

Color Developing Capacity of Plasma-treated Water as a Source of Nitrite for Meat Curing

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Abstract

The interaction of plasma with liquid generates nitrogen species including nitrite (NO_2^-). Therefore, the color developing capacity of plasma-treated water (PTW) as a nitrite source for meat curing was investigated in this study. PTW, which is generated by surface dielectric barrier discharge in air, and the increase of plasma treatment time resulted in increase of nitrite concentration in PTW. The PTW used in this study contains 46 ppm nitrite after plasma treatment for 30 min. To evaluate the effect of PTW on the cured meat color, meat batters were prepared under three different conditions (control, non-cured meat batter; PTW, meat batter cured with PTW; Sodium nitrite, meat batter cured with sodium nitrite). The meat batters were vacuum-packaged and cooked in a water-bath at 80°C for 30 min. The typical color of cured meat developed in cooked meat batter treated with sodium nitrite or PTW. The lightness (L^*) and yellowness (b^*) values were similar in all conditions, whereas, the redness (a^*) values of cooked meat batter with PTW and sodium nitrite ($p < 0.05$) were significantly higher than the control. These data indicate that PTW can be used as a nitrite source in the curing process of meat without addition of other nitrite sources.

Keywords: atmospheric-pressure plasma, nitrite, cured color, meat batter

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Introduction

Nitrite (NO_2^-) is commonly used in the curing of meat to develop cured color and flavor, and to inhibit lipid oxidation and spoilage due to microorganisms including *Clostridium botulinum* (Pegg and Shahidi, 2000). Sodium nitrite has been conventionally used as a nitrite source in manufacture of cured meat products, because it is an inexpensive and easy method. However, with increasing negative views of synthetic food additives lately, most consumers prefer meat cured with natural substances rather than chemical compounds such as sodium nitrite (Sebranek and Bacus, 2007). The use of vegetable juices

or concentrates containing nitrate or nitrite is a generally accepted alternative for sodium nitrite in processed meat industries (Sebranek *et al.*, 2012). However, the use of vegetable juices or concentrates has a few disadvantages; their inherent flavors and pigments can develop unpleasant flavor and color in the cured meat products (Sindelar *et al.*, 2007). Moreover, the use of vegetable juices or concentrates in curing meat often results in an increased cost of the product owing to the incorporation of their high cost and additional processes such as an incubation step, which are required for converting nitrate to nitrite (Horsch *et al.*, 2014).

Plasma is an ionized gas with charged particles (Bogaerts *et al.*, 2002). Plasma treatment technologies using atmospheric-pressure plasmas have widely been used for the sterilization of food or medical instruments, and surface modifications of dielectric or metallic materials (Bogaerts *et al.*, 2002; Song *et al.*, 2009; Yong *et al.*, 2015). Water can also be purified through plasma treatment to

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remove harmful contaminants including microorganisms (Foster *et al.*, 2012). Oehmigen *et al.* (2010) reported that the interaction of plasma with liquid resulted in the generation of nitrogen species such as nitrate (NO_3^-) and nitrite (NO_2^-) as well as reactive oxygen species. Therefore, we hypothesized that the nitrite formed in plasma-treated water can be used in curing of meat products.

The objective of this study is to investigate the nitrite concentration in plasma-treated water (PTW) and the color change of meat batter treated with PTW, after cooking.

Materials and Methods

Plasma treatment system

As schematically illustrated in Fig. 1(A), a plasma device consisting of a powered electrode, ground electrode, and a 0.6 mm thick Al_2O_3 plate placed between electrodes, was used for generating surface dielectric barrier discharge (SDBD). To prevent oxidation of the metallic electrode due to high levels of oxidant species, the ground electrode, directly exposed to the plasma was made of nickel-chromium alloy. The ground electrode was perforated with rounded squares (3×3 mm in size). The high voltage of bipolar square waveform with 15 kHz frequency was applied to the powered electrode. The average power was 3.14 W and the peak power was 200 W. To produce PTW, 100 mL of distilled water was exposed to SDBD in atmospheric air as seen in Fig. 1(A).

Quantification of nitrite concentration

Because the non-negligible amounts of nitric acid ($pK_a = -1.4$) and nitrous acid ($pK_a = 2.8-3.2$) which release H^+ ions are constantly formed in PTW, pH of PTW drops from 7 to 2-3. Thus, nitrite and nitrous acid coexist in PTW. The concentrations of nitrite and nitrous acid produced in PTW were estimated using UV-Vis absorption (MAYA

2000 Pro, Ocean optics Inc., USA). The absorption coefficients of nitrite and nitrous acid were adopted from Rior-dan *et al.* (2005). The concentrations of nitrite and nitrous acid were quantified from the absorption spectra in the wavelength range of 300-400 nm, as shown in Fig. 1(B).

Manufacture of meat batter

Pork hind leg meat and back fat were obtained from a commercial butcher (Korea). Visible fat and connective tissue was trimmed off and the meat was ground in a grinder with 6 mm plate. Ground meat was mixed with the back fat, cold water, and additives based on the type of treatment, as mentioned in Table 1 (control, non-cured meat batter; PTW, meat batter cured with PTW; Sodium nitrite, meat batter cured with sodium nitrite). Meat batter was vacuum-packaged in low-density polyethylene/nylon vacuum bags (10×10 cm, oxygen permeability of $22.5 \text{ mL/m}^2/24 \text{ h atm}$ at $60\% \text{ RH}/25^\circ\text{C}$, water vapor permeability of $4.7 \text{ g/m}^2/24 \text{ h}$ at $100\% \text{ RH}/25^\circ\text{C}$) using a vacuum-packaging machine (FJ-600XL; Hankook Fjeee Industries Co., Korea) at 650 mmHg. The meat was then cooked in a water-bath at 80°C for 30 min, until internal temperature of cooked meat batter reached 75°C .

Table 1. Formulations for manufacturing meat batter (g)

Ingredient	Control ¹	Sodium nitrite	PTW
Pork hind leg meat	600	600	600
Pork back fat	200	200	200
Ice water	200	200	-
PTW	-	-	200
Sodium chloride	12	12	12
Sodium pyrophosphate	2	2	2
L-ascorbic acid	0.5	0.5	0.5
Sodium nitrite	-	0.1	-

¹Control, non-cured meat batter; Sodium nitrite, meat batter cured with sodium nitrite; PTW, meat batter cured with plasma-treated water.

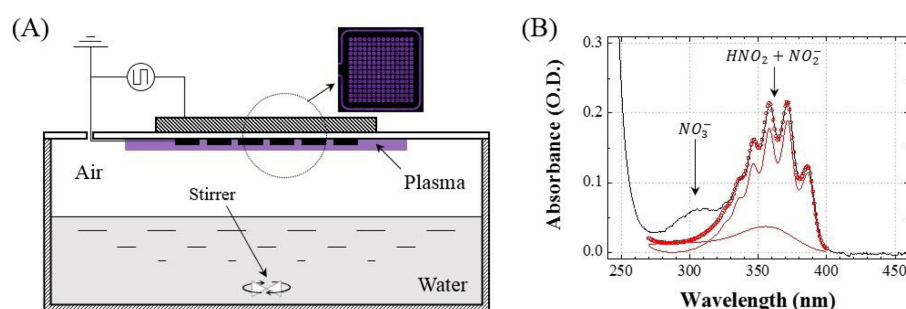


Fig. 1. (A) Schematic drawing of SDBD system and (B) a measured absorption spectrum (black solid line) of plasma-treated water (PTW) and fitting curves; red solid lines for nitrite and nitrous acid and red open symbol for their cumulative curve.

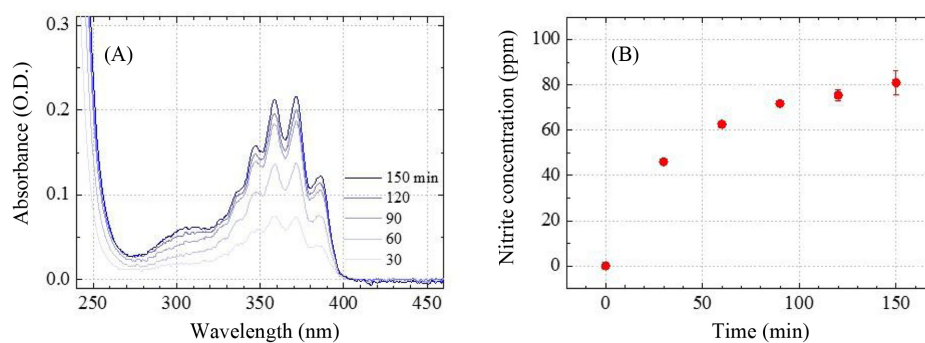


Fig. 2. (A) Absorption spectra and (B) nitrite concentrations of plasma-treated water treated for 30-150 min.

Instrumental color measurements

The lightness (L^*), redness (a^*), and yellowness (b^*) of the cooked meat batters were measured using a spectrophotometer (CR-300; Minolta Inc., Japan). Measurements were taken at 3 different locations per sample, perpendicular to the surface of the cooked meat batter, with illumination area 30 mm in diameter.

Statistical analysis

This study was performed in three individual three replicates. The general linear model was constructed using raw data, and Tukey's multiple range test was used to evaluate significant differences ($p < 0.05$). Least square mean values and standard error of the least square means (SEM) are reported. SAS software (version 9.3, SAS Institute Inc., USA) was used for all statistical analyses.

Results and Discussion

Nitrite concentration of PTW

Increase in plasma treatment time resulted in increase of nitrite concentration in PTW (Fig. 2). After 30 min of plasma treatment, the concentrations of nitrite and nitrous acid in PTW were 46 ppm and 45 ppm, respectively. As

nitrite combines with hydrogen atoms to form nitrous acid, resulting in nitrous acid being constantly broken down into nitrate and nitric oxide, PTW was used immediately after preparation for the curing process.

Instrumental color of cooked meat batter

Fig. 3 shows the typical color of cured meat developed in cooked meat batter treated with sodium nitrite or PTW. The L^* and b^* values of cooked meat batter treated with PTW or sodium nitrite were not significantly different from those of control (Table 2), as previously reported. Horsch *et al.* (2014) found that the L^* value was not different between non-cured ham and ham cured with sodium nitrite. As expected, a^* values of control was significantly lower than that of cooked meat batter cured with sodium nitrite or PTW ($p < 0.05$). The increase in a^* value is a characteristic of meat cured with nitrite, regardless of the type of cured meat (de Oliveira *et al.*, 2012; Horsch *et al.*, 2014; Tsoukalas *et al.*, 2011). Haldane (1901) demonstrated that addition of nitrite to meat batter resulted in the generation of nitric oxide, which subsequently produced nitrosylmyoglobin that imparts bright pink color to cured meat products after cooking. The a^* values of cooked meat batter cured with PTW was significantly lower than that of coo-

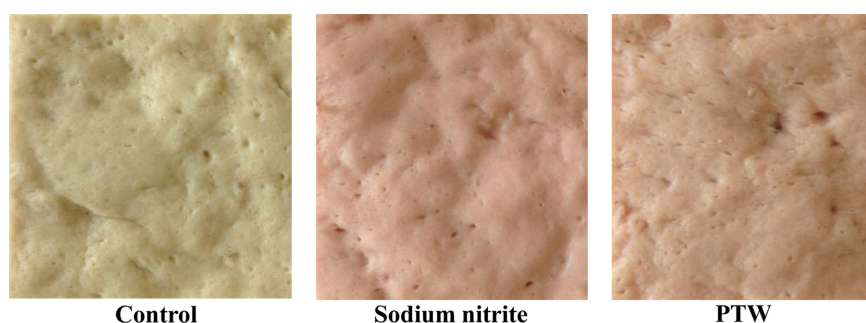


Fig. 3. The color of cooked meat batter. Control, non-cured meat batter; Sodium nitrite, meat batter cured with sodium nitrite; PTW, meat batter cured with plasma-treated water.

Table 2. Instrumental color (L^* , a^* , and b^*) of cooked meat batter

	Control	Sodium nitrite	PTW	SEM ¹
L^*	67.9	67.0	67.5	0.43
a^*	2.0 ^c	10.4 ^a	7.8 ^b	0.29
b^*	10.4	9.0	9.6	0.43

¹Standard errors of mean (n=9).

^{a-c}Different letters within same row differ significantly ($p < 0.05$).

ked meat batter cured with sodium nitrite ($p < 0.05$), owing to lower concentration of nitrite in the former. The PTW used in this study contained 46 ppm nitrite. Therefore, the nitrite in meat batter cured using PTW was 9.2 ppm while that in meat batter cured using sodium nitrite was 70 ppm. The increase in a^* values of cured ham as a consequence of increase in nitrite concentration, has been previously reported (Horsch *et al.*, 2014).

Thus, the cured color of cooked meat batter can be developed using PTW and it can be used as a nitrite source for curing, as an alternative to sodium nitrite. However, the plasma treatment system has to be improved to increase nitrite concentration in water. In addition, PTW can neither be distinctly classified as a synthetic nor a natural source of nitrite. Plasma treatment has previously been confirmed to be a safe water purification method (Foster *et al.*, 2012). Therefore, our work suggests that PTW is a potential nitrite source that can be used in meat curing; however, further studies are warranted to improve the quality of a PTW-mediated curing process.

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