COMBINED EFFECTS OF HIGH PRESSURE AND SODIUM HYDROGEN CARBONATE ON BEEF TEXTURE AND COLOR

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Abstract - Effect of combined high-pressure and sodium hydrogen carbonate ($NaHCO_3$) treatment on the physical properties and color of silverside Australian beef was investigated. Meat samples were pressurized at 100 to 500 MPa and the water content, weight reduction, rupture stress, and meat color were determined. The water content of meat treated with $NaHCO_3$ and high pressure (300 MPa) reached a maximum of 70.1%. Weight reduction tended to decrease with high-pressure treatment at 300 MPa. Meats treated with $NaHCO_3$ and high pressure at 400 MPa showed a more than 50% decrease in toughness. Whitening of the meat was reduced by the combined high-pressure and $NaHCO_3$ treatment, which had been maintained during refrigeration storage. Therefore the combined high-pressure and $NaHCO_3$ treatment is effective for improvement of Australian beef quality.

I. INTRODUCTION

There are a number of reports on the effects of high pressure processing of meat and meat products. In a previous study of high-pressure treatment of meat, Ananth *et al.* (1) reported that color, peak load, water-holding capacity, and moisture were not different between samples treated with high pressure (414 MPa) for 9 min at 25°C and controls with cooking. In contrast, Souza *et al.* (2) reported improvements in the water-holding capacity and pork palatability by high-pressure treatment. High-pressure treatment can accelerate meat conditioning and, as a result, induce a great tenderization of raw meat (3). However, its effectiveness is limited on cooking.

Many researchers have reported that myoglobin, which is associated with the red pigmentation of meat, is denatured by high-pressure treatment. Shigehisa *et al.* (4) observed a decrease in the L* and a* values of pork slurries pressurized at 100 to 600 MPa. Carlez *et al.* (5) reported that the color of minced beef changed markedly, especially above 300 MPa. They also reported that meat discoloration from pressure processing may result from a 'whitening effect' in the range of 200 to 350 MPa due to globin denaturation and heme displacement or release, or protein coagulation with a resulting loss of solubility of sarcoplasmic and/or myofibrillar proteins that affect structure and surface properties (6).

Sodium hydrogen carbonate ($NaHCO_3$) treatment has been used traditionally in cooking as a meat tenderizer. However, $NaHCO_3$ treatment causes cavity formation between the muscle fibers after heating. Kim *et al.* (7) applied a combined high-pressure and $NaHCO_3$ treatment for pork and showed improved tenderness and juiciness without any cavity formation after heating. In the present study, we investigated the effects of combined high-pressure and $NaHCO_3$ treatment on the physical properties and color of beef which is firm and difficult to chew.

II. MATERIALS AND METHODS

Sample preparation

Silverside Australian beef was used as the meat sample, this cut being a part of the outside round and the most tough in beef. The samples were purchased from Itoham Foods Inc. and stored at -20°C. The meat was thawed at 4°C overnight. The meat was cut along the grain into slices 1 cm in thickness. The meat samples were then placed individually in vacuum-sealed polyethylene bags with 4 vol (v/w) of 0.4 M $NaHCO_3$ solution or de-ionized water as the control.

The samples were sealed and placed in a 20°C water bath for 40 min. They were then removed from the soaking solution and each meat sample was again vacuum-sealed in a polyethylene bag. Meat samples were pressurized at 0.1, 100, 200, 300, 400, and 500 MPa at 20°C for 10 min using a high-pressure food processor (Dr. CHEF, Kobe Steel, Japan). Non-pressurized meat was expressed as the meat treated under 0.1 MPa. After pressurization, each meat sample was heated for 30 min at 80°C and cooled down in ice-cold water until the core temperature of the meat reached 20°C.

Measurement of water content and weight reduction

Water content was measured using a halogen moisture analyzer (HG63, Mettler Toledo, Switzerland). Approximately 3 g of each meat sample was heated at 137°C. For determination of weight reduction, the weight of the meat was measured after thawing, and re-measured after heating. Weight reduction was shown in ratio (%) for the meat weight after thawing.

Measurement of rupture stress

The rupture stress of each heated meat sample was measured using a rheometer (Creep Meter RE2-3305B, Yamaden, Japan). Samples were cut into pieces 25 × 20 × 10 mm in size and punctured by using a plunger (wedge shape, 8 × 0.25 mm, 20-mm long) at 10 mm/s, stopping at 100% of the thickness, using a load cell of 200 N. The rupture stress experiment was conducted at room temperature (20°C).

Measurement of meat color

Meat color was assessed during refrigeration storage under an atmospheric condition after high-pressure treatment. The L* (lightness), a* (redness), and b* (yellowness) values were determined using a chroma meter (CR-400, Konica Minolta, Japan) in the 1976 CIELAB system. Surface determinations were carried out on each sample.

Statistical analysis

Results are expressed as the mean ± SEM. All data were analyzed using one-way analysis of variance. The statistical significance of differences among means was evaluated using Student's *t*-test at the 1% level.

III. RESULTS AND DISCUSSION

Water content and weight reduction

The effects of high-pressure treatment on water content and weight reduction of meat were compared between control and $NaHCO_3$ treatment groups (Fig. 1).

Water content of $NaHCO_3$ treated meats (68.0±1.0%) increased by approximately 6.5% in comparison with untreated meats (61.5±1.1%) ($p<0.01$). Significant differences were not observed in the meats treated without $NaHCO_3$, regardless of the processing pressure. The effect of high-pressure treatment was obvious with 300 MPa and 400 MPa pressure treatments ($p<0.01$) in $NaHCO_3$ treated meats. Specifically, the water content of meats treated with $NaHCO_3$ and high pressure at 300 MPa (70.1±0.6%) increased approximately 8.6% in comparison with untreated meats (61.5±1.1%). In isolated myofibrils from rabbit skeletal muscle exposed to pressure at 200 MPa, the structural continuity of the sarcomere was completely lost with the loss of Z-line (8). The increase in water capacity in this study may be due to the high-pressure rupture of the myofibril ultrastructure.

The weight reduction of $NaHCO_3$ treated meats (22.6±1.9%) was approximately 16.8% less than of the untreated meats (39.4±0.3%) ($p<0.01$). Significant differences were not observed in either untreated or $NaHCO_3$ treated meats, regardless of the given pressure. However, weight reduction tended to decrease at 300 MPa. It is suggested that a combined high-pressure and $NaHCO_3$ treatment is effective for limiting the loss of water content and weight during the cooking of beef.

Rupture stress

The effect of high-pressure treatment on rupture stress in untreated and $NaHCO_3$ treated samples is shown in Fig. 2. The rupture stress of untreated and $NaHCO_3$ treated meats was 3.97×10^6 N/m^2 and 2.89×10^6 N/m^2, respectively. The values significantly decreased with high-pressure treatment above 100 MPa in untreated

samples and above 200 MPa in $NaHCO_3$ treated samples ($p<0.01$). In particular, meats treated with $NaHCO_3$ and high pressure at 400 MPa (1.74×10^6 N/m^2) showed a more than 50% decrease in hardness compared to untreated meats (3.97×10^6 N/m^2). Kim *et al.* (7) reported that pressurization at 400 MPa showed the greatest effect on pork ham tenderness. In this study, the combined high-pressure and $NaHCO_3$ treatment could improve the tenderness of beef as shown in pork.

Meat color

The effect of high-pressure treatment on the meat color of untreated and $NaHCO_3$ treated samples are shown in Table 1. The L* (lightness) value of $NaHCO_3$ treated meats (30.41±2.00) was approximately 8.83 units lower than untreated meats (39.24±2.98) ($p<0.01$). The L* value of meats treated with high pressure (more than 300 MPa) significantly increased ($p<0.01$). The b* (yellowness) value of $NaHCO_3$ treated meats (4.21±1.26) was also approximately 3.89 units lower than untreated meats (8.10±1.10) ($p<0.01$). As similar to the L* value result, the b* value of meats treated with high pressure (more than 300 MPa) significantly increased ($p<0.01$). The significant increases observed in L* and b* values were thought to be due to the whitening of the meat.

The trend a* (redness) value is characteristically different from that of L* and b* values. The a* value of $NaHCO_3$ treated meats (11.93±1.43) was approximately 1.92 units higher than untreated meats (10.01±0.75) ($p<0.01$). The a* value of meats treated with high pressure at 100 MPa and 200 MPa increased in comparison with untreated meats. However, a* value of meat subjected to high pressure more than 400 MPa decreased in comparison with that subjected to 300 MPa (12.28±1.34). This is considered to be due to myoglobin denaturation by high-pressure treatment (5). Since a* value of meat treated with $NaHCO_3$ and high pressure (more than 400 MPa) increased, it is suggested that $NaHCO_3$ treatment affects the structure of myoglobin and the effect on color is depending on the degree of pressure.

Therefore, in the color of silverside Australian beef, a darkening was induced by $NaHCO_3$ treatment, while the whitening effect was induced by high pressure at 300 MPa or more. On the other hand, by using a combined high-pressure and $NaHCO_3$ treatment, an inhibition of the increase of the L* value was induced with an increase of the a* value, which is desirable for consumers. The color of the meat processed with high pressure and $NaHCO_3$ was maintained during refrigeration storage, for approximately two weeks.

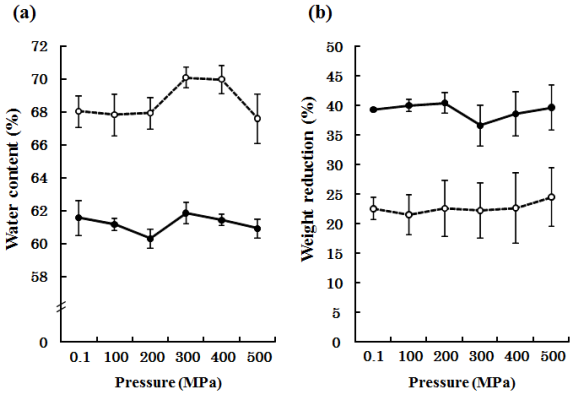

Fig. 1. Effect of high-pressure and $NaHCO_3$ treatment on (a) water content and (b) weigh reduction of beef.
-●-: untreated, -○-: $NaHCO_3$ treatment. Values are expressed as mean ± standard deviation, n=5.

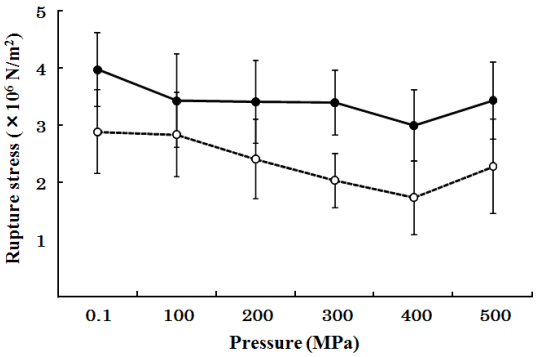

Fig. 2. Effect of high-pressure and $NaHCO_3$ treatment on the rupture stress of beef.
-●-: untreated, -○-: $NaHCO_3$ treatment. Values are expressed as mean ± standard deviation, n=22.

Table 1. Effect of high-pressure and $NaHCO_3$ treatment on the beef color.

	L*	a*	b*
untreated			
0.1 MPa	39.24 ± 2.98 d	10.01 ± 0.75 a	8.10 ± 1.10 b
100 MPa	38.17 ± 1.74 d	10.33 ± 1.08 ab	8.40 ± 1.13 bc
200 MPa	39.92 ± 1.62 d	11.50 ± 1.22 bc	9.35 ± 0.93 c
300 MPa	45.08 ± 1.96 e	12.28 ± 1.34 bc	10.40 ± 0.61 d
400 MPa	49.74 ± 1.63 f	11.66 ± 1.60 bc	11.85 ± 0.79 e
500 MPa	50.65 ± 1.84 f	10.81 ± 0.94 abc	12.28 ± 0.87 e
$NaHCO_3$ treatment			
0.1 MPa	30.41 ± 2.00 b	11.93 ± 1.43 bc	4.21 ± 1.26 a
100 MPa	29.50 ± 1.88 ab	11.85 ± 1.25 bc	3.76 ± 1.20 a
200 MPa	28.98 ± 1.61 a	12.96 ± 1.32 c	4.21 ± 0.66 a
300 MPa	34.20 ± 1.99 c	13.86 ± 1.70 cd	5.34 ± 1.56 a
400 MPa	45.02 ± 3.32 e	15.35 ± 2.11 d	8.49 ± 1.69 bc
500 MPa	47.70 ± 2.34 ef	15.36 ± 1.76 d	9.97 ± 1.40 c

Values are expressed as mean ± standard deviation, n=20. Significant differences among values in the same row are indicated by different letters ($p<0.01$).

IV. CONCLUSION

The combination of high-pressure at 300-400 MPa and 0.4 M sodium hydrogen carbonate treatment was shown to be effective for the improvement of Australian beef quality, resulting from several physical properties and color of the meat.

ACKNOWLEDGEMENTS

This work was supported in part by the Niigata Prefecture Collaboration of Regional Entities for the Advancement of Technological Excellence from Japan Science and Technology Agency.

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