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Flexible thin-layer dielectric barrier discharge plasma treatment of pork butt and beef loin: Effects on pathogen inactivation and meat-quality attributes

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The effects of a flexible thin-layer dielectric barrier discharge (DBD) plasma system using a sealed package on microbial inactivation and quality attributes of fresh pork and beef were tested. Following a 10-min treatment, the microbial-load reductions of *Listeria monocytogenes*, *Escherichia coli* O157:H7, and *Salmonella* Typhimurium were 2.04, 2.54, and 2.68 Log CFU/g in pork-butt samples and 1.90, 2.57, and 2.58 Log CFU/g in beef-loin samples, respectively. Colorimetric analysis showed that DBD-plasma treatment did not significantly affect L^* values (lightness) of pork and beef samples, but lowered a^* values (redness) significantly after 5- and 7.5-min exposures. The plasma treatment significantly influenced lipid oxidation only after a 10-min exposure. The texture of both types of meat was unaffected by plasma treatment. All sensory parameters of treated and non-treated samples were comparable except for taste, which was negatively influenced by the plasma treatment ($P < 0.05$). This thin-layer DBD-plasma system can be applied to inactivate foodborne pathogens. The observed minor deterioration of meat quality might be prevented by the use of hurdle technology.

1. Introduction

Meat and meat products are contaminated by microbes at distinct stages of the production chain, including the preparation, storage, and distribution stages. Thus, the quality of the products deteriorates and potential public-health problems develop unless the products are properly handled and preserved (Jayasena and Jo, 2013). Foodborne diseases are not limited to a particular age group or country and have emerged as a growing economic problem in most countries over the past few decades (Tauxe et al., 2010). In USA, 76 million cases of foodborne diseases are reported to occur annually leading to 325,000 hospitalizations and 5000 deaths (Mead et al., 1999; Tauxe et al., 2010); this results in high medical costs and in productivity losses in the range of US$ 6.6–37.1 billion (Tauxe et al., 2010). Furthermore, in Korea, the number of cases of foodborne diseases in 2010 was twice that in 2003 (Kim et al., 2013). In the case of meat and meat products, contamination by several pathogenic microorganisms (such as *Salmonella* Typhimurium, *Escherichia coli* O157:H7, other enterohemorrhagic *E. coli*, *Campylobacter jejuni*, *Listeria monocytogenes*, and *Clostridium* spp.) can cause severe foodborne diseases in consumers.

Conventional thermal treatments can inactivate foodborne pathogens, but they can have a negative impact on the nutrient value and the sensory qualities of food. Therefore, considerable attention is currently being focused on developing new non-thermal and highly energy-efficient techniques that can be used to effectively reduce microbial contamination in foods (Kim et al., 2014; Toepfl et al., 2006; van Boekel et al., 2010). One such emerging technology that has a high potential for application in the food-processing sector involves the use of plasmas, which are ionized gases in a quasineutral state (Lee et al., 2011). Plasmas generate highly reactive species such as free electrons, ions,

Non-standard abbreviations: DBD, dielectric barrier discharge; APP, atmospheric-pressure plasma.

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radicals, excited molecules, and UV photons that are widely recognized to exert microbial-inactivation effects (Kaushik et al., 2013; Kim et al., 2014). Given the recent developments in plasma technology, numerous distinct plasma systems have been designed, and, among these, low-temperature atmospheric-pressure plasma (APP) has attracted considerable attention; this is because the generation of non-thermal plasma discharges at atmospheric pressure helps reduce the difficulties and costs associated with the decontamination process (Kim et al., 2011, 2013).

The dielectric barrier discharge (DBD) plasma system, which is commonly considered the most widely used APP system (Lee et al., 2012), generates plasma between two electrodes that are covered with dielectric layers (Moreau et al., 2008). Sun et al. (2007) reported that as compared to the APP-jet and microwave-discharge methods, DBD-plasma system is considerably simpler but more effective in eliminating pathogens; the authors further stated that DBD plasma was discharged more stably and at a higher power level compared to the plasma generated using the other methods. The plasma technique has recently been tested on various animal-derived foods and products such as pork (Fröhling et al., 2012; Kim et al., 2013), chicken (Lee et al., 2011), cheese (Lee et al., 2012; Song et al., 2009), ham (Lee et al., 2011; Song et al., 2009), beef jerky (Kim et al., 2014), and bacon (Kim et al., 2011) by using distinct types of plasma devices, in particular DBD plasma. These studies indicated that plasma technology could be potentially applied to inactivate foodborne pathogens in the aforementioned foods. Furthermore, plasma devices that can generate APP in sealed packages are required, particularly for use in food-safety applications (Song et al., 2012). However, very few studies that describe plasma devices that can be used for large-area and uniform treatments have been published. Song et al. (2012) recently developed a cold atmospheric-plasma setup in a sealed package and demonstrated that this system could be used to inactivate *Candida albicans* coated on a thick glass plate; however, this device has not been tested on food products. Furthermore, many of the aforementioned studies have not evaluated the influence (s) of DBD-plasma treatment on various aspects of meat quality, such as texture and sensory attributes.

The main objectives of this study were to develop a flexible thin-layer DBD-plasma system for generating APP in a sealed food package and to examine the ability of the plasma system to inactivate common foodborne pathogens inoculated into pork-butt and beef-loin samples. Moreover, we compared the quality attributes of the DBD-plasma–treated pork and beef at various plasma-exposure times with the corresponding attributes of untreated samples.

2. Materials and methods

2.1. Sample preparation and sterilization

Pork butt and beef loin were purchased from a local market in Daejeon, Korea and each meat type was subdivided into two parts. One part from each meat type was used for the inoculation test before which slices (25 × 25 × 7 mm) of the meat samples were vacuum-packaged and sterilized by irradiation (35 kGy) in a linear electron-beam RF accelerator (2.5 MeV, 40 kW; EB Tech, Daejeon, Korea). The other part from each meat type was directly treated with DBD plasma and utilized to measure the physicochemical properties.

2.2. Microorganisms and inoculation

E. coli O157:H7 (KCCM 40406), *S.* Typhimurium (KCTC 1925), and *L. monocytogenes* (KCTC 3569) were cultivated respectively in tryptic soy broth, nutrient broth, and tryptic soy broth containing 0.6% yeast extract (Difco Laboratories, Detroit, Michigan, USA) at 37 °C for 48 h. The cultures were then centrifuged at 2090 × *g* for 15 min at 4 °C in a refrigerated centrifuge (UNION 32R, Hanil Science Industrial Co. Ltd., Korea). The pellets obtained were washed twice with sterile saline solution (0.85%) and then suspended in sterile saline solution to a final concentration of approximately 10^8–10^9 CFU/mL. The sterilized pork-butt and beef-loin samples were removed from the packages and separately inoculated with the test-culture suspensions (100 μL). After spreading, the meat samples were maintained for 10 min at room temperature (approximately 22 °C) under sterile conditions to enable the microorganisms to attach to the samples.

2.3. Treatment with flexible thin-layer DBD plasma

A flexible food-package system designed for generating DBD plasma within the food package was prepared by using the conductive layer of a commercial, zippered food package (129 × 199 mm) as the powered electrode (Fig. 1). A 0.28 mm-thick polytetrafluoroethylene (PTFE; 100 × 100 mm) sheet and a patterned conductive sheet (70 × 70 mm) were installed inside the package (Fig. 1). A bipolar square-waveform voltage at 15 kHz was applied to the outer electrode while the inner patterned electrode was grounded. The plasma was generated at the surface of the inner electrode at 100-W peak power and 2-W average power. The carrier gas used was atmospheric gas containing nitrogen and oxygen.

The pork-butt and beef-loin samples inoculated with *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes* and the non-inoculated samples were treated with the thin-layer DBD plasma for 0, 2.5, 5, 7.5, or 10 min. Each sample was placed inside the food package containing the DBD-plasma system; the package was then sealed using the zipper to confine the reactive chemical species generated during plasma treatment. Immediately after DBD-plasma treatment, respective samples were used for microbial analysis and instrumental color measurement. The other samples were stored under commercial storage conditions at 4 °C until the next day for the analysis of other physicochemical properties and sensory parameters.

2.4. Visible emission spectrum and determination of ozone levels

The visible emission spectrum of the plasma discharge was obtained using a spectrometer (MAYA2000 Pro, Ocean Optics, Inc., FL, USA) equipped with the relevant optical setup. The levels of ozone produced during DBD-plasma generation were measured using a UV ozone photometer (UV–H; Aeroqual Ltd., Auckland, New Zealand).

2.5. Microbial analysis

DBD-plasma–treated pork and beef samples (5 g each) were blended with 45 mL of sterile saline (0.85%) by using a Bag Mixer®

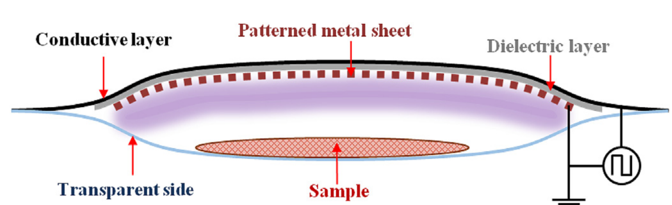

Fig. 1. Schematic diagram of the experimental setup used for generating flexible thin-layer dielectric barrier discharge plasma.