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ORIGINAL RESEARCH ARTICLE

OHMIC HEATING AS ALTERNATIVE PRESERVATION TECHNIQUE - A REVIEW

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ABSTRACT

The quest for new technologies in heating has drawn the attention of researchers to focus on energy saving and efficient techniques in heating food materials. Ohmic heating is one of these technologies because it heats both phases of food (liquid and solid) simultaneously by internal energy generated from electrical power. Using this method, the product undergoes minimum structural damage, retains its nutritional value, and is processed within a shorter time than with conventional heating methods. The technique also gives excellent processed quality products with lower energy cost. The heat energy generated during ohmic heating is transferred directly into the foods. The electrical conductivity of food products is linear with different temperature ranges and varies with heating time, food structure, and its constituents. As such, ohmic heating can be applied in different pre-processing and processing operations like drying, evaporation, dehydration, blanching, fermentation, extraction, sterilization, and pasteurization. This paper highlights ohmic heating as an emerging alternative novel heating technology to meet the demand for industrial and domestic food processing. Recommendations were made for further research to provide a more robust analysis of ohmic heating performance.

1.0 Introduction

Of recent, many researchers have the opinion that electro-technologies such as radiofrequency, microwave, pressure-assisted thermal sterilization, infrared heating, high hydrostatic pressure processing, irradiation, ultrasound, cold plasma, pulsed electric field, and ohmic heating technologies are used in the processing and preservation of foods (Fan et al. 2019; Jaeger et al., 2016; Kanjanapongkul, 2017; Muhammad et al. 2018a; Muhammad et al. 2018b; Ohlsson and Bengtsson, 2002; Senorans et al., 2011; Termrittikul, et al., 2018). However, ohmic heating also known as moderate electric fields heating has drawn much attention in the food processing industries. This technique has proven to be mild processing technology which preserves nutritional, functional, structural, and sensory properties of food products better than conventional heating technologies (Knirsch et al., 2010; Vorobiev and Lebovka, 2009).

Ohmic heating is sometimes referred to an electrical resistance heating or Joule heating. It is defined as the process of passing electric currents through foods or other materials during exposure to heat. Ohmic heating differs from other electrical methods like microwave and radiofrequency heating in the frequency and waveforms of the electric field. Also, they differ in the presence of electrodes that are in contact with the food being process. While microwave and radiofrequency have frequencies of 300 MHz – 300 GHz and 1 – 300 MHz, respectively, ohmic heating has frequencies of about 25 – 30 kHz (Neetoo and Chen, 2014). However, in conventional aseptic processing, the heat transfer is from the liquid phase then to the solid phase and long processing time is required. Furthermore, conventional aseptic processing has less productivity, high cost of energy, and it destroys the sensory attributes of the food products (Sakr and Liu, 2014; Shivmurti et al., 2014; Smith et al., 1990).

With regards to penetration depth, ohmic heating offers an attractive alternative with no limitations provided the inherent electrical resistance of the food is not too high. Moreover, liquids and solids under ohmic heating are heated simultaneously without requiring stirring or mixing as in the conventional aseptic processing (Cho et al., 2016). In this regard, ohmic heating could be considered as an energy saving process in comparison to the traditional aseptic technique (Gavahian et al., 2013; Goullieux and Pain, 2005). However, by reducing electrical energy consumption, the environmental impact can be reduced provided that the energy generated is from non-renewable energy sources. In obtaining 1 kWh of electricity from either coal or fuel, about 800 g of CO_2 will be released to the atmosphere during combustion (Ferhat et al., 2006).

Therefore, in this article, we present a short review of the ohmic heating system, working principles, and its application in food industries with the objective of elucidating on ohmic heating concept. Also, recommendations were made for further research.

1.1 Electrical Conductivity

Electrical conductivity (σ) of materials is a measure of the ability of a material to allow passage of electricity through it. It is the ratio of the current density to the electric field strength measured in Siemens per meter (S/m) (Sarkis et al., 2013). In conventional conduction heating, the heating rate depends on the heat conductivity of the sample. While in ohmic heating techniques, the most critical factor is the electrical conductivity (Cho et al., 2016). The electrical conductivity of some liquid foods are measured at different temperatures (Ruhlman et al., 2001). Ohmic heating works optimally in electrically conductive fluid systems due to the necessity of ions mobility. Therefore, materials that have low electrical conductivity such as ethanol-water or fermented alcoholic mixtures might require additional or extra electrolytes to improve their conductivity. Thus, salt solution is employed as liquid medium in some ohmic heating processes (Goullieux and Pain, 2005). Electrical conductivity varies not only with temperature difference as mentioned earlier but also with heating time, food structure, and constituents (Nistor et al., 2015). The basic concept and simple ohmic heating set-up are shown in Figure 1a and 1b, respectively.

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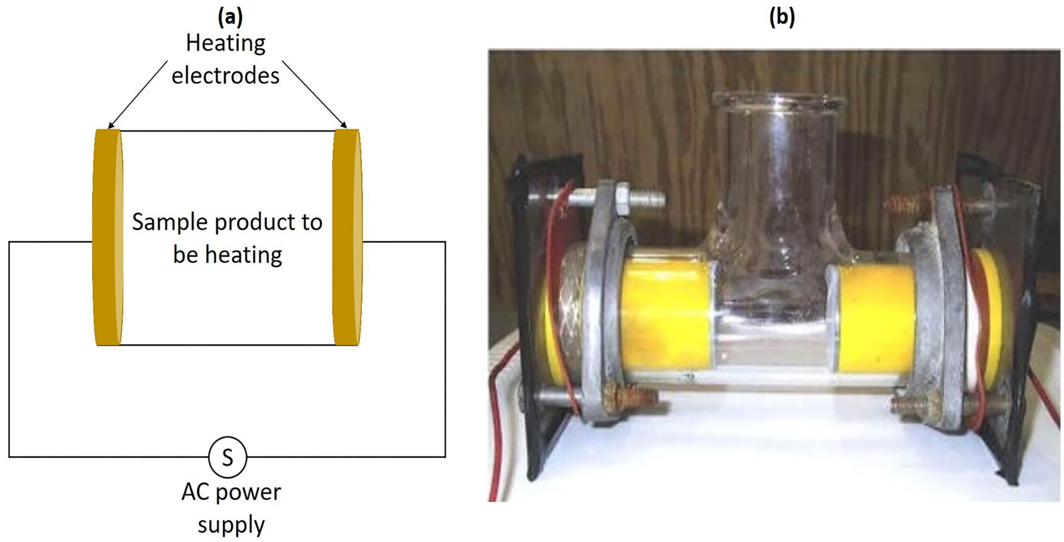

Figure 1. (a) Schematic diagram of ohmic heating principle. (b) Ohmic heating cell (Wongsa-Ngasri and Sastry, 2015)

Cho et al. (2016) reported the electrical conductivity of fermented red pepper paste to be 1.865 S/m when electric current was allowed to pass through and subsequently increased rapidly with the frequency (when it was higher than 1 kHz) for a constant voltage as illustrated in Figure 2a and 2b. The heating rate in fermented red pepper paste was peak at 5 kHz. Additionally, the specific heating rate (°C/g/s) increased linearly with the voltage at 60 Hz (Xu et al., 2013).

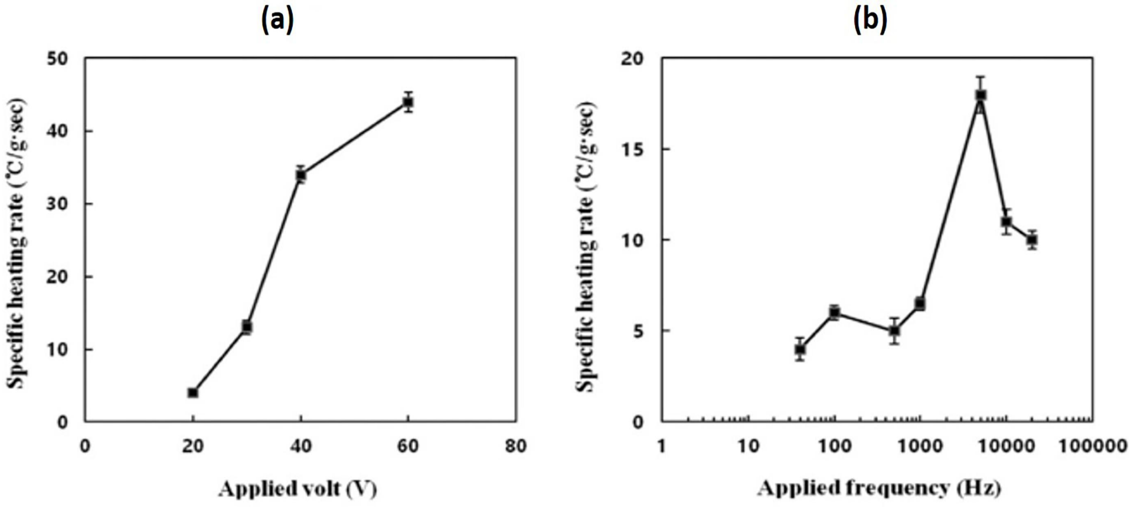

Figure 2. (a) The variance of specific heating rate versus voltage. (b) The variance of specific heating rate versus frequency (Cho et al., 2016).

2.1 Effects of Ohmic Heating on Physiochemical Properties of Food Products

A significant number of biomolecules such as proteins, polysaccharides, and lipids, in lower amounts and other functional substances such as polyphenols and vitamins are lost during processing of food. These biomolecules and functional components are also discarded along with waste by-products when using conventional processing techniques. However, most of these compounds, if recovered, can be reincorporated back into the food processing line for use in pharmaceutical products and energy production (Galanakis, 2012; Lin et al., 2013). Given the increasing demand of these bioactive compounds, new recovery methods were being developed to reduce the use of chemicals, organic solvents, and increase recovery efficiencies while maintaining low energy input (Chemat et al., 2012). To remedy these problems, Pereira et al. (2016) recovered value-added compounds from purple potatoes (*Solanum tuberosum*) using electro-heating treatments based on ohmic heating technology. As shown in Figure 3, this method is a suitable processing strategy that have shorter processing time and lower energy consumption than the conventional aseptic heating method.

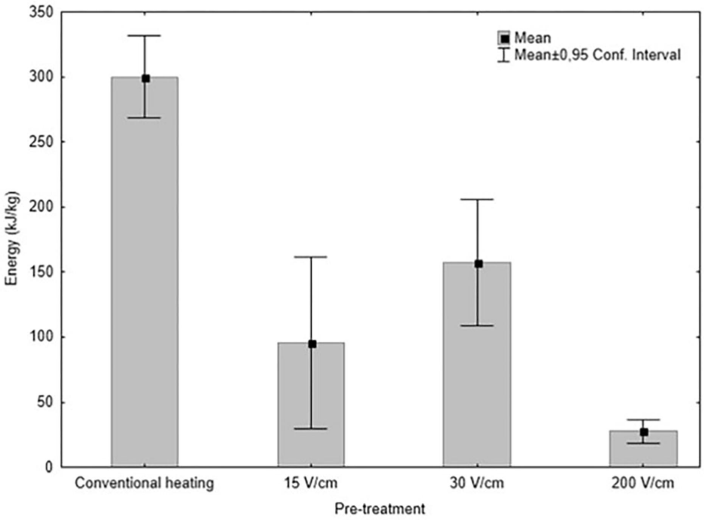

Figure 3. Total energy consumption of traditional and ohmic heating pre-treatments (Pereira et al., 2016).

Bastías et al. (2015) studied the effect of ohmic heating on texture, microbial load, cadmium (Cd), and lead (Pb) content in Chilean blue mussel (*Mytilus chilensis*) at shucking and subsequent canning. The study revealed a drastic reduction of 1.67±0.06 μg/g (DW) and 1.69 ± 0.08 μg/g (DW) in Cd content at 90±1°C by ohmic heating and blanching, respectively. At that same temperature, Pb content reduced to 4.18 ± 0.24 μg/g (DW) for ohmic heating and 4.14 ± 0.30 μg/g (DW) for blanching. Furthermore, the cutting strength of the fresh samples significantly decreased after processing by ohmic heating when compared with the blanched samples at the same temperature. The initial mean count for mesophilic aerobic microorganisms and *Enterobacteriaceae* were 3.8 log CFU/g and 2.5 log CFU/g, respectively. These values were found to reduce for mesophilic aerobic microorganisms count by 1.7 log CFU/g, while *Enterobacteriaceae* count was reduced to undetectable levels through ohmic heating at the same temperature. Investigation of Jasmine rice swelling behaviour, electrical conductivity, water diffusion, and cooking energy was conducted by Kanjanapongkul (2016). The researcher observed a tri-phased linear relationship between the electrical conductivity and temperature under transition temperatures of about 60 and 80°C. When the temperature exceeded 80°C, water diffused faster into the rice grain which becomes even quicker during the steeping of the rice. Thus, suggested that the gelatinization of the rice starch usually took place at around 60 - 80°C. Therefore, higher electric field strength caused the increase in diffusion rate. At temperatures beyond the gelatinization point, the crystalline structure of starch granules was disrupted due to breakage of hydrogen bonds, thereby resulting in a sudden increase in the volume (Kong et al., 2015). The energy consumed by the ohmic cooking process at a shorter cooking time (18 and 17 min) was about 1/4 of the total energy consumed by an electric rice cooker (Kanjanapongkul, 2017).

The influence of ohmic heating in combination with salt-lye has shown promise in tomato peeling which gave high peeled-product quality. In the study, Wongsa-Ngasri and Sastry (2016) stated that diffusion through tomato skin was significantly ($P<0.05$) improved at temperatures of 50 and 65°C. Nevertheless, this confirmed that electric field has enhanced the spread of lye through tomato skin after an initial period in which the diffusivities of lye peeling with ohmic heating were higher than those without ohmic heating at 50 and 65°C (Wongsa-Ngasri and Sastry, 2016).

Lakkakula et al. (2004) reported ohmic heating to be an alternative method for stabilization of rice bran due to its increased oil yield in rice bran to a maximum value of 92%, as compared to only 53% of oil extracted from the control samples. The above studies have demonstrated that ohmic heating can be an alternative novel heating process to conventional heating methods.

2.2 Advantages and Disadvantages of Ohmic Heating

The summary of the relative pros and cons of ohmic heating technology are presented in Table 1 as reported by many researchers (Ruan et al., 2001; Assiry et al., 2003; Assiry et al., 2010).

Table 1: Advantages and Disadvantages of Ohmic Heating

Advantages	Disadvantages
Uniform heating of the material	Narrow frequency band.
The target temperature achieved very quickly.	Coupling between temperature and electrical file distribution is very complicated.
High energy conversion efficiencies at low maintenance costs.	Lack of generalized information.
The instant shutdown of the system	Request adjustment based on the conductivity of the food material.
No residual heat transfers after current shut down.	Difficult to monitor and control.
Reduced maintenance costs because of the lack of moving parts	
Reduced problems of surface fouling	
A quiet environmentally friendly technology.	

Based on the limitations mentioned above, the following recommendations were drawn:

The development of predictive, measurable, and reliable models of ohmic heating patterns are encouraged.

I. More researches need to be conducted to develop a reliable feedback control to adjust the supply of power due to the change in the conductivity of food materials.

II. Development of real-time temperature monitoring systems for locating unheated cold spots and overheated regions during ohmic heating.

III. Enhancement of safety and quality assurance protocols to commercialize the ohmic heating technology.

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3.0 Food Processing Application of Ohmic Heating

In a study conducted by Neetoo and Chen (2014), it was stated that ohmic heating technology was successfully used in commercial pasteurization of liquid egg products and processing of whole fruits in UK and Japan. Also, the technology can be applied to a variety of food products such as vegetables, juices, meats, seafoods, soups, creams, and pasta dishes. Sterilization of food items to produce high quality shelf-stable low-acid foods (readily prepared meals) and high-acid foods (tomato-based sauces) were also carried out. Recently, ohmic heating has been employed in sweet whey processing (Costa et al., 2018), rice cooking (Kanjanapongkul, 2017), meat processing (van der Sman, 2017), and meat thawing (Duygu and Ümit, 2015). The effect of ohmic heating parameters on peroxidase inactivation, phenolic compounds degradation, and colour changes of sugarcane juice was also studied (Brochier et al., 2018).

On the other hand, Ramírez-Jiménez et al. (2019) studied the changes in the phytochemicals profile of two instant corn flours produced by different processes. These processes were the traditional nixtamalization (TN) and the ohmic heating process. The researchers reported the highest total phenolic content in the flour was recorded with the ohmic heating process as compared to the TN process.

3.1 Other Industrial Application of Ohmic Heating

Apart from food processing applications, ohmic heating also has other uses such as waste treatment in the sterilization of livestock wastes, heating animals' slurries, sewage sludge, and compost leachate. Murphy et al. (1991) suggested that sewage sludge could be ohmically heated rapidly from room temperature to boiling point and achieve uniformity in energy efficiencies greater than 98%. Sakr and Liu (2014) alternatively suggested that ohmic heating can be integrated with thermal energy storage such as electric thermal storage device. Since salts are good at storing heat, they can be heated to melting point and then stored in insulated containers. Whenever the energy is needed, such molten salts can be pumped out to release their heat through a heat exchange system. Another application is in seawater distillation whereby electrical energy or fossil fuel is required to heat the water in which steam boiler currently serve this purpose. However, this method is associated with the formation of scales on the heat exchanger tubes which affects the efficiency. The ohmic heating method can be employed to generate the heat required as an alternative heating method to be utilized in a desalination process rather than using a steam boiler (Assiry et al., 2010). Studies carried out by Assiry et al. (2003) opined that ohmic heating could be applied in the heating process of seawater but with some limitations regarding the colour change. Therefore, more studies are needed for a pilot production system and in modelling the potential use of ohmic heating in the desalination process.

3.2 Potential Research Perspectives

A large number of possible future research and applications exist for ohmic heating, among which are; blanching, evaporation, dehydration, fermentation, and extraction (FDA, 2000). Ohmic heating can enhance the drying of vegetable tissue such as potato and yam by 16% and 43%, respectively (Wang and Sastry, 2000). Extraction of valuable components such as rice bran oil from rice bran by ohmic treatment can be enhanced up to 74% (Lakkakula et al., 2004). Kanjanapongkul (2016) categorically recommended that more study should be conducted to conclude why the increasing rate of electrical conductivity was lower when the rice grains began

Corresponding author's e-mail address: aimuhammad.age@buk.edu.ng to swell rapidly under ohmic heating. Another emerging application that is currently receiving considerable attention as a result of its advantages is thermal energy storage (TES) systems, which is based on latent heat as in high heat fusion (Gang, 2013; Li et al., 2012; Raluy et al., 2014). The technique has been successfully applied in TES systems in which molten salt is used as a storage medium and is still under development worldwide (Li et al., 2012; Xu et al., 2013). Since ohmic heating performance increases with increasing ions on the heating solutions, molten salt can offer the best balance of capacity, cost, efficiency, and usability at high temperatures (Assiry et al., 2010).

4.0 Conclusion

The importance of recommended energy consumption in heating at food industries cannot be overemphasized. Thus, makes it mandatory for such firms not only to research a new alternative and sustainable methods, which save energy and cost, but also, to venture and invest in emerging technologies with an enormous number of present and future applications like ohmic heating technology. Its numerous applications in food processing are blanching, evaporation, dehydration, fermentation, extraction, sterilization, pasteurization, and heating of foods to the desired temperature. Another industrial application outside food industries is thermal energy storage when used in combination with a molten salt solution. This strategy can be used to generate electricity in a space heater. Research advancement in modelling heating needs to be carried out for complex foods, which might lead to the development of product packaging.

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Reference

Assiry, AM., Gaily, MH., Alsamee, M. and Sarifudin, A. 2010. Electrical Conductivity of Seawater during Ohmic Heating. Desalination, 260: 9–17.

Assiry, A., Sastry, SK. and Samaranayake, C. 2003. Degradation Kinetics of Ascorbic Acid during Ohmic Heating with Stainless Steel Electrodes. Journal of Applied Electrochemicals, 33: 187–196.

Bastías, JM., Moreno, J., Pia, C., Reyes, J., Quevedo, R. and Muñoz, O. 2015. Effect of ohmic heating on texture, microbial load, and cadmium and lead content of Chilean blue mussel (*Mytilus chilensis*). Innovative Food Science and Emerging Technologies, 30: 98–102.

Brochier, B., Mercali, GD. and Marczak, LDF. 2018. Effect of ohmic heating parameters on peroxidase inactivation, phenolic compounds degradation and color changes of sugarcane juice. Food and Bioproducts Processing, 111: 62–71.

Chemat, F., Vian, MA., and Cravotto, G. 2012. Green Extraction of Natural Products: Concept and Principles. International Journal of Molecular Science, 13(7): 8615–8627.

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

Corresponding author's e-mail address: aimuhammad.age@buk.edu.ng

Costa, NR., Cappato, LP., Pereira, MVS., Pires, RPS., Moraes, J., Esmerino, EA. and Cruz, AG. 2018. Ohmic Heating: A potential technology for sweet whey processing. Food Research International, 106: 771–779.

Duygu, B. and Ümit, G. 2015. Application of Ohmic Heating System in Meat Thawing. Procedia - Social and Behavioral Sciences, 195: 2822–2828.

Fan, L., Hou, F., Muhammad, AI., Lv, R., Watharkar, BR Guo, M., Ding, T., and Liu, D. 2019. Synergistic inactivation and mechanism of thermal and ultrasound treatments against *Bacillus subtilis* spores. Food Research International 116: 1094–1102.

FDA. 2000. Kinetics of Microbial Inactivation for Alternative Food Processing Technologies Report. Journal of Food Science, 65(s8): 5 - 107.

Ferhat, AM., Meklati, YB., Smadja, J. and Chemat, F. 2006. An improved microwave Clevenger apparatus for distillation of essential oils from orange peel. Journal of Chromatography, A, 1112: 121–126.

Galanakis, CM. 2012. Recovery of High Added-value Components from Food Wastes: Conventional, Emerging Technologies, and Commercialized Applications. Trends in Food Science and Technology, 26(2): 68–87.

Gang, L. 2013. Review of Thermal Energy Storage Technologies and Experimental Investigation of Adsorption Thermal Energy Storage for Residential Application. University of Maryland: College Park.

Gavahian, M., Farahnaky, A., Javidnia, K. and Majzoobi, M. 2013. A novel technology for extraction of essential oil from Myrtus communis: ohmic-assisted hydrodistillation. Journal of Essential Oil Resource, 25(4): 257–266.

Goullieux, A. and Pain, JP. 2005. Ohmic heating In Emerging Technologies for Food Processing. (Sun, D.W. Ed.). London: Elsevier Academic Press.

Jaeger, H., Roth, A., Toepfl, S., Holzhauser, T., Engel, KH., Knorr, D. and Steinberg, P. 2016. Opinion on the use of ohmic heating for the treatment of foods. Trends in Food Science and Technology, 55: 84–97.

Kanjanapongkul, K. 2017. Rice Cooking using Ohmic Heating: Determination of electrical conductivity, water diffusion, and cooking energy. Journal of Food Engineering, 192: 1–10.

Knirsch, MC., Alves dos Santos, C., Martins de Oliveira Soares Vicent, AA. and Vessoni Penna, TC. 2010. Ohmic Heating - A review. Trends in Food Science and Technology, 21(9): 436–441.

Kong, X., Zhu, P., Sui, Z. and Bao, J. 2015. Physicochemical Properties of Starches from Diverse Rice Cultivars varying in Apparent Amylose Content and Gelatinization Temperature Combinations. Food Chemistry, 172: 433–440.

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

Li, G., Hwang, Y. and Radermacher, R. 2012. Review of Cold Storage Materials for Air Conditioning Application. International Journal of Refrigeration, 35: 2053–2077.

Corresponding author's e-mail address: aimuhammad.age@buk.edu.ng

Lin, CSK., Pfaltzgraff, LA., Herrero-Davila, L., Mubofu, EB., Abderrahim, S., Clark, JH. and Luque, R. 2013. Food Waste as a Valuable Resource for the Production of Chemicals, Materials, and Fuels. Current Situation and Global Perspective. Energy and Environmental Science, 6(2): 426.

Muhammad, AI., Liao, X., Cullen, PJ., Liu, D., Xiang, Q., Wang, J., Chen, S., Ye, X., and Ding, T. 2018a. Effects of Nonthermal Plasma Technology on Functional Food Components. Comprehensive Reviews in Food Science and Food Safety 17: 1379–94.

Muhammad, AI., Xiang, Q., Liao, X., Liu, D., and Ding, T. 2018b. Understanding the Impact of Nonthermal Plasma on Food Constituents and Microstructure - A Review. Food and Bioprocess Technology, 11 (3): 463–86.

Murphy, AB., Powell, KJ. and Morrow, R. 1991. Thermal Treatment of Sewage Sludge by Ohmic Heating. IEE Proceedings: Science Measurement and Technology, 138: 242–248.

Neetoo, H. and Chen, H. 2014. Food Processing: Principles and Applications. In S. Clark, S. Jung and B. Lamsal (Eds.), Food Processing; Principles and Applications, John Wiley and Sons, Ltd.

Nistor, OV., Stãnciuc, N., Andronoiu, DG., Mocanu, GD. and Botez, ME. 2015. Ohmic Treatment of Apple Puree (Golden Delicious variety) in relation to Product Quality. Food Science and Biotechnology, 24(1): 51–59.

Pereira, RN., Rodrigues, RM., Genisheva, Z., Teixeira, A. and Freitas, VD. 2016. Effects of Ohmic Heating on Extraction of Food-grade Phytochemicals from Colored Potato. LWT - Food Science and Technology, 74: 493–503.

Raluy, RG., Serra, LM., Guadalfajara, M. and Lozano, MA. 2014. Life Cycle Assessment of Central Solar Heating Plants with Seasonal Storage. Energy Procedia, 48: 966–976.

Ramírez-Jiménez, AK., Rangel-Hernández, J., Morales-Sánchez, E., Loarca-Piña, G. and Gaytán-Martínez, M. 2019. Changes on the phytochemicals profile of instant corn flours obtained by traditional nixtamalization and ohmic heating process. Food Chemistry, 276: 57–62.

Ruan, R., Ye, X., Chen, P., Doona, CJ. and Taub, I. 2001. Ohmic Heating. In P. Richardson (Ed.), Thermal Technologies in Food Processing (pp. 241–365). Cambridge: Woodhead Publishing.

Ruhlman, KT., Jin, ZT. and Zhang, QH. 2001. Physical Properties of Liquid Foods for Pulsed Electric field Treatment. Lancaster: Technomic Publishing Co.

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

Sarkis, JR., Mercali, GD., Tessaro, IC. and Marczak, LDF. 2013. Evaluation of key parameters during construction and operation of an ohmic heating apparatus. Innovative Food Science and Emerging Technologies, 18: 145–154.

Shivmurti, S., Rinkita, P., Harshit, P. and Smit, P. 2014. Ohmic Heating is an Alternative Preservation Technique - A Review. Global Journal of Science Frontier Research: E Interdisciplinary, 14(4): 1–10.

Smith, JP., Ramasvamy, HS. and Simpson, B. 1990. Developments in Food Packaging Technology. Trends in Food Science and Technology, 1(5): 106–109.

Corresponding author's e-mail address: aimuhammad.age@buk.edu.ng

Termrittikul, P., Jittanit, W. and Sirisansaneeyakul, S. 2018. The application of ohmic heating for inulin extraction from the wet-milled and dry-milled powders of Jerusalem artichoke (Helianthus tuberosus L.) tuber. Innovative Food Science and Emerging Technologies, 48: 99–110.

Van der Sman, RGM. 2017. Model for electrical conductivity of muscle meat during Ohmic heating. Journal of Food Engineering, 208: 37–47.

Vorobiev, E. and Lebovka, N. 2009. Electro-technologies for Extraction from Food Plants and Biomaterials. Springer Science Business Media, LLC.

Wang, W. and Sastry, S. 2000. Effects of Thermal and Electrothermal Pretreatments of Hot Air Drying Rate of Vegetable Tissue. Journal of Food Process Engineering, 23: 299–319.

Wongsa-Ngasri, P. and Sastry, SK. 2015. Effect of ohmic heating on tomato peeling. LWT - Food Science and Technology, 61(2): 269–274.

Wongsa-Ngasri, P. and Sastry, SK. 2016. Tomato Peeling by Ohmic Heating with Lye-salt combinations : Effects of Operational Parameters on Peeling Time and Skin Diffusivity. Journal of Food Engineering, 186: 10–16.

Xu, C., Li, X., Wang, Z., He, Y. and Bai, F. 2013. Effects of Solid Particle Properties on the Thermal Performance of a Packed-bed Molten-salt Thermocline Thermal Storage System. Applied Thermal Engineering, 57: 69–80.

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