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EFFECT OF TEMPERATURE AND CONCENTRATION ON RHEOLOGICAL PROPERTIES OF BEETROOT JUICE

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Abstract

The rheological behaviour of beetroot juice as a function of soluble solid content (from 10°Bx to 50°Bx) at a wide range of temperatures (from 10°C to 60°C) was studied. The measurements were made using rotational rheometer (Brookfield Engineering Laboratories: model LVDV-II + PRO). The investigation showed that the beetroot juice was Newtonian in behaviour and the viscosity was changed from 0.77 mPa s to 28.4 mPa s. The Arrhenius-Guzman equation was used to calculate the values of flow activation energy. In order to evaluate the influence of soluble solid content two models were applied: the power law and exponential equation. A new equation was proposed to express the combined effect of temperature and concentration on beetroot juice viscosity.

Introduction

Beetroot juice is one of the richest sources of antioxidants (WOOTTON--BEARD et. al. 2011) and naturally occurring nitrates. It also contains many other promoting compounds such as magnesium, potassium, iron, zinc, calcium, phosphorus, sodium, niacin, biotin, soluble fibre and vitamins A, B and C (WOOTTON-BEARD, RYAN 2011). Additionally beetroot juice provides a number of polyphenolic compounds (KAUR, KAPOOR 2002) as well pigments such as carotenoids (DIAS et al. 2009) and betalains (PITALUA et al. 2010).

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Therefore, drinking beetroot juice could help to protect against heart disease and certain types of cancer, particularly lung and skin cancer (KAPADIA et al. 1996).

Processing beetroots needs knowledging of rheological properties. The rheological properties of juices is an important property, which has several application in developing food process, processing equipment, quality evaluation and structural understanding of food and raw material (MANJUNATHA, RAJU 2013). They are required to determine the power requirements for unit operation such as: pumping, sizing of pipes, pasteurization, filling, mixing, evaporation etc. They are also important in the calculation of heat, mass and momentum transfer phenomena (TELIS-ROMERO et al. 1999). Vegetable and fruit juice were subjected to different temperatures and concentration levels during processing, storage and transportation, where the rheological properties can be changed dramatically. Typical properties of the data for beetroot juice are rather limited. The aim of the paper was to study rheological behavior of beetroot juice as a function of temperature and solid concentration.

Material and methods

A sample of commercial beetroot juice was purchased from local market. The raw juice with approximately 10°Bx was concentrated to different concentration levels at 20, 30, 40 and 50°Bx by vacuum evaporation technique using laboratory rotary vacuum evaporator (Model; Buchi Rotavapor R-205) at 60°C with reduced pressure. The rotational speed of a flask was fixed at 60 rpm. The content of extract in juice was determined with the help of the refractometer Atago model Pal-1.

Rheological properties were measured using Brookfield viscometer (Brookfield Engineering Laboratories: model LVDV-II + PRO). A 500 ml sample of beetroot juice was used in a glass baker for all experiments. The temperature of sample was changed from 10 to 60°C and kept at constant value using water bath (Brookfield TC-502P). The flow curves at different temperatures were obtained in the range of shear rate of 12-130 s^{-1} using specific spindle S-61. The computer software (Rheolac 3.1) was applied to control viscometer and data acquisition. All experiments were carried out in three replications.

Results

The experimental flow curves obtained for the concentrated beetroot juice at different temperatures were shown in Figures 1–5. The rheograms of beetroot juice showed that there was linear increase in shear stress with respect to increase in shear rate. These results indicate the Newtonian behavior of concentrated beetroot juice.

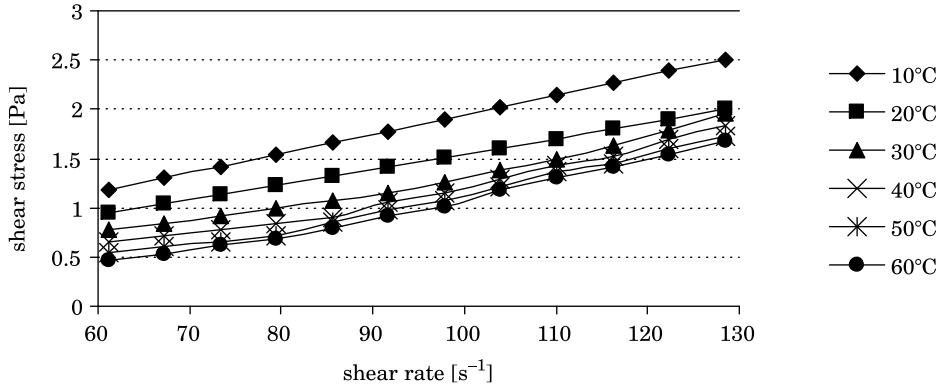

Fig. 1. Flow curves of concentrated beetroot juice (10°Bx) at different temperatures

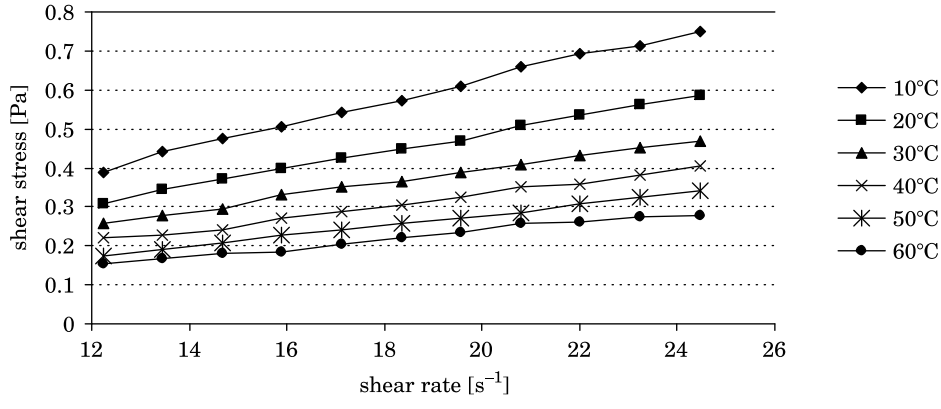

Fig. 2. Flow curves of concentrated beetroot juice (20°Bx) at different temperatures

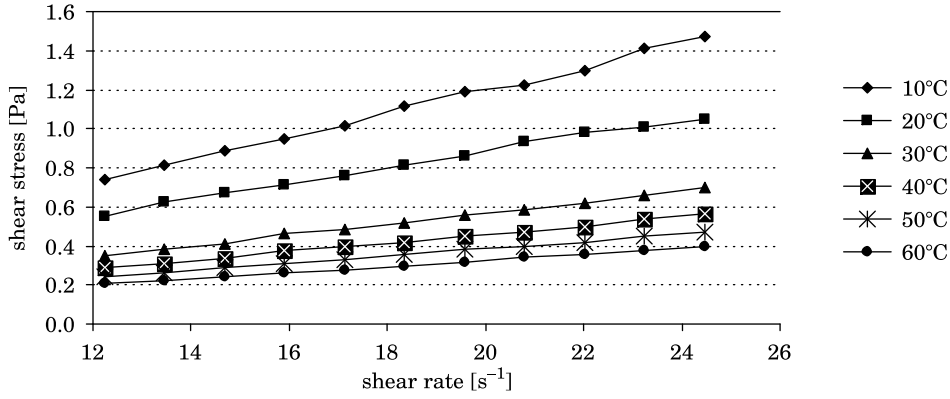

Fig. 3. Flow curves of concentrated beetroot juice (30°Bx) at different temperatures

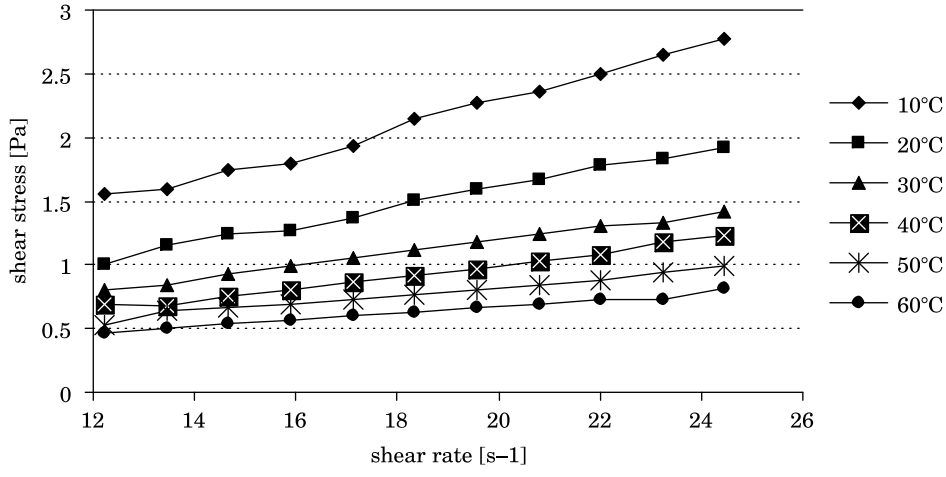

Fig. 4. Flow curves of concentrated beetroot juice (40°Bx) at different temperatures

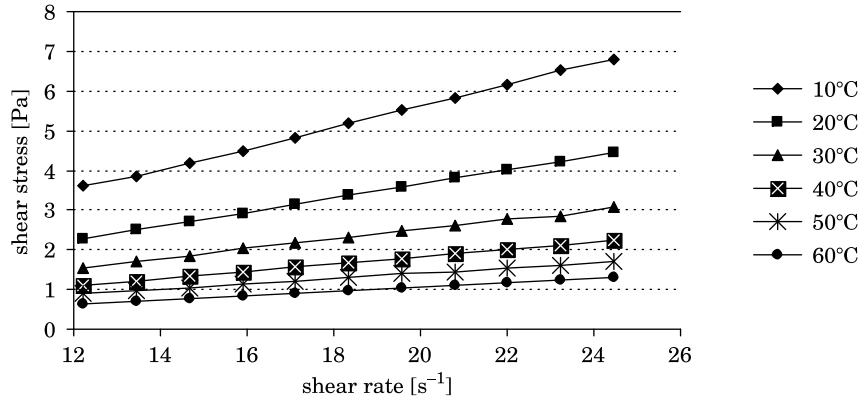

Fig. 5. Flow curves of concentrated beetroot juice (50°Bx) at different temperatures

Figure 6 shows the influence of temperature and soluble solid content on viscosity of beetroot juice.

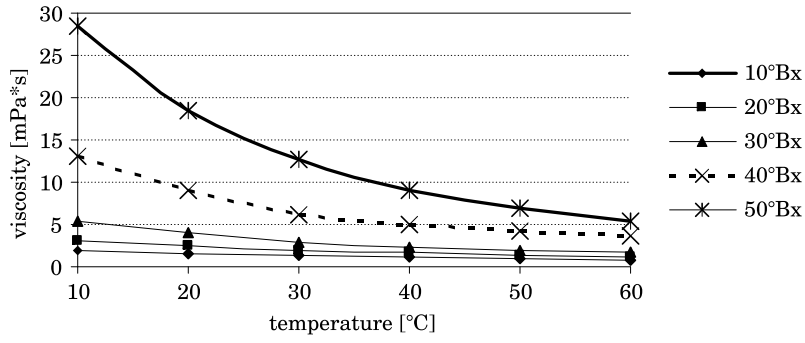

Fig. 6. The effect of temperature and the content of soluble solids on the viscosity of beetroot juice

Both the temperature and the soluble solid content had a significant effect on the viscosity of beetroot juice. The increase in temperature of fluid leads to increase in mobility of the molecules and increase in intermolecular spacing, which decreases the flow resistance. The viscosity of beetroot juice decreased markedly with increase in temperature. The variation in viscosity of beetroot juice with temperature was significantly high at a higher soluble solid content. The concentration of the soluble solids had a strong effect on viscosity of the Newtonian liquids. The increase in soluble solid content leads to change in degree of hydration of solute molecules, increase in hydrogen bonding with hydroxyl groups of solute and decrease in intermolecular spacing, which increases the flow resistance. The viscosity of beetroot juice increased rapidly with increase in soluble solid content.

The variation of viscosity with soluble solid content at particular temperature could be described by an exponential equation (IBARZ et al. 2009, PEROŃ et al. 2010]:

$$\eta = \eta_1 \exp(bC) \tag{1}$$

where:

η – is the viscosity [Pa · s],

η_1 – is the viscosity when the soluble solids content is 0°Brix [Pa · s],

b – is a constant [°Bx^{-1}],

C – is the concentration [°Bx].

Table 1 shows the values of the parameters, the determination coefficients and RMS for each temperature tested.

Table 1

Effect of soluble solids content on viscosity

Temperature	η_1	b	R^2	RMS
10	0.849	0.068	0.98	0.12
20	0.745	0.062	0.98	0.11
30	0.625	0.057	0.97	0.13
40	0.566	0.054	0.97	0.13
50	0.504	0.051	0.98	0.11
60	0.448	0.049	0.98	0.10

The parameter b decreases with the increase of temperature. The increase of viscosity at high temperature is smaller with the rise of concentration. Similar trends have been observed in other studies (RAO et al. 1984, IBARZ et al. 1992, 1994).

From the engineering viewpoint, it is useful to obtain a single equation that describes the combined effect of temperature and soluble solids contents on the viscosity of the beetroot juice. The parameters η_1 and b in equation 2 and 3 are dependent on juice temperature. Figure 7 shows the influence of temperature on values of constant η_1 and b.

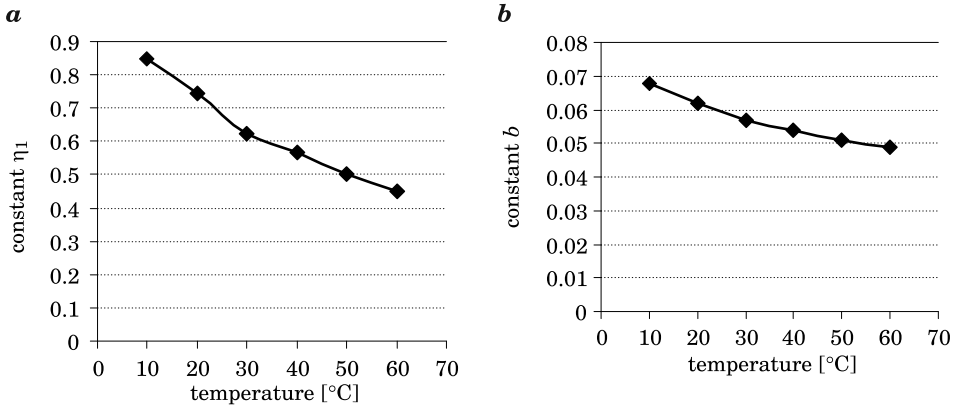

Fig. 7. Influence of temperature on values of constant η_1 (*a*) and b (*b*)

The relationship between temperature and constants η_1 and b could be written by linear equations:

$$\eta_1 = k_1 t + k_2 \tag{2}$$

and

$$b = k_3 t + k_4 \tag{3}$$

where:
k_1 – constant [$^oC^{-1} \cdot Pa \cdot s$],
k_2 – constant [$Pa \cdot s$],
k_3 – constant [$^oC^{-1} \cdot {}^oBx^{-1}$],
k_4 – constant [$^oBx^{-1}$],
t – temperature [^oC].

The final equation which represents combined effect of temperature and total soluble solid content on viscosity beetroot juice was given by:

$$\eta = (k_1 t + k_2)\exp[C(k_3 t + k_4)] \tag{4}$$

The parameters of the equation 4, the determination coefficient and RMS were reported in Table 2.

Table 2
The equation describing the dependency of viscosity against the temperature and the content of soluble solids

Equation	R^2	RMS
$\eta = (-0.008t + 0.915)\exp[C(-0.0005t + 0.0745)]$	0.99	0.16

The values of flow activation energy were calculated using Arrhenius-Guzman equation:

$$\eta = A_0 \exp\left(\frac{E_a}{RT}\right) \tag{5}$$

where:
η – viscosity [$Pa \cdot s$],
A_0 – material constant/pre-exponential coefficient/frequency factor [$Pa \cdot s$],
E_a – flow activation energy [$kJ \cdot mol^{-1}\ K^{-1}$],
R – gas constant [$kJ \cdot mol^{-1}\ K^{-1}$],
T – temperature [K].

Table 3 shows the values of the material constant and the flow activation energy for different soluble solid content.

Table 3

The Arrhenius equation parameters of beetroot juice

Soluble solid content [°Bx]	Material constant [mPa · s]	Flow activation energy [kJ · mol^{-1} K^{-1}]
10	0.0043	14.2
20	0.0063	14.6
30	0.0028	17.6
40	0.0023	20.2
50	0.0004	26.2

The flow activation energy is defined as minimum energy required which overcomes the energy barrier before the elementary flow can occur. The higher activation energy the greater influence of temperature on the viscosity.

The activation energy of beetroot juice rises with increase in soluble solid content. The values of flow activation energy of beetroot juice changed from 14.2 kJ · mol^{-1} K^{-1} for solid concentration of 10°Bx to 26.2 kJ · mol^{-1} K^{-1} for solid concentration of 50°Bx. A comparison of the results with literature data indicates that they were in conforming to values reported for other juice exhibiting Newtonian behavior (JUSZCZAK, FORTUNA 2004, IBARZ et al. 2009).

The variation of activation energy with solid soluble content could by described by two different models: the power law and exponential equation:

$$E_2 = a_1 C^{b_1} \tag{6}$$

$$E_a = a_2 \exp(b_2 C) \tag{7}$$

where:
C – total soluble solid content [°Bx],
a_1 – empirical constant [kJ · mol^{-1} · K^{-1} · °Bx^{-1}],
a_2 – empirical constants [kJ · mol^{-1} · K^{-1}],
b_1 – empirical constant [–],
b_2 – empirical constant [°Bx^{-1}].

The models were used to fit the values of flow activation energy with soluble solid content. The magnitudes of the parameters and determination coefficient and RMS were reported in Table 4. The results indicated that exponential model was more effective to describe the influence of total soluble solid content on flow activation energy of beetroot juice.

Table 3
The power law and exponential equation describing the dependency of flow energy activation against the content of soluble solids

Model	Equation	R^2	RMS
Power law	$E_a = 4.44C^{0.429}$	0.82	0.11
Exponential equation	$E_a = 10.88\exp(0.0168C)$	0.95	0.06

Conclusions

The rheological behaviour of beetroot juice was studied as a function of soluble solid content (from 10°Bx to 50°Bx) and temperature (from 10°C to 60°C). The results indicated that beetroot juice exhibits Newtonian behavior. The value of viscosity was strongly influenced by temperature and concentration of juice and changed in the range from 0.77 mPa · s to 28.4 mPa · s. The Arrhenius-Guzman equation was used to calculate the values of flow activation energy which ranged from 14.2 kJ · mol^{-1} K^{-1} for solid concentration at 10°Bx to 26.2 kJ · mol^{-1} K^{-1} for solid concentration at 50°Bx. The effect of soluble solids content on flow activation energy was described by exponential equation and the power law, but a better fit was obtained for the exponential function. A new equation was proposed to express the combined effect of temperature and concentration on viscosity beetroot juice.

References

Dias M.G., Camões M.F.G.F.C., Oliveira L. 2009. *Carotenoids in traditional Portuguese fruits and vegetables*. Food Chemistry, 113: 808–815.

Ibarz A., Gonzales C., Espluguas S., Vicente M., 1992. *Rheology of clarified juices*. I. *Peach juices*. Journal of Food Engineering, 15: 193–205.

Ibarz A., Gonzalez C., Esplugas S. 1994. *Rheology of clarified fruit juices*. III. *Orange juice*. Journal of Food Engineering, 21: 485–494.

Ibarz R., Falguera V., Garvín A., Garza S., Pagán J., Ibarz A. 2009. *Flow Behavior of Clarified Orange Juice at Low Temperatures*. Journal of Texture Studies, 40: 445–456.

Juszczak L., Fortuna T. 2004. *Effect of temperature and soluble solid content on the viscosity of cherry juice concentrate*. International Agrophysics, 18: 17–21.

Kapadia G.J., Tokuda H., Konoshima T., Nishino H. 1996. *Chemoprevention of lung and skin cancer by Beta vulgaris (beet) root extract*. Cancer Letters, 100: 211–214.

Kaur C., Kapoor H.C. 2002. *Anti-oxidant activity and total phenolic content of some Asian vegetables*. International Journal of Food Science and Technology, 37: 153–161.

Manjunatha S.S., Raju P.S. 2013. *Modelling the Rheological behaviour of tender coconut (Cocos nucifera L) water and its concentrates*. International Food Research Journal, 20: 731–743.

Peroń S., Surma M., Gryszkin A. 2010. *The impact of extract content on selected physical properties of garden beet juice and efficiency of its drying*. Agricultural Engineering, 2: 103–110.

PITALUA E., JIMENEZ M., VERNON-CARTER E. J., BERISTAIN C.I., 2010. *Antioxidative activity of microcapsules with beetroot juice using gum Arabic as wall material*. Food and Bioproducts Processing, 88: 253–258.

RAO M.A., COOLEY M.J., VITALI A.A. 1984. *Flow properties of concentrated juices at low temperatures*. Food Technology, 38: 113–119.

TELIS-ROMERO J., TELIS V.R.N., YAMASHITA F. 1999. *Friction factors and rheological properties of Orange juice*. Journal of Food Engineering, 40: 101–106.

WOOTTON-BEARD P.C., RYAN L. 2011. *A beetroot juice shot is a significant and convenient source of bioaccessible antioxidants*. Journal of Functional Foods, 3: 329–334.

WOOTTON-BEARD P.C., MORAN A., RYAN L. 2011. *Stability of the antioxidant capacity and total polyphenol content of 23 commercially available vegetable juices before and after in vitro digestion as measured by FRAP, DPPH, ABTS and Folin Ciocalteu methods*. Food Research International, 44: 217–224.