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Experimental study of physical and rheological properties of grape juice using different temperatures and concentrations. Part I: Cabernet Sauvignon

Maurício Bonatto Machado de Castilhos*, Lilian Fachin Leonardo Betiol,
Gisandro Reis de Carvalho, Javier Telis-Romero

São Paulo State University – UNESP, Institute of Biosciences, Humanities and Exact Sciences – IBILCE, Campus São José do Rio Preto, Food Engineering and Technology Department – DETA, Cristóvão Colombo St. 2265, 15054-000, São José do Rio Preto, Brazil

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ABSTRACT

The effect of the temperature and concentration on rheological behavior of Cabernet Sauvignon juice concentrates was assessed using a rheometer over a wide range of temperature (1–66 °C) and concentrations (13.6–45.0 Brix) at shear rates of 0.84–212.1 1/s. The Ostwald-De Waele was the best rheological model fitted the data (R^2 = 0.99957 and relative error = 7.77%). The Cabernet Sauvignon juice concentrates presented a non-Newtonian pseudoplastic behavior ($n < 1$). The consistency levels were significantly reduced with the increase of temperature and increased with the increase of the concentrations. The flow activation energy ranged from 28.87 (45.0 Brix) to 38.05 KJ/mol (37.0 Brix) with a R^2 = 0.9798 for both cases. Density and specific heat were influenced by both temperature and concentration; however, thermal conductivity was only influenced by concentration. The Cabernet Sauvignon juice concentrates will be useful as wine chaptalization agent in future studies.

1. Introduction

Cabernet Sauvignon grape cultivar, originated from the region of Bordeaux, France, is currently widespread in most wine countries. It presents a particular taste and a high resistance to fungal contamination. This cultivar is considered one of the most important *Vitis vinifera* grape which are used to produce juices and wines with high quality and specific features and it is considered a potential grape for the production of young red wines or wines submitted to maturation in oak barrels (Rizzon & Miele, 2002). Cabernet Sauvignon grape presents in its composition, a high content of phenolic compounds that is responsible for the high antioxidant activity, property that allows the reduction of the risk of coronary heart diseases and atherosclerosis. Due to this, the consumption of juices and wines produced from this type of grape cultivar is strongly recommended (Radovanovic, Jovancicevic, Arsic, Radovanovic, & Bukarica, 2016).

Rheological studies are important for the design of unit operations, high quality assurance of foods and beverages and process optimization. In addition, rheological approaches are employed mainly as essential tools for food engineering, since rheology is linked to food processing and stability, as well as to sensory perceptions. The physical properties of density, specific heat and thermal conductivity present high importance for food and beverages, mainly for juices, since these aforementioned properties are closely related to sensory features (Augusto, Ibarz, & Cristianini, 2012; Neto, De Castilhos, Telis, & Telis-Romero, 2014).

There have been many studies concerning the rheological behavior of juices from different botanical sources; however, there is a lack in studies that present rheological data regarding grape juices. The orange juice density and the energy dissipated as heat were correlated with different degrees of pectin extraction in a study of Galant, Widmer, Luzio, and Cameron (2014); Zuritz et al. (2005) reported the density, the rheological behavior and the activation energy of clarified Cereza, Criolla and Moscatel Rosada grape juices and the influence of the temperature and the soluble solid contents in these properties; rheological properties and fluid rheological behavior were also determined for peach juice processed by ultrasound technology (Rojas, Leite, Cristianini, Alvim, & Augusto, 2016) and for soursoup fruits (Quek, Chin, & Yusof, 2013).

In this context, the study of the Cabernet Sauvignon juice rheological behavior and physical properties is relevant for the juice industries and mainly for the wine producers, since this grape cultivar presents a great wine potential. In Brazil, for example, there is a procedure that is allowed by legislation, known as chaptalization, that consists in adding

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* Corresponding author at: São Paulo State University – UNESP, Institute of Biosciences, Humanities and Exact Sciences – IBILCE, Campus São José do Rio Preto, Food Engineering and Technology Department – DETA, Cristóvão Colombo street, 2265, São José do Rio Preto, São Paulo, Brazil.
E-mail address: mbonattosp@yahoo.com.br (M.B.M. de Castilhos).

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sucrose in the grape juice in order to correct the alcohol content of the resulting wine (Brasil, 2005). A possible alternative for the substitution of the sucrose as chaptalization agent is the insertion of concentrated juice of the same grape cultivar in order to maintain the wine features. Since this procedure is not applied in winemaking yet, the study of the rheological behavior of this type of juice become suitable and relevant.

Based on the above considerations, the present study aimed at evaluating the rheological behavior of Cabernet Sauvignon juice at different concentrations and temperatures and, additionally, predict a possible influence of these aforementioned parameters on density, specific heat and thermal conductivity.

2. Material and methods

2.1. Juice samples

Cabernet Sauvignon grape juice (*Vitis vinifera*) was produced from grapes grown in Santa Catarina State, Brazil. The grape juices were obtained directly from the producers and they were classified as “ready-to-drink”. A visual assessment showed that they presented no particulate matter. The juice (initial 12.2 Brix) was concentrated to 13.6, 21.0, 29.0, 37.0 and 45 Brix in a rotary low pressure evaporator (Marconi MA 130) at 44 °C. The soluble solid content of the juice and concentrates was assessed by a refractometer (PAL-BX/RI-Atago). All samples remained at rest for at least 24 h before being submitted to rheological measurements.

2.2. Rheological characterization

Steady shear rheological tests were carried out in a controlled stress rheometer, model ARG2 (TA Instruments, New Castle, USA) using a concentric cylinder geometry (inner cylinder – 42 mm × 28 mm; outer cylinder – 78.5 mm × 30.15 mm) with 5920 μm gap under controlled stress and temperature, the latter controlled by a Peltier system. The system was controlled by the Rheology Advantage software, in which steady flow was reached ranging shear rate from 0.84 to 212.1 s^{-1} at different temperatures (1, 10, 19, 28, 37, 46, 56 and 66 °C). These temperatures were chosen based on the pasteurization process, since the grape juice is pasteurized before its application in wineries and before consumption.

The steady state was obtained for each shear rate and a brief study was conducted in order to evaluate the necessary time to reach steady state conditions. These high temperatures were chosen aiming at covering a wide range of temperature. The accuracy of the rheometer was previously done using a rheological study of chlorobenzene and acetic acid (50:50 v/v) as standard substances according to Neto et al. (2014).

The rheological models were fitted to the experimental shear stress and shear rate data using the nonlinear estimation procedure of Statistica software StatSoft Inc. (2014). The experimental data were fitted to four rheological models as follows: Newton law of viscosity (Eq. (1)), Ostwald-de Waele (Eq. (2)), Bingham (Eq. (3)) and Herschel-Bulkley (Eq. (4)). This approach allowed the determination of the rheological parameters, which could be correlated with the aforementioned temperatures. The best rheological model that fitted the experimental data was selected according to the coefficient of determination (R^2) as well as by the minimization of the relative error (Eq. (5)) between observed and predicted values.

$$\tau = \mu\gamma \tag{1}$$

$$\tau = \mathrm{k}(\gamma)^n \tag{2}$$

$$\tau = \tau_0 + \mathrm{k}\gamma \tag{3}$$

$$\tau = \tau_0 + \mathrm{k}(\gamma)^n \tag{4}$$

$$\text{Error (\%)} = \frac{|observed - predicted|}{observed} \times 100 \tag{5}$$

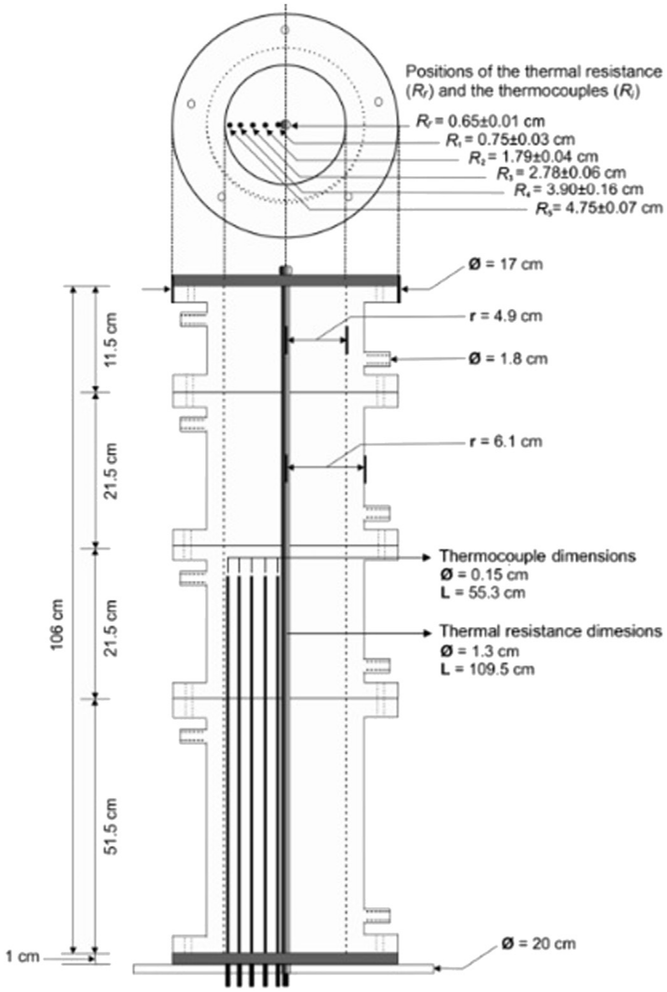

Fig. 1. Apparatus used to determine the thermal conductivity.

Table 1
Coefficient of determinations of Cabernet Sauvignon concentrates obtained by fitting the experimental data to the rheological models.

Model name	Model equation	R^2	Relative error (%)
Newtonian	$\tau = \mu\gamma$	0.99933 ± 0.0003	25.75 ± 9.7
Ostwald-de Waele	$\tau = \mathrm{k}(\gamma)^n$	0.99957 ± 0.0005	7.77 ± 5.9
Bingham	$\tau = \tau_0 + \mathrm{k}\gamma$	0.99933 ± 0.0003	20.21 ± 8.5
Herschel-Bulkley	$\tau = \tau_0 + \mathrm{k}(\gamma)^n$	0.99957 ± 0.0005	8.58 ± 6.2

The different values of n indicate the fluid behavior, i.e., $n = 1$ for Newtonian or Bingham plastic fluid, $n < 1$ for pseudoplastic fluid and $n > 1$ for dilatant fluid.

The rheological parameters as consistency level (k) and viscosity (μ) are influenced by temperature and the effect of this aforementioned variable was studied by fitting the rheological data to the Arrhenius equation (Eq. (6)):

$$k = k_0 \, exp\left(\frac{E_a}{RT}\right) \tag{6}$$

As only the consistency level dependency was assessed, in this expression k_0 is an empirical constant, R is the universal gas constant (8.314 J mol K^{-1}), T is the absolute temperature (K) and E_a (KJ mol^{-1}) is the activation energy required for the flow (Telis-Romero, Thomaz, Bernardi, Telis, & Gabas, 2006).