FLEXIBLE THIN-LAYER PLASMA IN PACKAGE: INACTIVATION EFFECT OF BACTERIA AND MOLD AND PHYSIOCHEMICAL PROPERTIES IN BEEF JERKY

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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. *L value and Hue angle were also significantly decreased, while *a**, Δ*E* value, chroma, and peroxide content significantly increased by increasing plasma exposure time. Sensory evaluation indicated negative effects of plasma treatment on flavor, off-odor, and overall acceptability, but there were no effects on the color, taste, and tenderness 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.**

Key Words – Atmospheric pressure plasma, Microbial test, Quality

I. INTRODUCTION

In general, jerkies are made by curing the meats with nitrite which controls bacterial growth, and drying for an extended period of time. Despite of the nitrite and low water activity, however, a number of foodborne diseases were related with jerky consumption and linked to *Escherichia coli* O157:H7, *Listeria monocytogenes*, several types of *Salmonella*, and fungal growth [1]. 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, called atmospheric pressure plasma (APP) or cold plasma, have several advantageous features: bactericidal and virucidal effects; inexpensive facilities and operation costs; high concentrations of energetic particles such as reactive species, electrons, ions, and UV photons [2].

In the food industry, both economical cost and product safety are the most important issues. 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. In addition, cross-contamination is a serious problem in the field. Foods treated with some APP systems can be exposed to the risk of cross-contamination during the post production process [3]. However, so far, only the limited number of study has dealt with a meat product by applying a sealed-type APP system using ambient air, which is worth studying for industrial utilization.

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 and changes in the physicochemical quality of the beef jerky were evaluated.

II. MATERIALS AND METHODS

Sample preparation and sterilization

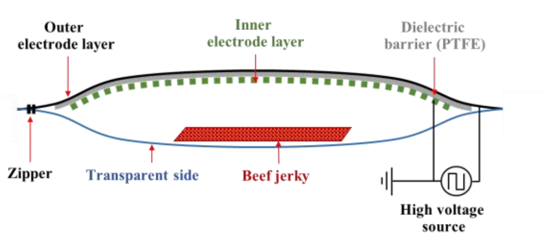
Commercial beef jerkies were irradiated in a linear electron-beam RF accelerator (35 kGy, 2.5 MeV, beam power 40 kW; EB-Tech., Daejeon, Korea) to achieve complete sterilization and use in the inoculation test. The other samples used for the analysis of physicochemical quality traits were not sterilized in the present study.

Inoculation and microbial analysis

L. monocytogenes (KCTC 3569), *E. coli* O157:H7 (ATCC 43894), *Salmonella* Typhimurium (KCTC 1925), and *Aspergillus flavus* (KCTC6905) were cultivated and inoculated on the prepared beef jerky (6 g), respectively. After treated plasma, 6 g of sample was blended with 54 mL of sterile saline solution and serially diluted. The media used for *L. monocytogenes*, *E. coli* O157:H7, *S*. Typhimurium, and *A. flavus* were tryptic soy agar containing yeast extract (Difco Laboratories, Detroit, MI, USA), tryptic soy agar (Difco), nutrient agar (Difco), and potato dextrose agar (PDA, Difco), respectively. Each microbial diluent 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. The results were expressed as log colony-forming units per gram (Log CFU/g).

Treatment of flexible thin-layer plasma
The plasma apparatus applied was a dielectric barrier discharge and is illustrated in Fig 1. The plasma was generated as a base for material treatment [2]. Ambient air was used as the carrier gas, and the plasma treatment times were for 0 (control), 2.5, 5, and 10 min. These experiments were repeated three times.

Figure 1. Experimental setup for the flexible thin-layer plasma treatment of beef jerky



Peroxide value
Peroxide value in beef jerky was determined according to Kim et al. [4].

Color measurement
The Hunter color, L^* (Lightness), a^* (redness), and b^* (yellowness) values of the beef jerky samples were determined with a spectrophotometer (CM 3500d; Konica Minolta Censing Inc., Osaka, Japan). Then, the total color difference ($\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$), hue ($H = \tan^{-1} b/a$), and chroma ($C = \sqrt{a^2 + b^2}$) were calculated from the L^*, a^*, and b^* values. The Browning index (BI) was calculated using the following formula:
BI = [100(x - 0.31)] / 0.172
$x = (a + 1.75L) / (5.645L + a - 3.012b)$

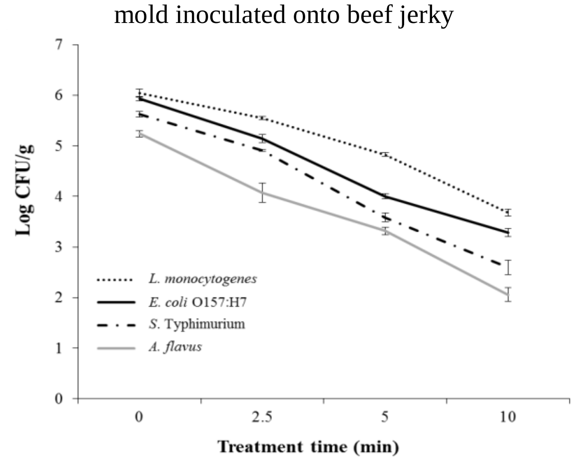
Sensory evaluation
Sensory evaluation of beef jerky (20 × 40 mm) was performed by a ten-member of panelist. A 9-point hedonic scale (1 = extremely dislike, 9 = extremely like) was employed for their color, flavor, taste, tenderness, and acceptability. Off-odor was assessed as follows: 1 = no off-odor; and 9 = very strong.

Statistical analysis
Statistical analysis was performed by one-way analysis of variance (ANOVA), and significant differences between mean values were identified using Duncan's multiple comparison test.

III. RESULTS AND DISCUSSION

Inactivation of foodborne pathogens
The flexible thin-layer plasma treatment exerted potential of inactivation effects on all the bacteria and mold tested (Fig 2). The populations of all inocula on beef jerky decreased with increasing treatment time (P<0.05). Energetic reactive species generated from APP can induce DNA damage and mitochondria dysfunction that mediate cell apoptosis. Moreover, reactive species cause reduction of membrane potential, membrane lipid peroxidation, and breaches of the membrane integrity [5]. These findings indicate that APP sufficiently leads to cellular death.

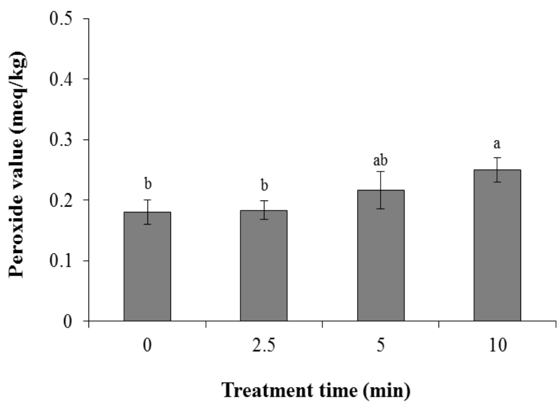
Figure 2. Inactivation effect of flexible thin-layer plasma against the growth of different bacteria and mold inoculated onto beef jerky



Peroxide value

The POV was significantly increased by the 10 min of thin-layer plasma treatment (Fig 3). Peroxides are commonly formed as the primary products during lipid oxidation, the POV in beef jerky can be used as a lipid oxidation value. Lipid oxidation might be initiated by radicals or other agents (UV, ionizing radiation, or heat). Therefore, conditions of increased plasma power, treatment time, and storage will result in lipid oxidation [6].

Figure 3. Average peroxide value measured in control and flexible thin-layer plasma-treated beef jerky samples



a-bBars with different letters are significantly different per Duncan's multiple comparison test (P<0.05).

Surface color

With increasing plasma exposure time, the L^* value and hue angle decreased whereas the a^*, ΔE value and chroma increased (P<0.05) (Table 1). No significant changes in b^* value and BI were observed among the samples. According to these results, the surface color of the beef jerky became not brown but more clearly dark-red with plasma treatment.

When APP is generated inside polymeric food packaging materials, organic bonds are broken. As such, the organic substances can react with oxygen species to form carbon dioxide or carbon monoxide [7]. If the carbon monoxide combines with myoglobin in meat products, carboxy-myoglobin (CO-Mb) can be formed and it can increases a* value [8].

In addition, plasma system is a source of reactive oxygen and nitrogen species, including NO. The combination of NO with myoglobin or met-myoglobin produces nitroso-myoglobin (NO-Mb, bright-red color) or nitroso-met-myoglobin (NO-MMB, dark-red color), respectively [9]. Both NO-Mb and NO-MMB can increase a* value of meat. It is assumed that the formation of NO-MMB will give beef jerky a dark-red color after plasma treatment. However, this is not conclusive because no changes were found in the met-myoglobin content with use of the same plasma (data not shown). Further in-depth study is needed to elucidate the mechanism of meat product discoloration by APP.

Table 1. Effect of flexible thin-layer plasma treatment on color parameter values of beef jerky

Color parameter values	Treatment time (min)				SEM[1)]
	0	2.5	5	10	
L^*	29.28[a]	29.39[a]	27.80[b]	27.48[b]	0.418
a^*	5.24[b]	6.19[a]	7.05[a]	6.92[a]	0.262
b^*	5.70	6.05	5.38	5.22	0.284
ΔE	0[b]	1.55[a]	2.63[a]	2.60[a]	0.385
Hue	47.41[a]	44.32[a]	37.36[b]	36.97[b]	2.026
Chroma	7.76[b]	8.67[a]	8.87[a]	8.67[a]	0.252
Browning index	33.93	37.60	38.90	38.37	1.579

1)Standard error of the mean (n = 12).
a-bDifferent letters within a column indicate significant difference per Duncan's multiple comparison test (P <0.05).

Sensory evaluation

Results indicated that the color, taste, and tenderness of the beef jerky were not affected by the flexible thin-layer plasma treatment (Table 2). However, plasma treatment over 10 min changed the flavor, off-odor, and acceptability of the beef jerky.

There are several causes of off-odor or different flavor. One is sulfur containing volatiles, including dimethyl disulfide, methyl mercaptan, and hydrogen sulfide, which are generated by the breakdown of sulfur-containing compounds by radical species. Dimethyl trisulfide is one of the most potent off-odor compounds, contributing fishy and putrid odors, followed by bis (methylthio) methane [10]. It will be needed to find methods that reduce plasma-generated off-odors for further implementation to industry.

Table 2. Effect of flexible thin-layer plasma

treatment on the sensory attributes of beef jerky

Sensory parameters	Treatment time (min)				SEM[1)]
	0	2.5	5	10	
Color	5.95	5.75	5.62	5.58	0.301
Flavor	5.50[a]	5.45[a]	4.33[ab]	3.53[b]	0.444
Taste	5.31	4.98	4.95	4.91	0.415
Tenderness	4.25	4.08	4.45	4.38	0.487
Off-odor	0.90[b]	1.00[b]	1.47[b]	2.28[a]	0.264
Acceptability	5.48[a]	5.25[a]	5.09[a]	3.48[b]	0.411

[1)]Standard error of the mean (*n* = 40).
[a-b]Different letters within a row indicate significant difference per Duncan's multiple comparison test ($P < 0.05$).

IV. CONCLUSION

Flexible thin-layer plasma treatment using ambient air reduced the number of bacteria and mold in packaged beef jerky. However, negative changes is caused by plasma treatment were observed in some sensory parameters, concerning off-odor. The undesirable sensory changes can be minimized by presently available methods, while the effectiveness of this technology for food safety and shelf-life extension may be rapidly developed for the food industry.

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