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Pulsed Light and Pulsed Electric Field-emerging Non Thermal Decontamination of Meat

Pramod Kumar Singh, Sunil Kumar, Pavan Kumar and Z.F. Bhat
Division of Livestock Products Technology, Faculty of Veterinary Sciences and Animal Husbandry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, R.S. Pura, 181102, India

Corresponding Author: Z.F. Bhat, Division of Livestock Products Technology, Faculty of Veterinary Sciences and Animal Husbandry, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, R.S. Pura, 181102, India

ABSTRACT

Growing awareness and preference of the consumers towards the minimum processed meat with natural sensory and nutritive characteristics leads to the introduction of non thermal techniques for the decontamination of meat. The Pulse Light (PL) and the Pulse Electric Field (PEF) are the latest non thermal techniques employed for decontamination of meat without production of any harmful toxic compounds. These techniques retain the natural freshness, colour and nutritive characteristics of meat in comparison to thermal and heat processing. The present review discusses the PL and PEF techniques in enhancing the storage life of meat.

Key words: Meat, pulse electric field, pulse light, non thermal preservation

INTRODUCTION

Meat is a rich source of high quality nutrients with very high digestibility. This includes all edible tissue of food animals that are intended for or have been judged as safe and suitable for human consumption. Meat contains water, high quality proteins, fat, carbohydrates, minerals and vitamins. Meat is specifically valuable as a source of omega-3 fatty acids, vitamin B12, protein and highly bioavailable iron (Verma and Banerjee, 2010; Bhat and Bhat, 2011). The buffalo meat, one of the cheapest source of animal protein, is low in fat and cholesterol and provides high quality proteins in various processed meat products (Kumar *et al.*, 2004; Kumar and Sharma, 2007). These rich nutrients base in water provide a conducive and ideal environment for the growth of spoilage microorganisms and food-borne pathogens (Shekhar and Kumar, 2005). The meat and meat products with high content of carbohydrate, protein and moisture are easily spoiled by microorganisms (Kumar *et al.*, 2010, 2011) leading to the wastage of precious biological material as well as outbreaks of diseases. The prevention of growth of these microorganisms in meat is essential for the quality of the meat products as well as safety of the consumers (Aymerich *et al.*, 2008).

The preservation of meat is done mainly by inhibiting the spoilage microorganisms and food borne pathogens. The shelf life and quality of meat is controlled by intrinsic and extrinsic factors. These are temperature, pH, availability of oxygen, water activity, light, endogenous enzymes. All these factors have detrimental effect on physicochemical (pH, Thiobarbituric Acid (TBA), peroxide value etc.) as well as sensory attributes (colour, appearance, texture, flavour, juiciness and binding) of meat either alone or by interacting with the other factors. Several processes such as proteolysis, lipolysis and oxidation also lead to the deterioration of meat but the microbial deterioration is more prominent (Lambert *et al*., 1991). This deterioration of meat can be prevented by artificially creating the conditions that inhibits the growth of microorganisms. Zhou *et al*. (2010) stated that the preservation of meat is based on one of these three principles:

- Controlling the temperature
- Moisture control
- Directly inhibiting the growth of microorganisms such as ionizing radiation, packaging etc.

With the growing education and awareness, consumers are preferring food that is processed very little and retains its natural colour and appearance, flavour, taste and nutritional values. The demands of minimally and naturally processed food are very high as compared to traditional foods (Chipurura and Muchuweti, 2010). One of the common methods of preservation of meat is by thermal processing and high temperature processing. These processes destroy the microorganisms and spores depending upon the time and temperature combinations (Knorr *et al*., 1994). But during the thermal processing and high temperature processing, the nutritive quality and freshness of meat is compromised. The preservation of meat without significantly increasing their temperature (non thermal preservation) will have higher nutritive value, retains the freshness of food in addition to saving energy. The common non-thermal preservation methods applicable in meat are new packaging techniques as modified atmospheric packaging, controlled atmospheric packaging and active packaging, irradiation, High Pressure Preservation (HPP), chemical preservation, oscillating magnetic field, pulse electric field, pulse light and high ultrasound waves. The lactic acid produced by the lactic acid bacteria plays an important role in the preservation of fermented foods including meat products (Ogunbanwo and Okallawon, 2009).

These non thermal preservation technologies have some advantages like energy efficient and environmental friendly, eliminating pathogen and spoilage micro-organisms while maintaining the natural appearance of meat. These non-thermal processes can be a suitable alternative to thermal processing (Guerrero-Beltran and Barbosa-Canovas, 2004). The present review describes the Pulse Light (PL) and Pulse Electric Field (PEF) methods of non thermal meat preservation.

PULSE LIGHT METHOD (PL)

It is one of the latest mild non thermal techniques for food preservation using short time high peak pulse of broad spectrum white light. Pulse light is used for decontamination of food surface and food packages. Temperature of food is increased very little and thus avoids undesirable reaction and byproduct formation as in other non-thermal techniques of food preservation. This technique retains the natural flavour of meat and very little changes occur in the content of essential nutrients and vitamins.

PRODUCTION

PL is known by several synonyms such as PL (Rowan *et al*., 1999) pulse white light (Marquenie *et al*., 2003a, b), pulsed UV light (Sharma and Demirci, 2003) and high intensity broad spectrum pulse light (Roberts and Hope, 2003). The pulse light is produced efficiently by amplifying power by storing the electromagnetic energy in a capacitor for fractions of second followed by releasing it in the form of light (Dunn *et al*., 1995). One or more xenon lamp units, a high voltage connection and a power unit make the necessary part of the pulse light producing units. High voltage connection permits transfer of high current electric pulse. The wavelength range of pulse light is 1000-11000 Å comprising UV rays (1000-4000 Å), visible light (4000-7000 Å) and infra red (7000-11000 Å). For effective inactivation of microorganisms in food preservation, the pulse light of 120 flashes per sec with energy range of 0.01-50 joule cm^{-2} should be used (Barbosa-Canovas, 1998).

MODE OF ACTION

The pulse light is more effective in inactivation of microorganisms than UV rays due to its high penetration, emission capacity and peak power distribution due to the several times amplification of energy during their production (FDA, 2000; Dunn *et al*., 1995; Demirci, 2002; MacGregor *et al*., 1998; McDonald *et al*., 2000). The rise in temperature in the PL is less when compared to UV rays due to short duration of pulses and cooling effect in between pulses (Krishnamurthy *et al*., 2004). The composition of the emitted spectrum largely determine the effectiveness of pulse light and the microbial inhibition by PL is due to the broad spectrum UV content and the energy density applied Marquenie *et al*. (2003a, b), Oms-Oliu *et al*. (2010). Rowan *et al*. (1999) reported the reduction of food pathogens were higher by using high UV spectrum than low UV spectrum in PL. Oms-Oliu *et al*. (2010) suggested the use of UV with short pulse and high width instead of traditional UV.

Wang *et al*. (2005) explained the mechanism of microbial inactivation by pulse light due to photochemical effect that results in denaturation of DNA and pyramid formation in dimmers in bacteria, virus and other pathogens. The microbial cell is disintegrated due to overheating of its constituents (Wekhof, 2003) and membrane disruption due to steam production in the cell (Fine and Gervais, 2004). The inactivation of microbes is also due to prevention of replication of cells (Rowan *et al*., 1999). The additional microbial inactivation due to photothermal and photophysical effects caused by pulse light has also been described (Wuytack *et al*., 2003; Krishnamurthy *et al*., 2007). When exposed to pulse light, the rapid increase in temperature is seen after achieving a minimum threshold of energy (Wekhof, 2003). Under the exposure to longer wavelength, the photochemical effects of PL are reversed by photo reactivation (McDonald *et al*., 2000). Thus sufficient precautionary measures such as wrapping etc should be taken to avoid it (MacGregor *et al*., 1998; Rowan *et al*., 1999; Anderson *et al*., 2000).

DECONTAMINATION OF MEAT

PL effectively reduced the microbial count on simple surface than the complex surface (Dunn *et al*., 1995). The food with high levels of lipids and proteins such as meat, fish etc requires high dose of PL as the proteins and lipids of surface absorb the radiation, thus reducing the amount of effective radiations on food surface (Gomez-Lopez *et al*., 2005). Protein shows a strong affinity towards lower (280 nm) as well as higher wavelength of UV-B (Hollosy, 2002). Dunn *et al*. (1997) reported the 2 log reductions in microbial count in PL treated (5 J cm^2) beef streaks stored for 3 days at refrigeration. A 2 log cycle reduction of *Listeria innocua* in hot dogs on PL treatment has been reported by Dunn *et al*. (1995). He also reported the edible quality of PL treated shrimps after 7 days of refrigerated storage while severe microbial spoilage in untreated shrimps. The 1 log reduction of *E. coli* O157:H7 or *L. monocytogenes* in PL treated salmon fillets with the energy value of 5.6 J cm^{-2} without compromising the quality of the product by marinating the proper distance and time combination (Ozer and Demirci, 2006). PL treatment of 30 J cm^{-2} does not causes any loss of protein, riboflavin and ascorbic acid in frankfurters and riboflavin content in beef, chicken and fish (Dunn *et al*., 1995). The colour and shear force values did not show any significant change in catfish treated with 2-4 pulses of 2.5-5 J cm^{-2} (Shuwaish *et al*., 2000). FDA (1996) has approved the PL treatment of foods.

Packaging plays an important role in the preservation, transporting and marketing of the products. Suitable packaging materials are selected for packaging of meat. The packaging material surfaces as well as food contacts surfaces in processing plants must be sterile or free of microbial contamination, otherwise they entry into meat and are responsible for spoilage of meat and meat products (Dunn, 1996). The PL inactivation of microbes on the smooth surface is less effective than rough surface due to cell clustering at smooth surface in comparison to rough surface, causing by the more reflection and formation of more hydrophobic bonds Woodling and Moraru (2005). However Oms-Oliu *et al*. (2010) found that the food surface should be free of crevices and pores for effective decontamination as these pores and crevices harbour microbes. This shadow effect limited the availability of PL to the microbes.

Inactivation of *S. aureus* by single pulse of 1.25 J cm^{-2} and spores of *B. cereus* and *Aspergillus* sp. by more than 2 J cm^{-2} (Dunn *et al*., 1991), *Bacillus subtilis* by combined PL and continuous UV (McDonald *et al*., 2000) and molds by PL (Turtoi and Nicolau, 2007) on the surface of packaging materials have been reported.

MERITS

- The inactivation of microbes by PL is very fast process and cause a rapid disinfection in a very short period
- It is a green technology as the consumption of energy is very less during its application
- PL has been proven as a safe technology for living being and their environment without producing any harmful residuals, chemicals and toxic by-products in the PL treated foods
- It does not significantly effect the nutritional and sensory quality of the products
- The concerns of ionized radicals and radioactive byproducts in foods by consumers are removed in PL due to its non-ionizing spectrum (Dunn *et al*., 1995)

LIMITATIONS OF PL

The PL application in meat industry has some constraints as the low penetration power and chances of lipid oxidation (Marth, 1998; Fine and Gervais, 2004). To get the desired outcome, the packaging materials showing high penetration of PL should be used while treating the packaging food in this method. The limited control of food heating still remains the main concern in PL technology (Gomez-Lopez *et al*., 2007; Elmnasser *et al*., 2007) and this limited its use in salmon fillets (Ozer and Demirci, 2006). To overcome these constraints and facilitates use of PL on commercial scale in meat industry.

PULSE ELECTRIC FIELD (PEF)

Pulse electric field is a one of the latest emerging non thermal food preservation technology which maintains the nutrition value, freshness, colour and flavour of the food. The exposure time as well as the increase in the temperature of foods in pulse electric field is very less in comparison to other non thermal technology. In this technology, high voltage electric field is applied through the food particles placed between two electrodes. It inactivates the all vegetative bacterial and yeast cell in comprising the all food borne pathogens and spoilage microorganisms without causing any harm to their spores (Singh and Kumar, 2011).

PRODUCTION

PEF processing system is made up of a source of high voltage, capacitor bank, switch and treatment chamber. PEF is produced by the fast discharge of energy within a short duration, preferably less than one second in very fast pulses of 1-100 μsec duration. This can be applied at ambient temperature or slightly above or below this in the form of exponentially decaying, square wave, bipolar and oscillatory pulse (Butz and Tauscher, 2002).

MODE OF ACTION

A strong electric field current is applied for short duration from microseconds to milliseconds in food during the PEF processing from radar like equipment. During this processing, the temperature of food increased slightly but the preservative effect is caused by the PEF. The microbial inactivation depends on the energy, frequency and intensity pulse, field strength and the type of food matrix (Toepfl *et al.*, 2007). The vegetative cells are killed at about 150000 V cm^{-1} and at 35000 V cm^{-1} microbes are destroyed. The frequencies of electric field in PEF technique is about 1000 times/sec.

The external electric field changes the electric potential of cell membrane and results in charge separation in cell membrane. It is known as dielectric rupture theory (Zimmermann, 1986; Zimmermann *et al.*, 1976). This rapidly enhances the porosity of microbial cells by increasing the size of existing pores as well as creation of new pores in the cell membrane of microbes known as electroporation or electropermeabilization. This electroporation is more prominent when the transmembrane potential above critical limit i.e. above 1 volt (Butz and Tauscher, 2002). This increase the permeability either temporary or permanent depending on the voltage applied, of membranes to larger extent results in the extrusion of cell contents followed by the death of the microbes Mertens and Knorr (1992). PEF does not kill the spores and enzymes. Thus the residual enzymes in active state cause the discoloration and off flavour in foods including meat (Singh and Kumar, 2011).

APPLICATION IN MEAT

The increases in the permeability cells due to electroporation or electropermeability during PEF have application in meat processing. This increase in permeability facilitates the easier uptake of the curing agents, spices, flavour enhancer etc into to meat and thus fasten the curing process. The retaining of freshness, satisfactory nutritional quality with enhanced shelf life upon application of PEF for less than second has been reported (Castro *et al.*, 1993; Kozempel *et al.*, 1998; Davies, 1995; Karel, 1975; Knorr, 1995; Knorr *et al.*, 1998). The preparation of raw ham is done in a short time by this technology due to the disintegration of animal tissue. Recently extensive studies have been done to analyse the effect of PEF treatment on different source of food materials of vegetative and animal origin (Sitzmann and Munch, 1988; Hafsteinsson *et al.*, 2000; Gudmundsson and Hafsteinsson, 2001). The pork muscles swollen and form a sponge like tissue after PEF treatment (Singh and Kumar, 2011). The efflux of cellular contents in the media provides a suitable medium for growth of fermenting microbes in the fermented meat products. In rabbit meat and chicken legs, antimicrobial effects upon low voltage PEF of 220-380 V have been reported by Mrigadat *et al.* (1980) and Lin *et al.* (1984). Gudmundsson and Hafsteinsson (2001) suggested the possibility of PEF in extracting the dehydrate byproducts, costlier items such as fish oil, enzymes as well as other precious metabolites from fish and meat industry due to enlargement of pores of cell membrane resulting in the extrusion of these materials. The better results are obtained when PEF is used with non thermal technology such as HPP (Heinz and Knorr, 2000). A 2-9 log cycles reduction in meat pathogenic and spoilage bacteria such as *E. coli*, *S. aureus*, *Salmonell* spp., *Listeria* spp., *B. subtilis* etc. have been observed by applying 2000-7000 KV/M (Hamilton and Sale, 1967; Hulsheger *et al.*, 1983; Dunn and Pearlman, 1987; Zhang *et al.*, 1994; Ho *et al.*, 1997; Marquez *et al.*, 1997; Barbosa-Canovas *et al.*, 1997; Calderon-Miranda *et al.*, 1999; Heinz *et al.*, 1999; Jeantet *et al.*, 1999; Alvarez *et al.*, 2000; Wouters *et al.*, 2001). High intensity pulsed electric field is an effective technique to inactivate microorganisms in several liquid media (Nagadi *et al.*, 2004).

MERITS

The rise in temperature of food is very low during PEF processing as this treatment is completed within one second. This reduces the chances of the alteration in the structure of food. PEF is an energy efficient green technology avoiding any significant heating of food, thus inactivating the micro organisms without compromising the nutritional and sensory quality (Barbosa-Canovas *et al.*, 1999; Jeyamkondan *et al.*, 1999). The PEF has extra advantage in filtration by killing the microbes as well as reducing the ability of bacteria to retain water.

LIMITATIONS

The pulse electric field technology provides satisfactory decontamination in liquids. The PEF is applied before packaging of food; hence the utmost care is necessary to prevent post process contamination. This needs aseptic packaging. The electric breakdown due to air bubble formation at above 20000 V cm^{-1} necessitates high pressure for application of this technology. The scaling up of systems and the resistance of certain microorganisms and spores still remain the major concerns (Singh and Kumar, 2011). Due to the protective effect as well as heterogeneity of substances in solid foods as meat demands higher intensity of PEF as compared to liquids foods. However, with the advancement of PEF technology and modern equipments and by proper processing of larger meat into meat cuts and extruded meat paste satisfactory results are obtained. These limitations can be overcome by proper modification in basic formulation as less salt, viscosity and particle sizes, proper equipment design etc. (Picart and Cheftel, 2003). The electrodes are degraded during the PEF treatment of liquid foods and this degradation can be overcome by application of short pulse and avoiding leak current in between pulses (Morren *et al.*, 2003). The higher cost of PEF equipment can be overcome by manufacturing them on commercial scale.

CONCLUSION

Pulse Light (PL) and Pulse Electric Fields (PEF) are latest emerging non thermal techniques applied in meat preservation. These significantly reduce the food borne and spoilage microorganism without significantly increasing the temperature of meat. This helps in maintaining the sensory and nutritive quality of meat. These techniques are energy efficient and very fast and devoid of production of any residual chemical or toxic materials as by-products. The penetration power of PL, application of PEF for solid foods, higher capital investments etc. are the major limitations faced in the popularization of these technologies on commercial scale. The proper research and development should be taken on priority basis to overcome these issues.

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