ISSN: 2347-467X, Vol. 13, No. (3) 2025, Pg. 1136-1144

Current Research in Nutrition and Food Science

www.foodandnutritionjournal.org

Ohmic Heating for Pasteurization using Electrical Conductivity in Fruit Juices

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Abstract

The ohmic heating, also called Joule heating is employed as pasteurization technique in juices of litchi, mango, guava and aloe vera. It is an advanced heating treatment where heating is homogenous and mainly employed for thermal treatment of food and juices. The temperature ranges from 20 °C - 70 °C at different voltage gradients (7V/cm, 12V/cm, 17V/cm, 22V/cm, 27V/cm) in present study. The observed electrical conductivity showed a linear rising behavior (0.04S/m – 1.73 S/m)with rise in temperature due to ohmic heating and the results indicated that the effect of voltage gradient was statistically significant on the ohmic heating rate ($p<0.05$). The significant changes were observed in the pH value of juices at room temperature for mango, guava and aloe vera before and after ohmic heating. The value of TSS of the chosen juices does not change significantly due to ohmic heating. The measurements of these parameters during ohmic heating are important in designing of ohmic heaters for commercial applications and food processing industry.

Article History

Received: 13 December 2024

Accepted: 29 April 2025

Keywords

Conductivity;
Heating Rate;
Juice;
Ohmic Heating;
Voltage Gradient.

Introduction

According to the United Nations committee on world food security, food security is the state in which all people always have physical, social, and financial access to enough wholesome food that satisfies their dietary requirements and food choices for an active and healthy life. Food security will be significantly impacted over the next few decades by a changing climate, an expanding world population, rising food prices, and environmental pressures. There is an urgent need for adaptation plans and policy responses to global change, including solutions for managing land use patterns, water allocation, food trade, postharvest food processing, food prices, and food safety. Certain food items, like fruits and vegetables, are only available during specific season and not in others. There are seasons when other foods are more plentiful than others. The techniques for preserving such seasonal foods intact for later use were adopted by human civilization. Since the beginning of time, men have used food preservation techniques. Given the

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Doi: http://dx.doi.org/10.12944/CRNFSJ.13.3.7

significance of these food processing techniques in human life, modern technology has now been widely implemented in this field. The conventional heating methods for preservation of food such as sterilization, pasteurization, evaporation and drying which are extensively employed in food industry on a commercial basis to ensure microbiological safety.[1] However, these techniques worsen the food's nutritional value.[2] Furthermore, the conventional methods are ineffective in terms of sustainability, energy requirements and recycling of waste. As the demand for high quality food with longer shelf life have increased exponentially over the last three decades, hence researchers have explored various new techniques to enhance the quality of food and its safety.[3] Ohmic heating and dielectric heating (including radio frequency and microwave heating) have advanced remarkably in the era of new technologies. These processing methods are effective because of uniformity, volumetric heating of foods. Joule heating, electrical resistance heating, and ohmic heating—all of which get their names from Ohm's law, where sample under study is enclosed between two electrodes and behaves as an electric resistor.[4] The quantity of heat produced is directly related to voltage gradient induced electric current.[5] The Ohmic heating falls under green technology where food is heated uniformly at low frequency and more than 90% of energy is converted into heat.[6]

The traditional methods of heating apply high temperature which generally degrade the sensory and nutritional qualities of food material. The internal heat generation and shortening of the treatment period which causes minimal degradation of heat sensitive compounds are the main features of ohmic heating.[7] The ohmic heating is a quick way to process both liquid and liquid-solid products.[8] Many researchers have observed that ohmic heating pasteurizes juices and food effectively. The efficiency of ohmic heating is affected by various intrinsic and extrinsic factors viz. pH, sugar concentration and electric field, frequency respectively.[9,10] It is important to mention here that due to electrode corrosion, high costs of energy and the difficulty of finding inert material and fast development of ultra-high temperature (UHT), ohmic heating was abandoned.[11] The ohmic heating once again has become an important alternative method of preservation in food viz. evaporation, dehydration, baking, extraction and balancing etc.

India is the world's second-largest producer of fruits and vegetables in 2019, according to the Food and Agriculture Organization (FAO) of the United Nations. The fruit juice processing is one of most important commercial activity for companies involved in this business. However, mechanical damage including cutting, slicing, pulping etc. lead to enzymatic browning which in turn leads to spoilage in quality parameters of fruits and vegetables. For deactivation of the enzymes and other organisms, the heating treatment is generally applied.[12] The conventional heating methods cause greater degradation of nutritional qualities of food material than ohmic heating. The ohmic heating which results in volumetric heating of samples without causing any transmission losses.[13,14] Investigations based on ohmic heating for pasteurization technique in juices are limited.[15] The present study made an attempt to report the work done to determine the ohmic heating for pasteurization using electrical conductivity of juices and its effect on pH and Total Soluble Solids (TSS) of juices.

Materials and Methods

The principle behind ohmic heating is that when electrical energy passes through the sample, it dissipates as heat energy. The electrical resistance offered by the sample causes volumetric heating. The ohmic heating has very high degree of efficiency which is generally > 90.0%.[6] On applying alternating current through sample, there is a movement of ions which causes collisions with each other, which in turn lead resistance to the movement of ions and causes heat loss. The quantity of heat loss depends on applied voltage, amount of current and electrical conductivity of the sample.[16]

The flow of the electrical current through the samples which act as resistance will be governed by Ohm's law of heating,

$$V \propto I$$

$$V = IR \qquad ...(1)$$

where V is applied voltage (volts) and I is current (in Amps) and R is the resistance offered by the sample. The ohmic method of heating is highly suitable for samples having conductivity between 0.1 and 10.0 S/m as the frequency of current used in ohmic heating is lesser than used in radio and microwave heating. The rate of heating is determined by the efficiency of the power source, parameters of the medium viz. conductivity, viscosity, specific heat capacity and the design of equipment.[17] However, various factors which affect the ohmic heating are electrical conductivity, concentration of ions, strength of applied field and orientation of particles.

Electrical Conductivity

The conductivity of the samples under investigation determines the efficiency of the ohmic heater. It is also the most important parameter from designing point of view of an efficient ohmic heater. The electrical conductivity of solids and liquids increases linearly, which in turn are affected by applied voltage, concentration and temperature. When alternating current passes through the samples, change in its electrical conductivity indicates that electrical energy is converted into heat.[18] Electrical conductivities can be measured from voltage and current data using the below equation:

$$\sigma = IL/VA \qquad ...(2)$$

where, σ is the electrical conductivity of the sample (S/m), L is the length between electrodes or the length of the ohmic cell (m), A is the cross-sectional area of the cell (m_2), I stand for electrical current in the sample and V is the voltage applied.

Electric Field Strength

Ohmic heating rate depends upon the strength of the applied field and the distance between the electrodes. However, acidity of the sample, solid content and viscosity can also affect the ohmic heating rate. The voltage gradient has significant effect on heating rate of the samples and higher the voltage gradient, faster is the heating. Icier and Yildiz reported the same result that fruits and vegetable products were successfully ohmically heated.[5,19] At a particular voltage gradient (24V/cm) the heating rate was 0.086, 0.100, 0.128, 0.130, 0.152 °C/sec for 60%, 70%, 80%, 90%, 100% concentration of samples, respectively. In other words, heating rate is less for lower concentrations, which in turn can be explained by the decreasing number of charge carriers or free ions, hence less collision between the ions. Thus, less heat transfer occur which is the basic cause of increase of temperature with the passage of current through the juice.

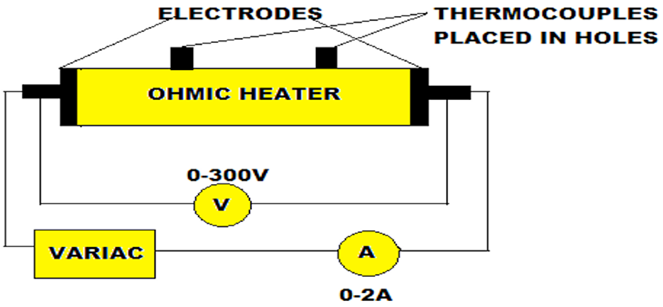

Fig.1. Schematic diagram of ohmic heater

Electrode Selection

The selection of electrodes plays an important role in heat loss during ohmic heating and sometimes can lead to a very high temperature gradient.[20] The possible choices are titanium, stainless-steel and aluminum electrodes. It has been observed that titanium electrodes have a higher temperature in heating than the stainless-steel electrodes of the same thickness. The contamination of the juices may be due electrolysis of aluminum electrodes. The platinized titanium electrodes are the best materials and show greater degree of resistance to electrolysis and offer a satisfactory heating rate.[21]

Experimental Setup

The ohmic heating unit comprised of a variable transformer power supply (AC, 50Hz and applied voltage: 0-255V) and an ohmic heating cell. The ohmic cell employed was constructed from PVC (polyvinyl tetrachloride) cylinder having length of 10.5 cm and diameter 3.47 cm. Two steel (stainless) electrodes having thickness of 0.2 cm were placed at extreme corners of the ohmic tube. Although stainless steel electrodes exhibit pronounced corrosion rates and changes pH of the heating media, yet steel electrodes were preferred as they are comparatively cheaper and easily available. In order to measure temperature changes in the juice samples, two K-type thermocouples were used. The observed variation in temperate was ±1°C inside the cell during ohmic heating. A digital ammeter of the range 0-2 A was connected in series and a voltmeter of range 0-300 V was connected in parallel between the power source and the heating tube to measure the values of current passing through the juice sample and the voltage applied across the two ends of the ohmic heater respectively. Figure 1 depicts the designed ohmic heater's schematic diagram. The present study was aimed to determine the temperature dependence of electrical conductivity, effect on pH and Total Soluble Solids (TSS) of selected juices of litchi, mango, guava and aloe vera, by heating it at a particular voltage gradient. The pH was measured with water proof pH tester of HANNA probemeter (HI 98127) having range is -2.0 to 16.0. The TSS was measured using analogue hand held refractometer (ERMA type). The distilled water was used for calibration purpose. The pH and Total Soluble Solids (TSS) of selected juices was measured before and after ohmic heating for each voltage gradient at room temperature. Each measurement was repeated three times to minimize the experimental errors. The juices were procured from the local market of reputed brand. All analyses were carried out in triplicates and t-test was used to compare the quantified variables in the samples. The significance was calculated for $p < 0.05$. The statistical analyses were performed with the SAS 9.3.

Results

Figures 2 to 5 illustrate how electrical conductivity changes with temperature for litchi, mango, guava, and aloe vera juices. The curves depicting the variation of electrical conductivity with temperature for juices of litchi, mango, guava and aloe vera are shown in Figs. 2 to 5. It has been observed from these plots that the variation of electrical conductivity with temperature follows an increasing linear trend and is higher for higher values of voltage gradient. The maximum variation in electrical conductivity as a function of voltage gradient was found for aloe vera juice (0.35 - 1.79 S/m) and minimum variation was observed for mango juice (0.04 – 0.17 S/m). The heating time is significantly impacted by the voltage gradient. This can be clearly seen from the figures that the slope of curves for the 27 V/cm data has a higher value than that for 7 V/cm, which indicate that the processing time is shorter in case of higher voltage gradient and that the temperature increase is exponential in comparison to lower voltage gradient. As the electrical conductivity values increased (0.35 - 1.79 S/m), the heating time to reach the target temperature (70°C) decreased significantly. The pH and TSS are two important quality parameters used to assess the freshness. taste, and overall quality of fruit juices. These values of juices were measured at different voltage gradients before and after the ohmic heating and obtained values are reported in the Tables 1 and 2.

Discussion

The electrical conductivity increases with temperature (30-70˚C) for all the juices for a given voltage gradient, and consistent with earlier measurements.[22-26] The increase in conductivity with temperature can be attributed to breakdown of membrane inside the cells which leads to the released of ionic compound and simultaneously increased the electrical conductivity.[27] By increasing the voltage gradient, more current flowed through the product and the ionic components were able to travel quickly, increasing the juices' electrical conductivity at given temperature. Further, it can be concluded that processing time is very shorter for aloe vera juice and is longer for mango juice using ohmic heating. However, the sugar content and soluble solids the samples also have an impact on electrical conductivity which decreased following the increase in concentration and sugar content.[28] The juices in general are acidic in nature, and acidity is one of the factors which can affect the rate of ohmic heating. The pH values of the juices were measured at different voltage gradients before and after the ohmic heating. It has been observed that the pH value of juices changes after ohmic heating as depicted in the Table 1. A statistical analysis of pH values was carried out by using paired t-test before and after giving ohmic heating treatment to juices at different voltage gradients. The results obtained from the analysis of pH has been listed in the Table 1. It has been observed that the pH values for mango and guava juices were increased with increase in the voltage gradient and is significant also. Further, the results revealed that for juices under consideration have higher pH value (less acidic character and more shelf-life) at gradient of 24V/cm. Hence, it is concluded that ohmic heating has an overall effect on pH values but depends upon the type of juice under investigation. It has been reported in literature that ohmic heating may causes hydrolysis of juices and corrosion reactions between the electrodes and the electrolyte solution may occur, which can affect and alter the pH values, a significant loss of buffering capacity was also noted.[27] The results were in accordance with the study.[29-31] Another important factor which affects electrical conductivity is Total Soluble Solids (TSS). The change of TSS value of juices during ohmic heating, which is an important parameter in food processing and to determine the sugar content in the product. The measured values of TSS (o Brix) of selected juices are listed in the Table 2. All the values have been measured before and after ohmic heating of the juice. For statistical analysis, paired t-test was applied to obtained values before and after ohmic heating at different voltage gradients (Table 2). It has been found that the ohmic heating does not causes statistically significant change in the TSS of selected juices. These results are in accordance with results of where they have reported that TSS values of grape juice changes slightly after ohmic heating.[5]

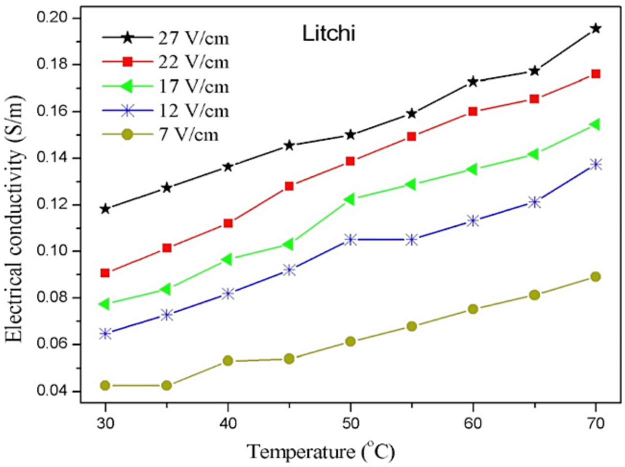

Fig. 2:The variation of electrical conductivity with temperature of litchi juice at different voltage gradient

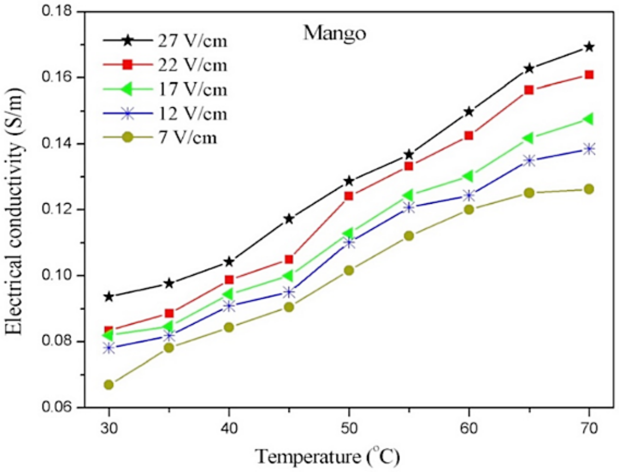

Fig. 3:The variation of electrical conductivity with temperature of mango juice at different voltage gradient

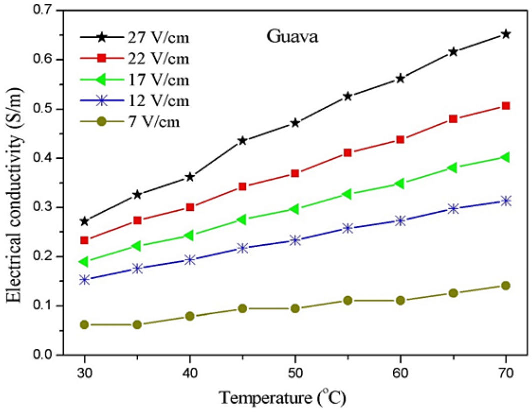

Fig. 4:The variation of electrical conductivity with temperature of guava juice at different voltage gradient

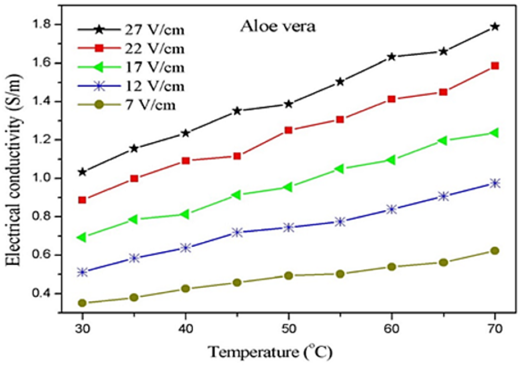

Fig. 5:The variation of electrical conductivity with temperature of aloevera juice at different voltage gradient.

Table 1: The pH and t- values at different voltage gradients before and after ohmic heating

Juice	pH before heating	pH after ohmic heating				
		Voltage Gradient (V/cm)				
		24 (t-values)	20 (t-value)	16 (t-value)	12 (t-value)	8 (t-value)
Litchi	3.33	3.31 (0.33^{NS})	3.2 (9.02^{NS})	2.94 (7.85^{NS})	2.90 (5.80^{NS})	2.86 (9.05^{NS})
Mango	2.78	3.57 (51.72**)	2.9(7.17*)	2.84(20.79**)	2.62(13.99**)	2.49 (25.11**)
Guava	3.8	5.2(122.98**)	4.77(14.20**)	4.53(34.36**)	4.36 (47.98**)	4.27 (18.17**)
Aloe Vera	4.18	4.04 (2.02^{NS})	3.59 (52.83^{NS})	3.54(27.78*)	3.41 (5.75*)	3.34 (6.79*)

t-values are in parentheses
*significant at 5% level of significance ($p < 0.05$)
** significant at 1% level of significance ($p < 0.01$)
NS – non significant

Table 2: The TSS and t-values at different voltage gradients before and after ohmic heating

Juice	TSS before heating	After ohmic heating				
		Voltage Gradient (V/cm)				
		24 (t-values)	20 (t-value)	16 (t-value)	12 (t-value)	8 (t-value)
Litchi	15	15.5 (5.00^{NS})	15 (1.00 NS)	15.6 (3.00^{NS})	15.8 (1.01^{NS})	15.3 (5.00^{NS})
Mango	13	13.2 (3.65*)	13.4 (3.14NS)	13.6 (6.00^{NS})	13.8 (6.93^{NS})	13.6 (5.20^{NS})
Guava	12.2	12.2 (0.48^{NS})	12.2 (0.38NS)	12.0 (3.21^{NS})	12 (3.02^{NS})	11 (4.86^{NS})
Aloe Vera	5	5.4 (5.0^{NS})	5 (1.26NS)	5.1(--)	4.3 (7.62^{NS})	5 (2.00^{NS})

t-values are in parentheses
*significant at 5% level of significance ($p < 0.05$)
NS – non significant

Conclusion

In addition to being an energy-efficient method, ohmic heating has been shown to have several potential future uses in the food and other industries. In present study, we have reported the effect of ohmic heating on electrical conductivity, pH and TSS of juices. The electrical conductivity, an important parameter in food processing industry was found to increase with rise in temperature. The ohmic heating system's performance, electrical conductivity, and heating rate were all significantly impacted by the voltage gradient. As the processing time decreases with high voltage gradient but need to take utmost take to avoid bubble formation in the heater. Hence an optimum value of voltage gradient is needed to ensure that there is no bubble formation. The significant change in the pH of mango and guava juices was observed ($p<0.01$), for aloe vera change in pH is also significant but at ($p < 0.05$) while the change is non-significant for litchi juice before and after ohmic heating for various voltage gradients. However, the ohmic heating does not causes statistically significant change in the TSS of selected juices. The uniform distribution of temperature as well as uniform heating are the main advantages of ohmic heating. This technique can be extended to wider variety of food and juices in future by having special design of the ohmic heaters for different types of food and juices.

Acknowledgement

The author is highly grateful to the Head of the Department of Mathematics, Statistics and Physics for providing the necessary infrastructure for this work and to the Dean of College of Basic Sciences & Humanities for providing financial support under the scheme SFS-2 of the college. The authors are also thankful to Dr Paramjit Singh (Professor) for his consistent guidance and motivation to conclude this work.

Funding Sources

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest

The author(s) do not have any conflict of interest.

Data Availability Statement

The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Clinical Trial Registration

This research does not involve any clinical trials.

Permission to Reproduce Material from Other Sources

Not applicable.

Author Contributions

- **Rashneet Kaur:** Data Collection, Analysis, Visualization, Design of the experiment
- **Rajeev Kumar Sharma:** Conceptualization, Methodology, Writing – Original Draft, Analysis, Supervision.

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