INFLUENCE OF OHMIC HEATING ON THE MICROBIOLOGICAL AND PHYSICO-CHEMICAL PROPERTIES OF MILK PRODUCTS

Abstract

In recent years, research has been focusing on innovative technologies that do not compromise the structural properties of foods. One of these innovative technologies is ohmic heating. This technique provides efficient microbial inactivation by enabling rapid and uniform heating on a large scale. Ohmic heating systems can be adapted to aseptic processing systems in pumpable food lines and can be used in preheating and pasteurization lines. Due to its ability to provide rapid and homogeneous heating, ohmic heating is considered an alternative pasteurization method in the processing of dairy products, which play an important role in the nutrition diet of our country, and it is believed to offer solutions to the global challenges of "energy" and "improvement in product quality and nutritional properties" that have become increasingly important today.

Keywords: Ohmic Heating; Conventional Heating; Milk; Bacterial İnactivation; Human Health

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I. INTRODUCTION

Heat treatment applications have been used as a crucial step in dairy technology for decades to protect public health and ensure the microbiological stability of milk. Traditional heat treatment practices can affect milk's sensory and functional properties by causing undesirable quality changes due to the temperature to which milk is exposed [1]. Therefore, in recent years, intensive research has been conducted on the use of non-thermal advanced preservation techniques as alternatives to traditional methods [2]. Among these technologies, one of the methods that has been extensively studied and has commercial applications is ohmic heating. Recently, many researchers have used the ohmic heating technique to inactivate foodborne bacteria [3, 4].

In recent years, there has been a noticeable increase in scientific research regarding the effects of ohmic heating systems on food quality, temperature controls in continuous systems, and process parameters. Intensive system development and optimization research has been conducted since its industrial use began [5]. One distinguishing feature of ohmic systems from other electro-thermal systems is that the electrode systems used can come into direct contact with food [6, 7]. This allows food to reach high temperatures quickly with less damage through the ohmic heating technique [8], preserving nutritional value and color compared to traditional methods [9]. Sensory properties that match preferred characteristics and minimal aroma loss can be achieved, leading to the processing of reliable food products [10]. Because of these benefits, ohmic heating has become more useful and has been used on a pilot and industrial scale for heating, pasteurization, boiling, evaporation, drying, fermentation, and extraction, especially in places where liquid foods like fruit juices, milk, and ready meals are common, such as the United States, the United Kingdom, Japan, and Italy [11-15].

As a result of current studies, ohmic heating has been considered an efficient heating method and an alternative for processing milk and dairy products, which hold significant importance in our country's dietary habits. It is believed that ohmic heating can offer a solution to the global challenges of energy consumption and improvement in the nutritional quality of dairy products. This section provides general information about ohmic heating systems used in the dairy industry and the pilot-scale studies conducted. The impact of ohmic heating on the microbiological and physicochemical properties of milk and its products is also discussed.

II. GENERAL PROPERTIES AND USABILITY IN FOODS

1. **Ohmic Heating Technique:** The technique is known as ohmic heating, which takes its name from Ohm's law, which dates back to the late 19th century [16] and describes the relationship between current, voltage, and resistance, is referred to in the literature by various names such as joule heating, electrical resistance heating, direct resistance heating, electro-heating, and electro-conductive heating [17]. It is noted that the pasteurization process developed by Fetterman in 1928 [18], called "Electropure" was a significant development in the dairy industry of that time [19]. In 1987, it was developed at the UK Electricity Research and Development Centre, licensed by APV Baker, and in 1990, the AVP company patented a system and introduced an alternative pilot-scale ohmic heating system to the industry [20].

This technique involves passing alternating current through electrodes in contact with a food product, utilizing the food's conductivity as resistance, and heating the food based on its electrical resistance [21, 22]. During the heat treatment process, the occurrence of electrolysis can lead to the formation of toxic compounds and may have adverse effects on the sensory and nutritional characteristics of the product. The frequency range used in the process is a crucial factor to consider, as it can either prevent or contribute to these adverse effects [23]. Low-frequency alternating current (50 or 60 Hz) below 100 kHz has a less intense electrolytic effect compared to direct current [17, 24]. Additionally, the use of stainless steel, pure carbon, and platinum-coated titanium electrodes is reported to mitigate this issue [25, 26]. The schematic diagram of ohmic heating is shown in Figure 1.
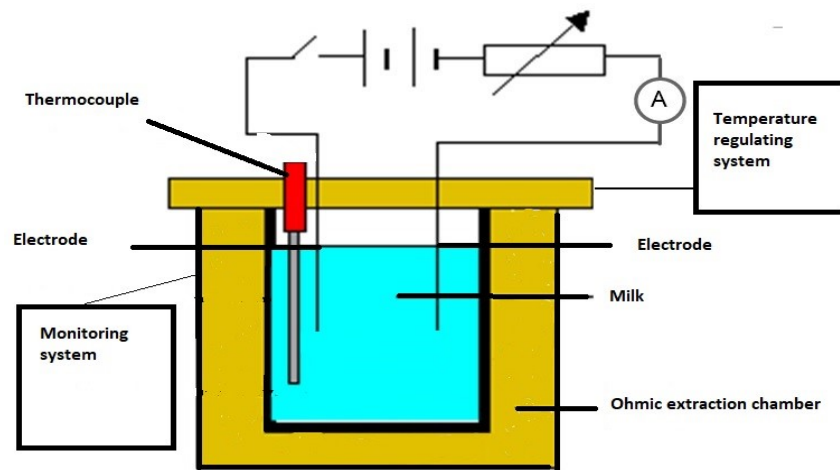

Figure 1: Schematic Diagram of Ohmic Heating

2. **Ohmic System Properties:** The system occupies less space compared to other equipment and operates silently [27]. Since there is no heating surface, issues related to accumulation or the formation of burnt layers in heat exchangers do not arise. Additionally, the system can operate continuously, 24 hours a day, 7 days a week, without the need for mixing processes [24, 28]. The system does not have moving parts, making it particularly suitable for food mixtures that are sensitive to mechanical damage [10, 27, 29].

   Dairy products are high-mineral-content foods, and during ohmic heating, corrosion occurring on the surface of electrodes can lead to an increase in electrical resistance and changes in the system's operating conditions [30-32]. In a study conducted by Stancl and Zitny [33], skim milk samples were evaluated using stainless steel, TiN, and graphite electrodes under different electric current densities (at a fixed frequency of 50 Hz) and temperatures (65-75°C). The results indicated that corrosion was not observed on the graphite electrodes. In a study by Bansal and Chen [31] using a cylindrical ohmic heater, the effect of power supply frequency (10 kHz and 50 Hz) on electrode surface wear was examined. They found that corrosion significantly decreased at higher frequencies.

3. **Important Parameters Affecting the Ohmic Heating of Food:** The applicability of ohmic heating is dependent on the electrical conductivity of the food material, but it has been noted that this method is suitable for heating many food materials due to the presence of free water containing dissolved salt ions [34]. The electrical current in the food generates heat, especially in liquid foods, resulting in homogeneous heat and temperature distribution [35]. Additionally, the energy conversion efficiency in ohmic heating for liquid foods is high, reaching approximately 90% [21, 36]. Temperature differences of 55°C or more can be achieved in less than 1 second [28]. The heating rate varies directly with the square of the electrical field intensity and electrical conductivity. The electrical field intensity can be adjusted by altering the gap between the electrodes and the applied voltage [21].

In ohmic heating of foods, important factors include the electrical conductivity of the food and how it changes with temperature, the design of the heating system, the thermophysical properties of the food, the electrical field intensity, the application time, the movement of liquids inside the food, etc. (Table 1). [37-39].

Table 1: Important Parameters in the Ohmic Heating Process

Parameters	Factor
Processing parameters	Electric field strength
	Time
	Heat
	Electric current frequency
Product parameters	Electrical conductivity
	Viscosity
	Intensity
	Extract
	Homogeneous or solid-liquid systems
Equipment parameters	Ohmic cell size
	Size and shape of the electrodes
	Electrode composition

It has been noted that ohmic heating can achieve the required temperature for the UHT process, with no issues of surface contamination or product overheating. It is beneficial for products that require preheating before the preservation process. Additionally, ohmic heating offers high energy conversion efficiency, is suitable for continuous processes, and has a lower investment cost compared to microwave and traditional heating methods [40]. Additionally, intrinsic factors such as the properties of lipids, proteins, carbohydrates, and their quantities in foods also influence the ohmic heating of food [4, 41].

III. **THE EFFECT OF OHMIC HEATING TECHNIQUE ON QUALITY PARAMETERS OF MILK AND PRODUCTS**

1. **Effect of Ohmic Heating Technique on Microbiological Properties of Dairy Products:** The thermal effect on microbial cell membrane structures and enzymes is the

main mechanism underlying the ohmic heating-induced microbial inactivation [42]. Initial studies suggested that the primary effect on microbial inactivation in ohmic heating was due to temperature increases, with the electrical effect being relatively low [43]. However, subsequent studies on yeast and *Escherichia coli* inactivation revealed that electrical current damaged the microbial reproductive mechanisms. This is because when low frequencies are used in ohmic heating, charges build up on the cell wall and pores form in the cell membrane [44-48].

It has been observed that ohmic heating, compared to traditional thermal processing, offers shorter processing times and a higher level of effectiveness in the inactivation of microorganisms. In addition to its thermal effects, ohmic heating has been found to provide significant advantages in terms of bacterial inactivation when compared to other methods, due to its induction of electroporation in the cell membranes of microorganisms [49]. Table 2 summarizes some studies on the impact of ohmic heating on microorganisms and its potential to meet safety limits in milk products.

Table 2: Studies Examining the Effect of Ohmic Heating of Milk and Its Products on Microbiological Properties

Parameter	Finding	References
Contamination of milk samples with *Escherichia coli* O157:H7, *Salmonella* spp., and *Listeria monocytogenes*.	Ohmic heating resulted in the inactivation of the target microorganisms.	[50]
The effect of milk fat on the inactivation of microorganisms with ohmic heating.	Ohmic heating has a greater impact on the microbial inactivation of dairy products with a fat content in the range of 0-3%.	[51]
The combined inhibitory effect of milk fat and lactose on the inactivation of *E. coli* O157: H7, *S. typhimurium*, and *L. monocytogenes* with ohmic heating.	Inactivation of *E. coli* O157:H7 with ohmic heating has a quadratic relationship with lactose and fat. The inactivation of *S. typhimurium* and *L. monocytogenes* is significantly influenced by the process time.	[52]
Comparison of thermal resistance of goat milk samples with added *E. coli* ATCC 25922, subjected to ohmic heating and conventional heat treatment at the same temperature profile.	Ohmic heating (at 50 kHz, 63 and 65°C) resulted in the inactivation of the target microorganism and reduced the D and z values compared to the conventional method.	[53]
Comparison of thermal resistance in milk samples with added *Streptococcus thermophilus* 2646, subjected to ohmic heating and conventional heat treatment at the same temperature profile.	Ohmic heating (at 20 kHz, 7.3-2 A; 70-12 V; 70, 75, and 80°C) led to the inactivation of target microorganisms and reduced the D and z values compared to the conventional method.	[42]

The UHT milk samples, each measuring 200 mL, with varying fat contents of 3.1% (full-fat), 1.5% (semi-skimmed), and 0.14% (skimmed), were inoculated with a 0.5% concentration of L. monocytogenes 4b (ATCC 13932) strain.	During the 6th minute of the ohmic heating process, there was an average reduction of approximately 5.30 log CFU/mL in both semi-skimmed and skim milk compared to the initial load, and L. monocytogenes was completely inactivated.	[49]

2. **Effect of Ohmic Heating Technique on Physico-chemical Properties of Dairy Products:** According to prior research, internal factors like the makeup and concentrations of lipids, proteins, and carbohydrates in the food have an impact on the electrical conductivity of ohmic heating as well as external factors like voltage and frequency. These factors collectively play a significant role in influencing electrical conductivity [4, 41].

   It has been noted that the fat content and temperature have a substantial impact on the electrical conductivity value during the Ohmic heating of dairy products [54]. The presence of fat droplets in the milk matrix during ohmic heating has been found to cause a decrease in electrical conductivity. They have also pointed out that an increase in fat content leads to non-uniform heat distribution in the samples [51]. Furthermore, it has been observed that the increased fat content not only reduces the electrical conductivity of milk but also provides protection against thermal damage to *L. monocytogenes*. It was noted that the low electrical conductivity resulting from high-fat-content milk also leads to a decrease in the thermal efficiency of ohmic heating [49]. While no color change and lipid oxidation were observed after ohmic heating, a slight decrease in pH values was observed [52]. Compared to the traditional heating method, this approach prevents the formation of hot surfaces, reduces temperature gradients, and, as a result, plays a significant role in providing rapid heating as well as ensuring uniform heating in terms of thermophysical, electrical, and rheological properties [55]. In Table 3, various studies investigating the effects of ohmic heating on the physicochemical properties of dairy products have been summarized.

Table 3: Studies Examining the Effect of Ohmic Heating of Milk and its Products on Physico-Chemical Properties

Parameter	Finding	References
Different milk samples with varying fat content (0, 3, 7, and 10% w/w)	It was determined that ohmic heating significantly increased electrical conductivity and heating rate compared to conventional methods, and an increase in milk fat content led to non-uniform heat distribution in the samples.	[51]
Milk	An increase in voltage resulted in a decrease in heating time.	[52]
Full-fat milk and reconstituted milk	The effect of ohmic heating (heating from 20°C to 80°C with a voltage gradient of 30 V/cm) on	[56]

	rheological properties was examined. It was found that viscosity was sensitive to temperature increases during ohmic heating for reconstituted milk samples.	
Ice cream	Maraş-style ice cream heated ohmically in the voltage range of 20-60 V/cm showed higher rheological constants (consistency coefficient, flow behavior index) compared to traditional ice cream mix and varied with temperature. It was observed that ohmic heating times decreased as the voltage increased.	[54]
Goat's milk	Under traditional conditions (72°C / 15s) and ohmic treatment (14.4 V/cm, 5-30 A), there were no significant changes in short-chain fatty acid composition when ohmic heating was compared to conventional heating.	[53]
Milk	Ohmic treatment (20 kHz; 7.3-2 A; 70-12 V) showed no significant effect on protein denaturation compared to conventional thermal treatment under the same conditions.	[42]
Baby food based on milk	Ohmic treatment (25 kHz, 15 kW; 300/4000 V) was compared to UHT processing in terms of different quality indicators. Ohmic heating resulted in higher values for Furosin, Carboxymethyllysine (CML), and vitamin C compared to UHT processing.	[57]

Milk contains approximately 30 proteins that have the potential to elicit allergic reactions. Among these proteins, casein (alpha-s1) [58-60], beta-lactoglobulin [61], and alpha-lactalbumin (alpha-La) [60,61]are known to have the highest allergenic potential in cow's milk. Thermal processing can lead to protein denaturation and a decrease in the allergenic potential of milk and its products due to the loss of tertiary structure, which can result in aggregation [61]. However, it has been reported that the maillard reaction, which occurs during processing, can increase allergenicity by forming neoallergenic compounds [55].

In contrast, the non-thermal effects of ohmic heating can lead to different outcomes compared to conventional processing, even at the same temperature profiles. Process parameters such as electric frequency and electric field can influence casein micelles and protein structures, resulting in different outcomes compared to conventional heating systems [55]. Electroporation, with its non-thermal effects, can lead to a decrease in the heating rate during the process. This, in turn, results in a reduction in the formation of neoallergenic compounds from the maillard reaction [55, 59]. Conversely, due to the decrease in the total thermal load, it may cause a reduction in the allergenicity of previously denatured proteins [55].

IV. CONCLUSIONS

In recent years, modeling and characterization of both batch and continuous ohmic heating systems, as well as process control, have gained increasing importance. Studies of how ohmic heating affects different steps in liquid food processing lines and the collection of data on electrical conductivity have laid the groundwork for industrial applications. Despite these positive attributes, the system still requires proper electrical insulation and control system design.

To define the benefits and optimum process parameters of ohmic heating, it is essential to evaluate its impact on the quality and sensory properties of the final product. The same thermal process indicators commonly used in conventional processes can also be employed to determine the intensity of ohmic heating. Since different process conditions may need to be applied depending on the product, identifying all variables that can affect the ohmic heating rate for dairy products is necessary. Furthermore, pilot and industrial-scale studies are required to obtain more precise and practical data regarding the impact of ohmic heating on microbial inactivation.

Studies on the effects of ohmic heating on nutrient components and quality characteristics are ongoing, with limited research available on changes in texture properties. Researchers comparing ohmic heating with UHT in dairy technology have observed similar results and have suggested that ohmic heating is a promising technology for preserving certain nutrients in dairy products. Additionally, they mention the potential for estimating its effects on nutritional compounds in infant formula-based foods. However, there is a lack of studies in the literature assessing the allergenic properties of milk proteins processed with Ohmic heating. There is also a dearth of research on processed dairy products such as cheese, butter, fermented milk, etc., which presents opportunities for further investigation in this field.

REFERENCES

[1] Y. Li, H. S. Joyner, B. G. Carter, M. A. Drake, "Effects of fat content, pasteurization method, homogenization pressure, and storage time on the mechanical and sensory properties of bovine milk", Journal of Dairy Science, vol.101, 2018, pp. 2941-2955.

[2] C. F. Balthazar, L. Cabral, J. T. Guimarães, M. F. Noronha, L. P. Cappato, A. G. Cruz A. S. Sant'Ana, "Conventional and ohmic heating pasteurization of fresh and thawed sheep milk: Energy consumption and assessment of bacterial microbiota during refrigerated storage", Innovative Food Science & Emerging Technologies, vol. 76, 2022, 102947.

[3] X. Tian, L. Shao Q. Yu et al. "Evaluation of structural changes and intracellular substance leakage of *Escherichia coli* O157: H7 induced by ohmic heating", Journal of Applied Microbiology, vol. 127, 2019, pp. 1430-1441.

[4] L. Shao, Y. Liu, X. Tian et al. "Inactivation and recovery of *Staphylococcus aureus* in milk, apple juice and broth treated with ohmic heating", LWT, vol. 139, 2021, 110545.

[5] O. Kaya and F. İçier, "İndüksiyon ve ohmik ısıtma işlemlerinin gıdalara uygulanabilirliğinin karşılaştırılması", Akademik Gıda, vol. 17(1), 2019, pp. 111-120.

[6] Y. Chen, Y. Llave, Y. Jiao, E. Okazaki, N. Sakai, M. Fukuoka, "Ohmic tempering using a high frequency ohmic heating and model food of minced tuna based on Allaska Pollock surimi – Evaluation of electrical conductivities", Innovative Food Science & Emerging Technologies, vol. 76, 2022.

[7] N. G. Ribeiro, D. Xavier-Santos, P. H. Campelo, J. T. Guimaraes, T.C Pimentel, M. C. K. H Duarte et al. "Dairy foods and novel thermal and nonthermal processing: A bibliometric analysis", Innovative Food Science & Emerging Technologies, vol. 76, 2022.

[8] E. Waziiroh, R. Schoenlechner, H. Jaeger, G. Brusadelli, D. Bender, "Understanding gluten-free bread ingredients during ohmic heating: Function, effect and potential application for breadmaking", European Food Research and Technology, 1–14, 2022.

[9] E. R. Cho, D. H. Kang, "Combination system of pulsed ohmic heating and 365-nm UVA light-emitting diodes to enhance inactivation of foodborne pathogens in phosphate-buffered saline, milk, and orange juice", Innovative Food Science & Emerging Technologies, vol. 83, 2023, 103250.

[10] P. Tempest, "Electroheat technologies in food processing" APV Marketing Bulletin, 16 P.1996.

[11] G. Piette, M. E. Buteau, D. Halleux, L. Chiu, Y. Raymond, H. S. Ramaswany, "Ohmic cooking of processed meats and its effects on product quality", Journal of Food Science, vol. 69, 2004, pp. 71-78.

[12] H. Bozkurt and F. İçier, "Alternative thawing methods; Ohmic thawing", 1st International Congress of Seafood Technology, 18-21 May, İzmir-Çeşme, 2008, pp. 261-265.

[13] F. Marra, M. Zell, J. G. Lyng, D. J. Morgan and D. A. Cronin, "Analysis of heat transfer during ohmic processing", Journal of Food Engineering, vol. 91, 2009, pp. 56-63.

[14] H. Bozkurt and F. İçier, "Electrical conductivity changes of minced beef-fat blends during ohmic cooking", Journal of Food Engineering, vol. 96(1), 2009b, pp. 86-92.

[15] G. Yildiz-Turp, I. Y. Şengün, P. Kendirci, F. İçier, "Effect of ohmic treatment on quality characteristic of meat: A review", Meat Science, vol. 93, 2013, pp. 441– 448.

[16] R. Stirling, "Ohmic heating- A new process for the food industry", Power Engineering Journal, November, 1987, pp. 365-371.

[17] F. İçier, "Gıdaların ohmik ısıtma yöntemiyle ısıtılmasının deneysel ve kuramsal olarak incelenmesi", Ege Üniversitesi Fen Bilimleri Enstitüsü, Doktora Tezi, Bornova, İzmir, 2003.

[18] J. C. Fetterman, "The electrical conductivity method of processing milk", Agricultural Engineering, vol 9(4), 1928, pp. 107- 108.

[19] A. D. De Alwis and P. Fryer, "The use of direct resistance heating in the food industry", Journal of Food Engineering, vol 11, 1990, pp. 3-27.

[20] H. Bozkurt, "Köfte üretiminde ohmik pişirmenin uygulanması, matematiksel modellenmesi ve ekserjetik optimizasyonu", Yüksek lisans tezi, Ege Universitesi, Izmir, 2009a, pp. 292.

[21] R. Ruan, X. Ye, P. Chen, C. J. Doona, I. Taub, "Ohmic heating, termal tech. in food processing", Ed. Richardson, P., Woodhead Publishing Limited, Cambridge, 2001.

[22] T. Baysal, F. İçier, C. Ilıcalı, "Gıda işlemede elektriksel yöntemler", 3. Gıda Mühendisliği Kongresi, 2-4 Ekim Ankara 2003 pp. 143-157.

[23] J. W. Park, "Surimi gel colors as affected by moisture content and physical conditions" Journal of Food Science, vol. 60, 1995, pp. 15-18.

[24] P. Tempest, "Ohmic heating systems", In APV Processed Food Sector Process Manual Section-9, Electrical Heating, Issue 1, 1995, 54.

[25] S. K. Sastry and S. Salengke, "Ohmic heating of solid-liquid mixtures: A comparison of mathematical models under worst-case heating conditions", Journal of Food Process Engineering, vol. 21, 1998, pp. 441–458.

[26] Y. Zhao, E. Kolbe, "A method to characterise electrode corrosion during ohmic heating", Journal of Food Process Engineering, vol. 22, 1999, pp. 81-89.

[27] D. Reznick, "Electroheating" www.raztek.com/electroheating.html(Unpublished), 2000.

[28] D. Reznick, "Ohmic heating of fluid foods", Food Technology, May,1996, pp. 250-251.

[29] K. Allen, V. Eidman, and J. Kinsey, "An economic-engineering study of ohmic food processing", Food Technology, 1996, pp. 269-273.

[30] M. A. Ayadi, J. C. Leuliet, F. Chopard, M. Berthou, and M. Lebouche, "Experimental study of hydrodynamics in a flat ohmic celldimpact on fouling by dairy products", Journal of Food Engineering, vol. 70, 2005, pp. 489-498.

[31] B. Bansal and X. D. Chen, "Effect of temperature and power frequency on milk fouling in an ohmic heater", Food and Bioproducts Processing, vol. 84, 2006, pp. 286-291.

[32] L. Fillaudeau, P. Winterton, J. Leuliet, J. Tissier, V. Maury, F. Semet, et al. "Heat treatment of whole milk by the direct joule effect dexperimental and numerical approaches to fouling mechanisms" Journal of Dairy Science, vol. 89, 2006, pp. 4475-4489.

[33] J. Stancl, R. Zitny, "Milk fouling at direct ohmic heating", Journal of Food Engineering, vol. 99, 2010, pp. 437-444.

[34] D. L. Parrott, "Use of ohmic heating for aseptic processing of food particulates", Food Technology, December, 1992, 68-72.

[35] S. K. Sastry, "A model for continuous sterilization of particulate foods by ohmic heating", Presented at the 5th Int. Cong. Eng. Food, Cologne, Germany, May 28-June 03, 1989.

[36] F. İçier and C. Ilicali, "Temperature dependent electrical conductivities of fruit purees during ohmic heating, International Food Research", vol. 38(10), 2005a, pp. 1135-1142.

[37] S. Chen, L. Li, C. Zhao, and J. Zheng, "Surface hydration: principles and applications toward low-fouling/nonfouling biomaterials", Polymer, vol. 51, 2010, pp. 5283-5293.

[38] J. Crattelet, S. Ghnimi, P. Debreyne, I. Zaid, A. Boukabache, D. Esteve, et al., "Online local thermal pulse analysis sensor to monitor fouling and cleaning: Application to dairy product pasteurization with an ohmic cell jet heater", Journal of Food Engineering, vol. 119, 2013, pp. 72-83.

[39] K. S. Varghese, M. C. Pandey, K. Radhakrishna, A. S. Bawa, "Technology, applications and modeling of ohmic heating: A review", Journal of Food Science and Technology, vol. 51, 2014, 2304-2317.

[40] S. D. Bhale, "Effect of ohmic heating on color, rehydration and textural characteristics of fresh carrot cubes", Louisiana State University and Agricultural & Mechanical College, 2004.

[41] S. S. Kim, D. H. Kang, "Synergistic effect of carvacrol and ohmic heating for inactivation of *E. coli* O157: H7, *S. typhimurium*, *L. monocytogenes*, and MS-2 bacteriophage in salsa", Food Control, vol. 73, 2017, pp. 300-305.

[42] H. Sun, S. Kawamura, J. I. Himoto, K. Itoh, T. Wada, T. Kimura, "Effects of ohmic heating on microbial counts and denaturation of proteins in milk" Food Science and Technology Research, vol. 14, 2008, pp. 117-123.

[43] S. Palaniappan, S. K. Sastray, E. R. Richter, "Effects of electroconductive heat treatment and electrical pretreatment on thermal death kinetics of selected microorganisms", Biotechnology and Bioengineering, vol. 39, 1992, pp. 225-232.

[44] S. K. Sastry, J. T. Barach, "Ohmic and inductive heating", Journal of Food Science, vol. 65, 2001, pp. 42-46.

[45] S. Yoon, C. Yung, K. Lee, C. H. Lee, "Leakage of cellular materials from *Saccharomyces cerevisiae* by ohmic", Journal of Microbiology Biotechnology, vol. 12, 2002, pp. 183-188.

[46] N. I. Lebovka, I. Praporscic, S. Ghnimi, E. Vorobiev, "Does electroporation occur during the ohmic heating of Food?", Journal of Food Science, vol. 70, 2005, E308-311.

[47] H. Sun, F. Masuda, S. Kawamura, J. I. Himoto, K. Asano, T. Kimura, "Effect of electric current of ohmic heating on nonthermal injury to *Spreptococcus thernophilus* in milk", Journal of Food Process Engineering, vol. 34, 2011, pp. 878-892.

[48] I. K. Park, D. H. Kang, "Effect of electropermeabilization by ohmic heating for inactivation of *Escherichia Coli* O157: H7, *Salmonella enterica* serovar *typhimurium*, and *Listeria monocytogenes* in buffered peptone water and apple juice", Applied and Environmental Microbiology, vol. 79, 2013, pp. 7122-7129.

[49] S. Özkale, H. A. Kahraman, "Determination of the effect of milk fat on the inactivation of *Listeria monocytogenes* by ohmic heating" Ankara Üniversitesi, Veteriner Fakültesi Dergisi, 2023. pp. 1-22.

[50] S. Murinda, L. Nguyen, H. Nam, R. Almeida, S. Headrick, S. Oliver, "Detection of sorbitol-negative and sorbitol-positive shiga toxin-producing *Escherichia coli*, *Listeria monocytogenes*, *Campylobacter jejuni* and *Salmonella* spp. in Dairy Farm Environmental Samples", Foodborne Pathogens & Disease,vol. 1, 2004, pp. 97-104.

[51] S. S. Kim, D. H. Kang, "Effect of milk fat content on the performance of ohmic heating for inactivation of *Escherichia coli* O157:H7, *Salmonella enterica serovar typhimurium* and *Listeria monocytogenes*" Journal of Applied Microbiology, vol. 119, 2015, pp. 475-486.

[52] S. S. Kim, Y. Jo, D. H. Kang, "Combined inhibitory effect of milk fat and lactose for inactivation of foodborne pathogens by ohmic heating" Food Science and Technology, vol. 86, 2017, pp. 159-165.

[53] R. Pereira, R. C. Martins, A. Vicente, "Goat milk free fatty acid characterization during conventional and ohmic heating pasteurization", Journal of Dairy Science, vol. 91, 2008, pp. 2925-2937.

[54] F. İçier, Ş. Tavman, B. Ergin, "Maraş usulü dondurma karışımının elektriksel ve reolojik özellikleri", Gıda, vol. 30(5), 2005.

[55] H. Jaeger, A. Roth, S. Toepfl, T. Holzhauser, K. H. Engel, D. Knorr, et al. "Opinion on the use of ohmic heating for the treatment of foods", Trends in Food Science & Technology, vol. 55, 2016, pp. 84-97.

[56] H. Bozkurt and F. İçier, "Ohmic cooking of ground beef: Effects on quality", Journal of Food Engineering, vol. 96, 2010, pp. 481-490.

[57] S. Roux, M. Courel, I. Birlouez-Aragon, F. Municino, M. Massa, J. P, Pain, "Comparative thermal impact of two UHT technologies, continuous ohmic heating and direct steam injection, on the nutritional properties of liquid infant formula" Journal of Food Engineering, vol.179, 2016, pp. 36-43.

[58] F. Cabrera-Chavez, A. M. De La Barca, "Bovine milk intolerance in celiac disease is related to IGa reactivity IO Alpha- and Beta-Caseins", Nutrition, vol. 25, 2009, pp. 715-716.

[59] A. Nowak-Wegrzyn, A. Fiocchi, "Rare, Medium, or Well Done? The effect of heating and food matrix on food protein allergenicity", Current Opinion Allergy Clinical Immunology, vol. 9, 2009, pp. 234-237.

[60] J. Micinski, I. M. Kowalski, G. Zwierzchowski, J. Szarek, B. Pierożyński, E. Zabłocka, "Characteristics of cow's milk proteins including allergenic properties and methods for its reduction", Polish Annals of Medicine, vol. 20, 2013, pp., 69-76.

[61] U.K. Shandilya, R. Kapila, R. M. Haq, S. Kapila, V. K. Kansal, "Effect of thermal processing of cow and buffalo milk on the allergenic response to caseins and whey proteins in mice", Journal of the Science of Food and Agriculture, vol. 93, 2013, pp. 2287-2292.