Food Sci. Biotechnol. Vol. 14, No. 6, pp. 808 ~ 812 (2005)

Food Science and Biotechnology

Effects of Time-Dependent High Pressure Treatment on Physico-chemical Properties of Pork

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Abstract The effects of high pressure processing, pressure level (50, 100, 150, and 200 MPa) and pressurized time (0, 5, 10, 15, 30, 45, and 60 min) on the physico-chemical properties of pork *M. longissimus dorsi* were evaluated. The pH value was affected by both pressure level and pressurized time, especially at 200 MPa ($P<0.05$). In color measurement, L^* and a^*-values were increased by both pressure level and pressurized time, but b^*-value did not differ significantly ($P>0.05$). Water holding capacity (WHC) was significantly decreased ($P<0.05$) depending on pressure level and pressurized time, while cooking loss was gradually increased. Warner-Bratzler shear force did not differ significantly ($P>0.05$) among the treatments. These results indicate that high pressure processing below 200 MPa for 1 hr had no effect on the quality of cooked meat, although some alterations were observed before cooking.

Keywords: high pressure, color, WHC, cooking loss, shear force

Introduction

In principle, high pressure inactivates microorganisms, denatures proteins, and gelatinizes starches, properties that are similar to the effects given by thermal processing. However, unlike heat treatment, high pressure maintains the natural flavor, color, and nutrients of natural foods, i.e., the original properties of the biological material. Therefore, high pressure treatment may be applied not only to food materials but also biological materials such as organs and tissues (1).

The first studies on the application of high pressure in food technology were carried out at the end of the 19th century (2). In 1990, the first high pressure processed food, a fruit jam, was introduced onto the Japanese retail market (3). Recently, a number of other high pressure processed food products have been launched, including oysters in the USA, orange juice in France, and guacamole in Mexico (4). However, no high pressure processed meat products are known to be available on the commercial market.

Since tenderization of meat by high pressure was first proposed by Macfarlane (5) on pre-rigor meat, numerical investigations on pre-rigor meat have been published (6-10). However, the application of high pressure in the pre-rigor period is difficult to perform as it requires hot-boning which is not widely used in industry and pressurizing muscle when the pH is still high, i.e. during a short period of time that varies from one muscle to another depending on rigor onset (11). Therefore, investigations moved to meat treatment after completion of rigor (12-16).

Although extensive studies have dealt with the effects of high pressure on post-rigor meat under various conditions, very few results have yet been published on the mechanical and the sensory properties of meat. Therefore, this study analyzed the effect of various pressurization conditions on the physico-chemical properties of pork meat in order to obtain basic data on the effect of high pressure on alterations to post-rigor meat quality.

Materials and Methods

Sample preparation Porcine *M. longissimus dorsi* stored for 24 hr at 4°C after slaughter were obtained from a local market. Sample was prepared by the method of our previous study (17). For each treatment, 75 cylindrical samples approximately 30 mm in diameter and 100 mm in length were cut from the centre of the muscle with their axis parallel to the fiber direction and were vacuum sealed in a polyethylene bag. All samples were frozen at -40°C to prevent meat changes during the holding period and were later thawed by flowing water for 15 min prior to analysis.

Pressure treatment High pressure treatments were performed in a vessel manufactured by ourselves, as shown Fig. 1. The compression fluid was ethylene glycol and pressurization was carried out combining different parameters of pressure (50, 100, 150, and 200 MPa) and time (0, 5, 10, 15, 30, 45, and 60 min) at 4°C. Pressure level was monitored by digital gauge (SSGA, Sensys Co., Bucheon, Gyeonggi, Korea).

pH Measurement pH measurements were carried out with a pH meter (Model 440, Corning, Schiphol-Rijk, the Netherlands) on 5 g of sample mixed with 20 mL of water and homogenized at 13,000 rpm for 1 min in an SMT process Homogenizer (SMT Co. Ltd., Tokyo, Japan).

Color measurement Color measurements were taken with a color meter (JC801S, Color Techno System Co. Ltd., Tokyo, Japan) calibrated with a white standard plate ($X = 97.83$, $Y = 81.58$, $Z = 91.51$). CIELAB L^*, a^* and b^*

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Received July 12, 2005; accepted September 29, 2005

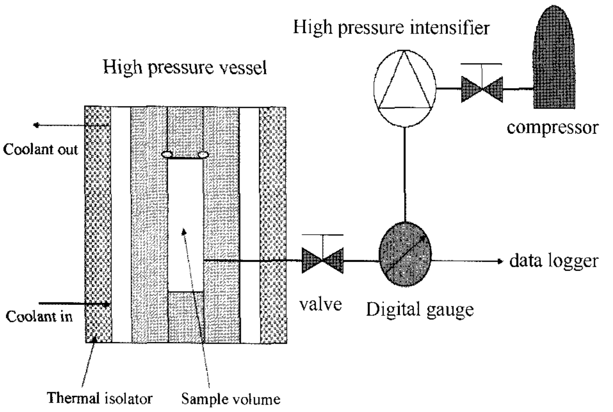

Fig. 1. Schematic diagram of high pressure processing device.

values were determined as indicators of lightness, redness and yellowness, respectively. The sample was oxygenated for 10 min after pressure treatment and three measurements were taken from each surface of the sample. The total color difference, $\Delta E=[(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$, between control and pressurized sample was calculated numerically.

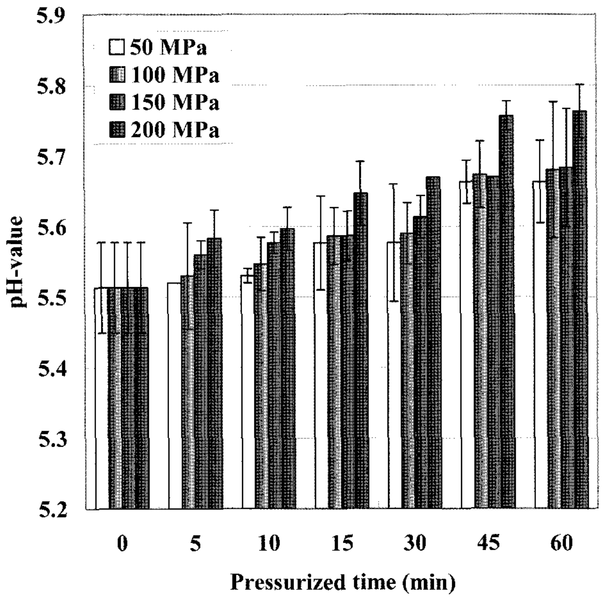

Fig. 2. Changes in pH of pork under variable pressure conditions (n=3). Means with different letters are significantly different ($P<0.05$). Vertical bars represent the standard deviation.

Water holding capacity Water holding capacity (WHC) was determined by the method described by Montero *et al.* (18). One gram of meat was weighed and placed in a centrifuge tube, along with gauze as absorbents. Samples were centrifuged for 10 min at 2250 × g in an automatic refrigerated centrifuge (RC-3, SORVALL Co., CA, USA) at 20°C. After centrifuging, the meat was removed and the centrifuge tube was weighed before and after drying. WHC was expressed as a percentage of the moisture content to the meat.

Cooking loss Cooking loss was determined by assessing the value of exudation after thermal treatment. Three pork samples from each treatment were weighed before and after cooking in a water bath (DX9, Hanyoung Co., Seoul, Korea) at 75°C for 30 min, and expressed as a percentage of the initial weight.

Shear force After measuring the cooking loss, 10 mm diameter × 35 mm length strips were cut parallel to the longitudinal orientation of the muscle fibers. Each strip was sheared using a texture analyzer (TX-XT2i, Stable Micro Systems, London, England) and an average was calculated. Analysis was conducted using at least 12 samples. Three measurements were taken from each of three samples.

Statistical analysis The data were analyzed by ANOVA using the SAS (19) statistical program and differences among the means were compared using Duncan's Multiple Range test. The entire experiment was replicated twice, and all determinations were done in triplicate.

Results and Discussion

pH The change in pH of pork under variable pressure conditions is shown in Fig. 2. The pH value increased both with increasing pressure level and pressurized time, especially at 200 MPa. When meat was subjected to 200 MPa, a significant increase ($P<0.05$) begun from 5 min compared to from 30 min at 150 MPa and 45 min at 50 and 100 MPa. Carlez *et al.* (20) also reported that the pH value of minced meat increased from 5.55 to 5.77-5.79 at 400 or 500 MPa. A similar trend was observed by Ma and Ledward (21) who noted that the increasing pressure level at ambient temperature led to an increase in pH. Angsupanich and Ledward (22) concluded that the pH of cod muscle increased slightly after pressure treatment, probably due to denaturation of some protein fractions. In accordance with the above result, the change in pH value was probably caused not only by increasing pressure level, but also by the duration of pressurized time.

Color The changes in L^*, a^*, and b^*-values under variable pressure conditions are shown in Figs. 3, 4, and 5, respectively. Both L^* and a^*-values increased significantly ($P<0.05$) both with increasing pressure level and pressurized time, while b^*-value did not differ significantly ($P>0.05$) and ranged from 9.8 to 12.0. Carlez *et al.* (20) reported that when minced beef meat was subjected to different pressure levels, L^*-value increased from 200 to 350 MPa and a^*-value decreased with increasing pressure, especially above 400 MPa. They concluded that meat discoloration through pressure processing may result from a whitening in the range 200-350 MPa due to globin denaturation or to heme displacement or release, and oxidation of ferrous myoglobin to ferric metmyoglobin above 400 MPa. In contrast with the decreasing a^*- value, Jung *et al.* (23) observed that treatment at 520 MPa for 260 s led to increases in L^*, a^* and b^*-values. Moreover, they noted that the increase in pressure increased a^*-value until around 350 MPa, after which it decreased. In consequence, the evolution of metmyoglobin with pressure

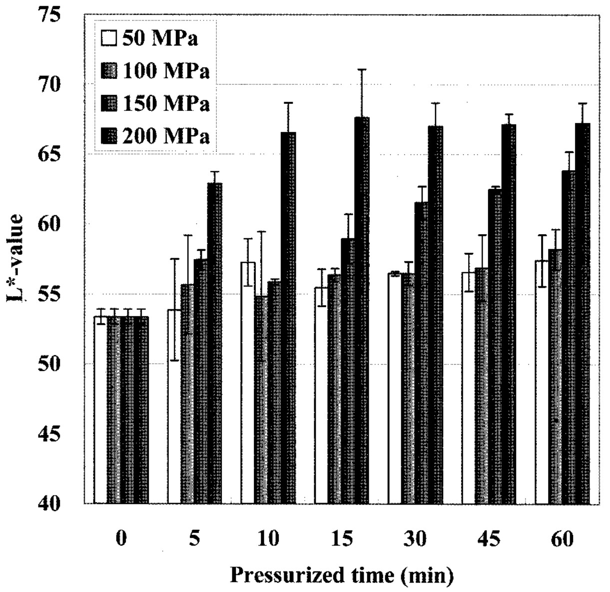

Fig. 3. Changes in L*-value of pork under variable pressure conditions (n=9). Means with different letters are significantly different ($P<0.05$). Vertical bars represent the standard deviation.

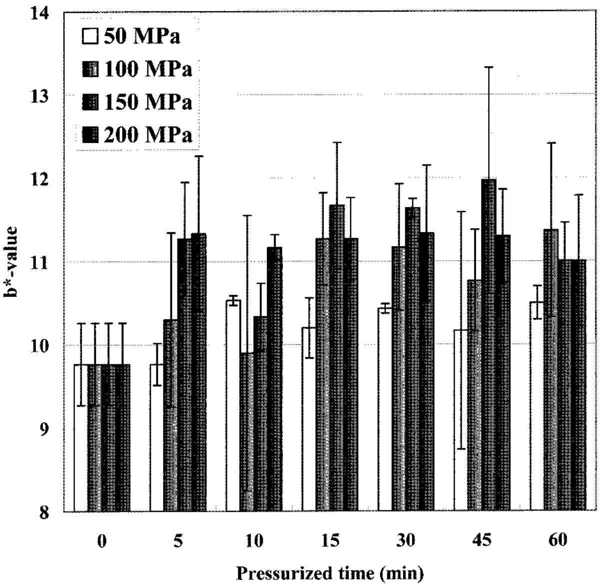

Fig. 5. Changes in b*-value of pork under variable pressure conditions (n=9). Means with different letters are significantly different ($P<0.05$). Vertical bars represent the standard deviation.

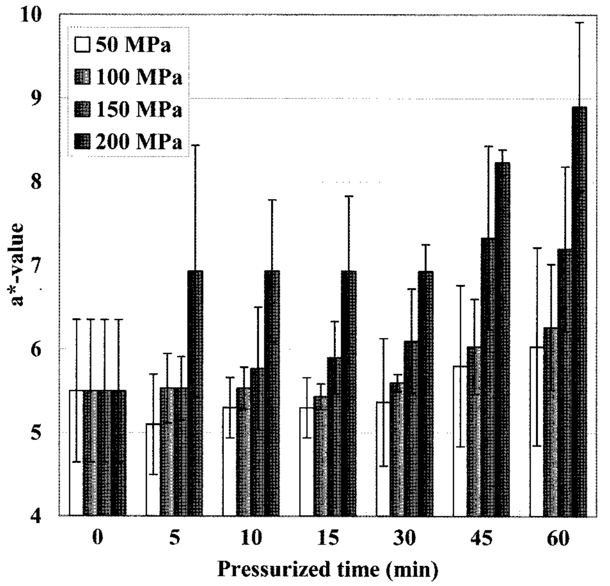

Fig. 4. Changes in a*-value of pork under variable pressure conditions (n=9). Means with different letters are significantly different ($P<0.05$). Vertical bars represent the standard deviation.

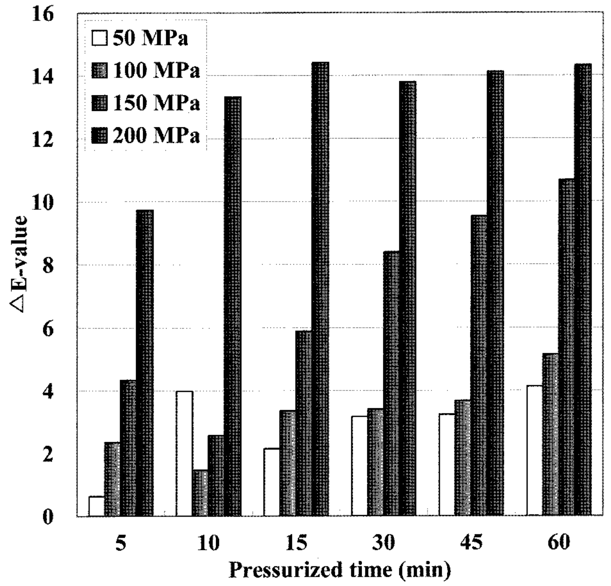

Fig. 6. Changes in ΔE-value of pork under variable pressure conditions. Means with different letters are significantly different ($P<0.05$). Vertical bars represent the standard deviation.

and holding time demonstrates that up to around 300 MPa the treatment decreased metmyoglobin but increased it at higher pressure (24). Fig. 6 shows the change in ΔE-value as the total color difference. In the current study, the total color difference was affected mainly by L*-value, and showed a similar trend with lightness.

Water holding capacity Effect of variable pressure conditions on WHC of pork is shown in Fig. 7. WHC was significantly lower ($P<0.05$) both with increasing pressurized time and pressure level compared to the non-pressurized control. Sequerira-Munoz *et al.* (25) observed that the amount of moisture loss from carp muscle was relatively independent of the pressurization duration. However, the amount of moisture loss increased with pressure at levels above 110 MPa. Wada and Ogawa (26) also reported that the WHC of sardine was 37.1% for the original non-treated sample, but decreased to 33.5% after the treatment, which agreed with our result. Jiménez-Colmenero *et al.* (27) concluded that pressure above 200 MPa negatively affected water binding properties for fresh meat. In the current study, WHC of pressurized meat was lower than that of the control, probably due to the denaturation of some protein fraction for the same reason as the change in

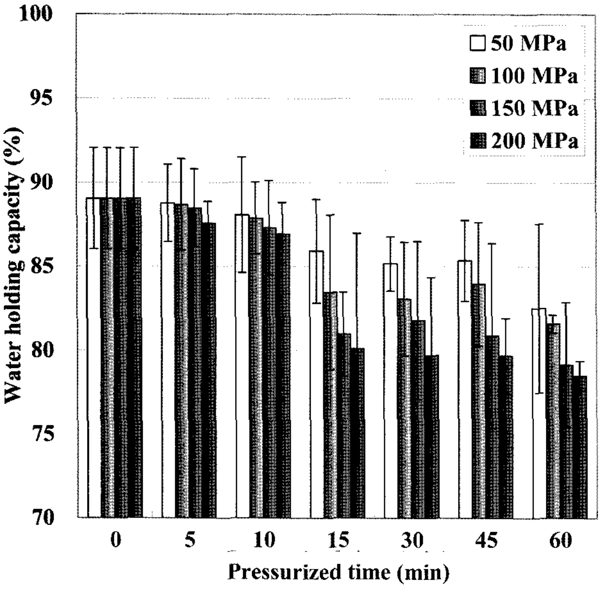

Fig. 7. Changes in WHC of pork under variable pressure conditions (n=3). Means with different letters are significantly different (P<0.05). Vertical bars represent the standard deviation.

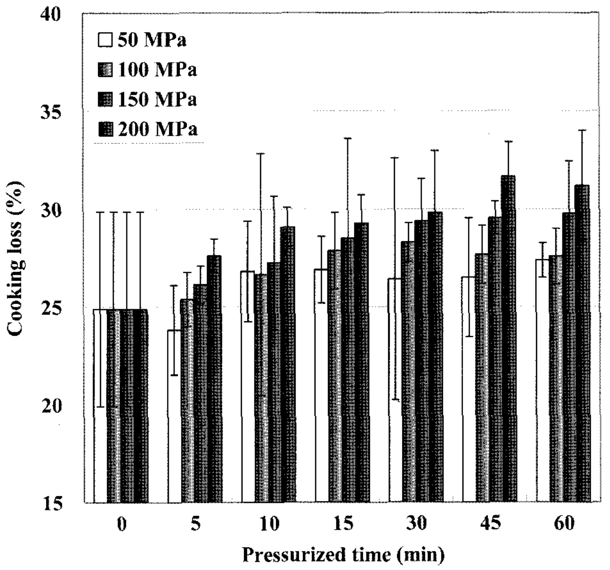

Fig. 8. Changes in cooking loss of pork under variable pressure conditions (n=3). Means with different letters are significantly different (P<0.05). Vertical bars represent the standard deviation.

pH value.

Cooking loss Fig. 8 shows the effect of variable pressure conditions on the cooking loss of pork. The cooking loss of all treatments increased gradually both with increasing pressure level and pressurized time compared to the non-pressurized control, although none of the differences among the treatments were significant (P>0.05) with the exception of that at 200 MPa treatment. A similar tendency was shown by Schubring *et al.* (28) who reported that fish fillets treated at 200 MPa had more water loss than those at non-pressurized treatment. They concluded that the water binding ability of pressurized treatment seems to be reduced compared to that of non-pressurized control. Jung *et al.* (23) reported that cooking losses were significantly higher in beef treated at 520 MPa for 260 s under 10°C than in the control due to severe shrinkage and probably myofibrillar changes. Therefore, these results indicate that the modification of structure in myofibrillar protein is correlated not only with pressure level, but also with pressurized time. In addition, no significance in the current study was attributed to any drip loss in the pressurized samples, although no data were suggested. In our preliminary investigation, a higher drip loss, of up to approximately 5%, was shown during pressurization compared to the 2% level of control, although the difference was not significant.

Shear force In general, both pressure level and pressurized time had no effect (P>0.05) on shear force, although significant differences (P<0.05) were partially observed (Table 1). A similar result was obtained by Macfarlane *et al.* (29) who reported that pressure application at low temperature did not have any beneficial effects on beef, even at long treatment, although it caused severe damage in the sarcomere ultrastructure and increased proteolysis. In consequence, their result indicates that proteolysis and ultrastructural modifications are not directly or simply linked to meat tenderness (11). In contrast with the above result, Macfarlane *et al.* (30) and Riffero and Holmes (31) observed a significant decrease in shear value when high pressure was applied with heating treatment due to changes in myofibrillar component. Locker and Wild (32) reported that pressure-heat treatment tenderized post-rigor meat effectively only after a considerable period at an elevated temperature. This pressure-heat treatment, however, is no good for meat due to the cooked color caused by the excessive pressure and heat. Macfarlane and McKenzie (33) concluded that high pressure without high temperature produced only limited improvement of texture and

Table 1. Changes in Warner-Bratzler shear force (mean±S.D.) of pork under variable pressure conditions (Unit: N)

Pressure Level	Pressurized time (min)						
	0	5	10	15	30	45	60
50 MPa	8.2±0.9^{Aa}	8.6±1.2^{Aa}	7.7±0.4^{Aa}	7.7±1.3^{Ba}	9.4±2.3^{Aa}	10.3±1.4^{Aa}	9.0±1.5^{Aa}
100 MPa	8.2±0.9^{Ab}	10.1±2.2^{Aab}	7.9±0.6^{Ab}	9.6±0.6^{ABab}	10.0±1.1^{Aab}	11.4±0.7^{Aa}	11.1±2.4^{Aa}
150 MPa	8.2±0.9^{Ab}	9.4±1.4^{Aab}	9.4±2.1^{Aab}	11.2±1.5^{Aab}	12.2±1.2^{Aa}	11.0±0.5^{Aab}	9.9±2.3^{Aab}
200 MPa	8.2±0.9^{Aa}	10.4±1.2^{Aa}	8.5±1.6^{Aa}	8.2±1.3^{Ba}	9.5±1.3^{Aa}	9.6±1.0^{Aa}	10.4±1.9^{Aa}

$^{A\text{-}B}$Means within the same column with different superscript letters are significantly different (P<0.05).
$^{a\text{-}b}$Means within the same row with different superscript letters are significantly different (P<0.05).

required up to 4 hr of long pressure application. In the current study, the absence of any difference in shear force among the treatments was probably caused by the result in cooking loss. Consequently, these results indicate that high pressure processing below 200 MPa for 1 hr had no effect on the qualities of cooked meat, although some alterations were observed before cooking.

Acknowledgments

This study was financially supported by a grant of Digital Appliance Research Laboratory (LG Electronics Inc., Korea).

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