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Review Article

Ohmic heating: Factors affecting on its application in food processing

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Abstract - Ohmic heating (OHM) has gained much interest in the food industry as a novel thermal food processing technology which improves food quality and nutritional value as well as reducing both processing time and cost. OHM, also referred to as Joule heating, electrical resistance heating, and resistive heating is an alternative method of warming food by passing an electric current through a conductor. It has significant advantages over conventional heating including reduced heating time (rapid heat generation), uniform heating, reduced quality losses and diminished energy consumption. However, the successful application of OHM in food processing depends on several parameters including the electrical conductivity and specific heat capacity of the food materials, systematic design, product size, heat capacity and viscosity which were reviewed here.

Keywords: Ohmic heating, electrical conductivity, food processing, electric field strength

1. Introduction

Heat treatment is a common commercially used method in food processing to preserve food products by inactivating the enzymes and destroying the microorganisms. Food and biological materials are heated primarily to extend their shelf life or improve taste. In conventional heating, heat is generated outside the material to be heated by one of three transfer forms as conduction, convection and radiation. However, major problems include low and non-uniform heating and long processing time (Sarang *et al*., 2008). A high-quality product with minimum changes in structure, nutrition, or organoleptic properties can be achieved using a method with short operating time (Rahman, 1999). Ohmic heating (OHM) is one of the most promising methods of food processing, also known as Joule heating, electrical resistance heating, resistive heating, and electroconductive heating which utilizes the inherent electrical resistance of food materials to generate heat (Wang *et al*., 2006). Most food materials contain ionic constituents such as salts and acids which allow the conduction of electrical current (Palaniappan and Sastry, 1991). This process can be used to generate heat within the product, transforming the electrical energy into thermal energy and thus heating the materials at exceptionally rapid rates without the need for a heating medium or surface. This process also avoids excessive thermal damage to labile substances such as vitamins and pigments (Castro *et al*., 2004; Sastry and Barach, 2000; Palaniappan and Sastry, 1991). OHM is applicable in several processes including blanching, evaporation, dehydration, pasteurization and extraction (FDA/CFSAN, 2000). This review, therefore, focused on the process parameters of OHM and discussed its potential applications in food processing compared with other existing thermal methods.

2. OHM generation

OHM, Joule heating or electrical heating is defined as a process that occurs when electrical (alternative) current is passed through a food material, and heat is generated by virtue of the material's electrical resistance (Vicente *et al.*, 2006; Lakkakula *et al*., 2004). The basic design of an ohmic heater is shown in Figure 1. Heating creates internal energy transformation (from electric to thermal) within the food material (Sastry and Barach, 2000). Food materials containing sufficient water and electrolytes allow the passage of electric current, and OHM can then be used to generate heating inside the product (Imai *et al*., 1995). Therefore, OHM can be considered as an internal thermal energy generation technique and not as a thermal energy transfer as it does not depend on heat transfer either through a solid-liquid interface or inside a solid in a two-phase system (Knirsch *et al*., 2010). Interestingly, OHM processing enables the heating of food materials at rapid rates (within a few seconds to a few minutes) (Sastry, 2005), and also under certain circumstances, large particulates and carrier fluids to heat at comparable rates. OHM, therefore, can be used for high temperature/short time (HTST) and ultrahigh temperature (UHT) technology on solids or suspended materials (Imai *et al*., 1995), resulting in an increase in final product quality and value added products (Vicente *et al*., 2006; Castro *et al*., 2003; Kim *et al*., 1996; Parrott,

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1992; Tucker, 2004). Currently, OHM is gaining popularity in the food industry as an alternative thermal food processing method which preserves both quality and nutritional value. However, the efficiency and success of OHM with regard to food processing depends on key parameters including electricity, the specific heat capacity of the food materials, electrical conductivity, OHM systematic design, product size, heat capacity and viscosity.

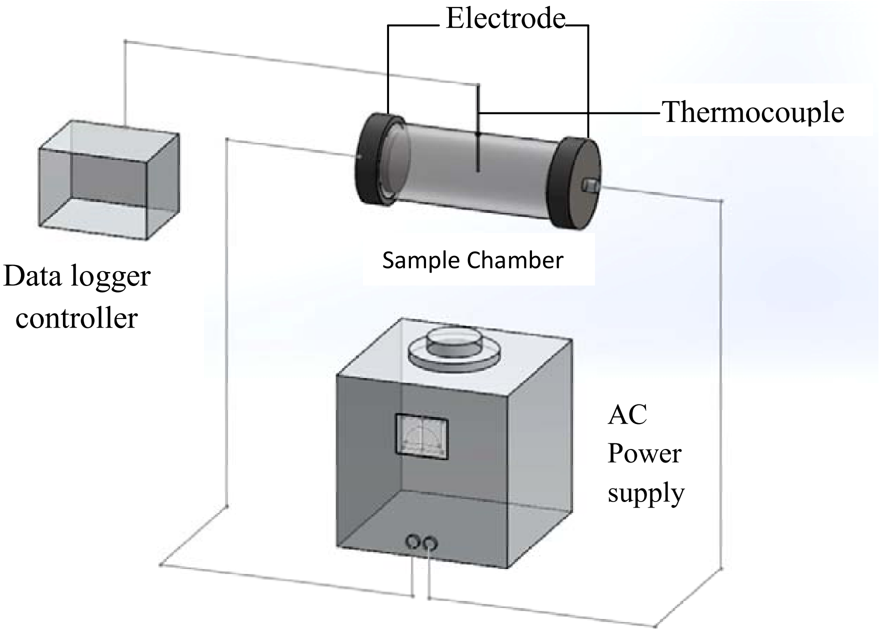

Figure 1. Schematic diagram of a basic ohmic heating generator

3. Parameters of OHM affecting food processing

3.1 Electricity

The movement of charge carriers throughout a substance is known as electricity and includes electrical current, voltage or electric field strength (E) and resistance. An increase in electrical conductivity or current through fruit and cereal samples during OHM at a constant voltage gradient has been reported (Darvishi *et al*., 2012; Loypimai *et al*., 2009; Castro *et al*., 2004). Sastry and Palaniappan (1992) noted that the rate of OHM generation was directly proportional to the square of E and the electrical conductivity. Diffusion of beet dye from beet root into a liquid media was enhanced by OHM, and the yield of dye extracted was proportional to the E used (Lima *et al*., 2001; Schreier *et al*., 1993; Halden *et al*., 1990). Loypimai *et al*. (2015) demonstrated that OHM with optimum Es (30% and 40% moisture content of the bran and E = 100, 150, and 200 Vcm^{-1}) improved the extraction of anthocyanins, tocols, and γ-oryzanol from black rice bran. Knirsch *et al*. (2010) discovered that naturally porous cell walls had a specific dielectric strength which could be exceeded by the electric field and resulted in electroporation. Interestingly, in the extraction process, the electric energy applied under OHM is responsible for the breakdown of the plant cell membranes, which enables much easier extraction when compared to the process without OHM (Loypimai *et al*., 2015; Nair *et al*., 2014; Uemura *et al*., 2010) (Table 1). Electrical current is measured and expressed in amperes (A) (where one ampere is the flow of ~$6x10^{-18}$ electrons per second through a substance). Voltage is the electron pressure or a measure of the ability to move an electrical charge through a resistance (opposition to flow of electricity) (Shugar and Ballinger, 1996). Voltage can be calculated by multiplying the current and the resistance. This is known as Ohm's Law, first published by physicist Georg Ohm in 1827.

$$V = I \text{ x } Z \tag{1}$$

where voltage = V, current = I, and impedance = Z.

3.2 Specific heat capacity

Specific heat is the amount of energy required to change the temperature of a substance by a certain interval. This value can be useful for determining the temperature distribution in a food material as it is heated ohmically. The specific heat of a substance can be calculated using the variables of heat energy used, mass of the substance, and the change in temperature of the system. The energy added to a system can be calculated from the electricity used to heat the substance to a particular temperature, and also the time taken to reach that desired temperature. Alternatively, equation 2 below can be used.

$$C_p = \frac{Q}{m \text{ x } \Delta T} \tag{2}$$

where the specific heat of a substance = C_p, heat added = Q, mass = m, and the change in temperature = ΔT.

3.3 Electrical conductivity

Electrical conductivity is the most critical factor for electrical thermal processing. A food material with higher electrical conductivity during OHM increases in temperature better than a food material with low electrical conductivity. This process mostly focuses on 'cold spots' which are located at the slowest heat generating zones of a food material. They require special consideration as current knowledge of conventional heating cannot be extrapolated to OHM technology (FDA/CFSAN, 2000). Electrical conductivity measures the ability of a substance to transmit an electric charge and is expressed in Siemens per meter (Sm^{-1}). Electrical conductivity is the ratio of substance density to electric field strength and depends on the chemical composition of the substance. In OHM, conductivity is a measure of the mineral, ionic, and moisture contents. Most foods consist of ionic ingredients such as salts and acids, therefore, electric current under OHM passes through food and generates heat inside it (FDA/CFSAN, 2000). Higher conductivity is observed in substances with larger amounts of dissolved sodium chloride (Table 1). The efficiency and success of OMH are dependent on the electrically conductive nature of the food material to be processed (Zoltai and Swearingen, 1996). A total dissolved solids (TDS) meter is a popular method for measuring electrical conductivity. TDS is the total amount of mobile charged ions in a substance, calculated by measuring the number of cations (positively charged) and anions (negatively charged) (HM Digital, Inc., 2005). Loypimai *et al.* (2009) observed that bran with high moisture content had less electrical resistance, whereas electrical conductivity was high. Moisture and ionic components increased electrical conductivity (Bengston *et al.*, 2006).The electrical conductivity of rice bran and liquid fruit products like juices and purees has been studied and reported (Loypimai *et al.*, 2009; Icier and Ilicali, 2005; Castro *et al.*, 2004; Palaniappan and Sastry, 1991). Electrical conductivity of pear and apple at 25ºC was observed by Mitchell and de Alwis (1989). Castro *et al.* (2003) reported that the electrical conductivity of fresh strawberry ranged from 25 to 100°C and was a linear function of the temperature. Electrical conductivity was calculated from voltage and current data using equations 3 and 4 (Icier *et al.*, 2008).

$$\frac{dT}{dt} = \left[\frac{V^2\sigma}{Kmc_p}\right] \tag{3}$$

$$\sigma = \frac{L}{AR} \tag{4}$$

where σ is electrical conductivity (Sm^{-1}), V is voltage, I is current, R is resistance, m is mass, L is the gap between the electrodes (m) and A is the electrode surface area (m^2).

In general, electric conductivity is a function of the material structure and changes as food samples are heated; however, in some foods heat treatment barely alters the pattern of electrical conductivity (Pongviratchai and Park, 2007). Electrical conductivity of materials below 0.01 Sm^{-1} and above 10 Sm^{-1} are not applicable to OHM because very high voltages or very large amperes are needed for sufficient heat generation by Joule power (Knirsch *et al.*, 2010; Piette *et al.*, 2004; Piette *et al.*, 2001).

3.4 OHM systematic design

Nowadays, there are limitless possibilities for the design of an OHM system, but key components as a power supply and an OHM generator are required to create electricity. The generator is connected to all electrodes in physical contact with the substance to pass the electrical current. The electrode gap (distance between the electrodes) can oscillate depending on the capacity of the system, and both electrode gap and electric field strength can be varied and adjusted depending on the frequency and waveform of the electric field. In an in-line field system, the food material upstream is exposed to higher field strength than the food downstream due to the drop in voltage throughout the system. In a cross-field system, the electric field strength is constant throughout (FDA/CFSAN, 2000). Qihua *et al.* (1993) developed an ohmic heater consisting of a power supply system, a flow control system, a data acquisition system and two OHM units (one for static medium and the other for continuous flow). Tulsiyan *et al.* (2008) used an ohmic device consisting of ten electrodes stuck on a base made from acetal and an aluminum top. Sarang *et al.* (2008) studied the electrical conductivity of meat and fruits using an OHM unit with ten cylindrical cells made from Ultem® equipped with platinized titanium electrodes.

3.5 Product size, heat capacity and viscosity

In a food with small particles (no more than 5 mm) such as emulsions and colloids, the electric conductivity will be ignored, but for larger particles ranging from 15–25 mm, orientation relative to the electrical field has a significant effect on electrical conductivity and the relative heating rates (McKenna *et al.*, 2006). When a food contains solid particles in a fluid medium and both have similar electrical conductivities, then, the other components with lower heat capacity will be heated faster. Foods with high densities and high specific heat values tend to have low conductivity, and as a consequence heating rates are slow (Palaniappan and Sastry, 1991). Shirsat *et al.* (2004) studied the conductivity of different pork cuts at 20°C. Results indicated that lean was highly conductive compared to fat. Sarang *et al.* (2008) reported that fruits (red apple, golden apple, peach, pear, pineapple and strawberry) were less conductive than chicken, pork and beef samples. Within fruits, peach and strawberry were more conductive than apples, pear, and pineapple mainly due to differences in heat capacity and chemical components. On the other hand, the viscosity of the fluid phase in solid-liquid mixture has an important role in OHM and also affects heating generation rate i.e. the higher viscosity fluids tend to result in the faster OHM than the lower viscosity fluids (Marcotte *et al.*, 2000). However, the viscosity of the fluid must be adequate to create uniform heating and prevent from cold shadow within the liquid (Ahmed *et al.*, 2009).

3.6 Frequency and waveform

The common frequencies employed for OHM of foods are 50 Hz and 60 Hz. Previous studies reported that both frequency and waveform influence OHM generation and final quality of food products. Lima *et al.* (1999) showed that frequency and waveform affect the electrical conductivity and heat generation of food samples. They suggested that at low frequency the electrical conductivity was high, and the electrical conductivity of turnip tissue was significantly higher for sine and saw tooth waves compared to square waves at 4.0 Hz. Determination of the lowest effective frequency would be a worthwhile subject for further research since improved mass transfer was reported for frequencies as low as 4.0 Hz (Lima and Sastry, 1999). Kim and Pyun (1995) and Imai *et al.* (1995) proposed that the frequency of alternative current influenced the capacity, efficiency of extraction and the heating rate. Lakkakula *et al.* (2004) reported that lowering the frequency of the alternating current by 1 Hz significantly increased the capacity to extract rice bran oil. However, use of low frequencies for OHM may come from the polarization and capacitance of the system and the problem from the oxidation-reduction (redox) reaction. Altering the frequency and waveform during OHM also influences the heat and mass transfer properties of foods and some results are shown in Table 1.

4. Electroporation effect

Cell electroporation is defined as the formation of pores in cell membranes due to the presence of an electric field. As a consequence, the permeability of the membrane is enhanced and material diffusion throughout the membrane is achieved by electro-osmosis (An and King, 2007; Lima and Sastry, 1999). The electric breakdown or electroporation mechanism is dominant for non-thermal effects of OHM (An and King, 2007; Sensoy and Sastry, 2004). Yoon *et al.* (2002) observed that under OHM the electric field appeared to have both direct and indirect effect on the cell wall, and intracellular materials were exuded to the culture medium. The exudates seemed to be composed of amino acids, protein, nucleic acids, coenzymes, and related material. Few studies have been conducted on the electroporation of rice bran during OHM; however, these showed that naturally porous cell walls allowed the cell membrane to build up charges, which formed disruptive pores resulting in electroporation (Cho *et al.*, 1996). The electric energy applied was responsible for the breakdown of the rice bran cell membranes, which enhanced pigment extraction compared to extraction without OHM (Loypimai *et al.*, 2015; Nair *et al.*, 2014; Uemura *et al.*, 2010) (Figure 2).

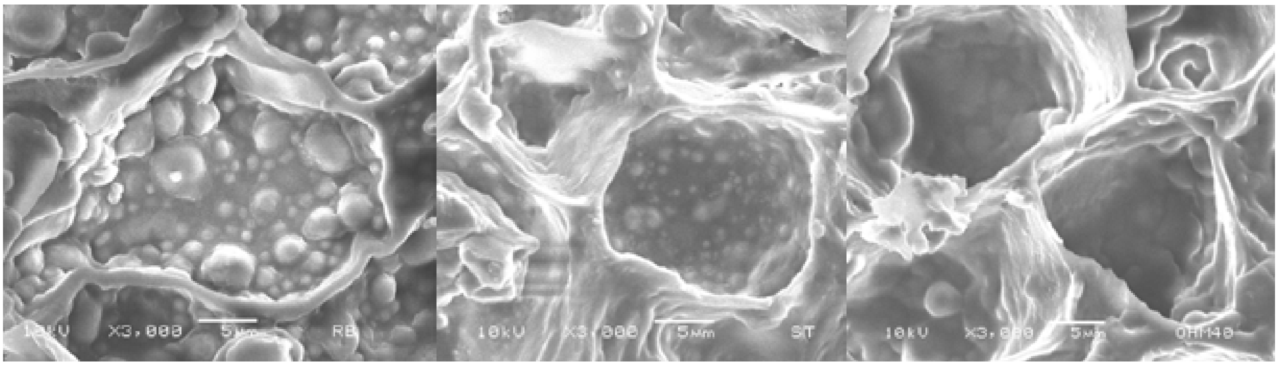

Figure 2. SEM images of aleurone layer of untreated raw bran (A), steamed rice bran(B), and (C) ohmically treated bran (40% MC and E = 200 Vcm^{-1})

5. Advantages and disadvantages of OHM

There are many advantages of OHM technology for food processing and preservation. Heating in the food materials is created by internal heat transfer from electrical to thermal without the limitations of either conventional heat transfer or radiative dielectric penetration for microwave heating (Skudder, 1988). Higher temperatures in particulates than liquids can be achieved by OHM which is not possibly by conventional heating. Reduction of fouling at the heat transfer surface and burning of the food products results in minimal mechanical damage and reduces nutrient and vitamin losses (Loypimai *et al.*, 2015; 2016). OHM is efficient as over 90% of the electrical energy is converted into heat and the heating system is easy to control (instant switch-on and shut-down) (Skudder, 1988; Kim *et al.*, 1996; Palaniappan and Sastry, 1991). Optimal capital investment, food product quality and safety as well as high solid loading capacity were achieved using OHM. OHM can also allow high temperature/short time (HTST) processing of particulates, thus avoiding excessive thermal damage to labile substances such as vitamins, pigments, and other thermally sensitive compounds (Kim *et al.*, 1996; Castro *et al.*, 2004). OHM can be considered as an environmentally friendly or alternative green technique.

However, there are some drawbacks in the OHM such as type of food (a food containing fat globules can be troublesome to effectively heat ohmically), difficulties to control the rate of heat generation during OHM process due to change of electric conductivity of heating material, and electrochemical reactions (Rahman, 1999; Sakr and Liu, 2014). Therefore, by utilizing the knowledge of the aforementioned issues in designing an OHM system, these disadvantages may be more easily eliminated and controlled.

Table 1. Food processing using ohmic heating and the factors affecting food quality.

Food material items	Objective	Factors/conditions used	Results/ Advantages	References
Black rice bran	OHM-assisted extraction of anthocyanins and bioactive compounds from black rice bran to prepare functional food colorant powder	Different moisture content (MC) of black bran : 30–40% (wet basis) Four levels of electric field strengths (E) : 50, 100, 150, and 200 Vcm^{-1}	The colorant powder obtained from rice bran extracted using OHM to assist extraction with 30% MC (E = 100, 150, and 200 Vcm^{-1}) and 40% MC (E = 50, 100, 150, and 200 Vcm^{-1}) had the highest levels of α-tocopherol, γ-oryzanol, individual anthocyanins (cyanidin-3-*O*-glucoside, cyanidin-3-*O*-rutinoside, delphinidin and malvidin) and total anthocyanins.	Loypimai *et al*. (2015)
Cabernet Sauvignon red grapes pomace	OHM-assisted extraction of polyphenols	E at 400 Vcm^{-1}, Extraction time for 60 min at 50°C, 30% of ethanol in water as solvent.	The highest extraction yield of polyphenols. Polyphenol content extracted by OHM was 36% higher than samples without OHM.	Dara *et al*. (2013)
Rice bran (Red Triveni and Basmati rice)	OHM as a pre-treatment in solvent extraction of rice bran oil	Three current levels : 5, 15, and 20 A, Three concentrations of sodium chloride: 1, 0.1 and 0.01 M, Heating time: 1, 2, and 3 min)	OHM treated rice bran with 1 M sodium chloride solution and a current of 20 A for 3 min gave maximum oil extraction with minimum extraction time.	Nair *et al*. (2014)
Rice bran	Rice bran stabilization using OHM	Es ranged from 75 to 225 Vcm^{-1} MC of rice bran was 20, 30, and 40 (% wet basis).	The Es at 150-225 Vcm^{-1} and MC of 30-40% were appropriate conditions to retard the free fatty acid (FFA) content, lipase activity and lipid oxidation during storage. The ohmically-treated rice bran yielded higher levels of phenolic compound, α-tocopherol, γ-oryzanol, and antioxidant activity than those obtained using conventional methods.	Loypimai *et al*. (2009)
Rice bran	Rice bran oil extraction	Two frequencies (1 and 60 Hz) Three moisture contents of rice bran (10.5%, 21%, and 30%)	OHM using an alternating current of 1 Hz yielded significantly more oil than OHM conducted at 60 Hz for all moisture levels.	Lakkakula *et al*. (2004)
Tomato	Tomato peeling by OHM	a combination of OHM and low lye concentrations (NaCl/NaOH or NaCl/KOH, NaCl/CaCl$_2$ or NaCl/NaOH/CaCl$_2$ mixture)	The best condition for tomato peeling in terms of quality, weight loss, and peel cracking time was observed for 0.01/0.5% (NaCl/KOH) at 2020 Vm^{-1}.	Wongsa-Ngasri and Sastry (2016)
Red pepper paste (Gochujang)	Pasteurization of fermented red pepper paste by OHM	Frequencies ranged from 40–20,000 Hz and applied voltages ranged from 20–60 V.	The entire sample was heated uniformly, and the specific heating rate was highly dependent on the frequency which peaked at 5 kHz and 60 V.	Cho and Chung (2016)

Table 1. Food processing using ohmic heating and the factors affecting food quality. (cont.)

Food material items	Objective	Factors/conditions used	Results/ Advantages	References
Orange juice	Inactivation of *Escherichia coli* O157: H7, *Salmonella enterica* Serovar Typhimurium and *Listeria monocyto genes* in orange juice	pHs of juice sample: 2.5, 3.0, 3.5, 4.0, and 4.5	*E. coli* O157:H7 and *L. monocytogenes* were inactivated most rapidly at pH 4.5, while *S. Typhimurium* was inactivated most rapidly at pH 2.5. However, the overall quality of orange juice subjected to OHM was not influenced greatly at any pH level.	Kim and Kang (2015)
Acerola pulp	Determine the effect of the electric field frequency on ascorbic acid degradation and color changes in acerola pulp during OHM	Electric field frequencies ranged between 10 and 10^5 Hz	Low electric field frequency (10 Hz) resulted in greater ascorbic acid degradation and higher visual color changes, while high levels did not affect the degradation kinetics of ascorbic acid and pigment compounds.	Mercali *et al.* (2014)
Cold water shrimp	Apply OHM to cold water shrimp and brine mixtures	Salt concentrations : 10, 15, and 20 kg m^{-3} Es ranged from 1150 Vm^{1} to 1,725 Vm^{-1}	A linear relationship between the heating time (the time to reach 72°C) and process variables (E and the salt concentration) was observed over the experimental range.	Pedersen *et al.* (2016)
Pomegranate juice	Investigate the effect of OHM on electrical conductivity, heating rate, system performance and pH of the juice	Voltage gradient: 30–55 Vcm^{-1}	The change in the pH at voltage gradients of 30–45 Vcm^{-1} decreased and as the voltage gradient increased the change increased.	Darvishi *et al.* (2013)
A reusable and ligand-free Suzuki–Miyaura reaction in water	OHM-assisted synthesis of bioactive 3-arylquinolin-4(1H)-one	Using an efficient, reusable, and ligand-free protocol developed for the Suzuki–Miyaura coupling of 1-substituted-3-iodoquinolin-4(1H)-ones with several boronic acids in water using Pd $(OAc)_2$ as a catalyst and tetrabutylammonium bromide (TBAB) as the phase transfer catalyst	OHM could generate libraries of B ring-substituted 3-arylquinolin-4(1H)-ones and showed good substrate generality, ease of execution, and short reaction time.	Pinto *et al.* (2015)
A Diels–Alder cycloaddition, a nucleophilic substitution, and an N-alkylation	As a new efficient process for organic synthesis in water	Organic synthesis in aqueous media based on a direct OHM reactor	OHM reactor increased dynamics/mobility of charged species leading in several cases to higher reaction yields and shorter reaction times	Pinto *et al.* (2013)

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References

Ahmed, J., Ramaswamy, H. S., Kasapis, S. and Boye, J. I. 2009. Introduction and plan of the book. In: Ahmed, J., Ramaswamy, H. S., Kasapis, S. and Boye, J. I. (Eds.), Novel Food Processing: Effect on Rheological and Function Properties. CRC press, Boca Raton, pp. 1-27.

An, H. J. and King, J. M. 2007. Thermal characteristics of ohmically heated rice starch and rice flours. Journal of Food Science 72(1), 84-88.

Bengston, R., Birdsall, E., Feilden, S., Bhattiprolu, S., Bhale, M. and Lima, M. 2006. Ohmic heating and induction heating. In: Hui, Y. H. (Ed.), Handbook of Food Science, Technology, and Engineering (Vol. 3). FL: CRC Press, pp. 1-8.

Castro, I., Teixeira, J. A., Salengke, S., Sastry, S. K. and Vicente, A. A. 2004.Ohmic heating of strawberry products: electrical conductivity measurements and ascorbic acid degradation kinetics. Innovative Food Science and Emerging Technologies 5, 27-36.

Castro, I., Teixeira, J. A., Sealengke, S., Sastry, S. K. and Vicente, A. A. 2003. The influence of field strength, sugar and solid content on electrical conductivity of strawberry products. Journal of Food Process Engineering 26(1), 17-29.

Cho, H. Y., Yousef, A. E. and Sastry, S. K. 1996. Growth kinetics of lactobacillus acidophilus under ohmic heating. Journal of Biotechnology and Bioengineering 49, 334-340.

Cho, W. and Chung, M. S. 2016. Pasteurization of fermented red pepper paste by ohmic heating. Innovative Food Science and Emerging Technologies 34, 180-186.

Darra, N. E., Grimi, N., Vorobiev, E., Louka, N. and Maroun, R. 2013. Extraction of polyphenols from red grape pomace assisted by pulsed ohmic heating, Food Bioprocess Technology 6(5), 1281-1289.

Darvishi, H., Hosainpourd, A. and Nargesi, F. 2012. Ohmic heating behaviour and electrical conductivity of tomato paste. Journal of Nutritional and Food Science2, 2-9.

Darvishi, H., Khostaghaza, M. H. and Najaf, G. 2013. Ohmic heating of pomegranate juice: Electrical conductivity and pH change. Journal of the Saudi Society of Agricultural Sciences 12,101-108.

FDA/CFSAN. 2000. Kinetics of microbial inactivation for alternative food processing technologies-Ohmic and inductive heating. http://www.cfsan.fda.gov/~comm/ift-ohm.html. In.

Halden, K., de Alwis, A. and Fryer, P. 1990. Changes in the electrical conductivity of foods during ohmic heating. Journal of Food Science and Technology 25, 9-25.

HM Digital Inc. 2005. http://www.tdsmeter.com/faq.html. Culver City, CA.

Icier, F. and Ilicali, C. 2005. Temperature dependent electrical conductivities of fruit purees during ohmic heating. Food Research International 38, 1135-1142.

Icier, F., Yildiz, H. and Baysal, T. 2008. Polyphenoloxidase deactivation kinetics during ohmic heating of grape juice. Journal of Food Engineering 85(3), 410-417.

Imai, T., Uemura, K., Ishida, N., Yoshizaki, S. and Noguchi, A. 1995. Ohmic heating of Japanese white radish *Raphanussativus* L. International Journal of Food Science and Technology 30, 461-472.

Kim, H. J., Choi, Y. M., Yang, T. C. S., Taub, I. A., Tempest, P., Skudder, P. J., Tucker, G. and Parrott, D. L. 1996. Validation of ohmic heating for quality enhancement of food products. Food Technology 50(5), 253-261.

Kim. J. and Pyun, Y. 1995. Extraction of soy milk using ohmic heating. Abstract no. P125, 9th Congress on Food Sci and Technol. Budapest, Hungary

Kim, S. S. and Kang, D. H. 2015. Comparison of pH effects on ohmic heating and conventional heating for inactivation of *Escherichia coli* O157:H7, *Salmonella enterica Serovar* Typhimurium and *Listeria monocytogenes* in orange juice. LWT - Food Science and Technology 64, 860-866.

Knirsch, M. C., Santos, C. A., Vicente, A. A. and Penna, T. C. 2010. Ohmic heating — A review. Trends in Food Science and Technology 21(9), 436-441.

Lakkakula, N., Lima, M. and Walker, T. 2004. Rice bran stabilization and rice bran oil extraction using ohmic heating. Journal of Bioresource Technology 92(2), 157-161.

Lima, M., Heskett, B. F. and Sastry, S. K. 1999. The effect of frequency and waveform on the electrical conductivity-temperature profiles of turnip tissue. Journal of Food Process Engineering 22, 41-54.

Lima, M., Heskitt, B. F. and Sastry, S. K. 2001. Diffusion of beet dye during electrical and conventional heating at steady-state temperature. Journal of Food Process and Engineering 24(5), 331-340.

Lima, M. and Sastry, S. M. 1999. The effects of ohmic heating frequency on hot-air drying rate and juice yield. Journal of Food Sciences 41, 115-119.

Loypimai, P., Moongngarm, A., Chottanom, P. and Moontree, T. 2015. Ohmic heating-assisted extraction of anthocyanins from black rice bran to prepare a natural food colorant. Innovative Food Science and Emerging Technologies 27, 102-111.

Loypimai, P., Moongngarm, A. and Chottanom, P. 2009. Effects of ohmic heating on lipase activity, bioactive compounds and antioxidant activity of rice bran. Australian Journal of Basic and Applied Sciences 3(4), 3642-3652.

Loypimai, P., Moongngarm, A. and Chottanom, P. 2016. Phytochemicals and antioxidant capacity of natural food colorant prepared from black waxy rice bran. Food Bioscience 15(1), 34-41.

Marcotte, M., Trigui, M. and Ramaswamy, H. S. 2000. Effect of salt and citric acid on electrical conductivities and ohmic heating of viscous liquids. Journal of Food Processing and Preservation 24(5), 389-406.

McKenna, B. M., Lyng, J., Brunton, N. and Shirsat, N. 2006. Advances in radio frequency and ohmic heating of meats. Journal of Food Engineering 77(2), 215-229.

Mercali, G. D., Schwartz, S., Marczak, L. F., Tessaro, I. C. and Sastry, S. 2014. Ascorbic acid degradation and color changes in acerola pulp during ohmic heating: Effect of electric field frequency. Journal of Food Engineering 123, 1-7.

Mitchell, F. R. G. and de Alwis, A. A. P. 1989. Electrical conductivity meter for food samples. Journal of Physics E 22, 554-556.

Nair, G. R., Divya, V. R., Prasannan, L., Habeeba, V., Prince, M. V. and Raghavan, G. S. V. 2014. Ohmic heating as a pre-treatment in solvent extraction of rice bran, Journal of Food Science and Technology, 2692-2698.

Palaniappan, S. and Sastry, S. K. 1991. Electrical conductivities of selected foods during ohmic heating. Journal of Food Process Engineering 14(3), 221-236.

Parrott, D. 1992. Use of ohmic heating for aseptic processing of food particulates. Food Technology 46(12), 68-72.

Pedersen, S. J., Feyissa, A. H., Kavli, S. T. B. and Frosch, S. 2016. An investigation on the application of ohmic heating of cold water shrimp and brine mixtures, Journal of Food Engineering 179, 28-35. doi.org/10.1016/j.jfoodeng.2016.01.022.

Piette, G., Buteau, M. L., Halleux D. de, Chiu, L., Raymond, Y., Ramaswamy, H. S. and Dostie, M. 2004. Ohmic heating of processed meat and its effects on product quality, Journal of Food Science 69(2), 71-77.

Piette, G., Dostie, M. and Ramaswamy, H. S. 2001. Is there a future for ohmic cooking in meat processing? Canadian Meat Science Association News, May 2001, 8-10.

Pinto, J., Silva, V. L. M., Silva, A. M. G., Silva, A. M. S., Costa, J. C. S., Santons, L. M. N. B. F. Enes, R., Cavaleiro, J.A.S., Vicente, A. A. M. O. S. and Teixeira, J.A.C. 2013. Ohmic heating as a new efficient process for organic synthesis in water. Green Chemistry 15(4), 970-975.

Pinto, J., Silva, V. L. M., Silva, A. M. G., Santons, L. M. N. B. F. and Silva, A. M. S. 2015. Ohmic heating-assisted synthesis of 3-arylquinolin-4(1H)-ones by a reusable and ligand-free Suzuki-miyaura reaction in water. The Journal of Organic Chemistry 80, 6649-6659.

Pongviratchai, P. and Park, J. W. 2007. Electrical conductivity and physical properties of Surimi-Potato starch under ohmic heating. Journal of Food Science 72(9), 503-507.

Qihua, T., Jindal, V. K. and van Winden, J. 1993. Design and performance evaluation of an ohmic heating unit for liquid foods, Computers and Electronics in Agriculture 9(3), 243-253.

Rahman, M. S. 1999. Handbook of Food Preservation. In: Rahman, M.S. (Ed.). Dekker, New York, pp. 521-532.

Sakr, M. and Liu, S. 2014. A comprehensive review on applications of ohmic heating (OH). Renewable and Sustainable Energy Reviews 39, 262-269.

Sarang, S., Sastry, S. K. and Knipe, L. 2008. Electrical conductivity of fruits and meats during ohmic heating. Journal of Food Engineering 87, 351-356.

Sastry, S. K. 2005. Advances in ohmic heating and moderate electric field (MEF) processing. In: G. V. Barbosa-Ca´novas, M. S. Tapia, & M. P. Cano (Eds.), Novel Food Processing Technologies. Boce Raton, FL: CRC Press.

Sastry, S. K. and Barach, J. T. 2000.Ohmic and inductive heating. Journal of Food Science 65(4), 42-46.

Sastry, S. K. and Palaniappan, S. 1992. Mathematical modeling and experimental studies on ohmic heating of liquid-particle mixtures in a static heater. Journal of Food Engineering 15, 241-261.

Sensoy, I. and Sastry, S. K. 2004. Extraction using moderate electric fields. Journal of Food Science 69(1), 7-13. 575-579.

Shirsat, N., Lyng, J. G., Brunton, N. P. and McKenna, B. 2004. Ohmic processing: electrical conductivities of pork cuts, Meat Science 67(3), 507-514.

Shugar, G.J. and Ballinger, J. T. 1996. Chemical Technicians' Ready Reference. Handbook, Inc, McGraw-Hill.

Skudder, P. J. 1988. Ohmic heating: New alternative for aseptic processing of viscous foods. Food Engineering 60, 99-101.

Tucker, G. S. 2004. Food waste management and value added products. Journal of Food Science 69(3), 102-104.

Tulsiyan, P., Sarang, S. and Sastry, S. K. 2008. Electrical conductivity of multi component systems during ohmic heating. International Journal of Food Properties 11, 233-241.

Uemura, K., Kobayashi, I. and Inoue, T. 2010. Inactivation of *bacillus subtilis* spores in orange juice and the quality change by high electric field alternating current. Japan Agricultural Research Quarterly 44(1), 61-66.

Vicente, A. A., Castro, I. and Teixeira, J. A. 2006. Thermal food processing: New technologies and quality issues. Chapter Ohmic Heating for Food Processing. CRC Press, Taylor & Francis Group.

Wang, L. and Weller, C. L. 2006. Recent advances in extraction of nutraceuticals from plants. Trends in Food Science and Technology 17(6), 300-312.

Wongsa-Ngasri, P. and Sastry, S. K. 2016. Tomato peeling by ohmic heating: Effects of lye-salt combinations and post-treatments on weight loss, peeling quality and firmness. Innovative Food Science and Emerging Technologies 34,148-153.

Yoon, S. W., Lee, C. Y. J., Kim, K. M. and Lee, C. H. 2002. Leakage of cellular material from *Saccharomycies cerevisiae* by ohmic heating. Journal of Microbiology and Biotechnology 12,183-188.

Zoltai, P. and Swearingen, P. 1996. Product development considerations for ohmic processing. Food Technology 50, 263-266.