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Flexible thin-layer plasma inactivation of bacteria and mold survival in beef jerky packaging and its effects on the meat's physicochemical properties

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ABSTRACT

The aims of the present study were to examine the use of a flexible thin-layer plasma system in inactivating bacteria and mold on beef jerky in a commercial package and to evaluate the physicochemical changes of the jerky. After plasma treatment for 10 min, *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Salmonella* Typhimurium, and *Aspergillus flavus* populations on the beef jerky were reduced by approximately 2 to 3 Log CFU/g. No significant changes in metmyoglobin content, shear force, and myofibrillar fragmentation index were found in the plasma-treated beef jerky. On the other hand, the peroxide content and L^* value were decreased whereas the a^* and ΔE value were increased in the plasma-treated sample. Sensory evaluation indicated negative effects of plasma treatment on flavor, off-odor, and overall acceptability of the beef jerky. In conclusion, the flexible thin-layer plasma system could be employed as a means for decontamination of beef jerky, with slight changes to the physicochemical quality of the product.

1. Introduction

Jerky, a ready-to-eat meat product, is a snack food in high demand owing to its flavorful taste, nutritional value, and storage stability without refrigeration (Kim, Lee, Choi, & Kim, 2014). In general, jerkies are made by curing the meats with nitrite, which controls bacterial growth, especially *Clostridium botulinum*, and drying for an extended period of time (Sofos, Busta, & Allen, 1979).

Despite of the nitrite and low water activity, however, over 250 cases of foodborne diseases were epidemiologically related with jerky consumption from 1966 to 2003. These accidents were linked to *Escherichia coli* O157:H7, *Listeria monocytogenes*, *Staphylococcus aureus*, and several types of *Salmonella* (Dierschke, Ingham, & Ingham, 2010; Kim, Lee, Choi, & Kim, 2014). Moreover, spoilage of jerky occurs easily as a result of fungal growth (Clavero, 2010). Therefore, it is necessary to find a safe, efficient, and cost-effective system for the microbial decontamination of jerky.

Plasma devices operated under atmospheric pressure at room temperature have attracted a great deal of attention as a non-thermal technology (Misra, Keener, Bourke, Mosnier, & Cullen, 2014a). These devices, called atmospheric pressure plasma (APP) or cold plasma, have many advantageous features: (i) bactericidal and virucidal effects; (ii) inexpensive facilities and operation costs; (iii) ease of use; and (ix) high concentrations of energetic particles such as reactive oxygen species (ROS), reactive nitrogen species (RNS), other reactive species, electrons, ions, and UV photons (Heuer et al., 2015; Jayasena et al., 2015). Many previous research studies have reported the antimicrobial effect of APP on foods (Kim et al., 2011; Suhem, Matan, Nisoa, & Matan, 2013; Yong et al., 2014).

In the food industry, both economical cost and product safety are the most important issues (Antle, 2000). To adopt the APP system in this industry, the operating cost of the process gas has to be considered. An ideal gas for operating APP would be ambient air (Misra et al., 2014a). In addition, cross-contamination is a serious problem in the field (Wilks, Michels, & Keevil, 2006). Foods treated with some APP systems can be exposed to the risk of cross-contamination from other contaminated foods, food handlers, or equipment during the post production process (Wilks et al., 2006). Therefore, a few studies have attempted APP generation using ambient air in packages or containers. Misra et al. (2014b) reported that aerobic mesophilic bacteria, yeasts, and molds of strawberries were reduced by 2 Log CFU after in-package APP treatment with ambient air for 5 min and storage for 24 h. Using a sealed type of flexible thin-layer plasma and encapsulated plasma for 10 min, the numbers of *L. monocytogenes* on cheese and milk were reduced to 2.4 and 2.1 Log CFU/g, respectively (Kim et al., 2015; Yong et al., 2015).

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However, so far, only a limited number of studies have dealt with a processed meat product by applying a sealed-type APP system using ambient air, which is worth studying for industrial utilization. In addition, there is very limited information available on the quality of the processed meat products like jerky including lipid oxidation, color, and textural properties after application of APP. Therefore, the present study used a flexible thin-layer plasma system inside a commercial food package and investigated its inactivation of different bacteria and molds on the beef jerky. Changes in the physicochemical quality of the beef jerky were also evaluated.

2. Materials and methods

2.1. Study design and sample preparation

Commercial beef jerky (Kojubu Co., Ltd., Suwon, Korea) were purchased from a local market and cut into 40 × 40 mm pieces (totally 216 samples, each sample was approximately 6 g). Then, the samples were divided into two groups. The study design was shown in Fig. 1. For inoculation test, one group of samples (48 pieces) was irradiated on both sides in a linear electron-beam RF accelerator (2.5 MeV, beam power 40 kW; EB-Tech., Daejeon, Korea). To achieve complete sterilization of the samples, a radiation dose of 35 kGy was employed. The sterilized samples were inoculated with prepared inocula and then antimicrobial effect of flexible thin-layer plasma was investigated. The other group of sample was not sterilized and used for the analysis of physicochemical quality traits after the plasma treatment.

2.2. Inoculation test

2.2.1. Preparation of inocula

L. monocytogenes (KCTC 3569), *E. coli* O157:H7 (ATCC 43894), and *Salmonella* Typhimurium (KCTC 1925) were cultivated in tryptic soy broth containing 0.6% yeast extract (Difco Laboratories, Detroit, MI, USA), tryptic soy broth (Difco), and nutrient broth (Difco), respectively, at 37 °C for 48 h. The cultures were centrifuged (2419 ×*g* for 15 min) using a refrigerated centrifuge (Union 32R; Hanil BioMed Inc., Incheon, Korea). Then, the resulting pellets were washed twice with sterile saline solution and further processed by following the method of Kim et al. (2011). *Aspergillus flavus* (KCTC6905) was obtained from mycelia grown on potato dextrose agar (PDA; Difco) acidified with 10% citric acid. Spores were collected by flooding the surface of the PDA with a sterile saline solution containing Tween 80 (0.1%, v/v). After counting the spores using a hemocytometer (Paul Marienfeld GmbH & Co. KG, Lauda-Königshofen, Germany), the suspension was standardized to a concentration of 10^7 spore/mL by dilution with sterile saline. The viability of each strain in each suspension was checked using quantitative colony counts, and the final concentrations were approximately 10^7–10^8 CFU/mL.

2.2.2. Inoculation and microbial analysis

The prepared beef jerky (6 g) was inoculated with each different microbial solution (100 μL) separately. To enable the microorganisms to attach to the meat, all samples were placed on a clean bench and air dried for 15 min at room temperature. Then, beef jerky was exposed to plasma except for control sample (plasma treatment time for 0 min). Both plasma-treated and non-treated whole beef jerkies (6 g) were blended separately with sterile saline solution (54 mL) in a stomacher bag. A serial dilution using sterile saline is followed. The media used for *L. monocytogenes*, *E. coli* O157:H7, *S.* Typhimurium, and *A. flavus* were tryptic soy agar containing 0.6% yeast extract (Difco), tryptic soy agar (Difco), nutrient agar (Difco), and PDA (Difco), respectively. Each microbial dilution (100 μL) was spread on the appropriate medium. The agar plates for the three bacteria were incubated at 37 °C for 48 h, whereas the PDA plates were incubated at 25 °C for 5 days. Once the colonies had been counted, the results were expressed as log colony-forming units per gram (log CFU/g). The decimal reduction time (*D* value) was calculated as the negative reciprocal slope of the log (N_0/N) versus time curve (N_0 = initial CFU, N = CFU after exposure to plasma).

2.3. Treatment with flexible thin-layer plasma

The plasma apparatus applied was a dielectric barrier discharge and is illustrated in Fig. 2. To construct the flexible thin-layer plasma system, a polytetrafluoroethylene sheet (100 × 100 mm) and a patterned conductive sheet (70 × 70 mm) were installed inside the commercial, zippered food package (129 × 199 mm). The package was sealed using the zipper once the sample had been placed inside. Thereafter, a bipolar square-waveform voltage at 15 kHz was applied to the conductive layer (outer electrode) of the food package while the patterned conductive sheet (inner electrode) was grounded. The plasma was generated as a base for material treatment (Yong et al., 2015). Ambient air was used as the carrier gas, and the plasma treatment times were for 0

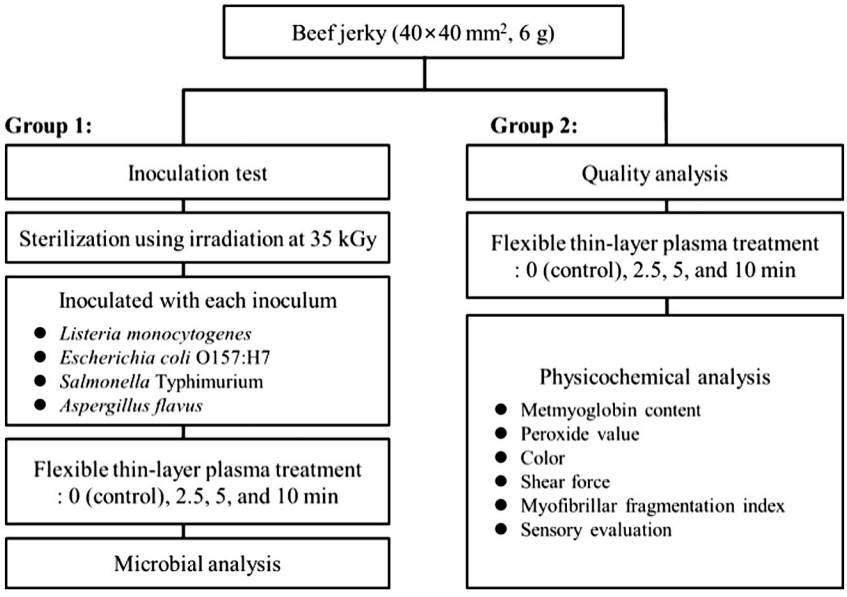

Fig. 1. Diagram illustrating the experimental procedure of the present study.