0.90 ± 0.08	0.9968	28.8
	30	0.06 ± 0.02	0.82 ± 0.02	0.9992	26.2	0.4 ± 0.1	0.03 ± 0.02	0.91 ± 0.09	0.9952	23.5
	35	0.51 ± 0.02	0.82 ± 0.03	0.9985	23.8	0.4 ± 0.1	0.03 ± 0.03	0.90 ± 0.11	0.9940	20.2
	40	0.05 ± 0.02	0.82 ± 0.03	0.9986	19.6	0.3 ± 0.1	0.02 ± 0.02	0.91 ± 0.10	0.9967	17.3
	45	0.03 ± 0.01	0.84 ± 0.03	0.9994	15.6	0.2 ± 0.1	0.43 ± 0.01	0.81 ± 0.10	0.9928	14.0
	50	0.03 ± 0.01	0.83 ± 0.04	0.9994	14.2	0.3 ± 0.1	0.28 ± 0.02	0.84 ± 0.12	0.9929	12.8
	55	0.03 ± 0.02	0.82 ± 0.02	0.9976	13.7	0.3 ± 0.1	0.23 ± 0.03	0.84 ± 0.15	0.9947	12.0
	60	0.04 ± 0.01	0.85 ± 0.05	0.9986	19.5	0.2 ± 0.1	0.19 ± 0.02	0.85 ± 0.16	0.9969	9.7

***Table 4**.- Parameters of Arrhenius Equation for Type I redcurrant juices*

C	Newton Model			Power-law Model		
	E_a	$h_{¥}\cdot 10^{7}$	r	E_a	$h_{¥}\cdot 10^{7}$	r
ºBrix	kJ/mol	mPa·s		kJ/mol	mPa·s	
68	54.4	0.83	0.9902	47.7	0.01	0.9903
65	43.1	36.74	0.9745	40.2	0.18	0.9938
60	34.7	430.56	0.9841	30.1	41.83	0.9900
55	30.1	1346.95	0.9878	28.9	42.65	0.9963
50	23.0	13217.36	0.9580	25.1	10481.07	0.9938
45	20.1	35113.56	0.9929	20.5	50061.41	0.9920

Table 5.- *Parameters of Arrhenius Equation for Type II redcurrant juices*

C	Power Law			Herschel-Bulkley		
	E_a	$h_{¥}·10^7$	r	E_a	$h_{¥}·10^7$	r
°Brix	kJ/mol	mPa·s		kJ/mol	mPa·s	
63	41.42	56.15	0.9940	56.49	0.02	0.9819
58	40.17	37.75	0.9986	44.77	6.16	0.9977
53	37.66	63.54	0.9536	38.49	39.97	0.9981
44	29.71	362.50	0.9987	31.38	72.56	0.9969
38	23.85	2332.04	0.9304	27.20	422.40	0.9834

derivates (Saravacos 1970; Ibarz et al 1988) and plum and peach pulp (Ibarz and Lozano 1992). The h¥ values obtained of the clarified and depectinized juice were within the same order as those for depectinized peach, blackcurrant and banana juice above mentioned.

CONCLUSION

From the experimental results obtained from depectinized and non-depectinized redcurrant juices in the temperature range of 5-60°C and soluble solids content between 38 an 68°Brix, the following conclusions may be drawn:
Redcurrant juices containing pectins showed rheological behavior which was better described by the power-law model. Herschel-Bulkley model also fitted experimental data.
Clarified and depectinized redcurrant juices showed rheological behavior which can be described by the Newtonian model. The parameters obtained for power-law model also fit well.
For both depectinized and non-depectinized redcurrant juices, the effect of temperature in apparent viscosity at $100 s^{-1}$ can be described by an exponential Arrhenius-type equation.

NOTATION

C	Concentration (°Brix)
E_a	Activation energy (kJ/mol)
k	Consistency index ($Pa·s^n$)
n	Flow behavior index (dimensionless)
R	Gas constant (8.314 J/mol K)
T	Temperature (°C or K)
$\dot{y}$	Shear rate (s^{-1})
h	Viscosity (mPa·s)
h_a	Apparent viscosity (mPa·s)
$h_{¥}$	Apparent viscosity at great temperatures (mPa·s)
σ	Shear stress (Pa)
S_0	Yield stress (Pa)

BIBLIOGRAPHY

1. Alvarez E, Cancela MA, Maceiras R (2006) Effect of temperature on rheological properties of different jams. International Journal of food properties 9(1): 135-146
2. Boehringer Mannheim 1984. Food Analysis. Ed. Boehringer Mannheim Biochemica, Germany
3. De Giorgi A, Tomasicchio M, Andreotti R (1985) Determinazione rapida desse sostenze pectiche nelle confiture e nelle mermellatte. Industria Conserve 60:36-38
4. Falguera V, Ibarz A (2010) A new model to describe flow behavior of concentrated orange juice. Food Biophysics 5:114-119
5. Falguera V, Vélez-Ruiz JF, Alins V, Ibarz A (2010) Rheological behavior of concentrated mandarin juice at low temperatures. International Journal of Food Science and Tecnology 45: 2194-2200
6. Haminiuk CW, Sierakowski MR, Izidoro DR, Masson ML (2006). Rheological characterization of blackberry pulp. Brazilian Journal of Food Technology 9(4): 291-296
7. Haminiuk CW, Sierakowski MR, Branco IG, Maciel GM, Masson ML (2007) Rheological study of ternary mistures and pectic gels of red fruit pulps. International Journal of Food Science and Technology 42(6): 629-639
8. Haminiuk CW, Sierakowski MR, Izidoro DR, Maciel GM, Scheer A, Masson ML (2009) Rheological behavior of pectic systems of red fruit pulps. Ciencia e Tecnologia de Alimentos 29(1): 225-231
9. Ibarz A, Pagán J (1987) Rheology of raspberry juices. Journal of Food Engineering 6:269-289
10. Ibarz A, Ciutat O, Graell J (1988) Comportamiento reológico de productos derivados del tomate. Alimentaria 196:53-62
11. Ibarz A, Lozano JE (1992) Caracterización reológica de pulpas concentradas de ciruela y melocotón. Revista Española de Ciencia y Tecnología de Alimentos 32(1):85-94
12. Ibarz A, González C, Esplugas S, Vicente M (1992a) Rheology of clarified fruit juices. I: Peach juices. Journal of Food Engineering 15:49-61
13. Ibarz A, Pagán J, Miguelsanz R (1992b) Rheology of clarified fruit juices. II: Blackcurrant juices. Journal of Food Engineering 15:63-73
14. Ibarz A, Marco F, Pagán J (1993) Rheology of persimmon juices. Fruit Process 5(93): 182-187
15. Ibarz A, Garvín A, Costa-López J (1996) Rheological behaviour of sloe (prunus spinosa) fruit juices. Journal of Food Engineering 27:423-430
16. Khalil KE, Ramakrisha P, Nanjundaswamy AM, Patwardhan MV (1989) Rheological behavior of clarified banana juice: effect of temperature and concentration. Journal of Food Engineering 10:231-240
17. Ramaswamy HS, Basak S (1992) Pectin and raspberry concentrate effects on the rheology of stirred commercial yogurt. Journal of Food Science 57(2): 357-360

18. Ramos AM, Ibarz A (2006). Comportamiento viscoelástico de pulpa de membrillo en función de la concentración de sólidos solubles. Ciencia y Tecnologia de Alimentos 26: 214-219
19. Rao MA, Cooley MJ, Vitali AA (1984) Flow properties of concentrated juices at low temperatures. Food Technologies 38(3):113-119
20. Saravacos GD (1970) Effect of temperature on viscosity of fruit juices and purees. Journal of Food Science 35:122-125
21. Sato ACK, Cunha RL (2009) Effect of particle size on rheological properties of jaboticaba pulp. Journal of Food Engineering 91: 566-570
22. Sousa MB, Canet W, Alvarez MD, Tortosa ME (2006) Effect of processing on the texture and structure of raspberry (cv. Heritage) and blackberry (cv. Thornfree). European food research and technology 223(4): 517-532
23. Tonon RV, Alexandre D, Hubinger MD, Cunha RL (2009). Steady and dynamic shear rheological properties of açai pulp. Journal of Food Engineering 92: 425-431
24. Vandresen S, Quadri MGN, Souza JAR, Hotza D (2009). Temperature effect on the rheological behavior of carrot juices. Journal of Food Engineering 92: 269-274
25. Vitali AA, Rao MA (1984) Flow properties of low-pulp concentrated orange juice: Effect of temperature and concentration. Journal of Food Science 49:882-888