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Non-Thermal Methods of Food Preservation

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Abstract: ***Consumers nowadays are well aware of ongoing addition of the chemical preservatives and all detrimental health effects that come along with the use of such food additives. Food industries on the other hand, have invested and are majorly relying mostly on conventional thermal processing, which poses a great threat to heat labile food components such as pigments, anti-oxidants, bio-active compounds etc. Retaining such heat labile nutrients involves great amount of innovation and complex process design.Non-thermal processing methods have recently gained importance and interest because of consumers growing demand for minimally processed and fresh like foods. Some of the popular non-thermal methods include:-Ohmic heating, microwave heating, high-hydrostatic pressure treatment, ultrasonication, pulsed electric field method and cold plasma. The following review aims to summarize various techniques, which are available for implementing and practicing non-thermal ways of preservation as these processes not only meet industry needs by offering value-added products and new market opportunities but also serve today's consumers with evolved eating habits.***

1. Introduction

Food preservation is basically a never ending scrimmage against microorganism proliferation, and to make food safer for consumption for longer periods. Most of the foods that we consume nowadays are processed in some way or the other, in spite of knowing the fact that many food groups pose great health benefits when consumed raw and fresh. But knowing the present day scenario of the modern supply chain, most foods are subjected to some degree of processing to preserve their freshness.

Food preservation technologies are based on the prevention of microbial growth or on microbial inactivation, i.e. either by altering temperature, water activity and pH, or by addition of preservatives and modifying atmosphere. Most of the non-thermal processing methods are not effective on bacterial spores, and in such cases microorganisms will still be metabolically active and viable if given favorable conditions.

Novel non-thermal processes are able to inactivate microorganisms at ambient or sub-lethal temperature. Many of these need very high treatment intensities to achieve adequate microbial destruction in low-acid foods. Combining non-thermal processes with conventional preservation methods or hurdle technology can effectively lead to microbial inactivation and allow the use of lower individual treatment intensities.

1.1 Pulsed Electric Field

It is a novel non-thermal method of food preservation, which uses short electrical pulses for microbial inactivation; it is a very superior method of preservation with respect to other thermal treatments as it imposes minimal detrimental influence on food quality and nutrition, and safeguards the sensorial and physical attributes of food.This treatment applies short pulses to avoid excessive heating or undesirable electrolytic reactions.

Main principle of working is it uses pulses with high electric fields for a few micro to milliseconds with intensities in the range of 10-80kV/cm. During the process, the food product is held between two electrodes, and the gap between electrodes is called treatment gap of the chamber. Once the food product is properly placed in between the electrodes, high voltage is applied resulting in inactivation of microorganisms in food. The most remarkable feature of PEF is that it increases permeabilization, in other words, it can be efficiently used to enhance mass and heat transfer to assist increased yield during juice extraction and drying of plant tissues.

Another successful commercial usage of PEF treatment is extraction of vitamins, pigments, proteinsandanti oxidative and bioactive substances from different varieties of macro- and microalgae. PEF treatment for algae extracts provides a gentler processing approach and encourages yield increase.

The two factors that can be altered during the process are temperature and electric field, the temperature of procedure can be either ambient, sub-ambient or above room temperature. Electrical field to be applied on the other hand can be applied in exponential, decaying, and bipolar or oscillatory waves. Electrical pulses mainly travel in the food with ions, which can successfully transfers pulses from one point to the other in the food. It is very important that electric field intensity should be evenly distributed in the treatment chamber to achieve an efficient treatment, as PEF inactivation greatly depends upon intrinsic parameters of microorganisms like, shape, size, species, or growth stage

Many food products like apple and orange juice, yoghurt drinks, apple sauce and salad dressings, milk, tomato juice, carrot juice, pea soup, liquid whole egg and liquid egg products when treated with PEF technology have shown to retain fresh like characteristics with increased shelf life.

This technology however, is not successful for bacterial spores, so application of this method mainly focuses on food borne pathogens and spoilage microorganisms, especially for acidic foods. It has also been seen that, gram positive vegetative cells are more resistant to PEF, than gram negative. Yeasts on the other hand show greater sensitivity than bacteria.

Advantages

- Less treatment time and low treatment temperature thus, can be a great substitute for conventional heat pasteurization and increases shelf life and maintain food safety with low processing costs
- Provides minimally processed foods of fresh quality, which have higher nutritional value because of color and flavor retention

- PEF inactivates vegetative micro-organisms including yeasts, spoilage micro-organisms and pathogens and can be used to pasteurize fluids such as juices, milk and soups without using additives.
- PEF causes the formation of large, permanent pores in cellular tissues, which can be used to improve juice yield and increase concentrations of functional components
- Low electric field causes reversible cell rupture stimulating a stress reaction in plants or cell cultures and allowing enzymes or proteins with potential health benefits to be harvested
- PEF can be used for pretreatment applications for improvement of metabolite extraction.

Disadvantages

- Capital cost is high.
- Refrigeration is required to extend shelf-life.
- Treatment does not inactivate enzymes and vegetative spores.
- PEF is a continuous processing method, which is not suitable for solid food products that cannot be pumped easily.
- PEF processing is restricted to food products with no air bubbles and with low electrical conductivity.
- During juice extraction using PEF, destruction of cell membranes is there, which accelerates the sugar release but also infuses pectin, which is a cell wall component into the extracted media, thus, resulting in less clarity of juices.

1.2 High Hydrostatic Pressure Processing (HPP)

As already discussed, consumers nowadays have a greater inclination towards convenient yet healthy and minimally processed food having a decent shelf life. HPP is a promising "non-thermal" method of preservation that efficiently inactivates the vegetative microorganisms, thus, allowing most foods to be preserved with minimal effect on taste, texture and nutritional characteristics. This process is successful for both liquid and semi-solid foods.

The process is carried out with intense pressure in the range of 100-1000 MPa, with or without the use of heat. Now, question here arises, that what actually happens during the process. High pressure basically alters the permeability of cell membrane and disturbs the physicochemical balance of the cell. The leakage of intercellular constituents through the damaged cell membrane leads to cell death and simultaneously inhibits DNA replication and gene expression enzymes. Another notable point is although the whole process is considered to be non-thermal, but with every 100 MPa increase in pressure, 3-6^0 C increase in temperature is observed.

However, the extent of microbial inactivation depends upon type and number of microbes, their growth stage, magnitude and duration of treatments, temperature and composition of food. It has been however observed that gram positive bacterial are more resistant than gram negative bacteria, and bacterial spores are even more resistant to HPP.

Foods that are to be processed with HPP must be pre-packed in vacuum packs or any flexible pack for that matter, this is to ensure that packaging material must withstand high temperature and pressure during the process, without losing seal integrity. Main packaging materials used for HPP treatment are plastics, oxygen impermeable opaque packaging material are specifically used.After packaging, food article is placed in a pressure chamber, which is isolated and filled with potable water. The chamber has a pump connected to it, which pressurizes the chamber, and this pressure is transmitted to the food article through packaging via. water. The most important feature of the process is that, pressure acts instantaneously and is equally distributed, and there is no obvious crushing effect on packaged food. Once the desired pressure is achieved for required time, the chamber depressurizes and food article is removed.

One of the most successful commercial application of HPP nowadays is preservative free guacamole, and the process successfully maintains avocado flavor, texture and green color without harming food safety or shelf life.Other commercial practices include, easy shell removal of molluscs, easy extraction of meat from crustacean products and increases the yield up to 55%.

Physico-chemical Effects of HPP

- Cooked meals and meat color is largely unaffected, but there can be a slight softening of cell walls of fruits and vegetables.
- In fats and lipids there can be reversible crystallization.
- Fruit juices have little or no effect on taste and aroma.
- Heat labile flavors are generally unaffected.

Shortcomings of HPP

- Not suitable for products with encapsulated air, such as bread, mushrooms and marshmallows.
- Installation and processing costs are high
- Handling of equipment is difficult and thus, requires skilled labor for operation precision and adds a lot of amount in maintenance as well.

1.3 Cold Plasma

Plasma is considered to be the fourth state of matter, containing reactive species like ions, atoms and radicals formed by dissociative electron attachment process. It is a novel non-thermal food processing technology, which uses energetic and reactive gases to achieve microbial deactivation in food products. Popular gases that can be put to use are air, helium, nitrogen and oxygen.

State of matter can be changed by giving matter the required amount of energy, resulting in the breaking down of both intra and intermolecular atomic structure, resulting in generation of free electrons. In other words, plasma can be generated by giving electrical charge to inert gases, reactive substances like charged particles, free radicals, photons etc. are formed. This whole formulation is termed as plasma and the driving force is generally electricity. Ionized gases thus, formed from plasma processing, creates unique conditions that have no thermal equivalent.

Plasma is of two types

- High temperature plasma, also known as equilibrium plasma.
- Low temperature plasma or cold plasma.

This classification is based upon relative temperature of ions and electrons.Low temperature plasma is further of two types, Thermal Plasma (quasi equilibrium) and Non-Thermal Plasma (non-equilibrium plasma). Non-thermal plasma is produced at reduced or atmospheric pressures by an electric discharge in a gas, this discharge can be initiated by applying heat, electricity, using lasers, microwave or by dissociation of gas molecule. That is the reason, that composition of plasma, is different in various type of carrier gases. A common example of cold plasma is when a fluorescent lighting tube is switched on, cold plasma is setup within the tube at ambient temperature, and thus, can be used for food applications. The temperature of plasma can reach thousands of degrees, above ambient temperature, which decreases treatment durations in the range of 3-120 seconds.

Applications in Food Processing

It has been successfully implemented in the areas of microbial inactivation, surface decontamination, in products such as, poultry, meat, grains and fresh produce, enhancement of mass transfer and decontamination of packaging materials. During plasma treatment, microorganisms are exposed to an intense bombardment by the free radicals, and provokes surface lesions, that living cells cannot repair easily and sufficiently fast, and it leads to inactivations of spores and viruses as well, which in other non-thermal treatments seems a bit tough. This process is termed as Etching. The plasma constituents like, positive and negative ions, electrons, metastables, free radicals etc. contribute to lethal action by interacting with biological material of microbes, as these reactive species poses oxidative stress on the exteriors of microorganisms.

Cold plasma sterilization is safe, fast and chemical free method, widely applicable to enormous range of packaging material and does not leave any residues. This is an efficient method to sterilize packaging materials like plastics, lids and films, without even altering their properties. Study also shows that the water vapor permeability of packaging material reduced after plasma treatment.

Wastewater disposal is the new challenge faced by food industry, major reason being the water coming out of food industry is loaded with high concentration of organic matter. Reactive Oxygen Species in cold plasma have been successfully used to initiate the degradation of liquid waste, with the help of UV photons produced during cold plasma treatment, causing the pyrolytic effect thus, producing cavities in the biological and chemical matter. Hence cold plasma application can be considered as potential technique for Industrial effluent treatment.

Shortcomings of Cold Plasma

- Treatment of bulky and irregularly shaped food is difficult.
- Restricted volume and size of the food for treatment.
- Several Reactive Oxygen species has limited penetration into food products.
- It may affect the sensory and nutritional attributes of the food to some extent during processing.
- In few cases it has been observed that, it accelerates lipid oxidation and has negative impact on the sensory and other quality attributes of the food product.
- Many impacts and areas of the technology are unexplored namely, sensory and nutritional qualities of treated foods.
- Optimization and scale up to commercial treatment levels require a more complete understanding of these technical processes.

1.4 Irradiation

Irradiation treatment exposes food products to a controlled amount of radiation energy in the form of gamma rays (Co-60 or Cesium-137 radioisotope), electron beams (high energy of up to 10 MeV), or X-rays (high energy of up to 5 MeV). These interactions result in the formation of energetic electrons, throughout the matter, and results in the formation of energetic molecular ions. Irradiation works by passing energy waves through food or beverage products to generate reactive ions, free radicals and excited molecules. These agitated particles or free radicals chemically attack essential biomolecules including the DNA and RNA,membrane lipids, proteins and carbohydrates of bacteria, as well as other pathogens and pests, causing their death or preventing them from reproducing. These free radicals mainly react with cellular DNA causing radiation damage asDNA is considered “radiation sensitive” portion of cells.Effects of radiation on matter depend on the type of the radiation and its energy level, as well as the composition, physical state and the temperature.

In irradiation, foods are exposed to a form of energy, which produces free radicals that then reacts with foodbiochemical alternatively, the radiation directly attacks thecellular nuclei. Forms of ionizing radiation include UV, gamma and beta ray or electron beam. High dose (10–74kGy) is required for sterilization, which usually damages the food, but a lower dose (0.1kGy) may be employed forpasteurization. The technology may be compared to pasteurization and is sometimes called 'cold pasteurization', as the product is not heated. With proper application, irradiation can be an effective means of killing bacteria, molds and insect pests, reducing the ripening and spoiling of fruits and at higher doses inducing sterility. The World Health Organization has declared that irradiation of any food commodity, up to 10 kGy, is not a toxicological hazard. Gamma irradiation has been shown to preserve nutritive content and prolong shelf life by preventing post-harvest insect and pest infestation of beans and grains. The advantage of gamma radiation over chemicals, e.g. fumigation with ethylene oxide, is that the irradiation does not leave a chemical residue or induce other adverse effects in the quality of products being treated such as spices. It has been found that at low doses, irradiation has little effect on nutritional and organoleptic food qualities,

The biggest barrier to the marketing and sale of irradiated foods is an incorrect belief on the part of some consumers that irradiated foods are radioactive. But because irradiation energy simply passes through food products, and the acceptable levels of irradiation are not enough to cause changes at the atomic level, there is no possibility of irradiated foods retaining radioactivity after treatment.

Advantages

- This technology replaces the need for chemical fumigation.
- This method is cheaper than freezing and refrigeration.
- Extends shelf life of some food products and leads to less food spoilage.
- Reduces risk of food-borne diseases caused by micro-organisms such as *Campylobacter*, *Salmonella*, *E. coli* and *Listeria* (especially in meat, poultry and fish)
- Less dosage of pesticides and antioxidants is required for extending shelf life.
- Lower risk of importing or exporting food shipments.
- Reduced sprouting in potatoes, onions, potatoes, herbs and spices.

Disadvantages

- Irradiation is not effective against viruses and prions.
- It cannot eliminate toxins already formed by microorganisms.
- Not all foods are suitable for irradiation processes. Milk and other protein foods can develop off-flavor, odor and color.
- Some fruits may exhibit softening and discoloration, especially at higher dose levels.
- Apart from gamma radiation, UV radiation is also reported to have a negative influence on anthocyanins.
- It minimally affects some vitamins such as thiamin.

References

[1] Barbosa-Cánovas G.V., Pothakamury U., Palou E., and Swanson B.G. (1997). Nonthermal Preservation of Foods. New York: Marcel Dekker, Inc. [This presents a comprehensive review of Nonthermal technologies, including, High Hydrostatic pressure, Irradiation, Light Pulses, Pulsed Electric Fields, Oscillating Magnetic Fields, and Hurdle approach].

[2] Barbosa-Cánovas G.V., Góngora-Nieto M.M., Pothakamury U.R., and Swanson B.G. (1999).Preservation of Foods with Pulsed Electric Fields. San Diego CA: Academic Press. [This presents acomprehensive compilation of this technology from the fundamentals to its potential implementation inthe food industry].

[3] Baka M, Mercier J. Photochemical treatment to improve storability of fresh strawberries. Journal of Food Science. 1999; 64(6)1068-1072.

[4] Barbosa-Canovas GV, Pierson MD, Zhang QH. Schaffner DW. Pulsed electric fields. Journal of Food Science, 2001; 65-79, 1750-3841.

[5] Bardos L. Barankova H. Cold atmospheric plasma: Sources, processes, and applications, Thin Solid Films, 2010, 518, 6705-6713.

[6] Bintsis T. Litopoulou T E. Existing and potential applications of ultraviolet light in the food industry – A critical review. Journal of the Science of Food and Agriculture, 2000, 80 637–645.

[7] Black EP. Setlow P. Response of spores to high-pressure. Comprehensive Reviews in Food Science and Food Safety. 2007; (6)103-119.

[8] Brewer S. Irradiation affects on meat color-A review. Meat Science, 2004; 68:1-17.

[9] Bull MK, Zerdin K, Howe E, Goicoechea D, Paramanandhan P, Stockman R. The effect of high pressure processing on the microbial, physical and chemical properties of Valencia and Navel orange juice. Innovative Food Science and Emerging Technologies. 2004; 5(2)135-149, 466-8564

[10] Butz P, Tauscher B. Emerging technologies: chemical aspects. Food Research International. 2002; 35:279-284.

[11] Choi LH, SS Nielsen, The effects of thermal and nonthermal processing methods on apple cider quality and consumer acceptability. Journal of Food quality. 2005; 28:13-29.

[12] Claude CJ, Joseph C. Effects of high pressure on meat: A review. Meat Science, 1997; 46(3)211-236.

[13] Cleland MR, Pageau GM. Comparison of X-ray and gamma-ray sources for industrial radiation processes, Nucl. Instrum. Methods, 1987; 24/25 967-972.

[14] Crawford LM, Ruff EH. A reviewof the safety of cold pasteurization through irradiation. Food Control. 1996; 7 (2):87.

[15] Critzer FJ, Winterberg KK, South SL, Golden DA. Atmospheric plasma inactivation of foodborne pathogens on fresh produce surfaces. Journal of Food Protection. 2007; 70:2290-96.

[16] Deng S, R Ruan RKC. Mok G, Huang X Lin, P Chen. Inactivation of Escherichia coli on almonds using nonthermal plasma. Journal of Food Science. 2007; 72:62- 66.

[17] Earnshaw RG. High pressure technology and its potential use. In: A. Turner (ed.) Food Technology International Europe. Sterling Publications International, London. 1992; 85-88.

[18] Ekem N, T Akan. Sterilization of Staphylococcus aurous by atmospheric pressure pulsed plasma. Surface Coating and Technology, 2006, 201:993-97.

[19] Erkmen O. Inactivation of Salmonella typhimurium by high pressure carbon dioxide. Food Microbiology. 2000 17(2)225-232, 0740-0020

[20] Erkmen O. Karaman H. Kinetic studies on the high pressure carbon dioxide inactivation of Salmonella typhimurium. Journal of Food Engineering. 2001; 50(1) 25-28, ISSN 0260-8774

[21] Forney LJ, Pierson JA. Ultraviolet disinfection improved methods of UV processing for fruit juices. Resource (Jan/Feb Issue), 7-8 Downloaded from http:// atrp.gatech.edu/pdfsUltraviolet_Resource. Pdf on 08/03/07.

[22] Frost and Sullivan Research Service. (2006).Growth opportunities in the food & beverage ingredients markets. Frost & Sullivan Food & Beverage Ingredients Practice, Vol.3 (1). URL: Downloaded from http:// prod/servlet/cop/59873697 on 21/02/07.

[23] Gardner DW, Shama G. Modelling UV-induced inactivation of microorganisms on surfaces. Journal of Food Protection. 2000; 63(1)63-70.

[24] Grimi N, Lebovka NI. Effect of a pulsed electric field treatment on expression behavior and juice quality of chardonnay grape. Food Biophysics. 2009; 4(3)191-198.

[25] Guderjan M, Toepfl S. Impact of pulsed electric field treatment on the recovery and quality of plant oils, J. Food Eng. 2005; 67(3):281-287.

[26] Gupta R. Balasubramaniam VM. Novel Thermal and Non-Thermal Technologies for Fluid Foods, 2012,109-133.

[27] Hayashi T. Decontamination of dry food ingredients and seeds with soft electrons (low-energy electrons), Food Sci. Technol. Int. Tokyo, 1998, 4 114 120.

[28] Hong SI, Pyun YR. Membrane damage and enzyme inactivation of Lactobacillus plantarum by high pressure CO2 treatment. Internat. J. Food Micro. 1999; 63:19-28.

[29] Hong SI, Park WS. High-pressure carbon dioxide effect on kimchi fermentation. Biosci. Biotech. Biochem. 1997; 63:1119-1121.

[30] Hong YH, Park JY, Park JH, Chung MS, Kwon KS, Chung K, et al. Inactivation of Enterobactersakazakii, Bacillus cereus, and Salmonella typhimurium in powdered weaning food by electron-beam irradiation. Radiation Physics and Chemistry. 2008; 77(9)1097-1100. ISSN: 0969-806X

[31] Kim SR, Rhee MS, Kim BC, Lee HJ, Ki KH. Modeling of the inactivation of Salmonella typhimurium by supercritical carbon dioxide in physiological saline and phosphate-buffered saline. Journal of Microbiological Methods. 2007; 70(1)132-141, ISSN 0167-7012

[32] Kudra T, Majumdar AS. Advanced drying technologies, Edn 2, CRC Press, Boca Rotan, 2009,

[33] Lacroix K, Orsat V, Nattress DF, Raghavam GSV. Dielectric heating of fresh meat for antimicrobial treatment. In: Proceedings of the 93rd Annual International Meeting of ASAE, 2000

[34] Lado BH, Yousef AE. Alternative food preservation technologies: efficacy and mechanisms. Microbes and Infection. 2002; 4(4)433-440.

[35] Liang Z, Mittal GS. Griffiths MW. Inactivation of Salmonella Typhimurium in orange juice containing antimicrobial agents by pulsed electric field. Journal of Food Protection, 2002; 65(7)1081–1087, ISSN 0362-028X

[36] Liesbeth V. Plancken, I.V.D. Thermal versus high pressure of carrots: A comparative pilot-scale study on equivalent basis. Innovative Food Science and Emerging Technologies, 2012, 151-13.

[37] Lin HM, Cao NJ, Chen LF. Antimicrobial effect of pressurized carbon dioxide on Listeria monocytogenes. J. Food Sci. 1994; 59:657-659.

[38] Lin HM, Yang ZY, Chen LF. Inactivation of Leuconostocdextranicum with carbon dioxide under pressure. Chem. Engg. J. Biochem. Engg. J. 1993, 52: B29–B34.

[39] Maitland JE, Boyer RR, Eifert JD, Williams RC. High hydrostatic pressure processing reduces Salmonella entericaserovars in diced and whole tomatoes. International Journal of Food Microbiology, doi:10.1016/j.ijfoodmicro.vol.5(24), ISSN 0168-1605

[40] Martins CG, Behrens JH, Destro MT, Franco BDGM, Vizeu DM, Hutzler B, et al. Gamma radiation in the reduction of Salmonella spp.inoculated on minimally processed watercress (Nasturtium officinalis). Radiation Physics and Chemistry. 2004; 71(1)89-93, ISSN 0969- 806X

[41] Matak KE. Effects of UV irradiation on the reduc-tion of bacterial pathogens and chemical indicators of milk. PhD thesis. Virginia Polytechnic Institute and State University.

[42] McHugh M, Krukonis V. Introduction. Supercritical Fluid Extraction Butterworth-Heinemann. Newton, MA, 1993, 1-16.

[43] Misra NN, Keener KM, Bourke P, Mosnier JP, Cullen, PJ. In-package atmospheric pressure cold plasma treatment of cherry tomatoes, Journal of Bioscience and Bioengineering, 2014, xx (1-6),

[44] Mohd AN, Benchamaporn P. Potential of Non-Thermal Processing for Food Preservation in Southeast Asian Countries. ASEAN Food Journal. 2007; 14 (3):141-144.

[45] Montenegro J, Ruan R. Ma H, Chen P. Inactivation of E. coli 0157:H7 using a pulsed non-thermal plasma system. Journal of Food Science. 2002; 67:646-48.

[46] Mosqueda-Melgar J, Raybaudi-Massilia RM, MartínBelloso O. Influence of treatment time and pulse frequency on Salmonella Enteritidis, Escherichia coli and Listeria monocytogenes populations inoculated in melon and watermelon juices treated by pulsed electric fields. International Journal of Food Microbiology. 2007; 117(2)192-200, ISSN 0168-1605

[47] Olivieira C, Salgado J, Botelho ML, Ferreira LM. Dose determinations by Monte Carlo calculations, Radiat. Phys. Chem. 2000, 57, 667 670.

[48] Osterholm MT, Norgan AP. The role of irradiation in food safety. New England Journal of Medicine. 2004; 350(18):1898

[49] Palmieri L, Cacace D. High intensity pulsed light technology. In Da-Wen Sun (Ed.), Emerging technologies for food processing. New York: Academic Press, 2005.

[50] Park JG, Yoon Y, Park JN, Han IJ, Song BS, Kim JH et al. Effects of gamma irradiation and electron beam irradiation on quality, sensory, and bacterial populations in beef sausage patties. Meat Science. 2010; 85(2)368- 372, ISSN 0309-1740.

[51] Patterson MF. Microbiology of pressure-treated foods. Journal of Applied Microbiology. 2005; 98:1400-1409.

[52] Pereira RN, AA. Vicente Environmental impact of novel thermal and non-thermal technologies in food processing. Journal of Food Research, 2009, 1-8.

[53] Pereira RN, Vicente AA. Environmental impact of novel thermal and non-thermal technologies in food processing. Food Research International. 2010, 43.

[54] Purevdorj D, Igura N, Hayakawa I, Ariyada O. Inactivation of Escherichia coli by microwave induced low temperature argon plasma treatments. Journal of Food Engineering. 2002; 53:341-46.

[55] Rastog NK, Eshtiaghi MN. Accelerated mass transfer during osmotic dehydration of high intensity electrical field pulse, 1999.

[56] Resurreccion AVA. Consumer attitudes toward irradiated food: Results of a new study. Journal of Food Protection. 1995; 58(2):193-196.

[57] Ross AVI, Griffiths Review: Combining no thermal technogies to control food borne microorganisms.

International Journal of Food Microbiology. 2003; 89(2- 3):125-138.

[58] Sastry SK, AK Datta, RW Worobo. Ultra-violet light. Journal of Food Science Supplement. 2008; 90(2).