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Design of ultrasonic probe and evaluation of ultrasonic waves on *E.coli* in Sour Cherry Juice

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Introduction: The common method used for juice pasteurization is the thermal method since thermal methods contribute highly to inactivating microbes. However, applying high temperatures would lead to inefficient effects on nutrition and food value. Such effects may include vitamin loss, nutritional flavor loss, non-enzyme browning, and protein reshaping (Kuldiloke, 2002). In order to decrease the adverse effects of the thermal pasteurization method, other methods capable of inactivation of microorganisms can be applied. In doing so, non-thermal methods including pasteurization using high hydrostatic pressure processing (HPP), electrical fields, and ultrasound waves are of interest (Chen and Tseng, 1996). The reason for diminishing microbial count in the presence of ultrasonic waves could be due to the burst of very tiny bubbles developed by ultrasounds which expand quickly and burst in a short time. Due to this burst, special temperature and pressure conditions are developed which could initiate or intensify several physical and/or chemical reactions. The aim of this study is to evaluate the non-thermal ultrasonic method and its effective factors on the E.coli bacteria of sour cherry.

Materials and methods: In order to supply uniform ultrasonic waves, a 1000 W electric generator (Model MPI, Switzerland) working at 20±1 kHz frequency was used. The aim of this study is to evaluate the non-thermal ultrasonic method and its effective factors on the E.coli bacteria of sour cherry. For this purpose, a certain amount of sour cherry fruit was purchased from local markets. First, the fruits were washed, cleaned and cored. The prepared fruits were then dewatered using an electric juicer. In order to separate pulp suspensions and tissue components, the extracted juice was poured into a centrifuge with the speed of 6000 rpm for 20 min. For complete separation of the remaining suspended particles, the transparent portion of the extract was passed through a Whatman filter paper using a vacuum pump (Mehmandoost *et al.,* 2011). Afterwards, the samples were poured into a reactor with diameter and height of 80 and 50 mm, respectively. It is necessary to mention that the dimensions of the reactor were optimized during pretests.

Probe design: One of the most common types of horns used for ultrasonic machining technologies is step type horn (Nad', 2010). For obtaining the governing equations on deformation along the step type horn in steady state conditions, Eq. (1) was used. In the solution of the mentioned differential equation, the answers are divided into two subsets and each of the answers is obtained considering the boundary conditions (Hosseinzadeh *et al.,* 2013):

$$c^2.\left[\frac{\frac{\partial S}{\partial x}}{S(x)}.\frac{\partial u(x,t)}{\partial x}+\frac{\partial^2 u(x,t)}{\partial x^2}\right]=\frac{\partial^2 u(x,t)}{\partial t^2} \quad (1)$$

From Eq. (1), it can be concluded that:

$$u(x,t)=(A\cos\frac{\omega x}{c}+B\sin\frac{\omega x}{c})(C\cos\omega t+D\sin\omega t) \quad (2)$$

The boundary conditions for Eq. (2) are written as follows:

$$\begin{Bmatrix} a) & \frac{\partial u(x)}{\partial x}=0, x=0 \\ b) & \frac{\partial u(x)}{\partial x}=0, x=l \\ c) & u(0)=u_{in} \end{Bmatrix} \quad (3)$$

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One of the most important parts in probe design is preventing stress concentration in locations in which the area changes. To avoid this problem, the displacement in this section must be equal to zero (Hosseinzadeh *et al.*, 2013). For obtaining the probe length, the displacement equation and the l_1 parameter are used:

$$\sigma = -E.u_{in}.\frac{\omega}{c}.\sin\frac{\omega.x}{c} \quad (4)$$

In order to determine the maximum axial stress in step type probe, Eq. (3) and (4) are derived and set equal to zero. Therefore, the maximum stress will be equal to:

$$\sigma_{max} = \pi.E.\frac{u_{in}}{l} \quad (5)$$

Optimization and Modeling using Response Surface Method: Response surface methodology (RSM) has an important application in the design, development and formulation of new products, as well as in the improvement of existing product designs. It defines the effect of the independent variables, alone or in combination, on processes. In addition, to analyzing the effects of the independent variables, this experimental methodology generates a mathematical model which describes the chemical or biochemical processes (Anjum *et al.,* 1997, Halim *et al.,* 2009).
In order to obtain the optimum value, Eq. (1) will be used:

$$Y_i = \beta_0 + \sum \beta_i X_i + \sum \beta_{ij} X_i X_j + \sum \beta_{ij} X_i^2 + \varepsilon \quad (6)$$

where, β0, βj, βij, βjj are regression coefficients for intercept, linear, interaction and quadratic coefficients, respectively, while Xi and Xj are coded independent variables and ε is the error.
For this purpose, four factors of ultrasonic power (200 to 600 W), wave exposure time (5 to 15 min), probe diameter (20 to 40 mm), and probe penetration depth in sour cherry juice container (0 to 40 mm) were selected. First, the probes with the desired diameters were designed using the related formulas by using CAD-CAM.

Results and Discussion: Surface Method (RSM) indicated that the quadratic model with 0.96 coefficient of friction, standard error of 1545.3, and coefficient of variation of 14% is the best model for estimating the number of E.coli bacteria among the different studied treatments. The results showed that with increasing probe diameter and probe depth, the destructive effects of ultrasonic wave increase. It was also revealed that as the probe diameter and penetration depth increase, the destructive effect of ultrasonic wave is initially increased and then follows by a decreasing trend. With the increasing power of ultrasonic, ultrasonic intensity increases and leads to reducing number of E.coli in sour cherry juice. The increase in time of treatment with ultrasonic causes a decrease in the number of E.coli in sour cherry juice. This is due to the fact that the increase of ultrasonic exposure time leads to the increase of sonic stream in reactor and results in higher contributions of ultrasonic waves to E.coli. Finally, the examined variables were optimized by RSM and the values of ultrasonic power, waves exposing time, probe diameter, and probe penetration depth were obtained as 600 W, 15 min, 35.31 mm, 20.83 mm, respectively. Considering the mentioned values, the amount of E.coli bacteria reduction was estimated to be 1.97 logarithmic period.

Conclusions:

1. Increasing probe diameter and probe depth increasesthe destructive effect of ultrasonic wave.
2. The examined variables were optimized by RSM and the values of ultrasonic power, waves exposure time, probe diameter, and probe penetration depth were obtained as 600W, 15 min, 35.31 mm, 20.83 mm, respectively. Considering the optimum values, the amount of E.coli bacteria reduction was estimated to be 1.97 logarithmic period.
3. With the increasing power of ultrasonic waves, ultrasonic intensity increases and leads to a reduction of the number of E.coli in sour cherry juice.
4. The increase in time of treatment with ultrasonic causesa decrease in the number of E.coli in sour cherry juice.

Keywords: Cavitation, Pasteurization, Power, Probe, Response surface, Ultrasonic