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The effects of ultrasound application durations on the rheological properties of tomato (*Lycopersicon Esculentum*) juice

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In this study, effects of ultrasound application durations on the rheological properties of tomato juice were investigated. Tomato juice having 6.18 ± 0.04 % soluble solid contents was ultrasonicated using a 1500 W ultrasonic processor at a constant frequency of 20 kHz for different application durations (0, 5 and 10 min). The empirical data for tomato juice samples obtained from the viscometer (Brookfield LVDV II Pro, USA) were converted into viscosity function. Rheological properties of juice at 20 °C were determined by fitting shear stress-shear rate data to some rheological models (Newtonian, Bingham, Power Law, Herschel Bulkley). It was found that samples showed Non-Newtonian fluid (pseudoplastic) behavior. As the ultrasonic application duration increased the apparent viscosity of the tomato juice increased. Herschel Bulkley model was the best model for all application durations investigated (For raw juice and chi-square (χ^2) 0.203, root mean square error (RMSE) 0.045, Regression coefficient (R^2) 0.995; for 5 min: χ^2 = 0.219, RMSE = 0.053, R^2 = 0.994 and for 10 min: χ^2 = 0.225, RMSE = 0.056, R^2 = 0.994). Rheological data obtained in this study showed the importance of ultrasonic application duration. Application time should be optimized for ultrasonic processing of tomato juices by considering pumping requirements and changes on quality attributes.

Key words: *Ultrasound, rheology, tomato juice, models*

INTRODUCTION

Tomato (Lycopersicon Esculentum) has important place in daily consumption in the form of fresh or manufactured products (tomato paste, ketchup, tomato juice), and hence provides important economic contributions in the food industry. Tomato juice is obtained by squeezing the whole tomatoes. After the squeezing, skin and seeds are removed with a fine sieve. Tomato juice is composed of serum and colloidal particles [1] larger than diameter of 150 μm.

Tomato juice is produced generally by using conventional production methods [2,3]. In addition, the studies about using of new technologies for increasing of yield, enzyme inactivation, microbial inactivation, reduction of color changing, improvement of rheological properties etc. have been increased in recent years [4-8]. Ohmic heating, microwave treatment, high pressure applications, pulsed electric field, ultrasound are common technologies [2,3,9-11]. Further studies are needed to investigate the effects of process conditions for these technologies on the quality of variety of fluid foods.

High power ultrasound technology, which is one of the non-thermal techniques, provides desired molecular physical and chemical changes in the food. The ultrasound technology is mainly used for enhancing the emulsion applications, cell fractionations, chemical reactions, cutting the sensitive foods, and inactivation of enzymes and microorganisms [12-14]. The application of ultrasound affects as the viscosity and water binding properties of biopolymers [15]. It is applied as an alternative technique for different purposes such as microbial and enzyme inactivation, extraction, drying, filtration, crystallization, degas, cutting etc.[14]. Especially, the combination of ultrasound with heat and pressure improves the rheological properties of tomato juice [2,3].

Rheology is a physical property and is important for product development, process control, design and feasibility [16,17]. The considerable amount of studies on the changes of rheological properties of tomato juice during processing have been made [2,3,18-20]. In the light of this information, it can be said that the tomato juice has a pseudoplastic character. On the other hand, any study regarding the determination of the effects of ultrasound application on the changes of rheological properties of tomato juice was not found, within the knowledge of the authors.

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The aim of this study was to investigate the effects of ultrasound durations on the changes of rheological properties of tomato juice, and to obtain the rheological model best fitting the experimental rheological data. This data will be useful in the adaptation of this novel technology in tomato juice processing lines and the optimization of ultrasonic processing conditions for tomato juices by considering pumping requirements and changes on quality attributes

EXPERIMENTAL

In this study, tomato juice having 6.18 ± 0.04 % soluble solid contents was supplied from a local commercial firm, and transported at cold conditions (4°C) after production immediately. Tomato juice was ultrasonicated using a 1500 W ultrasonic processor (Selecta Ultrasons H-D Model, Spain) at a constant frequency of 20 kHz for different application durations (0, 5 and 10 min). Ultrasonic bath was filled with 500 ml water, and 25 ml tomato juice in the glass beaker was submerged into the ultrasonic bath. Rheological measurements were done at constant temperature of 20 °C, immediately.

Rheological measurements

Brookfield viscometer (Model LVDV-II Pro, Brookfield Engineering Laboratories, USA) was used for rheological measurements. Shear stress, shear rate, viscosity and % torque values were recorded. Percent changes in the apparent viscosity were obtained from the rheological measurements of the ultrasound-treated samples and control group (0 min) samples as given in Equation (1).

$$\text{Percent change in the apparent viscosity} = \frac{\mu_{app,ultrason} - \mu_{app,control}}{\mu_{app,control}} \times 100 \quad (1)$$

The experimental shear stress-shear rate measurements were fitted to selected the rheological models to obtain the rheological properties of tomato juice. Four different rheological models were applied; Newton model, Power Law Model, Bingham model and Herschel Bulkley model [16].

Statistical analysis

Compatibility of the model with experimental data were determined by using a non-linear regression analysis of statistical software package (SPSS. ver. 20). Regression coefficient (R^2), root mean square error (RMSE) and chi-square (χ^2) values were calculated [21]. Duncan test was applied to compare the differences between any rheological property depending on ultrasound durations. The statistical criteria of having highest R^2, lowest RMSE and lowest χ^2 were chosen for selection of the best model fitted.

RESULTS AND DISCUSSION

According to rheological measurement results of the tomato juice, the apparent viscosity decreased as the shear rate increased (Figure 1). Therefore rheological characteristics of tomato juice show Non-Newtonian pseudoplastic behavior. Similarly, this nature of tomato juice has been previously found [22,23]. However, there was no enough information on the change of rheological behavior during ultrasound treatment in the literature, according to the knowledge of authors.

While the time extent of ultrasound treatment was increased, the apparent viscosity of tomato juice is increased (Figure 1). The difference between apparent viscosity of untreated (0 min) and ultrasonicated tomato juice for 10 min samples was statistically significant for shear rate range of 0 – 36.4 s^{-1} ($p < 0.05$). On the other hand, the viscosity of the ultrasonicated samples for 5 min was similar to that of the untreated samples ($p > 0.05$). The percent change in the apparent viscosity of tomato juice ultrasonicated for 10 min was between 1.83 % and 11.97 % for shear rates applied in the range of 0 – 36.4 s^{-1}. At higher shear rates applied, there was no significant effect of ultrasonication duration on the changes of viscosities ($p > 0.05$). The rheological behavior of tomato juice is influenced with water soluble and non-soluble pectin amount and cellulose, hemicelluloses compounds which are present in structure. This pectin amount could influence the viscosity with possible interesterification occurred by ultrasound [7,20]. Similarly, there is limited information that the combination of ultrasound with other thermal/nonthermal methods could enhance the rheological properties of tomato juice [3].

Different rheological models (Newton, Bingham, Power Law and Herschel Bulkley models) were used to determine the changes on the consistency coefficients and flow behavior indexes of ultrasound treated tomato juices. The rheological models were fitted to the experimental shear stress- shear rate data. The statistical evaluation of model agreement was given in Table 1. Statistical criteria were the biggest regression coefficient (R^2) for the model and the lowest errors (RMSE and χ^2) between experimental and predicted shear stresses for each shear rate value.

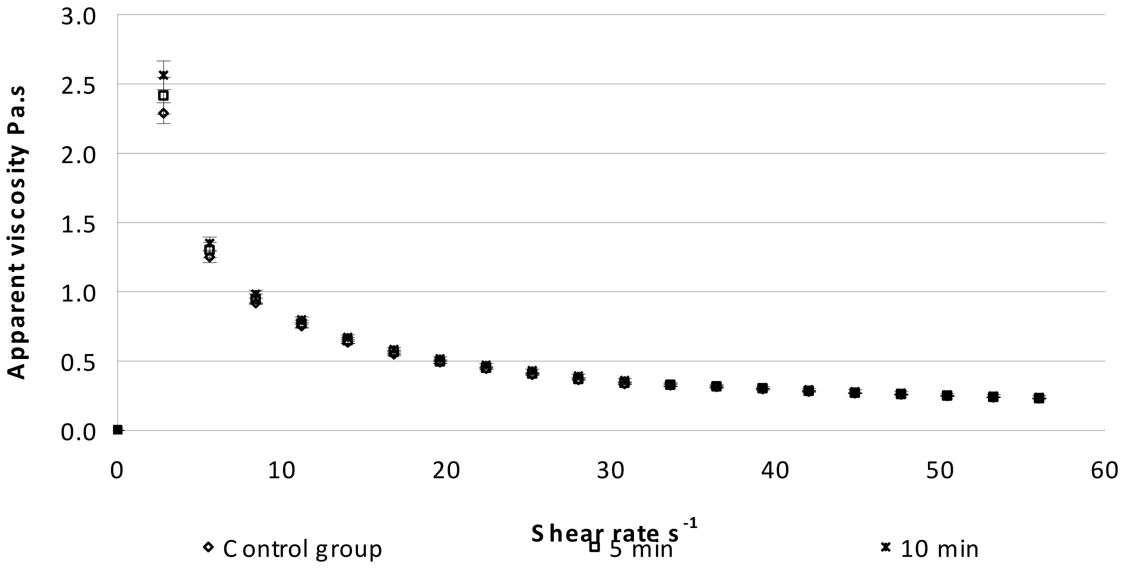

Fig. 1. Change of apparent viscosity of untreated and ultrasonicated tomato juices depending on shear rate.

Table 1. Statistical evaluation for the agreement of rheological models with experimental data.t.

Treatment	Statistical Criteria	Newton model	Bingham model	Power Law model	Hershel-Bulkley model
Untreated (0 min)	R^2	NC	0.769	0.993	0.995
	RMSE	11.38	1.95	0.06	0.04
	χ^2	3.29	1.33	0.23	0.20
Ultrasound treatment (5 min)	R^2	NC	0.742	0.992	0.996
	RMSE	12.27	2.14	0.06	0.05
	χ^2	3.41	1.39	0.24	0.21
Ultrasound treatment (10 min)	R^2	NC	0.743	0.991	0.993
	RMSE	13.49	2.38	0.06	0.05
	χ^2	3.58	1.47	0.24	0.22

NC*: statistically non compatible.

Table 2. Rheological properties of untreated and ultrasonicated tomato juice.

Treatment	Consistency coefficient (K, $Pa.s^n$)	Flow behavior index, n (-)	Yield Stress (τ_0, $Pa.s^n$)
Untreated (0 min)	4.067 ± 0.28	0.273 + 0.01	0.052 ± 0.02
Ultrasound treatment (5 min)	4.365 ± 0.32	0.261 ± 0.01	0.059 ± 0.01
Ultrasound treatment (10 min)	4.674 ± 0.65	0.251 ± 0.02	0.098 ± 0.01

It was determined that Herchel Bulkley model was described best the rheological behavior of untreated and ultrasonicated tomato juices since its regression coefficient was highest and its statistical errors were lowest (Table 2). The good agreement of this model to the experimental data has been shown in Figure 2 for each of the ultrasound durations. Similarly, Sharma et al.[18] established the most proper model is Herchel Bulkley model for untreated tomato juice samples having different compositions.

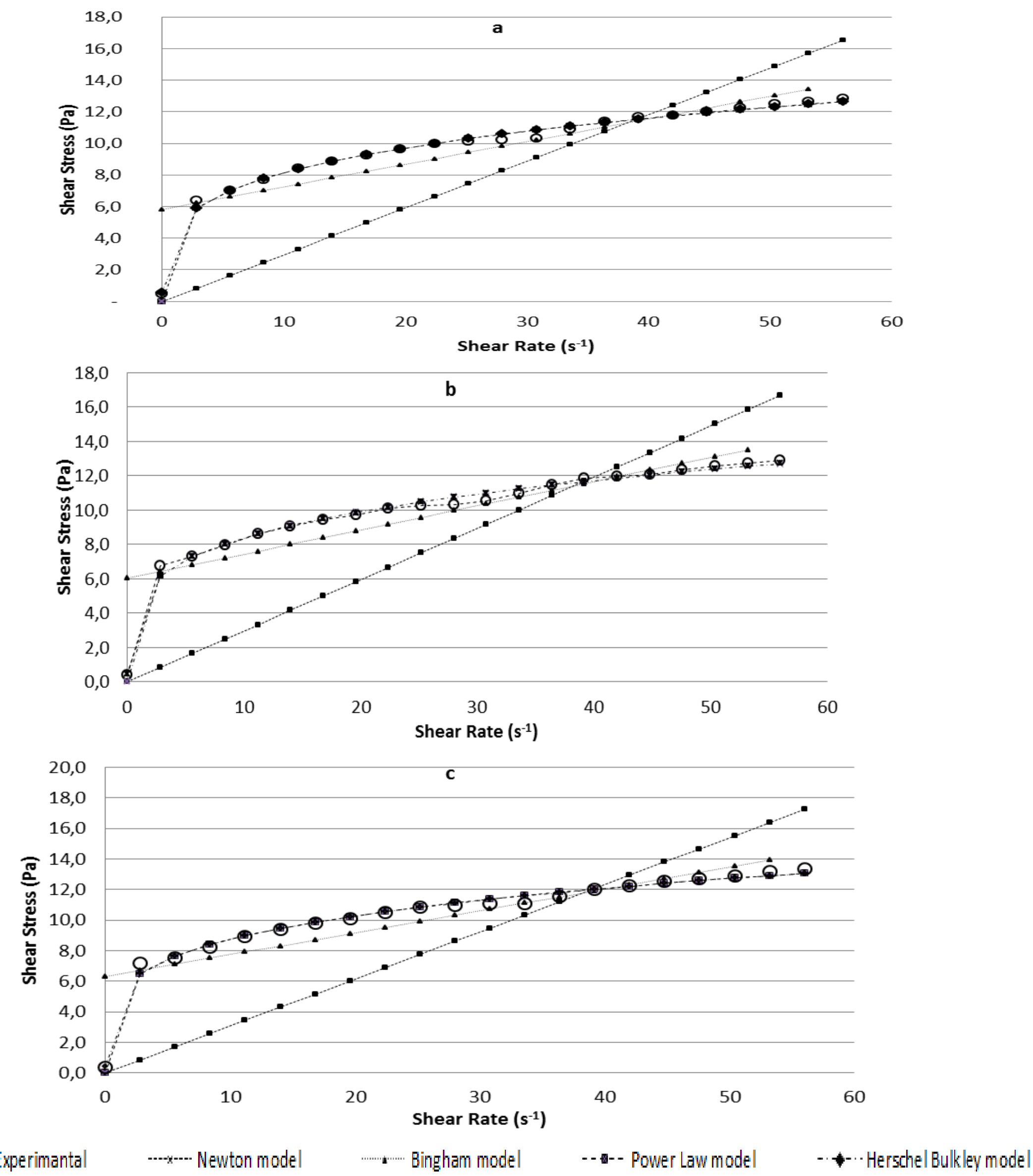

Fig. 2. Comparison between the model predictions and experimental rheological data; a) untreated sample, b) ultrasonicated sample for 5 min, c) ultrasonicated sample for 10 min.

The consistency coefficient, flow behavior index, yield stress values of tomato juices were determined by using Herschel-Bulkley model since it was found as the most proper model for describing the rheological behavior best (Table 2). It was found that the consistency coefficient of tomato juice statistically changed after ultrasound application ($p < 0.05$). As the ultrasound treatment time increased consistency coefficient increased and the flow behavior index decreased. However, the rheological behavior of tomato juice remained unchanged as non-Newtonian fluid having yield stress. Similarly, the change of viscosity has showed similar trend demonstrating the general evaluation of change in its rheological behavior. It could be said that ultrasound treatment caused the increasing of the apparent viscosity value of tomato juice by increasing its consistency coefficient and decreasing the flow behavior index.

It is recommended that the ultrasound treatment time for 10 min and above at low shear rates (< 36.4 s^{-1}) could be used if the main purpose is to increase the consistency of tomato juice higher than 12 %. The optimization of ultrasound conditions regarding the treatment time and shear rate is necessary for design and setting up of piping and ultrasound processing equipment for each individual fluid foods.

The effects of ultrasound applications on the rheopectic and thixotropic characteristics of tomato juice will be determined in flowing projects. In addition, the effects of frequency and power density of ultrasound applications on both rheological properties and other quality attributes of different fruit and vegetables juices should be investigated further in future studies.

The considerable change on viscosity of tomato juice has been obtained for ultrasonication for 10 min. On the other hand, the consistency coefficient increased and the flow behavior index decreased as the ultrasonication duration increased. Herchel Bulkley model was determined as the most proper model describing the rheological changes of untreated and ultrasonicated tomato juices. It was characterized that tomato juice had Non-Newtonian fluid having yield stress. Since it was determined that the ultrasound could increase the overall consistency of tomato juice, the application conditions for ultrasonication applied to tomato juices could be optimized for the individual purposes such as being used in sauce making and high consistency past production, etc.

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ВЛИЯНИЕ НА ПРОДЪЛЖИТЕЛНОСТТА НА УЛТРАЗВУКОВОТО ВЪЗДЕЙСТВИЕ ВЪРХУ РЕОЛОГИЧНИТЕ СВОЙСТВА НА ДОМАТЕН (Lycopersicon Esculentum) СОК

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(Резюме)

В настоящата работа е изследван ефектът на продължителността на ултразвуковото въздействие върху реологичните свойства на доматен сок. Доматен сок със съдържание на разтворими твърди вещества 6.18 ± 0.04 % беше подложен на ултразвук, използвайки 1500 W ултразвуков генератор при постоянна честота 20 kHz за различно време (0, 5 and 10 min). Емпиричните данни за образците доматен сок получени чрез вискозиметър Brookfield LVDV II Pro, USA бяха конвертирани като функция на вискозитета. Реологичните свойства на сока при температура 20 °C бяха получени чрез интерполация на зависимостта на тангенциалното напрежение от вискозитета с някои реологични модели: Нютонов модел, степенен модел, модел на Бингам и модел на Хершел-Балкли. Беше установено, че образците проявяват ненютоновско (псевдопластично) поведение на течене. При увеличаване на продължителността на ултразвуковото въздействие, вискозитетът на доматения сок нараства. Моделът, който най-добре описва експерименталните данни при всички продължителности на ултразвука, е този на Хершел-Балкли (за необработен сок и χ^2=0.203, средно-квадратична грешка RMSE=0.045 регресионният коефициент е R^2=0.995; за 5 min ултразвуково въздействие χ^2 =0.219, RMSE = 0.053, R^2=0.994 и за 10 min ултразвуково въздействие: χ^2 =0.225, RMSE=0.056, R^2 =0.994). Реологичните данни, получени при това изследване, показват важността на продължителността на ултразвуковото въздействие. Тази продължителност следва да бъде оптимизирана при ултразвуково обработване на доматен сок съобразно с изискванията за помпене и промените в качествените показатели.