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Changes on rheological properties of pomegranate (*Punica granatum* L., cv. Hicaznar) juices during concentration process

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The investigation of the changes on rheological properties during evaporation process could diminish the severe effects of thermal processing at any individual soluble solids content. In this study, the rheological properties of pomegranate juices at different soluble solids content (20, 30, 40 and 50 %) during concentration process applied by using the rotary evaporator were determined. Rheological measurements were conducted in the range of 0 – 264 s^{-1} shear rates by using the concentric cylinder type viscometer. It was found expectedly that apparent viscosity increased as the soluble solids content increased. The apparent viscosity was 0.0024 ± 0.0001 Pa.s for raw pomegranate juices (15.73 ± 0.30 % soluble solids) while it increased to 0.01342 ± 0.0003 Pa.s for the concentrated juice having 50 % soluble solids contents. Four different rheological models were applied to find the suitable model best fitting the experimental data; Newton model, Power Law model, Bingham model and Herschel – Bulkley model. The statistical criteria having highest regression coefficient, lowest root mean square error and lowest chi-square were chosen for selection of best model for fitting. It was determined that the Power law model was best described the experimental shear stress-shear rate relation for pomegranate juices at different concentrations. It was predicted that the consistency coefficient of pomegranate juice increased from 0.005 Pa.s^n to 0.013 Pa.s^n as the soluble solid content was increased from 20 % to 50 %. The rheological data obtained in this study could serve valuable data for calculation of changes in flow behaviors of pomegranate juice in pumping systems depending of their concentration.

Keywords. Rheology, pomegranate juice, model, concentration.

INTRODUCTION

Pomegranate is an important fruit in Middle East, Mediterranean, American, and Arab countries[1-4]. Pomegranate fruit consists of hundreds of seeds and thick reddish skin which covers these seeds, and fruit body is its edible part. Edible parts contain a significant amount of acid, sugar, vitamins, polysaccharides, polyphenols and mineral matters [1,3,5,6].

Rheological measurements are made in order to observe changes in the structure of foodstuffs. Rheology examines changes in viscosity and deformation of a substance that is under the force. It is used for quality control, sensory properties, and development of engineering design in juice industry [3,6]. Several researchers [7-9] have reported that several fruit juices such as tomato juice, liquor extract and grape juice showed Newtonian type fluid properties. Bozkurt and İcier [10] have reported that quince juice have time independent, pseudoplastic and non-Newtonian fluid properties. The rheological properties of pomegranate juice depend on the chemical composition of pomegranate, the pressing method, the operation temperature and the concentration method applied. Yildiz et al. [6] used two different processing methods for obtaining the pomegranate juice regarding pressing with or without peels. They reported that the pressing methods did not affect the rheological properties of raw pomegranate juice. They showed non-newtonian dilatant properties. Altan and Maskan [5] investigated the effects of the concentration method (microwave heating, rotary vacuum evaporation, evaporating at atmospheric pressure) and the temperature which the rheological measurement conducted (10 – 55 °C) on rheological properties of pomegranate concentrate (17.5 – 65 %). They determined that all of the pomegranate juice samples have Newtonian character.

In this study, the changes of apparent viscosity for different soluble solid contents (20, 30, 40 and 50 %) during concentration process were examined. It was also aimed to determine the most appropriate

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rheological model fitting the experimental shear stress and shear rate data best, and to predict the changes of consistency coefficients and flow behavior indexes during concentration process of pomegranate juice.

EXPERIMENTAL

The pomegranates (Punica granatum L., cv. Hicaznar) used in this study were supplied from a local market in İzmir, Turkey. Pomegranates were washed in cold tap water and drained. They were manually cut up and the outer leathery skin was removed. The aril in the sacs was pressed, and fruit juice was extracted. The juice having an initial concentration of 15.73 ± 0.10 % soluble solid contents was concentrated at 60 °C in the vacuum by using a laboratory type rotary vacuum evaporator (Buchi R-3) rotating at 400 rpm.

Total soluble solids content determination. The soluble solids content of the juice samples was measured by refractometer (Hanna Instruments 96801) at 20 °C and expressed in % soluble solid contents.

Rheological measurements. Rheological properties were measured using a concentric cylinder type viscometer (Brookfield LVDV-II, Brookfield Engineering Laboratories, USA). The measurement range of viscometer between 0 and 100 % full scale torques was adjusted by selecting the specific spindle (S-18) and its rotational speed (0.0 – 200 rpm) for pomegranate juice. During the rheological measurement, shear stress (SS), shear rate (SR) and % torque (T) values were recorded for each rotational speed (rpm). Experimental shear stress-shear rate measurements were fitted to selected rheological models to obtain viscous rheological properties of pomegranate juice. Four different rheological models were applied to find the suitable rheological model best fitting the experimental data; Newton model, Power Law Model, Bingham model and Herschel-Bulkley model [10].

Statistical analyses. Compatibility of the model with experimental data was determined by using a non-linear regression analysis of statistical software package (SPSS ver. 20, yıl). Regression coefficient (R^2), root mean square error (RMSE) and chi-square (χ^2) values were calculated. Duncan test was applied as a comparative statistical analysis. The statistical criteria of having highest R^2, lowest RMSE and lowest χ^2 were chosen for selection of best model for fitting [11].

RESULTS AND DISCUSSION

The apparent viscosity of pomegranate juices increased as their water-soluble solids increased ($p < 0.05$) (Figure 1). As the soluble solids content increased from 20 % to 50 %, the apparent viscosity increased approximately 4 folds. Several studies have reported similarly that the water content of juices decreased during concentration process, since the change of viscosity as the increased trend has been expected[5, 7, 8]. However, this result could be only used for overall discussion of the effects of concentration process on rheology of pomegranate juice. For detailed investigation of changes of rheological behavior, the experimental data were fitted to some rheological models, which were generally described the changes of rheological properties of fruits juices.

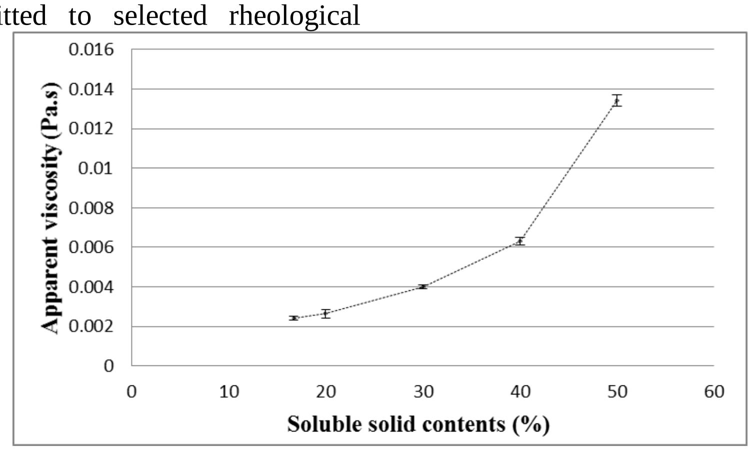

Fig. 1. The change of apparent viscosity as a function of soluble solids content of pomegranate juice during concentration process.

Table 1. The statistical evaluation of rheological models applied to fit the experimental shear stress-shear rate data.

% Soluble Solid Content	Statistical Criteria	Models			
		Bingham model	Power Law model	Hershel-Bulkley model	Newton model
Raw (15.73)	R^2	0.991	0.996	NC*	0.984
	RMSE	0.0038	0.00014	NC*	0.0017
	χ^2	0.01863	0.011	NC*	0.0397
20	R^2	0.996	0.998	0.998	0.987
	RMSE	0.0015	0.0002	0.0006	0.0046
	χ^2	0.0352	0.0157	0.022	0.0660
30	R^2	0.996	0.997	0.998	0.989
	RMSE	0.0047	0.0004	0.0013	0.0038
	χ^2	0.0653	0.02	0.0334	0.0599
40	R^2	1.0	1.0	NC*	0.999
	RMSE	0.001	0.0008	NC*	0.0019
	χ^2	0.032	0.0260	NC*	0.0423
50	R^2	NC*	1.0	1.0	1.0
	RMSE	NC*	0.0070	0.0070	0.0024
	χ^2	NC*	0.0800	0.0754	0.0478

NC*: statistically non compatible.

For different soluble solids contents of pomegranate juices, the statistical evaluation of rheological models fitted to experimental data were given in the Table 1. For raw, 20 – 40 % soluble solids contents, the best model fitted was chosen as the Power Law due to its highest R^2, lowest RMSE and χ^2. On the other hand, the 50 % concentrated juice showed Newtonian character. Similarly, Yildiz et al. [6] reported that non-concentrated pomegranate juice has non-Newtonian and dilatant properties depending on temperature (20 - 90 °C) and pressing method used. On the contrary, Kaya and Sözer [12] found that pomegranate juice samples at higher concentrations (45.7 – 71 % soluble solid contents) at different temperatures (5 – 60 °C) showed Newton model. Altan and Maskan[5] reported that the pomegranate juice samples having the soluble solids contents of 17.5 – 65 % at different temperatures (10 – 55 °C) showed Newtonian fluid behavior. They found that R^2 values of Newtonian model are greater than 0.966 at all concentration processes. However, the change of consistency coefficient and flow behavior indexes during concentration process of pomegranate juice was not investigated in these studies. The contrary between rheological characters of pomegranate juices given in different studies may be due to differences on the type of pomegranate used, the processing pressure, the temperature range applied, the concentration method, method of the rheological measurement, etc.

The change in the consistency coefficient and flow behavior index of pomegranate juice during vacuum concentration process were predicted by using Power Law model (for raw juice and 20 – 40 % soluble solids), which was obtained as the best model

Table 2. The consistency coefficient and flow behavior indexes of pomegranate concentrates.

% Soluble Solid Content	Consistency coefficient K, $Pa.s^n$	Flow behavior index, n
Raw (15.73)	0.005 ± 0.001	0.836 ± 0.04
20	0.005 ± 0.001	0.854 ± 0.053
30	0.007 ± 0.001	0.872 ± 0.019
40	0.007 ± 0.001	0.974 ± 0.031
50	0.013 ± 0.00	1.0 ± 0.00

describing the rheological changes. To make the comparison of the change in rheological properties of pomegranate concentrates in the range of 15.73 – 50 %, the viscosity value for the concentrated juice having 50 % soluble solids was used as its consistency coefficient with n = 1. It was obtained that consistency increased as the soluble solids increased ($p < 0.05$). Similar to the result obtained regarding the change of the apparent viscosity, the consistency coefficient increased more than two-folds as the soluble solids content increased from 20 % to 50 %. On the other hand, the flow behavior index increased from 0.836 to 1.0 as the soluble solids content increased from 15.73 % to 50 % (Table 2). Although pomegranate juice samples having the soluble solids content in the range of 15.73 – 40 % showed non-Newtonian and pseudoplastic behavior, the juice having soluble solids content of 50 % has Newtonian fluid character. Results showed that the consistency coefficient and flow behavior index could be used to discuss the change of rheological properties of pomegranate juice during concentration process in detail.

The apparent viscosity of pomegranate juices increased as their soluble solids increased. As the soluble solids content increased from 20 % to 50 %, the apparent viscosity increased as 4 folds. Although the pomegranate juice having soluble solids content up to 40 % showed pseudoplastic non-Newtonian fluid character, the juice having soluble solids content of 50 % has Newtonian character. During the concentration of pomegranate juice, the consistency coefficient K values increased, and the flow behavior index approaches to unity (1). These results could give valuable data for designing and setting up of pumping and mixing systems for pomegranate concentrates. The effects of novel concentration methods on quality and rheology of fruit juices should be studied in detail. Further studies on the determination of the rheological properties of different fruit juices during concentration process are recommended.

REFERENCES

1. S. A. Al-Maiman, S. Ahmad. *Food Chem*., **76**, 437 (2002).
2. H. Vardin, H. Fenercioğlu. *Nahrung Food*, **47**, 300 (2003).
3. M. Maskan. *J. Food Eng*., **72**, 218 (2006).
4. M. Ozgen, C. Durgac, S. Serce, C. Kaya. *Food Chem*., **111**, 703 (2008).
5. A. Altan, M. Maskan. *J. Texture Stud*., **36**, 68 (2005).
6. H. Yildiz, H. Bozkurt, F. Icier. *Food Sci. Technol. Int*., **15**, 503 (2009).
7. J. Giner, A. Ibarz, S. Garza, S. Xhian-Quan. *J. Food Eng*., **30**, 147 (1996).
8. M. Maskan. *J. Food Eng*., **39**, 389 (1999).
9. A. Kaya, K. B. Belibagli. *J. Food Eng*., **54**, 221 (2002).
10. H. Bozkurt, F. Icier. *Int. J. Food Prop*., **12**, 844 (2009).
11. S. Sabancı, C. Celebi, F. İcier. *Acad. Food* J., **12**, 11-15. (2014).
12. A. Kaya, N. Sözer. *Int. J. Food Sci. Technol*., **40**, 223 (2005).

ПРОМЕНИ В РЕОЛОГИЧНИТЕ СВОЙСТВА НА СОК ОТ НАР (Punicagranatum L.Hicaznar) ПРИ ПРОЦЕСА НА КОНЦЕНТРИРАНЕ

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(Резюме)

Изследването на промените в реологичните свойства по време на процеса изпарение би могло да намали неблагоприятните ефекти на термична обработка върху разтворими твърди вещества. В настоящата работа са определени реологичните свойства на сок от нар при различно съдържание на разтворими твърди вещества (20, 30, 40 и 50 %) по време на процеса на концентриране, извършващ се от ротационен изпарител. Реологичните измервания бяха осъществени чрез ротационен вискозиметър с датчик тип „цилиндър в цилиндър“ при градиент на скоростта в интервала 0–264 s^{-1}.

Беше установено, че както може да се очаква, вискозитетът нараства при увеличаване съдържанието на разтворимите твърди вещества. За необработен сок от нар (концентрация на твърдите вещества 15.73 ± 0.30 %) вискозитетът беше 0.0024 ± 0.0001 Pa.s, докато той се увеличи до 0.01342 ± 0.0003 Pa.s за концентриран сок, съдържащ 50% разтворими твърди вещества. С цел установяване на подходящ модел, най-добре описващ експерименталните данни, бяха приложени четири различни реологични модели: Нютонов модел, степенен модел, модел на Бингам и модел на Хершел-Балкли. При подбора на най-подходящ модел беше избран статистически критерии за най-висок регресионен коефициент, най-малка средно-квадратична грешка и най-малък χ-квадрат. Беше установено, че за сок от нар с различни концентрации, експерименталната зависимост на тангенциалното напрежение от градиента на скоростта се описва най-точно от степенния закон. Беше прогнозирано, че вискозитетният коефициент на сок от нар се увеличава от 0.005 $Pa.s^n$ до 0.013 $Pa.s^n$ при увеличаване съдържанието на твърди вещества от 20 % на 50 %. Получените при това изследване реологични параметри могат да послужат като ценни данни при изчисляването на промените в поведението на течене в помпени системи на сок от нар в зависимост от неговата концентрация.