Variation in Electrical Conductivity of Selected Fruit Juices During Continuous Ohmic Heating

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Abstract
Measurements and modeling of electrical conductivity (EC) of selected fruit juices were done during continuous ohmic heating. Ten-cm long acrylic heating cell with 3.8 cm internal diameter was utilized to measure the juice electrical conductivity. The variation in electrical conductivity of lab-squeezed juice of orange, pineapple and tomato fruits purchased from different retail markets were measured and modeled in terms of juice properties, such as total soluble solids and pH. EC of all juices had a linear variation with temperature as they were heated continuously to 80°C. EC of juice was affected by fruit maturity: 9-months old oranges had lower EC value of 0.392 S/m at 25°C, whereas 12 months old oranges had 0.475 S/m. The electrical conductivity of lab-squeezed orange juice from fresh fruits from different locations showed a 10% variation in the mean value of 0.343 S/m at 25°C and 0.971 S/m at 80°C. Mean electrical conductivity values for pineapple and tomato juice at 25°C, were 0.295 S/m and 0.504 S/m with maximum variations due to location at about 20% and 18.3%, respectively. These variations in EC of juices studied were observed to be higher at higher temperatures. The observed electrical conductivities for three juices were modeled in terms of temperature and total soluble solids with very high goodness-of-fit values.

***Keywords**: Electrical Conductivity, Ohmic heating, Modeling, Fruit juices*

1 Introduction

Passage of electricity within a food substance, liquid or solid, generates heat due to the resistance of the food material to current flow. When this heat is utilized to process the food product, the process is known as ohmic heating [1] or direct resistance heating. The heating of food takes place in the form of internal energy transformation- from electric energy to thermal energy- within the material [1, 2]. Ohmic heating of food enables extremely rapid heating rates usually from a few seconds to a few minutes [3, 4]. At the same time, ohmic heating was shown to carry considerable promise in producing high-quality sterile solid-liquid food mixtures via a continuous process [5]. A uniform temperature distribution in a composite food system is also possible, as both solid and liquid phases are heated simultaneously [6].

Electrical conductivity or specific conductance is a property of (food) material that measures a material's ability to conduct an electric current. Ohmic heating process is influenced, in a number of ways, by electrical conductivity of the food material [7]. Firstly, the electrical conductivity determines the local rate of heat generation as $Q = \sigma E^2$, where, Q = the heat generated, E = the local electric field strength, and σ = electrical conductivity of the food material. Secondly, the global distribution of electrical conductivity governs the field distribution, and hence, the local heating rate. This is because the electrical field obeys Laplace equation and relates the electrical conductivity of material with both position and temperature as $\nabla\left(\sigma\nabla v\right)=0$; v being the applied voltage. Thus, the electrical conductivity of food material is considered to be one of the important parameters during the design of ohmic heating process [8].

Electricity conductivity of food material is a function of product characteristics (composition, sugar and salt content, pH etc.) and is also influenced by the heating process itself, notably, by the temperature. Researchers have shown interest in measuring electrical conductivity of various food systems under different test conditions [4, 9, 10-13]. Such estimate of electrical conductivity of a sample could be made by a simple heat balance equation for ohmic heating, as

$$\frac{dT}{dt}=\frac{v^2\sigma}{k_c\ m\ c_p} \qquad \text{Eq. (1)}$$

where, dT is the temperature difference at any time interval dt, m is mass of the fluid in a measurement cell, v is the applied voltage, c_p is specific heat of the material, and k_c is the cell constant, which is equal to the ratio of length to cross-sectional area of the cell.

Empirical relationships have long been developed by many researchers relating electrical conductivity with process variables like temperature, soluble solid content, applied voltage etc. Palaniappan and Sastri [14] developed best-fit equations for electrical conductivity of tomato and orange juices as a function of total soluble solids and temperature at measurement. Gupta [15], also modeled electrical conductivity as a function of both temperature and total soluble solids (TSS), and reported an increasing effect of juice TSS on electrical conductivity. Lau et al. [16] also obtained similar results for reconstituted celery juice. Such lab-scale data, when described by suitable models, allow us to study the effect of variation of process parameter on whole process. Palaniappan and Sastri [17], Qihua [18], and Hung [19] worked on modeling the electrical conductivity as a function of temperature and total soluble solids. Sastri and Salengke [20] compared different mathematical models for ohmic heating of solid-liquid mixtures. Castro et al. [21] reported on ohmic heating of strawberry products, while Darvishi et al. [22] studied electrical conductivity and pH change in pomegranate juice. While the role

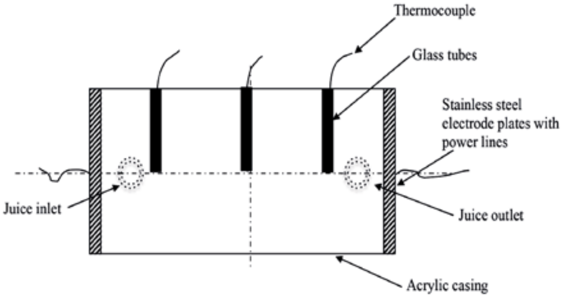


Figure 1: Schematic of the ohmic test cells used in the study.

of electrical conductivity in the ohmic heating process is of immense importance and is modeled as function of process parameters, for example, temperature and soluble solids, the variations in the electrical conductivity of a product due to composition/location/variety etc. and due to the process itself has not been investigated. This provides with a broad range of variation in electrical conductivity to anticipate during a process design.

The objectives of this study were (1) to observe the electrical conductivity of selected fruit juices with maturity level and storage conditions, (2) to measure (calculate) the variation in electrical conductivity of freshly squeezed fruit juices obtained from different market locations in Bangkok and relate to juice properties, (3) to evaluate the influence on electrical conductivity of increase in total soluble solids in juice via evaporation and sugar addition, and 4) to model the variation in electrical conductivity of fruit juices with total soluble solids during continuous ohmic heating.

2 Materials and Methods

2.1 *Test cells and ohmic heating system*

Test cells and cell factor: Figure 1 shows the representative schematic of the test cells constructed and used in the study. An acrylic pipe of inside diameter 38.5 mm and outside diameter 45 mm was used to fabricate three test cells of lengths- 5 cm (C1), 10 cm (C2), and 15 cm (C3). Three 5 mm diameter holes were drilled on each cell surface for thermocouple insertion. Two 10 mm diameter holes were drilled at 90° from thermocouple tubes for insertion of juice inlet and outlet tubes. Two stainless steel electrodes, 1.5 mm thick, were used to apply the voltage across the cell.

System voltage and current: The experimental ohmic heating system reported by Qihua [18] was used for evaluating electrical conductivity of fruit juices with different test cells. The system supplied and recorded applied voltage, amperage and the temperature of juice during heating. The data logging was with a Metrabyte EXP-16 board and A/D converter DAS-8. The internal calibration equations were developed and calibrated to the corresponding DC output signals from the interface circuit. The system calibration for both applied voltage and current drawn was necessary to record them in-line during a measurement. The interface produced signals which were fed into the EXP-16 Multiplexer for recording.

System voltage: $V = -0.516024 + 43.1913\ V_1$
($R^2 = 0.999$, SE = 0.856) Eq. (2)

where V is the applied system voltage read from a voltmeter and taken as standard, volts, V_1 is the DC voltage output measured at the interface, volts, and SE is standard error of predicted system voltage V using the calibration Equation (2)

System current: $I = 0.51996 + 3.4156\ I_1 - 0.045026\ I_1^2$
($R^2 = 0.999$, SE=0.0134) Eq. (3)

where I is the measured AC in the system, Amp, and I_1 is the DC voltage outlet at the current interface, volts., and SE is standard error of predicted system current I using the calibration Equation (3)

Temperature calibration in measurement cell: Calibration curves for recording temperatures during heating were developed using three T-type copper-constantan thermocouples. T-type thermocouples are cheaper and acceptable for the range of temperatures we wanted to measure. To shield it from field effects during measurement, thermocouples were inserted in small glass tubes 5 mm outer diameter containing UH-102 silicone heat transferring material. Glass tubes with thermocouples were then inserted into the cell by sticking them on cell surface (Figure 1). The experimental cell with thermocouples was then immersed in a water bath. Water bath temperature was increased from 25°C to 90°C in 5°C increments. The temperatures were recorded with a 0.1°C precision mercury-in-glass thermometer as well as with thermocouples in the cell. The thermocouple temperatures were then regressed with the thermometer readings through linear equation $T_a = b_0 + b_1 T_0$, where, T_0 is thermocouple readings (°C), T_a is thermometer readings (°C), and b_0 and b_1 are the regression coefficients. The regression coefficients developed for three thermocouples are given in Table 1.

Table 1: Regression coefficients b_0 and b_1 for the temperature calibration relation in cell: $T_a = b_0 + b_1 T_0$, where, T_0 is thermocouple readings (°C); T_a is thermometer readings (°C).

Thermocouple	b_0	b_1	R^2	Standard Error
#1	3.957	3.957	0.999	0.67
#2	4.246	4.246	0.999	0.47
#3	3.432	3.432	0.999	0.20

Cell factor determination: Cell factor of a test cell is a measure of the accuracy in determining the electrical conductivity values, as it is the ratio of measured conductivity values to actual values of a reference liquid. Cell factors were estimated for the test cell at voltage gradients of 10, 15, and 20 V/cm. The reference liquid 0.1 N NaCl [20] was filled into the cell and heated ohmically. The electrical conductivity (σ) of the solution at a given temperature was calculated as $\sigma_{mes} = (I \times L)/ (V \times A)$; where σ_{mes} is measured electrical conductivity of the reference liquid, S/m, I is the current drawn at any temperature, Amp; V is the applied voltage, volts, L is the linear distance between two electrodes, m, and A is the cross-sectional area of the cell, m^2. These measured conductivity values at a given temperature were plotted against the reference values for 0.1 N NaCl as $\sigma_{mes} = k\ \sigma_{ref}$, where σ_{ref} is the electrical conductivity of the reference liquid and k is the cell factor, which is the slope of the plot.

2.2 *Fruits and juice preparation*

Locally available Thai tangerine, pineapple and tomato were used for the study. Oranges were used for evaluating effect of maturity on electrical conductivity and were obtained from a nearby farm at 8, 9, 10, 11 and 12 months after flowering. Fruits for other tests were obtained from at least six local markets, including a nearby wholesale fruit market (Talat Rangsit). The oranges were squeezed in the lab with a juice extractor (Braun Citromatic MPZ 6 Juicer) as and when needed. Pineapple juices were obtained by pressing cut pieces using a hydraulic press. Tomatoes were liquefied in a food mixer. The juices were then strained through two layers of cheesecloth and filled into the heating cells for electrical conductivity measurements. Total soluble solids (TSS) and pH of juices were also measured with an Abbe refractometer (model no. 2WA) and a pH meter (Orion, model no. 525A), respectively. Three replicates of juice measurement were carried out and average conductivity values were compared.

2.3 *Electrical conductivity of fruit juices under different conditions*

For storage effect on electrical conductivity of fruit juices, orange fruits were stored at 4°C, and ambient temperature (25°C) for four weeks. The electrical conductivity of the orange juice was then determined by squeezing the required amount of juice from oranges at both storage temperatures every week. The fruit at ambient temperature much shriveled by 4th week and the color of juice extracted turned slightly brownish. A voltage gradient of 10 V/cm was applied during measurement to prevent the excessive heating and bubble formation. In one variation, the freshly extracted orange juices were also kept at 4°C and 25°C until they spoilt due to fermentation and the electrical conductivity was measured at every 6 h for both juices along with TSS and pH. Bad smell that started after around 12 h reached a peak at around 20-24 h at which point the juice was discarded.

Variation in electrical conductivity of juice from fruits purchased from different market locations was evaluated by purchasing the same variety of fruits (orange, pineapple and tomato) from six different market localities within 20 km radius from Rangsit Market area so as to include as much variation as possible. The juice was then extracted and electrical conductivity was measured at voltage gradient of 15 V/cm using the cell C1. Three replicates of each measurement were performed for all fruits juices. The resulting conductivity values were then compared for the range of variations as a function of the temperature and TSS. Best-fit equations were modeled for the available data sets using multiple regression procedures.

2.3.1 Electrical conductivity of fruit juices at higher solids concentration

Gupta [15] studied the variation in the electrical conductivity of fruit juices at different solid concentrations based on static measurement, i.e., measuring conductivity after heating the sample separately to a certain prior temperature. He used the final concentration of 24°B for orange, 13.5°B for tomato and 29°B for pineapple. In the present study, the major objective was to measure the juice conductivities during continuous ohmic heating (as opposed to static measurements) at comparable solids concentrations in juices. So, juices were concentrated to the similar solids content- 11.5 to 24.6°B for orange, 16.0 to 28.5°B for pineapple, and 5 to13.6°B for tomato juice with two different methods: (1) evaporation in a rotary vacuum evaporator, and (2) sugar and acid addition to the fresh juice to make up to the same levels of TSS and pH as evaporation-concentrated juices. The pH of the juice was adjusted by adding citric acid in the sugar-added juice.

In addition, the electrical conductivity values of the juices were determined at lower TSS range as well by diluting fresh juices to various juice-water ratios (3:1; 1:1 and 1:3) with distilled water. The corresponding TSS and pH of the samples were also recorded. The electrical conductivity values observed for diluted juices were then modeled as a function of temperature and TSS.

Statistical analysis: The measurement means were compared with the general linear model, PROC GLM procedure, by using least squares difference at $p<0.05$ in the statistical software SAS system (SAS, SAS Institute Inc., Cary, NC, USA). At least three measurements/assays were carried out for a given treatment. SE_y is the standard error of predicted parameter from fitted equations.

3 Results and Discussions

3.1 *Cell factors and cell selection*

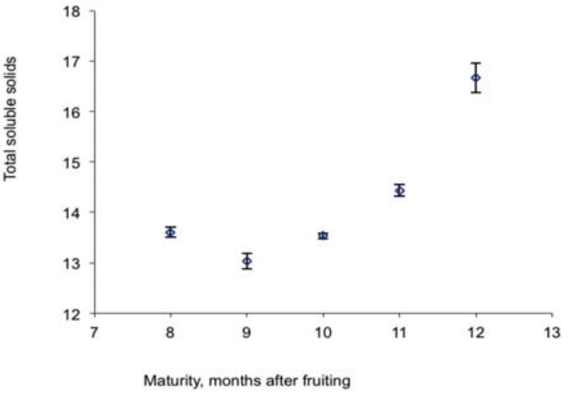
Cell factor was defined as the slope of the straight line obtained when the electrical conductivity values of reference solution were plotted against the observed values with a given test cell, the ideal cell giving a factor of 1. It was generally seen that the observed electrical conductivity values were lower than the reference values for up to 40°C, which then became higher at higher temperatures. Cell factors for test cell C1 at voltage gradients 10, 15 and 20 V/cm were 1.05, 1.02 and 1.07 respectively, which was found to be more consistent than for other cells. Cell C2 had cell factors of 0.923, 0.962 and 0.983 at the same voltage gradients; the cell length may have played a role in uniform distribution of electricity. No agitation was provided in both of the cells. Average cell factors of 1.05 and 0.956 for cells C1 and C2 were applied as the correction factors in later electrical conductivity measurements with these two cells.

3.2 *Variation in electrical conductivity of fruit juices*

The electrical conductivity of the three fruit juices studied- orange, pineapple and tomato -was considerably affected by the factors studied: the fruit maturity, storage conditions, market location and total soluble solids (TSS) and pH of juice. Electrical conductivity was a function of temperature, showing a linear relationship. Variability in electrical conductivity of the juices was appreciable in some cases, whereas it didn't change much in other cases.

3.2.1 Fruit maturity and electrical conductivity

Orange juices from more mature fruits showed increase in conductivity values along with the total soluble solids, the increase being significant for 10 to 11 month fruits. The minimum conductivity observed value was 0.4 S/m for nine months old fruit at 25°C, and the maximum value was about 1.8 S/m for eleven months old fruits at 100°C. It was observed that the electrical conductivity of juice from 12 month oranges were slightly lower than that of 11 months fruits. But the total soluble solids steadily increased from 13.03°B for 9 months oranges to 16.67°B for 12 months oranges. Figure 2 shows the average observed TSS and pH of orange juice at different maturity. The pH of the juices increased form 4.26 to 4.73 between 9 and 12 months fruit juices, respectively. When a fruit acquires maturity, many physicochemical changes occur within it, notable among them being the increase in sugar-to-acid ratio and increase in soluble sugars. The increase in juice TSS is mainly due to the increase in sugar and other salts and mineral concentration. Changes in one or all of these juice constituents affect the related properties like the electrical conductivity. Maturity of fruits results in increased TSS, hence the increase in electrical conductivity of the juices.



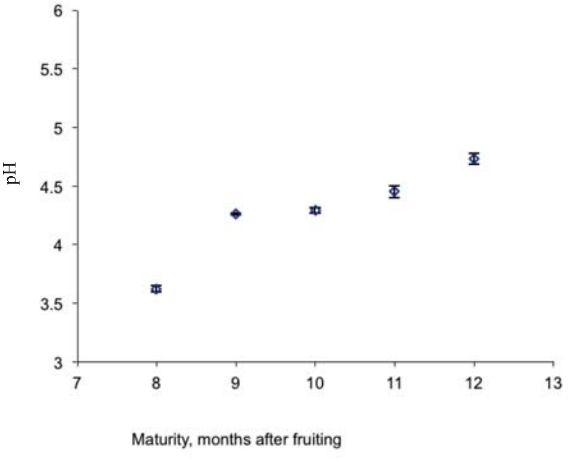


Figure 2: The average observed total soluble solids (top), and pH (bottom) of the orange juice at different maturity, months after flowering. Error bars indicate one standard deviation for the means.

The electrical conductivity values of the orange juice at different maturity levels were then related to juice properties, TSS and pH. Firstly, observed electrical conductivity (σ) and temperature (T) were related linearly as $\sigma = a + b\,T$, where, a is the intercept and b is the slope of the fitted line. The slope b of such an equation, in fact, is the change in electrical conductivity per degree change in temperature; the constant term 'a' shows the electrical conductivity (EC) value at 0°C. Parameters a and b were then related to juice TSS and pH for the observed data range as:

$a = 1.723 - 0.515 * TSS - 0.003 * TSS^2 + 1.07 * pH - 0.374 * pH^2 + 0.139 * TSS * pH^2$ Eq. (4)

and $b = 0.052 + 0.033 * TSS - 0.141 * pH + 0.023 * pH^2 - 0.007 * TSS^2 - 0.003 * TSS * pH^2$ Eq. (5)

The fitted relationship for '*a*' had an R^2 value of 0.683, i.e., about 68% in the variation in the constant was explained by the equation which, though not so good a fit, nevertheless indicated the dependence of '*a*' on the experimental values. But '*b*', the slope, indicated a strong relationship ($R^2 = 0.98$) with TSS and pH. Negative coefficient for pH in the equation for '*b*' showed the negative contribution of pH to the juice electrical conductivity. Such relationships are useful to prediction electrical conductivity of orange juice during maturity, especially during 9 to 12 months after flowering, as TSS and pH would change considerably during that time.

3.2.2 Electrical conductivity of fresh orange juices at different storage conditions

Spoilage of fresh orange juice affected electrical conductivity; juice left at ambient temperature fermented and spoilt compared to refrigerated storage. Electrical conductivity of orange juice left at ambient temperature increased up to 18 h. The change in electrical conductivity was prominent between 12 and 18 h-from 0.512 S/m to 0.6215 S/m at 30°C. But the changes in conductivity values were negligible for juice kept at 4°C for the period of 24 h. This indicated the degrading effect of temperature on fresh juice: fermentation of sugars takes place at elevated temperatures during storage, which was apparent by decrease in TSS values (not shown) and drop in pH values.

The electrical conductivities of freshly squeezed orange juice from whole fruits stored at refrigerated and ambient conditions were also measured weekly for a month. In this case, under both storage conditions, the conductivity values varied in a narrow range only, as opposed to fresh juice spoilage/storage. The minimum value of conductivity at 25°C for ambient storage varied from 0.37 S/m at 0 week to 0.470 S/m after two weeks of storage. The conductivity values at 25°C then remained almost constant during month-long storage showing no set pattern of variation. At any given temperature, there was no difference in electrical conductivity values of orange juice from ambient and refrigerated storage of whole oranges. While pH showed no significant variation for these two types of storages, total soluble solids for ambient-stored whole orange juice increased by 40%, from 10°B to 14°B. It would be expected that this increase in TSS should result in the increase in electrical conductivity values for ambient storage, but sugars do not produce ions upon dissolution, thus, are non-conductors of electricity. Also, the loss of moisture from the whole fruit during ambient storage could have contributed to the increase in TSS of the juice.

3.3 *Variation in electrical conductivity of fresh juices and dependence on juice properties*

While looking into the possible variation in electrical conductivity of the fruit juices in design of an ohmic processing system, one has to take into consideration the various pre- and post-harvest practices, and varietal and climatologic factors. These factors affect the soluble salts, minerals, acids and other related juice constituents, ultimately, resulting in electrical conductivity differences. In an industry, such as fruit juice, where raw materials have to be supplied from different farms or localities, the knowledge of the extent of possible variation in process parameter like the electrical conductivity would be of immense importance.

Figure 3 shows the plots of observed variation in electrical conductivity of freshly squeezed juice of orange, pineapple, and tomato obtained from six different market locations around Bangkok. Pineapple juice had the highest variation of ~20% around mean values, followed by tomato 15%, and orange 10%. Various factors could be affecting electrical conductivity of the juices collected from different market locations like the level of maturity, growing areas and their climatic characteristics and pre-harvest conditions. Maturity of salable pineapple fruits varied much from just ripe green fruits to well ripe yellow and reddish fruits. Orange fruits were rather uniform in maturity and appearance, whereas, tomato also showed considerable difference in maturity. These variations manifested in TSS and pH differences. Orange juice TSS ranged from 10 to 12.3°B, a 23% variation, with an average value of 11.2°B. The pH of orange juice was relatively stable ranging from 4.2 to 4.68. Pineapple juice TSS varied from 13.6 to 14.9°B, about 10% variation with an average of 14.3°B. The pH

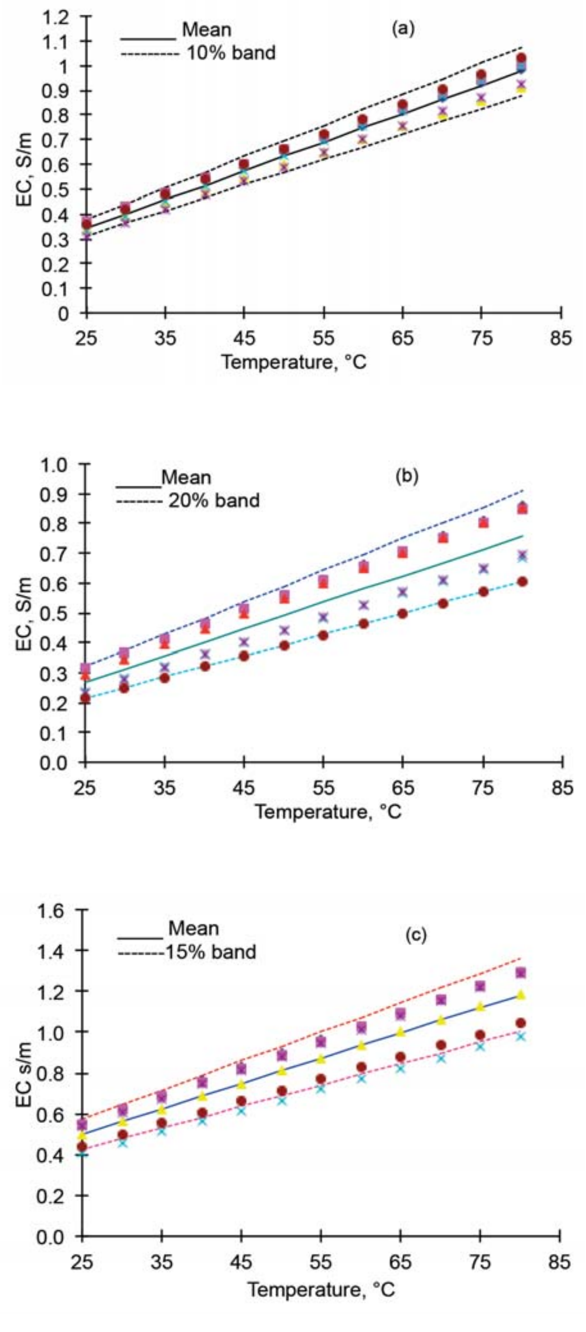


Figure 3: Measured variation in electrical conductivity (EC) with temperature for juice from orange (a), pineapple (b), and tomato (c) collected from different market locations in Bangkok area (indicated by different symbols). Solid lines are average EC values, and dashed lines are limits for the variation shown.

of pineapple juice was very stable at 3.92 to 4.2. The variations in tomato juice TSS were substantial ranging from 2.9 to 5°B, averaging at 3.85°B, whereas, its pH values varied between 3.92 and 4.2. It was observed that pH didn't vary much for all three juices while the TSS varied substantially, thus, contributing towards the variation in the juice conductivity values.

These variations in juice properties and their effect on the conductivity were modeled into an equation of the form $\sigma = f\{(T-T_{ref}), (B-Bref)\}$ [17], where Tref and Bref are reference measurement temperatures and TSS respectively. The equations obtained for fruit juices were as follows:

Orange: $\sigma = 0.346 + 0.011\,(T - T_{ref}) - 0.015\,(B - B_{ref})$ ($R^2 = 0.97$; SEy = 0.037) Eq. (6)

Pineapple: $\sigma = 0.429 + 0.013\,(T - T_{ref}) + 0.055\,(B - B_{ref})^2$; ($R^2 = 0.87$; $SE_y = 0.064$) Eq. (7)

Tomato: $\sigma = 0.429 + 0.012\,(T - T_{ref}) + 0.055\,(B - B_{ref}) + 0.0124\,(B - B_{ref})^2$ ($R^2 = 0.93$; SEy = 0.067) Eq. (8)

The reference temperature T_{ref}, was 25°C for all fruit juices, whereas, the reference soluble solids, B_{ref}, was 11°B for orange, 14.2°B for pineapple, and 3.88°B for tomato juices. These reference TSS values were the average values of juices obtained from different localities (Figure 3). The pH was not found to have significant influence over the electrical conductivity of fresh fruits juices. The effect of unit change in TSS on electrical conductivity was higher than unit change in temperature as seen in above equations, even though EC values increased at higher temperatures. A comparison between the fitted equations and the experimental values showed the errors to be less than 10%. Nevertheless, the equation could be considered satisfactory for fresh juice conditions where the variation in TSS is less than 3°B.

3.4 *Juice concentration and electrical conductivity*

3.4.1. Concentration methods

The heating rates during ohmic heating critically influence the electrical conductivity of food being heated; the information about variation in this important parameter is critical for a successful design [23]. This is even more important for concentrated liquid foods; this was evaluated with orange juice concentrate up to 25°B. The electrical conductivity of orange juice in this case, depended on concentration method itself. The addition of sugar to raise total solids in juice had an adverse effect on the conductivity, whereas, raising the concentration from 11.4°B to 25°B via evaporation increased the conductivity values from 0.4348 S/m to 0.633 S/m at 25°C. Sugar addition to raise the TSS to 25°B reduced the conductivity from 0.4348 S/m to 0.2901 S/m at 25°C, a 33% loss. Similar trend was observed at higher temperatures also; for example, for evaporative concentration, EC values increased from 1.25 S/m (11.4°B) to 1.8 S/m (25°B) at 80°C. However, for concentrating with sugar addition reduced EC value to 0.98 S/m for 25°B orange juice at 80°C. This is thought to be due to the poor electrical conductivity sugar solutions, as sucrose has zero conductivity. Food additives in processing affect the resulting conductivity values affecting the performance of the system.

3.4.2 General modeling

The range of total soluble solids obtained by evaporative concentration and dilution, and corresponding pH values are presented in Table 2. The electrical conductivity of fruit juices (orange, tomato and pineapple) at different temperatures for the range of juice TSS is shown in Figure 4. For diluted juices, the conductivity plots were almost equally spaced as per TSS of dilution, indicating that at a given temperature in dilute TSS range, the conductivity is a direct function of TSS, while the pH of the juice did not change much. However, at the higher solids due to evaporative concentration, EC didn't vary in proportion to their TSS increase. This was observed for all three juices, however, at varying degree- pineapple juice showed little increase in conductivity at any temperature when TSS was beyond 25.5°B. One possible reason for smaller changes in conductivity at higher TSS could be the higher juice viscosity limiting the mobility of free irons carrying electrical charges. Moreover, the drag for ionic movement increases when solid content of juice increases [17].

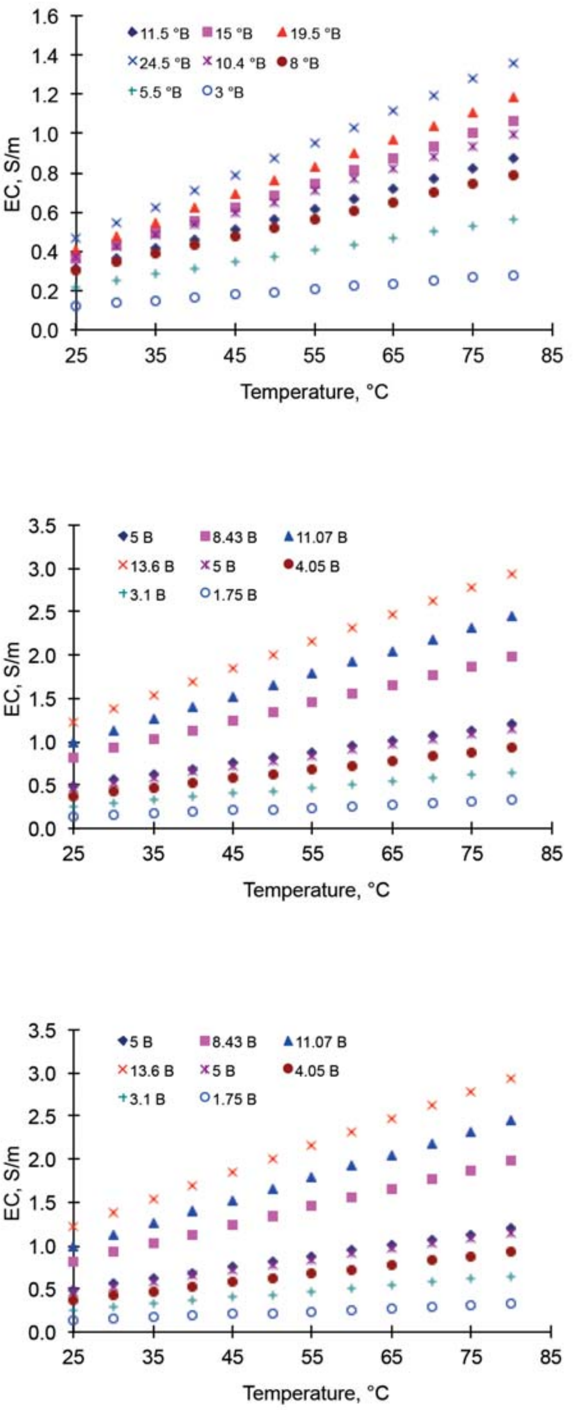


Figure 4: Variation in electrical conductivity of fruit juices- orange (top), pineapple (middle), and tomato (bottom) with different total soluble solids.

Table 2: Experimental range of TSS and pH values for evaporative concentration, and dilution experiments.

	Orange		Pineapple		Tomato	
	TSS (°B)	pH	TSS (°B)	pH	TSS (°B)	pH
Concentration	11.57	4.35	16.03	3.94	5	4.03
	15.03	4.34	20.2	3.88	8.43	3.92
	19.50	4.43	25.47	3.83	11.07	3.97
	24.57	4.35	28.47	3.82	13.6	3.94
	Orange		**Pineapple**		**Tomato**	
	TSS (°B)	pH	TSS (°B)	pH	TSS (°B)	pH
Dilution	10.40	4.73	16.1	3.56	5.0	4.12
	8.0	4.58	12.3	3.58	4.05	4.18
	5.0	4.55	8.55	3.63	3.10	4.2
	3.0	4.52	4.50	3.70	1.75	4.2

General modeling of electrical conductivity of fruit juices for the range of TSS from evaporative concentration and dilution was carried out in the general form $\sigma = f\{T - T_{ref}), (B - B_{ref})\}$. The reference temperature, T_{ref}, chosen was 25°C and the reference soluble solids, B_{ref}, were taken as the average of fresh juice TSS values, namely, 11°B for orange, 14.2°B for pineapple and 3.88°B for tomato. The best-fit equations from regression analysis are as follows:

Orange: $\sigma = 0.346 + 0.0096\,(T - T_{ref}) - 0.03\,(B - B_{ref}) + 0.0006\,(T - T_{ref})\,(B - B_{ref}) - 0.0011\,(B - B_{ref})^2$
($R^2 = 0.98$; $SE_y = 0.051$) Eq. (9)

Pineapple: $\sigma = 0.298 + 0.006\,(T - T_{ref}) - 0.009\,(B - B_{ref}) + 0.0004\,(T - T_{ref})\,(B - B_{ref}) - 0.0008\,(B - B_{ref})^2$
($R^2 = 0.98$; $SE_y = 0.031$) Eq. (10)

Tomato: $\sigma = 0.429 + 0.008\,(T - T_{ref}) - 0.109\,(B - B_{ref}) + 0.00254\,(T - T_{ref})\,(B - B_{ref}) - 0.0034\,(B - B_{ref})^2$
($R^2 = 0.99$; $SE_y = 0.047$) Eq. (11)

It could be seen from the above equations that the coefficients for temperatures in the fitted second-order equations are lower than that for total soluble solids coefficients indicating relative sensitivity of electrical conductivity of juice towards the TSS. The fitted equations predicted the EC values very well, as indicated by very high R^2 values.

4 Conclusions

The variations in electrical conductivity of orange, pineapple and tomato juices were evaluated during continuous ohmic heating process. Variations in electrical conductivity of fruit juices from different market locations were found to range between 10 to 20%. Electrical conductivity of fresh fruit juices was related, with sufficient accuracy to measurement temperature and total soluble solids; unit change in soluble solids had higher influence on electrical conductivity than unit change in temperature. Such empirical relations could be easily employed to predict electrical conductivity of juices, which will have bearing in the performance of ohmic heating processes. Expecting the variation and absorbing them will be the main utility of such relationships. However, validation of these fitted relationships with a wider data sets remains, and should be taken up further.

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