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Effect of physical properties of mango juice on the effectiveness of pulsed electric field treatment

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Abstract

Pulsed electric field technology is emerging as one of the effective non-thermal processing methods for liquid foods. The effectiveness of the PEF treatment was found to be dependent on the physical properties such as pH, electrical conductivity (EC), density and viscosity of food materials. The properties of the liquid food were measured at various temperatures ranging from 4 to 40 ˚C. From the measured values, the change in temperature (ΔT), the total energy delivered (P) and the Reynolds numbers (N_{Re}) were modeled. The results revealed that increase in temperature decreased the pH values from 5.25±0.03 to 4.52±0.02, density from 1050±13.25 to 1006.34±3.77 kg/m^3 and viscosity from 0.01295±0.000071 to 0.00719±0.00127 Pa.s. However, the rise in temperature increased the values of EC from 0.079±0.0064 to 0.1866±0.0052 S/m, change in temperature from 7.68 to 19.03 ˚C, total energy delivered from 32.92 to 79.14 J/ml and Reynolds number from 1698.51 to 2929.84. The observation showed that at 30 and 40˚C the temperature change, total energy delivered was found to be high, the flow was found to be turbulent and pH was lower. Processing the liquid food under these conditions can increase the effectiveness of the PEF treatment.

Keywords: Mango fruit, physical properties, pulsed electric field, total energy, temperature change

1. Introduction

PEF processing is one of the non-thermal processing methods employed to improve the shelf life of food products by inactivating the spoilage and pathogenic microorganism. Many researchers have worked on the feasibility of applying PEF for preservation of food (Timmermans *et al.*, 2016 [45], Sharma *et al.*, 2014 [41], Li *et al.*, 2012 [33], Mosqueda-Melgar *et al.*, 2008 [35], Korolczuk *et al.*, 2006) [31]. This processing method has the merit of minimizing the changes in products color, flavor and nutritional characteristics (Evrendilek 2016 [18], Kumar *et al.*, 2015 [32], Delsart *et al.*, 2013 [16], Buckow *et al.*, 2013 [14], Bi *et al.*, 2013 [13], Vervoort *et al.*, 2011 [47], Marsellés-Fontanet *et al.*, 2011 [34], Aguilo-Aguayo *et al.*, 2010 [1], Akın and Evrendilek 2009) [2]. The PEF system consists of a pulse forming network, processing chamber, fluid pumping system, and a control unit. PEF technology is delivering a pulsating power to the product placed between a set of electrodes confining the treatment gap in a PEF chamber. The electric field strength and treatment time are the most important factors of PEF processing (Zimmermann and Benz 1979) [51]. The physical properties of products being processed over a wide range of temperatures were necessary to design and optimize the PEF processing units. The critical processing units are electrical conductivity (EC), density, specific heat, and viscosity. Liquid food products contain many ionic species that carry an electrical charge and allows the food product to conduct the electricity. At a certain voltage, the electrical current flow is directionally proportional to the EC of the food (Zhang *et al.*, 1995) [50]. At a defined dosage, an increase in electrical conductivity causes an increase in overall energy input and a change in temperature during processing. During PEF treatment, the density and specific heat of the food product affect the temperature change during processing. It was observed that as the density of the food product decreases, the total change in temperature increases (Zhang *et al.*, 1995) [50]. A decrease in the specific heat of the product also increases the change in temperature during processing. Flow characteristics of the product are determined by viscosity, which is related to the Reynolds number. The flow found to be turbulent above Reynolds number of 2100, which provides uniform velocity profile and the uniform velocity profile can provide a uniform pulsed electric filed process (Ruhlman *et al.*, 2001) [40]. The PEF technology has demonstrated to be applicable for fruit juices such as orange, apple and cranberry juice having low viscosity and EC. Recent research works have revealed that in orange and apple more than a 3-log reduction was observed (Qin *et al.*, 1998) [37] (Evrendilek *et al.*, 2000) [17] and a 2-log reduction in cranberry juice

(Jin and Zhang 1999) [30]. The aim of this study to determine the electrical conductivity, density, and viscosity of mango juice to produce a database of physical properties to design a PEF treatment process.

2. Materials and Methods

2.1 Sample preparation

2.1.1 Selection of fruit

Alphonso is considered as the leading commercial mango variety and often rated as best in the world. The flavor of the mango is described as captivating with high-quality taste and an excellent sugar/acid ratio (Tharanathan *et al.*, 2006) [44]. Mangoes for this study were purchased from the local market of Coimbatore, Tamilnadu, India. Each fruit weighing between 225–325g chosen based on size, ovate oblique in shape with a prominent ventral shoulder and orange-yellow in color.

2.1.2 Mango juice preparation

The selected mangoes were cut into halves using a knife and the pulp was separated from the skin. One hundred grams of pulps were pureed with three hundred milliliters of distilled water for 3 minutes in a blender. The juice was strained through the four-layer filter cloth and stored in a refrigerator at 4 ˚C (Guan *et al.*, 2016) [23]. For each of the samples, the electrical conductivity (EC), density, and apparent viscosity were measured at 4 ˚C, 22 ˚C, 30 ˚C, and 40 ◦C. The measurements were replicated three times.

2.3 Electrical conductivity (EC)

The EC of the sample was determined using a portable E-1digital EC meter having a measuring range of 0 – 9999 µs/cm with an accuracy of ± 2%. The measurements were replicated three times.

2.4. Density

The density of the fruit juice was measured using a simple floatation technique. A 10 g sample was measured using an electronic weighing balance. The measured quantity was put into a 250 ml volumetric cylinder which containing distilled water as a floating liquid. The difference between the height of the floating liquid before and after the addition of 10 g sample is the volume taken by the sample. Hence, the density of the sample was calculated from the mass of the sample and the volume occupied by the sample (Ikegwu and Ekwu 2009) [28].

2.5 Viscosity

Viscosity is defined as the resistance of the fluid to flow. The viscosity was measured using a rheometer (ATAGO INDIA Instruments Pvt. Ltd, Mumbai, India) (AOAC, 2000). A volume of 2 ml sample was placed on the sample platform with a corresponding probe. Viscosity was determined at temperatures in the range of 4˚C, 22˚C, 30˚C, and 40◦C with a shear rate of 0 -1000 s^{-1} at 20 measuring points. Measurements were obtained in triplicate and the values are fitted as per the Herschel-Bulkley model.

2.6 pH

pH is a measure of the active acidity which influences the flavor or palatability of a product and defined as the logarithm of the reciprocal of hydrogen ion concentration in gram per liter. A digital pH meter (Elico pH meter, Model LI120) was utilized to measure the pH of the liquid foods with a glass electrode. Standardization of the pH meter was performed with double distilled water and buffers of pH 4.0, 7.0 and 9.2. Three replicates were taken after standardization, for each sample and the average value was reported. (AOAC, 2000).

2.7 Specific heat

The specific heat (Cp) was calculated at room temperature using a model estimation for food materials of high water content (w) (Singh and Heldman 2001) [42].

$$Cp = 1.675 + 0.025w \qquad (1)$$

The water content for each sample was determined by drying the sample in a hot air oven.

2.8 Fluid flow in the co-linear treatment chamber design

The flow regime in the co-linear treatment chamber can be determined by the ratio of inertial forces to viscous forces, defined as the Reynolds number:

$$N_{Re} = \frac{\rho D v}{\mu} \qquad (2)$$

Where ρ is the density of the fluid, v is the average fluid velocity, D is the characteristic treatment zone diameter and µ is the dynamic fluid viscosity.

2.9 Total energy and temperature change

Complex energy balance equations were required in order to estimate the energy requirement and the change in temperature. In recent years various estimation of energy density or energy per pulses are quantitatively correlated (Giner *et al.*, 2000, Evrendilek *et al.*, 2000) [22, 17]. For a continuous single-pass system, the total possible temperature change per pair of treatment chambers (∆T) and the total energy input during treatment per pair of chambers (P) was calculated using the following formula (Ruhlman *et al.*, 2001) [40]

$$\Delta T = (E^2 t\sigma/\rho Cp)/n \qquad (3)$$

$$P = E^2\sigma Vch \qquad (4)$$

Where ∆T is the change in temperature (˚C), E is the electrical field strength (V/cm), t is the total processing time (s), ρ is the density of the product (kg/m^3), Cp is the specific heat capacity of the product (kJ/kg ˚C), n is the total pair of processing chambers, P is the total energy (J/ml) and σ is the EC of the product (S/m) and Vch is the volume of the treatment chamber (m^3).

3. Results and Discussion

3.1 pH

A decreasing pattern in the pH of the mango juice was observed with an increase in temperature (Table 3.1). This increase in temperature increases the acidity of fruit juice and reduce the values in the pH scale. The EC increased with a decrease in pH or an increase in acidity or vice versa Figure (3.1). The value of pH decreased from 5.25±0.03 at 4˚C to 4.52±0.02 at 40˚C (R^2=0.80). Many studies have concluded that pH influences the inactivation of microorganisms by a pulsed electric field (Álvarez, Pagán, *et al.*, 2003, Aronsson and Rönner 2001) [5, 91]. Aronsson *et al.*, (2005) [10], Geveke and Kozempel (2003) [21], Álvarez *et al.*, (2002) [6] have reported that in acidic media microorganisms are found to be sensitive to PEF. However, Geveke and Kozempel (2003) [21], García *et al.,* (2003) [19], (Álvarez *et al.,* 2000) [8] reported that microbial resistance was lower at neutral pH and Smith *et al.,* (2002) [43], Ravishankar *et al.,* (2002) [39], Heinz *et al.,* (2001) [26] indicated the nondependence of the pH on inactivation of microbes by PEF. García *et al.,* (2005) [20] observed that the gram-negative microorganisms (*Escherichia coli, Escherichia coli O157*: *H7, Pseudomonas aeruginosa, Salmonella serotype Senftenberg 775W, Salmonella serotype Typhimurium*, *Yersinia enterocolitica*) *were* more resistant to acidic pH, however the gram-positive microorganisms (Bacillus subtilis ssp. niger, Listeria monocytogenes) resistance decreased under acidic pH. The mechanism of inactivation hypothesized that the sensitivity of the microorganisms in acidic media related to a change in the cell capacity to adjust the transmembrane pH gradient due to electroporation. The impairment of pH homeostasis leads to loss of membrane continuity, which might modify the intercellular pH affecting the DNA, RNA, enzymes, etc (Vega-Mercado *et al.,* 1996) [46].

Table 1: Physical properties of mango juice measured at increasing temperatures

Temperature (˚C)	pH	Electrical conductivity, σ (S/m)	Density (kg/m^3)	Viscosity, µ (pa. s)	Specific heat capacity Cp (kJ/kg ˚C)
4	5.25±0.03	0.079±0.0064	1050.78±13.25	0.01295±0.000071	4.08±0.0013
22	4.68±0.02	0.1257±0.0080	1031.57±15.15	0.0114±0.00566	4.12±0.0011
30	4.6±0.07	0.1468±0.0088	1022.38±11.77	0.00883±0.003352	4.13±0.0007
40	4.52±0.02	0.1899±0.0052	1006.34±3.77	0.00719±0.000127	4.13±0.0011

Table 2: Changes in process values as a function of increasing temperatures

Temperature (˚C)	time (s)	Number of pairs of the chamber, n	Reynolds number	Total energy input, P (J/ml)	Change in temperature, ∆T (˚C)
4	0.0001	1	1698.51	32.92	7.68
22	0.0001	1	1894.18	52.36	12.33
30	0.0001	1	2423.70	61.18	14.50
40	0.0001	1	2929.84	79.14	19.03

3.2 Electrical conductivity (EC)

The EC of mango juice at various temperatures presented in Table 3.1. The conductivity of mango juice was found to increase with an increase in temperature (R^2=0.9824). The same result was concluded for tomato and orange juice by Palaniappan and Sastry (1991) [36]. Halden *et al.,* (1990) [24] concluded that the ionic species found in foods such as salts and acids act as electrolytes that allow current to pass through the foods. The EC and ionic concentration are found closely related, however reducing the electrical conductivity of the treatment media, lowering the temperature and the power and therefore increasing the electrical field intensity and effectiveness of PEF treatment. However, this electrical conductivity should be at an optimal level to establish transmembrane potential (Barbosa-Canovas and Sepúlveda 2005, Jayaram *et al.,* 1993) [11, 29]. Along with an increase in temperature, the mobility of the ions in the solution increases, which in turn increases the electrical conductivity (Heinz *et al.,* 2001) [26]. Electrical conductivity increase when the energy input increases Figure (3.2) along with a change in temperature Figure (3.3). Higher the conductivity of the treatment medium lower the effect of the actual field strength, hence the higher input voltage has to be selected in order to obtain the same electrical field strength. Therefore, the achievement of greater microbial reduction could be explained by increasing the number of pulses applied with the same field strength and energy to a lower conducting food material. To achieve the same level of membrane permeabilization in *Lactobacillus Plantarum,* more energy level was required for the medium with 15 mS/cm than 4 mS/cm and also concluded that lower microbial reduction was observed in the treatment medium having higher electrical conductivity (Wouters *et al.,* 1999) [48]. Álvarez, Raso, *et al.,* (2003) [7], Álvarez, Pagán, *et al.,* (2003) [5], Álvarez, Manas, *et al.,* (2003) [4] measured the electrical conductivity of the treatment up to 4 mS/cm did not have any impact on the sensitivity of *Salmonella serovar Senftenberg, L. monocytogenes,* and *Y. enterocolitica.*

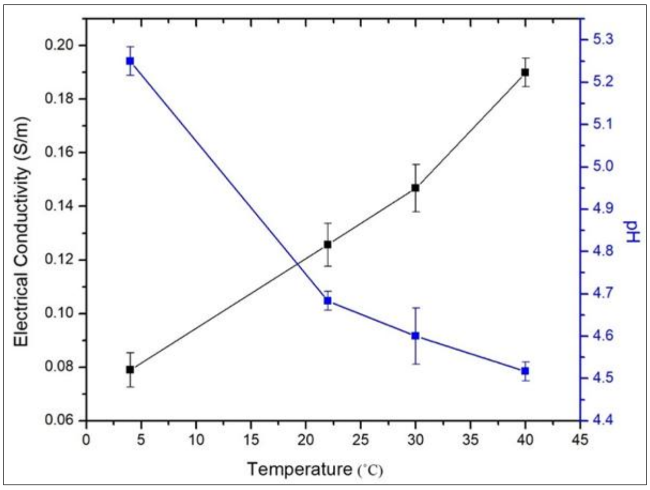

Fig 1: Electrical conductivity and pH vs. input temperature for mango juice

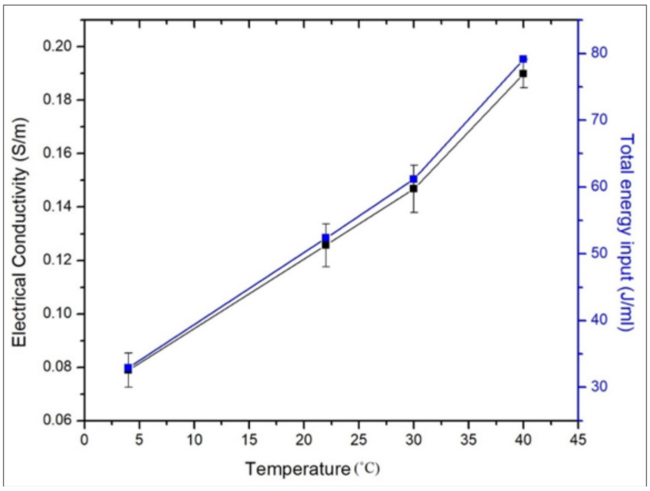

Fig 2: Electrical conductivity and total energy input vs. input temperature for mango juice

3.3 Density

The density of mango juice at various temperatures is presented in Table 3.1. The density of the mango juice was decreased with increase in temperature (R^2=0.9880). The result found is consistent with pectinised and clarified pear juice (Ibarz and Miguelsanz 1989) [27], grape juice (Bayindirli 1993) [12] and clarified apple juice (Constenla *et al.*, 1989) [15]. Temperature affects the intermolecular forces and the interaction between the water solutes which mainly contributes to the density of the product (Constenla *et al.*, 1989) [15]. Temperature rise from 4 ˚C to 40 ˚C causes 4.44% decrease in density. Similar results were concluded for peach, pear and orange juice (Ramos and Ibarz 1998, Ibarz and Miguelsanz 1989, Alvarado 1993) [38, 27, 3]. Density decrease causes increases in the mass flow rate of juice at fixed pump pressure. Shorter heating and holding times required during pasteurization can be achieved by low-density fruit juices (Zainal *et al.*, 2000) [49]. An analogous increase in the temperature change was observed with the decrease in product density Figure (3.4).

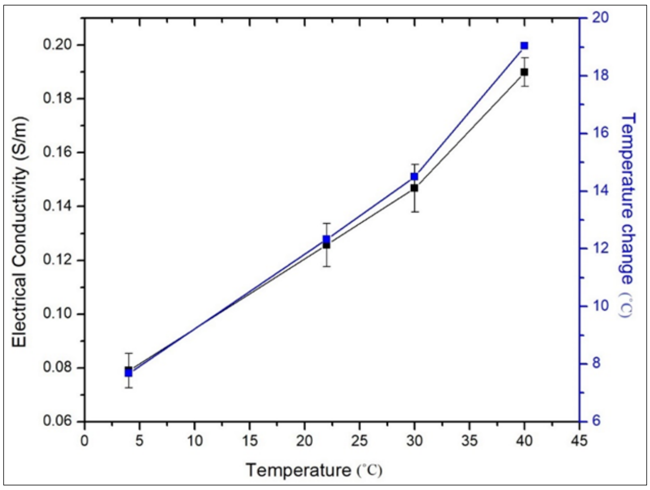

Fig 3: Electrical conductivity and calculated temperature change vs. input temperature for mango juice

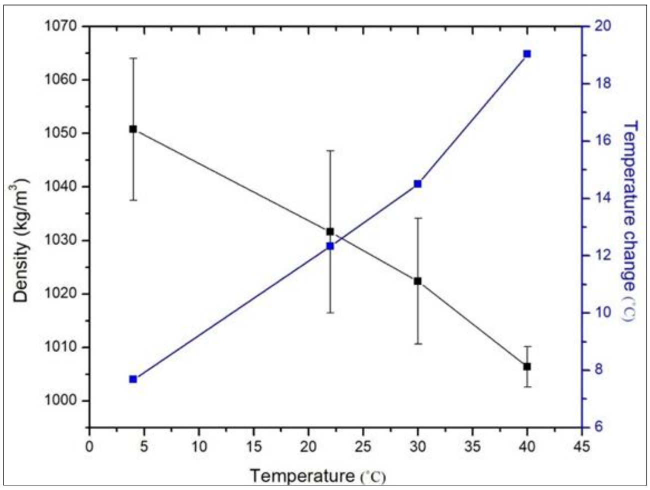

Fig 4: Density and calculated temperature change vs. input temperature for mango juice

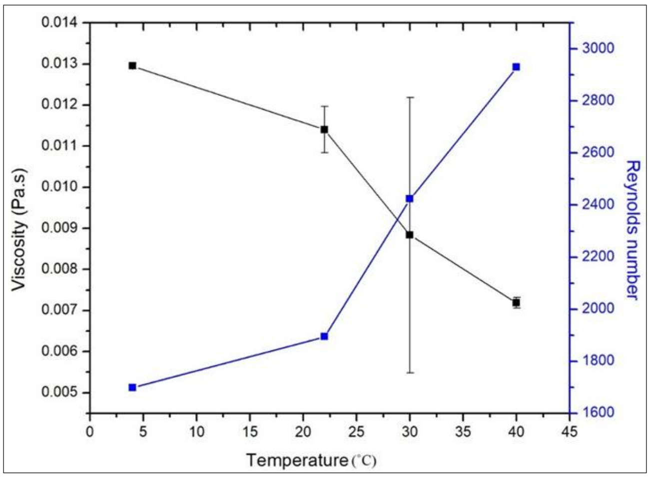

Fig 5: Viscosity and Reynolds number vs. input temperature for mango juice

3.4 Viscosity

The viscosity of mango juice decreased with an increase in temperature (Table 3.1). The Herschel-Bulkley model showed high values for the coefficient Rc and less than unity for the n index values. This indicates that the mango juice exhibited a typical pseudoplastic behavior. According to Hassan and Hobani (1998) [25], the viscosity decreases as the intermolecular distance between the molecule increases due to thermal expansion. The decrease in viscosity due to temperature was in the range of 23.4% from 4 to 40 ˚C. The reduction in viscosity due to temperature was in the range of 23.36%. Viscosity changes in the product observed with the change in temperature. This reduction in viscosity correlated with an increase in the Reynolds number. A dynamic relationship was found between temperature change, viscosity, and Reynolds number Figure (3.5). Reynolds number of the mango juice exceeded 2100 when the viscosity reduced to 0.008 Pa.s (R^2=0.9947). The flow was found to be turbulent above Reynolds number of 2100, which provides a uniform velocity profile and the uniform velocity profile can provide a uniform pulsed electric filed process (Ruhlman *et al.*, 2001) [40].

4. Conclusion

In this study the change in physical properties of mango juice and the process parameters of PEF treatment was quantified in response to the temperature. A considerable amount of reduction in the physical properties was observed. As the temperature increases from 4 to 40 ˚C, a 13.9%, 4.23% and 44.48% reduction in pH, density and viscosity of the juice was observed. However, it was observed that lower viscosity and density values at 30 and 40 ˚C increased the Reynolds number and flow behavior changed from laminar flow to turbulent flow which can provide a uniform velocity profile. Thus, it can able to provide a uniform pulsed electric field processing. As the electrical conductivity increases with temperature the total input energy increases thus change in temperature (∆T) during processing increases. Hence, to reduce the heating effect, heat exchangers should be employed to maintain the process as non-thermal process. The research concludes that the effectiveness of the pulsed electric field treatment also depends on the physical properties such as pH, electrical conductivity (EC), density and viscosity of food materials.

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