INFUSION OF NITRITE INTO MEAT BATTER BY ATMOSPHERIC PRESSURE PLASMA TREATMENT

Juri Lee[1], Yubong Lim[2,3], Wonho Choe[3], Hae In Yong[4] , Cheorun Jo[4] and Samooel Jung[1,*]

[1]Division of Animal and Dairy Science, Chungnam National University, Daejeon 34134, Korea; [2]Plasmapp Co., Ltd., 83 Jukdong-ro, Yuseong-gu, Daejeon 34127, Korea; [3]Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 34141, Korea; [4]Department of Agricultural Biotechnology, Center for Food and Bioconvergence, and Research Institute of Agriculture and Life Science, Seoul National University, Seoul 08826, Korea

[*]Corresponding author email: samooel@cnu.ac.kr

Abstract – This study aimed to investigate the influence of direct atmospheric pressure plasma (APP) treatment on nitrite levels and physiochemical quality of meat batter during the mixing process. A compact APP system was developed for installation on top of a food mixer. Meat batter composed of pork, water and sodium chloride (80:20:1, w/w/w) treated with APP during mixing. The nitrite level in meat batter increased steadily with increasing plasma treatment duration ($p < 0.05$), reaching 65.96 ppm at 30 min. Consequently, the CIE *a- and *b**-values of cooked meat batter gradually increased and decreased, respectively, as the time of plasma treatment increased. According to the results, direct APP treatment can replace nitrite addition in cured meat processing.**

Key Words – atmospheric pressure plasma, nitrite, meat batter, dielectric barrier discharge

I. INTRODUCTION

Nitrite is an essential curing ingredient because of its multifunctional role. Nitrite develops color and flavor, inhibits lipid oxidation, and limits spoilage and pathogenic microorganisms including *Clostridium botulinum* in processed meats. Recently, the increase of consumer demand for natural and organic food has precipitated the development of natural curing processes for processed meat. For natural curing processes, natural nitrite sources such as vegetable juice concentrate containing nitrate with starter cultures that reduce nitrate to nitrite, or pre-converted (nitrate to nitrite) vegetable concentrate is used instead of chemical nitrite sources such as sodium nitrite [1, 2]. However, a critical problem in the use of vegetable concentrates for curing has emerged. Jackson et al. [3] reported that the microbial safety of naturally cured meat products was lower than in sodium nitrite cured meat products. This because the concentration of added and residual nitrite in processed meat is important for limiting microorganism growth [3]. Nevertheless, the amount of nitrite added to processed meat by vegetable concentrates is lower than when sodium nitrite is used, due to the natural pigments and flavors they contain that cause undesirable sensory characteristics.

Plasma is ionized gas, literally defined as the fourth state of matter, along with solids, liquids, and gases. Plasma technology has been variously used in food processing for non-thermal sterilization [4]. Recently, Jung et al. [5] suggested plasma treated water as a potential nitrite source for curing of processed meat as it contains nitrogen species such as nitrate and nitrite created by plasma-liquid interaction. Therefore, we hypothesized that plasma treatment of meat batter could generate nitrite in meat batter by interaction of plasma with the liquid in meat batter.

In this study, the effect of direct atmospheric pressure plasma (APP) treatment on meat batter is investigated in terms of nitrite concentration of meat batter and color of cooked meat batter.

II. MATERIALS AND METHODS

Direct APP treatment

APP treatment was carried out using a dielectric barrier discharge (DBD) plasma system (Plasmapp PCS-20N, Plasmapp Co., Daejeon, Korea). The system was composed of a main chamber for mixing, a plasma chamber, a plasma power supply, and a gas circulating module (Figure. 1). The main chamber stored a meat product and provided a sealed space, and plasma was discharged by the power supply in

the plasma chamber, which was connected to the main chamber. The discharged gas was supplied into the main chamber to cure the processed meat by the gas circulating module in which a diaphragm pump of the module received the activated gas from the main chamber and provided it into the plasma chamber. The plasma generator in the plasma chamber included 16 DBD modules spaced apart from each other, and the two plasma electrodes, which had different polarities, were coated with silver (Ag) on the opposite sides of the rectangular alumina (Al_2O_3) plate of each DBD module. The modules were supported by copper (Cu) blocks at both ends of the ceramic plate, and electrodes were connected in parallel to the plasma power supply whose input power and frequency were 550 W and 25 kHz, respectively. The power generated a strong electric field near the boundary lines of the electrodes, and the plasma was discharged from the lines on both sides of the module. Ambient gas consisting mainly of nitrogen and oxygen was excited by the discharged plasma to produce reactive nitrogen species (RNS) including nitrite (NO_2), which was supplied into the meat batter composed of ground meat of pork hind leg, water and sodium chloride (80:20:1, w/w/w) in the main chamber.

Nitrite concentration

Samples were collected from three areas of meat batter at 5 min intervals during plasma treatment over 30 min. Nitrite in meat batter was measured according to AOAC method 973.31 [6].

Meat batter color following treatment

Collected meat batter samples of 30 g were individually vacuum-packaged (-650 mmHg) into 20 × 15 cm vacuum bags. The packaged meat batter samples were cooked in an 85°C water bath for 20 min and cooled in tap water for 10 min. After removal of the vacuum bag and surface moisture, the lightness (L^*), redness (a^*), and yellowness (b^*) of the cooked meat batter were measured using a spectrophotometer with the illuminant D_{65} (CM-3500d, Konica Minolta Inc., Tokyo, Japan). Measurements were taken perpendicular to the surface of cooked meat batter with an illumination area of 8 mm diameter at 2 different locations per sample.

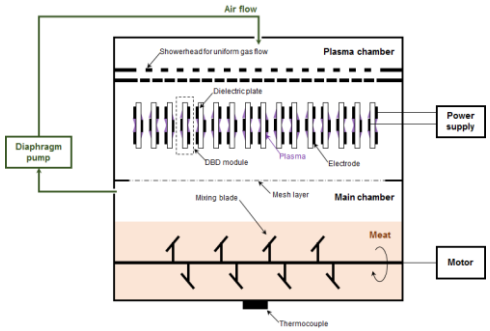

Figure 1. Atmospheric pressure plasma system

Statistical analysis

The experiment was performed in triplicate. In each experiment, three samples were collected per each plasma treatment time. The mean value from three samples was used as the data for each experiment. Data were analyzed using analysis of variance (ANOVA) in SAS software (version 9.3, SAS Institute Inc., Cary, NC, USA). Differences among the means were assessed by Tukey's multiple comparison test. The results are reported as mean ± SD. Statistical significance was assumed at $p < 0.05$.

III. RESULTS AND DISCUSSION

Nitrite revel

The nitrite level in meat batter gradually increased with increasing plasma treatment time ($p < 0.05$) (Figure. 2). The meat batter contained 65.96 mg kg^{-1} of nitrite after plasma treatment for 30 min. The energetic electrons in the discharge layer dissociate atmospheric nitrogen and oxygen molecules and consequently, nitrogen oxides such as NO_2, N_2O_3, and N_2O_5 form in the gas phase by several reaction pathways [7]. These nitrogen oxides react with H_2O to form nitric (HNO_3) and nitrous acids (HNO_2) which are finally decomposed into nitrate (NO_3^-) and nitrite (NO_2^-) via several chemical reactions [5, 8]. Oehmigen et al. [9] reported that plasma treatment decreased pH of liquids via generation of nitric and nitrous acids. The pH of deionized water was decreased from 7 to 2~3 after treatment with atmospheric cold plasma for 2 h [5]. Under acidic conditions, nitrite levels were decreased by the transformation of nitrite into nitrate [8].

However, nitrite level in plasma treated liquid was maintained in an alkaline environment by preventing transformation of nitrite into nitrate

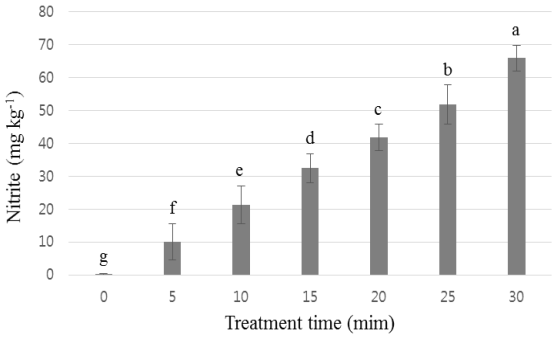

Figure 2. Nitrite level (mg kg^{-1}) of meat batter treated with atmospheric cold plasma
[a-g]Different letters among meat batters treated with atmospheric cold plasma at different time (0, 5, 10, 15, 20, 25, and 30 min) differ significantly ($p < 0.05$).

[5, 8]. In the present study, the pH of meat batter was slightly decreased after plasma treatment for 30 min because of the inherent buffering capacity of meat batter (data not shown). Therefore, nitrite in meat batter was not transformed into nitrate. However, it is possible that some nitrite in meat batter converts to nitric oxide during plasma treatment.

Meat batter color following treatment

After cooking, the cured pink color developed in all meat batter treated with plasma, and the negative control not treated with plasma had a brown color (data not shown). The *L** values of cooked meat batter were not significantly influenced by plasma treatment, implying that nitrite had no effect on the *L** values of cooked meat batter ($p > 0.05$, Table 1). This result is consistent with previous studies. Jung et al. [10] found that the *L** values of cooked meat batter cured with 70 ppm of sodium nitrite was no different to that of cooked meat batter with no nitrite added. Horsch et al. [11] reported that addition of 100 ppm of nitrite did not affect *L** values in processed ham.

The *a** values of cooked meat batter were significantly increased with increasing plasma treatment time ($p < 0.05$). This result was attributed to the increase of nitrite levels with increasing plasma treatment time. In meat batter, myoglobin and nitric oxide converted from nitrite combine by several reaction pathways to form nitrosomyoglobin which produces

Table 1. Color (*L**, *a**, and *b**) of cooked meat batter treated with atmospheric cold plasma.

	Treatment time (min)						
	0	5	10	15	20	25	30
*L**	70.29 ± 0.53	70.45 ± 0.53	70.41 ± 0.51	69.68 ± 0.95	69.98 ± 0.65	69.56 ± 0.88	69.46 ± 1.07
*a**	2.13 ± 0.57^{f}	3.98 ± 0.62^{e}	5.03 ± 0.67^{d}	5.96 ± 0.64^{c}	6.60 ± 0.54^{b}	6.98 ± 0.37^{ab}	7.20 ± 0.32^{a}
*b**	14.95 ± 0.51^{a}	13.16 ± 0.38^{b}	12.48 ± 0.66^{c}	12.31 ± 0.51^{c}	11.90 ± 0.37^{cd}	11.67 ± 0.11^{d}	11.92 ± 0.41^{cd}

Values shown are mean ± standard deviation (n=3).
[a-f]Different letters within same row differ significantly ($p < 0.05$).

the cured pink color (nitroso hemochrome) of processed meat after heat treatment [12]. It is well known that redness increases, producing the characteristic cured color in processed meat after curing with nitrite. Horsch et al. [11] found that the *a** values of ham cured with sodium nitrite and celery concentrate were higher than that of the control with no nitrite source added, and increasing nitrite concentration resulted in an increase of the *a** values of the ham.

The decrease in *b** values of cooked meat batter with increasing duration of plasma treatment was significant ($p < 0.05$). This result was proportional to the development of cured color in cooked meat batter. Horsch et al. [11] found the decrease of *b** values in ham cured with nitrite compared to that of control with no nitrite added.

IV. CONCLUSION

The treatment of meat batter with APP resulted in the infusion of nitrite into meat batter and consequently the development of the cured color. According to the results, direct APP treatment during batter mixing can be used as a replacement to nitrite addition during the curing process.

ACKNOWLEDGEMENTS

This study was supported by High Value-added Food Technology Development Program

(115014-03-1-HD020), Ministry of Agriculture, Food and Rural Affairs (MAFRA) Republic of Korea.

REFERENCES

1. Sebranek, J. G., Jackson-Davis, A. L., Myers, K. L., & Lavieri, N. A. (2012). Beyond celery and starter culture: Advances in natural/organic curing processes in the United States. Meat Science, 92, 267-273.
2. Parthasarathy, D. K., & Bryan, N. S. (2012). Sodium nitrite: The "cure" for nitric oxide insufficiency. Meat Science, 92, 274-279.
3. Jackson, A. L., Sullivan, G. A., Kulchaiyawat, C., Sebranek, J. G., & Dickson, J. S. (2011). Survival and growth of *Clostridium perfringens* in commercial no-nitrate-or-nitrite-added (natural and organic) frankfurters, hams, and bacon. Journal of Food Protection, 74, 410-416.
4. Yong, H. I., Kim, H. J., Park, S., Alahakoon, A. U., Kim, K., Choe, W., & Jo, C. (2015). Evaluation of pathogen inactivation on sliced cheese induced by encapsulated atmospheric pressure dielectric barrier discharge plasma. Food Microbiology, 46, 46-50.
5. Jung, S., Kim, H. J., Park, S., Yong, H. I., Choe, J. H., Jeon, H. J., Choe, W., & Jo. C., (2015). The use of atmospheric pressure plasma-treated water as a source of nitrite for emulsion-type sausage. Meat Science, 108, 132-137.
6. AOAC, Association of Official Analytical Chemists (1990). *Nitrites in cured meats* Official Method 973.31 (15th ed.) *Official methods of analysis*. Arlington, VA: AOAC.
7. Sakiyama, Y., Graves, D. B., Chang, H. W., Shimizu, T., & Morfill, G. E. (2012). Plasma chemistry model of surface micro-discharge in humid air and dynamics of reactive neutral species. Journal of Physics. D, Applied Physics, 45, 425201.
8. Thomas, D., & Vanderschuren, J. (2000). Nitrogen oxides scrubbing with alkaline solutions. Chemical Engineering & Technology, 23, 449-455.
9. Oehmigen, K., Hahnel, M., Brandenburg, R., Wilke, C., Weltmann, K. D., & von Woedtke, T. (2010). The role of acidification for antimicrobial activity of atmospheric pressure plasma in liquids. Plasma Processes and Polymers, 7, 250-257.
10. Jung, S., Kim, H. J., Park, S., Yong, H. I., Choe, J. H., Jeon, H. J., Choe, W., & Jo. C., (2015b). Color developing capacity of plasma-treated water as a source of nitrite for meat curing. Korean Journal of Food Science and Technology, 35, 703-706.
11. Horsch, A. M., Sebranek, J. G., Dickson, J. S., Niebuhr, S. E., Larson, E. M., Lavieri, N. A., Ruther, B. L., & Wilson, L. A. (2014). The effect of pH and nitrite concentration on the antimicrobial impact of celery juice concentrate compared with conventional sodium nitrite on *Listeria monocytogenes*. Meat Science, 96, 400-407.
12. Alahakoon, A. U., Jayasena, D. D., Ramachandra, S., & Jo., C. (2015). Alternatives to nitrite in processed meat: Up to date. Trends in Food Science and Technology, 45, 37-49.