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**Review Article**

# New Approaches in Non-thermal Processes in the Food Industry

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**Abstract:** In terms of product quality and food safety biological and chemical activities must be brought under control and this is usually provided by traditional thermal processing. To provide thermal processes, enzymatic and microbiological inactivations in food are the most basic methods that are used. However, the height of the applied temperature has a negative impact on important parameters, which are the color of food, nutritional value, sensory characteristics and flavor. Therefore, in recent years, producers and consumers are engaged in healthy food in the quest to obtain the quality parameters with less deviation. From this point of view non-thermal new techniques have emerged. This study gives information about new food preservation techniques and the applications that can be used in the food industry. These are hover electric field, ultrasonication, high-pressure application, microfiltration, X-rays, ionizing radiation, high voltage electrical discharge, Pulsed Light, magnetic field heating and moderate magnetic field.

**Keywords:** Non-thermal Process, Food Industry, Preservation Techniques, Health Benefits

## 1. Introduction

Non-thermal technologies, without causing the adverse effects of high temperature on food color, flavor, texture and nutritional value on microorganisms, possess the ability to inactivate room temperature and at temperatures near room temperature. Therefore, intensive research on non-thermal food preservation techniques continue such as heat treatment, ionizing radiation, high hydrostatic pressure (HHP), pulsed electric field (PEF), UV irradiation [108, 111].

In recent years, the interest for high-quality food products is constantly increasing due to consumer demand. This situation caused increasing demand for non-thermal food preservation technologies. That's why food industry started to use conventional processing techniques generally carried out at lower temperatures. Thus, the food thermal processing which reduce the negative effect on the quality of non-thermal technologies are began to be used [109, 110]. In this study, non-thermal food preservation techniques were given information on.

## 2. Non-thermal Processes in the Food Industry

### *2.1. Pulsed Electric Field*

Pulsed Electric Field (PEF) is a process that, high-voltage electric field is applied at very short term, that is used for the preservation of food stuffs with a non-thermal process. It is applied in very low temperatures in order to preserve taste, flavor, and nutritional components. It is aim is to inactivate microorganisms causing very little or no change in the properties that allow prolonging of the shelf life. In the process of PEF, electric field in the range of 12-35 kV $cm^{-1}$ liquid foods is being implemented with an emphasis on short-term (1- 100 µs), inactive enzymes and microorganisms on a physical mechanism [65, 66, 57]. In the food industry, this process is generally applied during pasteurization process of foods like milk, fruit juice, soups and liquid egg [65, 69]. The most popular PEF technology applications are the rectangular pulse model, logarithmic model, decreasing pulse,

sudden recycled beats, and pulsating beats model [68].

When the the inactivation of PET technology is investigated, it is obvious that according to the dielectric fragmentation theory, the clamping force of the electrostatic disruption of the cell membrane with the balance between opposite forces are emerging as a result of the deterioration of the balance. The cell membrane thickness is decreasing and as the cell membrane is not influenced. Thus, the ratio of fats in the fatty phase equilibrium between the layers is increasing. 1 As a result of the application of a -10 kV/cm force of 10-15 μs irreversibly to a cell, the cell membranes are breaking up.

To obtain electroporation via the formation of large diameter pipes, there are three incidents, which are the application of electric current intensity and the time of the formation of large diameter pipes and the decrease of the resistance of the ionic environment [68, 70]. According to researches done about PEF applications: bacteria, yeasts, moulds and the enzymes that create the distortion effect, applied to liquid foods and the results were successful. It is decided by researchers to be applied to liquid food [71 - 74].

### *2.2. Ultrasonication*

The term ultrasonication is defined as "vibration per second with sound waves of 20,000 or more that performs energy development" [90, 91, 99]. Devices developed for ultrasonication are typically at frequencies ranging from 20 kHz to 10 MHz [97, 98].The most important advantage of ultrasonication compared to thermal processing of the distortion is the process temperature. It should be low, when providing unwanted and pathogenic microorganisms to activation of enzymes engaged in corruption. Thus, the taste, smell, texture, and nutrients of the product are better preserved and fresh products, which are very close to the state properties, are obtained. [92-94, 99].

The effect of ultrasonication on microorganisms is expressed in three ways. Low frequency ultrasound applications that are used for food processing purposes can cause cavitation occurrence. At the time of the explosion, a very high degree of heat and pressure takes place in the structure of the cavitation bubbles. This dual effect enables inactivation of microorganisms to be performed [95]. The lethal effect of ultrasonication on bacteria is based on the destruction of the cytoplasmic membrane. Another mechanism for microbial inactivation is explained by free radical formation. During the application of ultrasound the OH-radicals and hydrogen peroxide are formed. Also occurring compounds has significant bactericidal effect [96].

When the studies in which changes in the inactivation of pathogenic microorganisms, quality parameters of food products and products in the activation of enzymes are analyzed, successful results were obtained [100-107].

### *2.3. Ionizing Radiation*

Radioactive substances emit some rays on the environment during the fragmentation of atoms continuously. Ionizing radiation causes the formation of electrically charged ions in the material strikes. Gamma rays, X-rays and accelerated electron beams are used for food preservation. X-rays are manufactured from 5 MeV (million electron volts) and from the resources that are running on low energy [49, 51, 52]. The results of the study on fresh strawberries against viruses, which are the norovirus, and Tulane, were successful [48]. Although successful results have been obtained as a result of microbial inactivation studies, instead of sterilization by irradiation of food, it is suggested that other suggested food preservation methods may give better results [49-51, 53]. Extreme high-dose irradiation, especially in foods that contain much fat will result in loss of aroma. Due to negative sensory properties, that effect milk and milk products negatively, these kinds of products are not eligible for teleportation [47].

### *2.4. High Hydrostatic Pressure*

High hydrostatic pressure application is a process of solid and liquid foods, as packaged or unpackaged being subjected to a pressure of 100 to 1000 MPa [1]. The basic principle of high hydrostatic pressure processing is based on the principle of compression of the force of the fluid applied to the fluid that surrounds the product [2]. Nowadays, this technique has found wide application in the food industry [3]. Some important application areas are; inactivation of microorganisms [18], protein denaturation and enzyme activation [19], or activation, gel formation [4], taste-smell and colour. Protection of sensory quality elements [6] is used in applications to increase the extraction yield [17]. The mechanism of the effect on microorganisms occurs as a result of; gas vacuoles under pressure of the jam, changes in cells, change of intracellular organelles, intracellular substances leaking out of the cell. At the same time it is very important to provide the activation of enzymes that affect food spoilage and quality [5, 8, 12, 18].

In order to increase their shelf life and to prevent microbial development vegetable products, fruit juice, beverage industry, meat products and crustaceans the application of high hydrostatic pressure is used at room temperature, in the range of 100-900 pressure MPa [7 - 9, 12]. At the same time, it is successfully used in the vegetable products, in protection of vitamins, in the fruit juice and beverage industry, for the removal of shellfish meat, for thawing of frozen meat, for removal of the bitterness of grapefruit juice, for the hardening of chocolate and for gelatinization of starch and proteins [10 - 13]. The application of high-pressure thermal processes, enzymatic mixtures and usage in connection with antimicrobial substances, and the application of high hydrostatic pressure increase the effectiveness of the method [14 - 16].

### *2.5. Plasma Sterilisation*

Irving Langmuir first discovered plasma in 1928 and it is regarded as the fourth state of matter due to its features considerably different from the solid, liquid and gaseous states of matter. Gas plasma is regarded as the fourth state of matter by some physicists and defined as, a gas comprised of ion and

free electrons [40, 44]. There are non-charged particles such as atoms, molecules and radicals in plasma used for sterilisation purposes. It is formed when a gas or gases are left on constant (direct) current or between two electrodes. Electrons and ions are released during plasma generation. This affects cell walls on microorganism. Therefore inactivation takes place and this helps sterilization. Studies show that it produces positive results in microbiological terms in lots of food such as vegetables, fruit and meat products [42, 43, 45, 46]. There are two types of plasmas, which are hot plasma and cold plasma. Ion temperature of cold plasma is near room temperature and more convenient for use in food [42].

### *2.6. Pulse Light*

Broad spectrum - wavelenghts (200nm - 1 mm) that are close to the infrared region within the UV region are used. A surface, which will be sterilised, is exposed to at least one pulse light, which has about 0,01-50 J/cm2 density of energy. This is the sterilization method which is found suitable for use by FDA (Food and Drug Administration) for food without damaging the content of the product and surface, reducing chemical preservative and the use of disinfectant and giving effect of antimicrobial. The time of pulses ranks between 1 μs and 0,1 s and 1-20 flashes are applied per second. In this application, Chemical change which occurs in microbial inactivation, protein, membrane and other cell components occur through various mechanisms like segregation of DNA chain The cell can repair itself in traditional UV applications under specified conditions but it has been noticed that the cell cannot repair itself and get damaged during the studies carried out via PL method which is applied densely and at a high energy. It has been observed that resistance of mold spores is higher than bacteria's [32, 34, 36, 37]. Successful results have been obtained during the studies carried out recently over the food safety and variations at the nutritional elements. It has been mostly used in meat industry [27-31]. It has made the method used in combination with other protection methods more effective at the studies from the point of food safety.

### *2.7. Microfiltration*

Micron inside liquid solution and larger size of particles are divided with microfiltration. Microfiltration membrane's hole varies between 0.05 and 5 mm. When membrane's resistance is low, they are operated under low pressure and they operate approximately up to 2.0 bar. Microfiltration has the ability to selectively allocate particles from the large molecular weights of more than 200 kDa. It's a technique that the pressure changes between 0.1 to 0.5 bar. The pore diameter of the membrane used varies between 0.1-10 μm [22 - 26]. Microorganisms and spores from milk or whey, fat globules, somatic cells, large molecules such as phospholipids are used for the separation of the particles. As a result of conducted researches, the milk that is subjected to microfiltration process is stored considerably longer than the duration of pasteurized milk [20-22].

### *2.8. Ultraviolet Light*

Ultraviolet (UV) light is an electromagnetic radiation with a wavelength between 10-400 nanometers. Ultraviolet light is divided to three categories according to its wavelength**:** UV-A 400-320 nm, UV-B 320-290 nm and it has two wavelenght between UV-C 290-200 nm [54, 57]. The usage of UV-C light in food has an effect on the microorganisms within a broad spectrum. Furthermore, it is known that UV-C has posovote effect on food products. Ultraviolet light demonstrates antimicrobial (germicidal) wave length effect from 100 nanometers to 280 nanometers. The sub-division of ultraviolet light in this part is UV-C [55, 58]. Generally, ultraviolet light causes damage to nucleic acids when it effects microorganism. Thus, it leads to prevention of reproduction. Nucleic acid absorbs the ultraviolet light between 200-310nm. As a result of damage microorganism becomes inactive [56, 57]. Effectiveness of the application of ultraviolet light depends on characteristics of light, feathures of foodstuff, microorganism types, processing conditions, and products being solid or liquid [57, 59]. UV light for inactivation of microorganisms on food surfaces is ever increasing and the technology required to be successful have been identified in many studies [60 - 64].

### *2.9. Magnetic Field Heating and Moderate Field Heating*

Magnetic field has a potential impact in microbial inactivation of foods. Static Magnetic Field (SMF) and mobile magnetic field (MMF) have a potential effect in microbial inactivation in foods. As in SMF, magnetic field intensity can change as sinusoidal waves. DNA synthesis of the magnetic field causes change in the sequence of biomolecules or biyomembranes, ionic movement between the plasma membrane. As a result, it causes change in the cell proliferation rate [76, 77]. It's applied in the processing of liquid, solid and packaged foodstuffs. Pressured Electric Field (PEF) and Static Magnetic Field (SMF) are both used for food freezing processes and successful results are obtained [75].

Moderate Magnetic Field (MMF) depends on the completion of the electrical circuit based on the principle of the food by passing the electrical current through. Generally, it is used for breaking down the cell wall to affect the efficiency of the fruit juice [82 - 84]. The voltage gradiyen below 100 V/cm is used for component extraction from microorganisms, fermentation yield, and combined with other methods to prolong the shelf life [78 - 81].

### *2.10. High-Voltage Electrical Discharge and Gliding Arc Discharge*

Recently, new technologies like high-voltage electrical discharges (HVED) are used to remove the valuable compound like polyphenols which are obtained from plant material [86, 87]. It leads to degradation by forming damage in cell walls and tissues with electrical and mechanical effects of technology HVED (0-400 kJ/kg). A study was conducted about pressed rapeseed. As a result, in order to decrease the loss of high components high voltage electrical discharges and

solid-liquid ratio (1:5–1:20, w/w) were used. Successful results have been obtained. Cayman arc discharge (CAD) is one of the new conservation methods in food. It is the technology that used with electric arc discharge [89]. A study of the slip arc discharge, the contaminated water with *Escherichia coli* , the first 10, 13 and 16, and 25 minutes along treated with GAD for 25 min and the best results 16 minutes of plasma treatment (approximately 2.7 log decrease) was inactivated [88].

## 3. Discussion

Literature review shows that there are new techniques in food processing. As a result of these new techniques, new alternative and non-thermal methods gained importance, which will have less impact on the overall quality and nutritional value of foods. In order to extent shelf life of foods ultrasonication, microfiltration, High Hydrostatic Pressure (HHP) Technology, and Hover Electric Field (PEF) applications have been developed. Nowadays, in the production of foodstuff, microbiologically safe and thermal process techniques are becoming increasingly important. Pulsed Light Technology is a method widely available on food surfaces, but it was concluded that more research is required. It has been identified in the literature that high-voltage electrical discharge in a magnetic field and heating of other technologies such as food practices are not adequate. UV and PEF technologies are especially found in the fruit juice and liquid foods. Studies demonstrate that usage of non-thermal preservation methods with other food preservation methods has been found to be more effective in the activation of other destructive microorganisms and enzymes.

## 4. Conclusion

The negative effects of thermal processes on the product have led manufacturers to avoid using these methods. The exploration of new techniques because of the new food processing methods that will have less impact on overall quality and nutritional value of food, are requested by the consumer. As a result of researches, non-thermal processes which are one of the new technologies are regarded as techniques that can be used successfully in obtaining a quality product in terms of sensory and nutritional content. Also it can be used on their own and other preservation methods. With these methods, loss of nutrients released by the effect of high temperatures in the food structure and the changes occurring in the sensory properties can be minimised. It is found that the applications of electrical field has increased and it has been seen as promising.

## References

[1] D. Hygreeva and M. Pandey, "Novel approaches in improving the quality and safety aspects of processed meat products through high pressure processing technology - A review", Trends in Food Science & Technology, vol.54, pp.175-185, 2016.

[2] I. Baptista, S. Rocha, Â. Cunha, J. Saraiva and A. Almeida, "Inactivation of Staphylococcus aureus by high pressure processing: An overview", Innovative Food Science & Emerging Technologies, vol.36, pp.128-149, 2016.

[3] G. Gao, P. Ren, X. Cao, B. Yan, X. Liao, Z. Sun and Y. Wang, "Comparing quality changes of cupped strawberry treated by high hydrostatic pressure and thermal processing during storage", Food and Bioproducts Processing, 2016.

[4] T. Leite, A. de Jesus, M. Schmiele, A. Tribst and M. Cristianini, "High pressure processing (HPP) of pea starch: Effect on the gelatinization properties", LWT - Food Science and Technology, 2016.

[5] P. Meinlschmidt, V. Brode, R. Sevenich, E. Ueberham, U. Schweiggert-Weisz, J. Lehmann, C. Rauh, D. Knorr and P. Eisner, "High pressure processing assisted enzymatic hydrolysis – An innovative approach for the reduction of soy immunoreactivity", Innovative Food Science & Emerging Technologies, 2016.

[6] M. Lavilla, J. Orcajo, A. Díaz-Perales and P. Gamboa, "Examining the effect of High Pressure Processing on the allergenic potential of the major allergen in peach (Pru p 3)", Innovative Food Science & Emerging Technologies, 2016.

[7] H. Yang, M. Khan, X. Yu, H. Zheng, M. Han, X. Xu and G. Zhou, "Changes in protein structures to improve the rheology and texture of reduced-fat sausages using high pressure processing", Meat Science, vol.121, pp.79-87, 2016.

[8] F. Liu, X. Zhang, L. Zhao, Y. Wang and X. Liao, "Potential of high-pressure processing and high-temperature/short-time thermal processing on microbial, physicochemical and sensory assurance of clear cucumber juice", Innovative Food Science & Emerging Technologies, vol.34, pp.51-58, 2016.

[9] Y. Zhang, X. Liu, Y. Wang, F. Zhao, Z. Sun and X. Liao, "Quality comparison of carrot juices processed by high-pressure processing and high-temperature short-time processing", Innovative Food Science & Emerging Technologies, vol.33, pp.135-144, 2016.

[10] R. Mengden, A. Röhner, N. Sudhaus and G. Klein, "High-pressure processing of mild smoked rainbow trout fillets (Oncorhynchus mykiss) and fresh European catfish fillets (Silurus glanis)", Innovative Food Science & Emerging Technologies, vol.32, pp.9-15, 2015.

[11] M. Santos, J. Saraiva and M. Gomes, "Pasting of maize and rice starch after high pressure processing: Studies based on an acoustic wave sensor", Sensors and Actuators B: Chemical, vol.209, pp.323-327, 2015.

[12] H. Huang, S. Wu, J. Lu, Y. Shyu and C. Wang, "Current status and future trends of high-pressure processing in food industry", Food Control, vol.72, pp.1-8, 2016.

[13] C. Afonso, L. Ferreira, H. Vila-Real, A. Alfaia and M. Ribeiro, "High pressure and temperature combination with naringin hydrolysis by naringinase Ca-alginate beads in grapefruit juice processing: Bitterness and microbial reduction", Journal of Biotechnology, vol.131, no. 2, p.S265, 2007.

[14] G. Knockaert, S. Pulissery, L. Lemmens, S. Van Buggenhout, M. Hendrickx and A. Van Loey, "Isomerisation of carrot β-carotene in presence of oil during thermal and combined thermal/high pressure processing", Food Chemistry, vol.138, no. 2-3, pp.1515-1520, 2013.

[15] C. Manassero, S. Vaudagna, A. Sancho, M. Añón and F. Speroni, "Combined high hydrostatic pressure and thermal treatments fully inactivate trypsin inhibitors and lipoxygenase and improve protein solubility and physical stability of calcium-added soymilk", Innovative Food Science & Emerging Technologies, vol.35, pp.86-95, 2016.

[16] B. Marcos, A. Jofré, T. Aymerich, J. Monfort and M. Garriga, "Combined effect of natural antimicrobials and high pressure processing to prevent Listeria monocytogenes growth after a cold chain break during storage of cooked ham", Food Control, vol.19, no. 1, pp.76-81, 2008.

[17] J. Xi and S. Luo, "The mechanism for enhancing extraction of ferulic acid from Radix Angelica sinensis by high hydrostatic pressure", Separation and Purification Technology, vol.165, pp.208-213, 2016.

[18] I. Baptista, S. Rocha, Â. Cunha, J. Saraiva and A. Almeida, "Inactivation of Staphylococcus aureus by high pressure processing: An overview", Innovative Food Science & Emerging Technologies, vol.36, pp.128-149, 2016.

[19] M. Khan, S. Ali, M. Abid, J. Cao, S. Jabbar, R. Tume and G. Zhou, "Improved duck meat quality by application of high pressure and heat: A study of water mobility and compartmentalization, protein denaturation and textural properties", Food Research International, vol.62, pp.926-933, 2014.

[20] G. Daufin, J. Escudier, H. Carrère, S. Bérot, L. Fillaudeau and M. Decloux, "Recent and Emerging Applications of Membrane Processes in the Food and Dairy Industry", Food and Bioproducts Processing, vol.79, no. 2, pp.89-102, 2001.

[21] G. Brans, C. Schroën, R. van der Sman and R. Boom, "Membrane fractionation of milk: state of the art and challenges", Journal of Membrane Science, vol.243, no. 1-2, pp.263-272, 2004.

[22] A. Avalli, M. Povolo, D. Carminati and G. Contarini, "Significance of 2-heptanone in evaluating the effect of microfiltration/pasteurisation applied to goats' milk", International Dairy Journal, vol.14, no. 10, pp.915-921, 2004.

[23] C. dos Santos, R. Scherer, A. Cassini, L. Marczak and I. Tessaro, "Clarification of red beet stalks extract by microfiltration combined with ultrafiltration", Journal of Food Engineering, vol.185, pp.35-41, 2016.

[24] D. Doulia, E. Anagnos, K. Liapis and D. Klimentzos, "Removal of pesticides from white and red wines by microfiltration", Journal of Hazardous Materials, vol.317, pp.135-146, 2016.

[25] A. Laorko, S. Tongchitpakdee and W. Youravong, "Storage quality of pineapple juice non-thermally pasteurized and clarified by microfiltration", Journal of Food Engineering, vol.116, no. 2, pp.554-561, 2013.

[26] V. Hakimzadeh, S. Razavi, M. Piroozifard and M. Shahidi, "The potential of microfiltration and ultrafiltration process in purification of raw sugar beet juice", Desalination, vol.200, no. 1-3, pp.520-522, 2006.

[27] B. Salinas-Roca, R. Soliva-Fortuny, J. Welti-Chanes and O. Martín-Belloso, "Combined effect of pulsed light, edible coating and malic acid dipping to improve fresh-cut mango safety and quality",Food Control, vol.66, pp.190-197, 2016.

[28] M. Siddique, P. Maresca, G. Pataro and G. Ferrari, "Effect of pulsed light treatment on structural and functional properties of whey protein isolate", Food Research International, 2016.

[29] W. Xu and C. Wu, "The impact of pulsed light on decontamination, quality, and bacterial attachment of fresh raspberries", Food Microbiology, vol.57, pp.135-143, 2016.

[30] F. Duarte-Molina, P. Gómez, M. Castro and S. Alzamora, "Storage quality of strawberry fruit treated by pulsed light: Fungal decay, water loss and mechanical properties", Innovative Food Science & Emerging Technologies, vol.34, pp.267-274, 2016.

[31] K. Avalos Llano, A. Marsellés-Fontanet, O. Martín-Belloso and R. Soliva-Fortuny, "Impact of pulsed light treatments on antioxidant characteristics and quality attributes of fresh-cut apples", Innovative Food Science & Emerging Technologies, vol.33, pp.206-215, 2016.

[32] V. Gómez-López, "Pulsed Light Technology", Reference Module in Food Science, 2016.

[33] M. Moreira, B. Tomadoni, O. Martín-Belloso and R. Soliva-Fortuny, "Preservation of fresh-cut apple quality attributes by pulsed light in combination with gellan gum-based prebiotic edible coatings", LWT - Food Science and Technology, vol.64, no. 2, pp.1130-1137, 2015.

[34] H. Hwang, C. Cheigh and M. Chung, "Relationship between optical properties of beverages and microbial inactivation by intense pulsed light", Innovative Food Science & Emerging Technologies, vol.31, pp.91-96, 2015.

[35] B. Chen, H. Lung, B. Yang and C. Wang, "Pulsed light sterilization of packaging materials", Food Packaging and Shelf Life, vol.5, pp.1-9, 2015.

[36] J. Proulx, L. Hsu, B. Miller, G. Sullivan, K. Paradis and C. Moraru, "Pulsed-light inactivation of pathogenic and spoilage bacteria on cheese surface", Journal of Dairy Science, vol.98, no. 9, pp.5890-5898, 2015.

[37] V. Heinrich, M. Zunabovic, J. Bergmair, W. Kneifel and H. Jäger, "Post-packaging application of pulsed light for microbial decontamination of solid foods: A review", Innovative Food Science & Emerging Technologies, vol.30, pp.145-156, 2015.

[38] M. Ferrario and S. Guerrero, "Effect of a continuous flow-through pulsed light system combined with ultrasound on microbial survivability, color and sensory shelf life of apple juice", Innovative Food Science & Emerging Technologies, vol.34, pp.214-224, 2016.

[39] M. Artíguez and I. Martínez de Marañón, "Inactivation of Bacillus subtilis spores by combined pulsed light and thermal treatments", International Journal of Food Microbiology, vol.214, pp.31-37, 2015.

[40] A. Fernández, N. Shearer, D. Wilson and A. Thompson, "Effect of microbial loading on the efficiency of cold atmospheric gas plasma inactivation of Salmonella enterica serovar Typhimurium",International Journal of Food Microbiology, vol.152, no. 3, pp.175-180, 2012.

[41] D. Ziuzina, S. Patil, P. Cullen, K. Keener and P. Bourke, "Atmospheric cold plasma inactivation of Escherichia coli, Salmonella enterica serovar Typhimurium and Listeria monocytogenes inoculated on fresh produce", Food Microbiology, vol.42, pp.109-116, 2014.

[42] Ş. Candan, Çelik yüzeylerin silikon temelli RF plazma filmler ile kaplanması, http://arsiv.mmo.org.tr/pdf/0000069E.pdf, accessed Aug. 3. 2016.

[43] F. Pasquali, A. Stratakos, A. Koidis, A. Berardinelli, C. Cevoli, L. Ragni, R. Mancusi, G. Manfreda and M. Trevisani, "Atmospheric cold plasma process for vegetable leaf decontamination: A feasibility study on radicchio (red chicory, Cichorium intybus L.)", Food Control, vol.60, pp.552-559, 2016.

[44] H. Kim, D. Jayasena, H. Yong and C. Jo, "Quality of Cold Plasma Treated Foods of Animal Origin", Cold Plasma in Food and Agriculture, pp.273-291, 2016.

[45] H. Lee, J. Kim, M. Chung and S. Min, "Cold plasma treatment for the microbiological safety of cabbage, lettuce, and dried figs", Food Microbiology, vol.51, pp.74-80, 2015.

[46] M. Moisan, J. Barbeau, S. Moreau, J. Pelletier, M. Tabrizian and L. Yahia, "Low-temperature sterilization using gas plasmas: a review of the experiments and an analysis of the inactivation mechanisms", International Journal of Pharmaceutics, vol.226, no. 1-2, pp.1-21, 2001.

[47] M. Atasever and M. Atasever, "Işınlamanın Gıda Teknolojisindeki Kullanımı", Atatürk Üniversitesi Vet. Bil. Derg, vol.2, no. 3, pp.107-116, 2007.

[48] E. DiCaprio, N. Phantkankum, D. Culbertson, Y. Ma, J. Hughes, D. Kingsley, R. Uribe and J. Li, "Inactivation of human norovirus and Tulane virus in simple media and fresh whole strawberries by ionizing radiation", International Journal of Food Microbiology, vol.232, pp.43-51, 2016.

[49] M. Harder, V. Arthur and P. Arthur, "Irradiation of Foods: Processing Technology and Effects on Nutrients: Effect of Ionizing Radiation on Food Components", Encyclopedia of Food and Health, pp.476-481, 2016.

[50] F. Hossain, P. Follett, K. Vu, S. Salmieri, C. Senoussi and M. Lacroix, "Radiosensitization of Aspergillus niger and Penicillium chrysogenum using basil essential oil and ionizing radiation for food decontamination", Food Control, vol.45, pp.156-162, 2014.

[51] Z. Berk, "Ionizing Irradiation and Other Non-Thermal Preservation Processes", Food Process Engineering and Technology, pp.607-620, 2013.

[52] D. Ehlermann, "The early history of food irradiation", Radiation Physics and Chemistry, 2016.

[53] A. Boumail, S. Salmieri and M. Lacroix, "Combined effect of antimicrobial coatings, gamma radiation and negative air ionization with ozone on Listeria innocua, Escherichia coli and mesophilic bacteria on ready-to-eat cauliflower florets", Postharvest Biology and Technology, vol.118, pp.134-140, 2016.

[54] M. Yel and H. Türker, "Ultrastructural effects of ultraviolet C radiation on the stratum basale of mole rats epidermis", Journal of Radiation Research and Applied Sciences, vol.7, no. 4, pp.406-410, 2014.

[55] L. Manzocco, A. Panozzo and M. Nicoli, "Effect of ultraviolet processing on selected properties of egg white", Food Chemistry, vol.135, no. 2, pp.522-527, 2012.

[56] T. Koutchma, "Basic Principles of UV Light Generation", Food Plant Safety, pp.3-13, 2014.

[57] N. Keklik, K. Krishnamurthy and A. Demirci, "Microbial decontamination of food by ultraviolet (UV) and pulsed UV light", Microbial Decontamination in the Food Industry, pp.344-369, 2012.

[58] V. Gómez-López, T. Koutchma and K. Linden, "Ultraviolet and Pulsed Light Processing of Fluid Foods", Novel Thermal and Non-Thermal Technologies for Fluid Foods, pp.185-223, 2012.

[59] W. Lim and M. Harrison, "Effectiveness of UV light as a means to reduce Salmonella contamination on tomatoes and food contact surfaces", Food Control, vol.66, pp.166-173, 2016.

[60] V. Lacivita, A. Conte, L. Manzocco, S. Plazzotta, V. Zambrini, M. Del Nobile and M. Nicoli, "Surface UV-C light treatments to prolong the shelf-life of Fiordilatte cheese", Innovative Food Science & Emerging Technologies, vol.36, pp.150-155, 2016.

[61] L. Manzocco, S. Da Pieve, A. Bertolini, I. Bartolomeoli, M. Maifreni, A. Vianello and M. Nicoli, "Surface decontamination of fresh-cut apple by UV-C light exposure: Effects on structure, colour and sensory properties", Postharvest Biology and Technology, vol.61, no. 2-3, pp.165-171, 2011.

[62] E. Gayán, D. García-Gonzalo, I. Álvarez and S. Condón, "Resistance of Staphylococcus aureus to UV-C light and combined UV-heat treatments at mild temperatures", International Journal of Food Microbiology, vol.172, pp.30-39, 2014.

[63] R. Yan, J. Mattheis, J. Gurtler, J. Sites and X. Fan, "UV-C inactivation of Escherichia coli and dose uniformity on apricot fruit in a commercial setting", Postharvest Biology and Technology, vol.95, pp.46-49, 2014.

[64] C. Cheigh, H. Hwang and M. Chung, "Intense pulsed light (IPL) and UV-C treatments for inactivating Listeria monocytogenes on solid medium and seafoods", Food Research International, vol.54, no. 1, pp.745-752, 2013.

[65] G. Kaletunç, "Gıda Endüstrisinde Alışılmamış Yöntemler", Tübitak Bilim ve Teknik Dergisi, vol.502, pp.61-63, 2009.

[66] H. Vega-Mercado, O. Martín-Belloso, B. Qin, F. Chang, M. Marcela Góngora-Nieto, G. Barbosa-Cánovas and B. Swanson, "Non-thermal food preservation: Pulsed electric fields", Trends in Food Science & Technology, vol.8, no. 5, pp.151-157, 1997.

[67] J. Raso and I. Álvarez, "Pulsed Electric Field Processing: Cold Pasteurization", Reference Module in Food Science, 2016.

[68] G. Barbosa-Cánovas, M. Góngora-Nieto, U. Pothakamury and B. Swanson, "Fundamentals of High-Intensity Pulsed Electric Fields (PEF)", Preservation of Foods with Pulsed Electric Fields, pp.1-19, 1999.

[69] M. Griffiths and M. Walkling-Ribeiro, "Pulsed Electric Field Processing of Liquid Foods and Beverages", Emerging Technologies for Food Processing, pp.115-145, 2014.

[70] U. Zimmermann, "The effect of high intensity electric field pulses on eucaryotic cell membranes: fundamentals and applications", Electromanipulation of cells, pp.1-106, 1999.

[71] F. Barba, O. Parniakov, S. Pereira, A. Wiktor, N. Grimi, N. Boussetta, J. Saraiva, J. Raso, O. Martin-Belloso, D. Witrowa-Rajchert, N. Lebovka and E. Vorobiev, "Current applications and new opportunities for the use of pulsed electric fields in food science and industry", Food Research International, vol.77, pp.773-798, 2015.

[72] C. Siemer, S. Toepfl and V. Heinz, "Inactivation of Bacillus subtilis spores by pulsed electric fields (PEF) in combination with thermal energy – I. Influence of process- and product parameters",Food Control, vol.39, pp.163-171, 2014.

[73] O. Martín-Belloso, Á. Marsellés-Fontanet and P. Elez-Martínez, "Enzymatic Inactivation by Pulsed Electric Fields", Emerging Technologies for Food Processing, pp.155-168, 2014.

[74] S. Toepfl, C. Siemer, G. Saldaña-Navarro and V. Heinz, "Overview of Pulsed Electric Fields Processing for Food", Emerging Technologies for Food Processing, pp.93-114, 2014.

[75] J. Mok, W. Choi, S. Park, S. Lee and S. Jun, "Emerging pulsed electric field (PEF) and static magnetic field (SMF) combination technology for food freezing", International Journal of Refrigeration, vol.50, pp.137-145, 2015.

[76] J. Filipič, B. Kraigher, B. Tepuš, V. Kokol and I. Mandic-Mulec, "Effects of low-density static magnetic fields on the growth and activities of wastewater bacteria Escherichia coli and Pseudomonas putida", Bioresource Technology, vol.120, pp.225-232, 2012.

[77] Y. Liu, S. Jia, J. Ran and S. Wu, "Effects of static magnetic field on activity and stability of immobilized α-amylase in chitosan bead", Catalysis Communications, vol.11, no. 5, pp.364-367, 2010.

[78] J. Mattar, M. Turk, M. Nonus, N. Lebovka, H. El Zakhem and E. Vorobiev, "S. cerevisiae fermentation activity after moderate pulsed electric field pre-treatments", Bioelectrochemistry, vol.103, pp.92-97, 2015.

[79] M. Walkling-Ribeiro, F. Noci, D. Cronin, J. Lyng and D. Morgan, "Shelf life and sensory attributes of a fruit smoothie-type beverage processed with moderate heat and pulsed electric fields", LWT - Food Science and Technology, vol.43, no. 7, pp.1067-1073, 2010.

[80] A. Vallverdú-Queralt, I. Odriozola-Serrano, G. Oms-Oliu, R. Lamuela-Raventós, P. Elez-Martínez and O. Martín-Belloso, "Impact of high-intensity pulsed electric fields on carotenoids profile of tomato juice made of moderate-intensity pulsed electric field-treated tomatoes", Food Chemistry, vol.141, no. 3, pp.3131-3138, 2013.

[81] D. Jaeschke, T. Menegol, R. Rech, G. Mercali and L. Marczak, "Carotenoid and lipid extraction from Heterochlorella luteoviridis using moderate electric field and ethanol", Process Biochemistry, 2016.

[82] L. Machado, R. Pereira, R. Martins, J. Teixeira and A. Vicente, "Moderate electric fields can inactivate Escherichia coli at room temperature", Journal of Food Engineering, vol.96, no. 4, pp.520-527, 2010.

[83] H. El Zakhem, J. Lanoisellé, N. Lebovka, M. Nonus and E. Vorobiev, "Influence of temperature and surfactant on Escherichia coli inactivation in aqueous suspensions treated by moderate pulsed electric fields", International Journal of Food Microbiology, vol.120, no. 3, pp.259-265, 2007.

[84] F. İçier, T. Baysal, A. Rayman, G. Özkan, S. Eroğlu and A. Aydın, "Domates suyu üretiminde ılımlı elektrik uygulamasının kullanımı: 2. Kalite özellikleri üzerine etkisi", Akademik Gıda, vol.112, pp.21-27, 2013.

[85] F. Barba, N. Boussetta and E. Vorobiev, "Emerging technologies for the recovery of isothiocyanates, protein and phenolic compounds from rapeseed and rapeseed press-cake: Effect of high voltage electrical discharges", Innovative Food Science & Emerging Technologies, vol.31, pp.67-72, 2015.

[86] C. Delsart, N. Grimi, N. Boussetta, C. Miot Sertier, R. Ghidossi, M. Mietton Peuchot and E. Vorobiev, "Comparison of the effect of pulsed electric field or high voltage electrical discharge for the control of sweet white must fermentation process with the conventional addition of sulfur dioxide", Food Research International, vol.77, pp.718-724, 2015.

[87] N. Boussetta and E. Vorobiev, "Extraction of valuable biocompounds assisted by high voltage electrical discharges: A review", Comptes Rendus Chimie, vol.17, no. 3, pp.197-203, 2014.

[88] H. Kim, Y. Cho, I. Hwang, D. Lee, D. Cho, A. Rabinovich and A. Fridman, "Use of plasma gliding arc discharges on the inactivation of E. Coli in water", Separation and Purification Technology, vol.120, pp.423-428, 2013.

[89] K. Wright, H. Kim, D. Cho, A. Rabinovich, A. Fridman and Y. Cho, "New fouling prevention method using a plasma gliding arc for produced water treatment", Desalination, vol.345, pp.64-71, 2014.

[90] S. Bhat and H. Sharma, "Combined effect of blanching and sonication on quality parameters of bottle gourd (Lagenaria siceraria) juice", Ultrasonics Sonochemistry, vol.33, pp.182-189, 2016.

[91] H. Deeth and N. Datta, "Heat Treatment of Milk | Non-Thermal Technologies: Pulsed Electric Field Technology and Ultrasonication", Encyclopedia of Dairy Sciences, pp.738-743, 2011.

[92] T. LEIGHTON, "What is ultrasound?", Progress in Biophysics and Molecular Biology, vol.93, no. 1-3, pp.3-83, 2007.

[93] J. Chandrapala, C. Oliver, S. Kentish and M. Ashokkumar, "Ultrasonics in food processing – Food quality assurance and food safety", Trends in Food Science & Technology, vol.26, no. 2, pp.88-98, 2012.

[94] D. J. McClement, "Advances in the application of ultrasound in food analysis and processing". Trends in Food, Science & Technology, 6, pp.293-299. 1995

[95] "Gıda Endüstrisinde Ultrason Kullanımı", http://www.food.hacettepe.edu.tr/turkish/ouyeleri/gmu809/Ultrason%2012.pdf, accessed Apr. 13. 2016.

[96] http://www.fda.gov/food/ScienceResearch/ResearchAreas/ Safe Practices for Food Processes/ucm100158.htm, accessed Jul. 5. 2016.

[97] K. Schössler, H. Jäger, C. Büchner, S. Struck and D. Knorr, "NON-THERMAL PROCESSING | Ultrasonication", Encyclopedia of Food Microbiology, pp.985-989, 2014.

[98] S. Jabbar, M. Abid, B. Hu, T. Wu, M. Hashim, S. Lei, X. Zhu and X. Zeng, "Quality of carrot juice as influenced by blanching and sonication treatments", LWT - Food Science and Technology, vol.55, no. 1, pp.16-21, 2014.

[99] B. Tiwari and T. Mason, "Ultrasound Processing of Fluid Foods", Novel Thermal and Non-Thermal Technologies for Fluid Foods, pp.135-165, 2012.

[100] F. Mohideen, K. Solval, J. Li, J. Zhang, A. Chouljenko, A. Chotiko, A. Prudente, J. Bankston and S. Sathivel, "Effect of continuous ultra-sonication on microbial counts and physico-chemical properties of blueberry (Vaccinium corymbosum) juice", LWT - Food Science and Technology, vol.60, no. 1, pp.563-570, 2015.

[101] H. Sagong, S. Lee, P. Chang, S. Heu, S. Ryu, Y. Choi and D. Kang, "Combined effect of ultrasound and organic acids to reduce Escherichia coli O157:H7, Salmonella Typhimurium, and Listeria monocytogenes on organic fresh lettuce", International Journal of Food Microbiology, vol.145, no. 1, pp.287-292, 2011.

[102] R. Saleem and R. Ahmad, "Effect of low frequency ultrasonication on biochemical and structural properties of chicken actomyosin", Food Chemistry, vol.205, pp.43-51, 2016.

[103] A. Durak, M. Erbaş and S. Arslan, "Ultrasonication to inactivate the proteolytic enzymes in suni bug-damaged wheat", Journal of Cereal Science, 2016.

[104] T. Garoma and D. Janda, "Investigation of the effects of microalgal cell concentration and electroporation, microwave and ultrasonication on lipid extraction efficiency", Renewable Energy, vol.86, pp.117-123, 2016.

[105] M. Valero, N. Recrosio, D. Saura, N. Muñoz, N. Martí and V. Lizama, "Effects of ultrasonic treatments in orange juice processing", Journal of Food Engineering, vol.80, no. 2, pp.509-516, 2007.

[106] K. Luo, S. Kim, J. Wang and D. Oh, "A combined hurdle approach of slightly acidic electrolyzed water simultaneous with ultrasound to inactivate Bacillus cereus on potato", LWT - Food Science and Technology, vol.73, pp.615-621, 2016.

[107] D. Millan-Sango, E. Garroni, C. Farrugia, J. Van Impe and V. Valdramidis, "Determination of the efficacy of ultrasound combined with essential oils on the decontamination of Salmonella inoculated lettuce leaves", LWT - Food Science and Technology, vol.73, pp.80-87, 2016.

[108] A. Ross, M. Griffiths, G. Mittal and H. Deeth, "Combining nonthermal technologies to control foodborne microorganisms", International Journal of Food Microbiology, vol.89, no. 2-3, pp.125-138, 2003.

[109] K. Ojha, B. Tiwari, C. O'Donnell and J. Kerry, "Emerging Nonthermal Food Preservation Technologies", Innovation and Future Trends in Food Manufacturing and Supply Chain Technologies, pp.257-274, 2016.

[110] O. Martín-Belloso, R. Soliva-Fortuny, P. Elez-Martínez, A. Robert Marsellés-Fontanet and H. Vega-Mercado, "Non-thermal Processing Technologies", Food Safety Management, pp.443-465, 2014.

[111] V. Santhirasegaram, Z. Razali and C. Somasundram, "Safety improvement of fruit juices by novel thermal and nonthermal processing", Food Hygiene and Toxicology in Ready to Eat Foods, pp.209-223, 2016.