Korean J. Food Sci. An.
Vol. 33, No. 5, pp. 581~586(2013)
DOI http://dx.do.org/10.5851/kosfa.2013.33.5.581

ARTICLE

Effects of Supercritical Carbon Dioxide Treatment on Meat Quality and Sensory Evaluation in Soy Sauce and Hot-pepper Paste Marinated Pork

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Abstract

The objective of this study was to investigate the effects of supercritical carbon dioxide (SC-CO_2) treatment on meat quality and sensory evaluation of marinated pork. Meat marinated in two traditional Korean marinades, soy sauce and hot-pepper paste, and raw marinated meat were then treated with 7.4, 12.2, or 15.2 MPa CO_2 at 31.1°C for 10 min. The SC-CO_2 treatments had no effect on the meat pH (p>0.05) or Warner-Bratzler shear force (p>0.05). There was no significant difference (p>0.05) in the total loss (sum of treatment loss and cooking loss) between the control and SC-CO_2 treated samples at 15.2 MPa (soy sauce marinated pork: 21.78 vs. 18.97%; hot-pepper marinated pork: 21.61 vs. 18.01%). After the SC-CO_2 treatment, lighter surface colors were observed in the treatment samples compared to those of the control samples (p< 0.001). However, tasting panelists were unable to distinguish a difference in color or in overall acceptability of the control and treatment (p>0.05). In the case of soy sauce marinated pork, when SC-CO_2 applied at 15.2 MPa and 31.1°C for 10 min, treatment samples showed a tenderer meat than the control samples. Therefore, the SC-CO_2 treatment conditions had no adverse effects on the sensory quality characteristics of the marinated meat products.

Key words: supercritical carbon dioxide, marinated pork, meat quality, sensory evaluation

Introduction

Marinated meat is one of the most popular meat products available worldwide. In Korea, the most common marinated meat products are soy sauce or hot-pepper paste marinated, and these products are prepared by marinating the meat in a mixture of soy sauce or hot-pepper paste together with garlic, pears, onion, ginger, sesame seeds, sesame oil, and other seasonings, and then cooking the meat prior to consumption. Recently, the demand for ready-to-cook marinated meat products, especially with adds an ethnic flavor to barbecuing (e.g., Korean BBQ marinated meat products), in many countries has significantly increased (Sloan, 2010; Wong and Kitts, 2002). However, the food safety of these marinated products is difficult to maintain due to the potential for pathogenic contamination and cross-contamination during processing, storage, and distribution, as well as from raw materials such as fresh meat and vegetables (Choi *et al*., 2009a).

Recently, the use of supercritical carbon dioxide (SC-CO_2) has been proposed as a non-thermal food preservation technology that can be used with fresh meat and meat products (Choi *et al*., 2009b; Garcia-Gonzalez *et al*., 2007). When fresh meat was treated with SC-CO_2 at 6.05 MPa, 45°C, for 150 min, *Brochothrix thermosphacta* was reduced by 5.9 Log (Erkmen, 2000). In addition, Choi *et al*. (2009a) reported that by treating the meat with with SC-CO_2 at 14 MPa, 45°C, for 40 min achieved 2.49 and 1.92 Log CFU/cm^2 reductions of *Listeria monocytogenes* in soy sauce and hot-pepper marinated pork, respectively. However, SC-CO_2 can affect molecular interactions and protein conformation, leading to protein denaturation (Messens *et al*., 1997) - changes that may influence meat quality. When fresh meat was treated with SC-CO_2, meat quality traits, including muscle pH and weight loss, were generally unaffected (Choi *et al*., 2008). While, SC-CO_2 treatment did influence the extent of sarcoplasmic protein denaturation, which is associated with a paler surface color (Choi *et al*., 2008). Thus, from the perspective of meat quality, SC-CO_2 treatment conditions should be minimized. However, the effect of SC-CO_2 treatment on

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improving the safety of meat products, including marinated pork products, under conditions that maintain meat quality have not yet been evaluated. Moreover, for practical use, meat sample sizes and the SC-CO_2 system need to be increased in scale to compare with previous studies (Choi *et al.*, 2008, 2009a, 2009b). The current study was conducted to evaluate the effects of SC-CO_2 treatment on meat quality and sensory evaluations of soy sauce and hot-pepper paste marinated pork products for application on a pilot plant scale.

Materials and Methods

Sample preparation and treatment

Twenty-five boneless pork loins, the *longissimus dorsi* muscle from the 8 to 13th thoracic vertebrae, were obtained from porcine carcass at 24 h postmortem at a local abattoir, and then transported to the laboratory under refrigerated conditions (4°C). The entire experiment was repeated five times (five pork loins per each batch). Meat quality characteristics were assessed, and a reddish pink, firm and non-exudative pork loin (lightness of 42 to 50 and drip loss of 2 to 6%; Choi *et al*., 2010) were used in this study. The meats were sliced into thirty-two rectangular-shaped pieces (2.5 cm thick, each weighing 70±5 g) that were then randomly selected for use in the following experiments to minimize bias.

Two marinades were used (Table 1), one containing soy sauce and one containing hot-pepper paste. The marinades were applied at a 1:1 ratio of pork loin weight to marinade weight, and the pork loins were marinated for 24 h at 4°C. The SC-CO_2 treatments were performed in five replicates at pressures of 7.4 (7.4-T), 12.2 (12.2-T) or 15.2 (15.2-T) MPa at 31.1°C for 10 min, using a SC-CO_2 system (Supercritical System, Tharex Co., Korea) that consisted of 2×12 liter vessels. The first is the high pressure vessel and the rest is the separator. After treatment, the samples were stored at 4°C under aseptic conditions and were immediately used for the measurements of meat quality traits and sensory evaluation.

Table 1. Formulas for soy sauce and hot-pepper paste marinades

Soy sauce marinade (%)		Hot-pepper paste marinade (%)	
Soy sauce	14.48	Hot-pepper paste	20.00
Water	43.45	Water	37.96
Garlic	3.64	Garlic	3.64
Spring onion	3.64	Spring onion	3.64
Onion	3.64	Onion	3.64
Pear	7.24	Pear	7.24
Ginger	0.72	Ginger	0.72
Sugar	7.24	Sugar	7.24
Starch syrup	7.24	Starch syrup	7.24
Refined rice wine	7.27	Refined rice wine	7.24
Pepper	0.28	Pepper	0.28
Sesame	0.44	Sesame	0.44
Sesame oil	0.72	Sesame oil	0.72
Total	100.00	Total	100.00

Meat quality traits

The color of marinated pork was measured with a Minolta chromometer (CR-300, Minolta Camera Co., Japan) and the results were expressed as Commission Internationale de l'Eclairage (CIE, 1978) lightness (L^*), redness (a^*), and yellowness (b^*) values. The average of triplicate measurements was used. The pH of the seasoned pork was measured using a spear-type electrode (IQ-150 pH meter and PH77-SS probe, IQ Scientific Instruments Inc., CA). The treatment and total weight loss values were expressed as percentages of the initial sample weight. Cooking weight loss was estimated by weighing before and after cooking (Honikel, 1998). The marinated samples were put in thin-walled polyethylene bags and placed in a water bath (80°C), until the core temperature reached 71°C. The samples were cooled in ice water for 15 min, and then weighed.

Preparation of cooked pork samples for Warner–Bratzler shear force (WBS) was similar to the procedure for cooking loss. WBS was determined by using an Instron Universal Testing Machine (Model Series IX, Instron Corp., USA) equipped with a Warner-Bratzler shearing device. Eight to ten cores (1.27 cm diameter) parallel to the longitudinal orientation of the muscle fibers were taken from each steak. The samples were sheared perpendicular to the long axis of the core.

Sensory evaluation

A total of twenty steaks (3-dimensional shape of steaks) per each batch were evaluated. A sensory panel consisting of 12 pork-consuming individuals (2040 years of age, 6 females and 6 males) was employed to evaluate the sensory attributes of the cooked pork. The majority of panelists were graduate students, professors and staff members from Korea University. The panelists were trained, and had previous experience in sensory evaluation of various food products including meat products. Before sensory evaluation, all panelists were trained at least 4 weeks (3 times per 1 week) and for up to 1 h in each training sessions. Training sessions were undertaken as recommended by the American Meat Science Association (AMSA, 1995) and in previously published procedures (Meilgaard *et al*.,

1991).

Meat samples were roasted in a dry oven (MCS312CF4, Electrolux, Sweden) at 180°C. The meat was turned every 3 min and cooked to an internal temperature of 71°C, which was measured using a thermometer with a hand-held probe (TES-1300, TES Electrical Electronic Co., Taiwan). Prior to being presented to the sensory panels, the marinated samples were warmed and maintained in a water bath (54°C). The samples were then cut into 1 cm^3 pieces without surface, placed on white plastic trays, and immediately served to each panelist.

The samples were individually labeled with three-digit random numbers and were served one at a time in a random order. To rate the samples, the panelists used a nine-point scale with word anchors at each end. The cooked samples were evaluated for color acceptability (1 = very unacceptable; 9 = very acceptable), tenderness (1 = very tough; 9 = very tender), juiciness (1 = very dry; 9 = very juicy), flavor intensity (1 = very weak; 9 = very strong), and overall acceptability (1 = very unacceptable; 9 = very acceptable). A total of fifteen sessions were conducted with four samples per session. Each session lasted 30 min, with a 5 min interval between the evaluations of each sample. Panelists were served distilled water (30°C) and salt-free crackers before the first sample and between each sample to cleanse the mouth.

Statistical analysis

The data were analyzed by ANOVA using the SAS statistical program (SAS Institute, 2008), and differences among the means were compared using Duncan's multiple range test. The entire experiment was replicated five

Table 2. Effects of supercritical carbon dioxide (SC-CO_2) treatment at 31.1°C for 10 min on meat quality traits of soy sauce marinated pork products

	Control	SC-CO_2 Pressure			Level of significance
		7.4 MPa	12.2 MPa	15.2 MPa	
Quality measurements					
Lightness (*L**)	38.57±1.98^{c}	54.52±1.59^{b}	56.81±1.52^{ab}	58.21±2.23^{a}	***
Redness (*a**)	8.63±0.29^{a}	6.52±0.98^{b}	6.64±0.33^{b}	6.68±0.70^{b}	**
Yellowness (*b**)	17.69±0.42^{b}	17.70±0.56^{b}	19.92±0.86^{a}	19.83±0.61^{a}	***
Meat pH	5.56±0.10	5.71±0.16	5.64±0.11	5.60±0.14	NS
WBS (N)	37.57±6.43^{a}	38.84±4.47^{a}	29.16±3.78^{ab}	24.47±3.54^{b}	*
Weight loss (%)					
Treatment loss	-	1.06±0.45	1.16±0.27	1.80±0.25	NS
Cooking loss	21.78±3.09	16.23±2.21	17.47±4.88	17.67±3.84	NS
Total loss	21.78±3.09	17.29±2.65	18.63±4.46	18.97±3.24	NS

Results are expressed as the mean±SD.
Levels of significance: NS = not significant; *p<0.05, **p<0.01, ***p<0.001.
$^{a-c}$Means within a row with different superscripts differ significantly (p<0.05).
WBS, Warner-Bratzler shear force.

Table 3. Effects of supercritical carbon dioxide (SC-CO_2) treatment at 31.1°C for 10 min on meat quality traits of hot-pepper marinated pork products

	Control	SC-CO_2 Pressure			Level of significance
		7.4 MPa	12.2 MPa	15.2 MPa	
Quality measurements					
Lightness (*L**)	39.73±2.07^{c}	53.29±1.35^{b}	57.51±3.68^{a}	58.47±3.55^{a}	***
Redness (*a**)	11.15±0.85^{a}	7.51±0.58^{b}	8.05±0.57^{b}	6.92±1.69^{b}	***
Yellowness (*b**)	16.99±0.94	17.67±1.56	19.96±1.91	19.64±3.01	NS
Meat pH	5.51±0.03	5.55±0.11	5.48±0.17	5.53±0.14	NS
WBS (N)	33.00±3.40^{a}	24.57±4.44^{b}	22.76±1.27^{b}	24.03±2.69^{b}	*
Weight loss (%)					
Treatment loss	-	1.35±1.01	1.10±0.92	2.19±0.47	NS
Cooking loss	21.61±1.47	17.43±2.07	16.77±3.14	15.24±1.26	NS
Total loss	21.61±1.87	18.78±1.91	17.87±2.09	18.01±2.03	NS

WBS, Warner-Bratzler shear force.
Results are expressed as the mean±SD.
Levels of significance: NS = not significant; *p<0.05, ***p<0.001.
$^{a-c}$Means within a row with different superscripts differ significantly (p<0.05).

times and all determinations were performed in triplicate.

Results and Discussion

Meat quality traits

Tables 2 and 3 present the effects of SC-CO_2 treatment on the meat quality traits of soy sauce and hot-pepper paste marinated pork products. When marinated pork products were treated with SC-CO_2, all treatment groups exhibited higher lightness values (p<0.001) and lower redness values (p<0.01) compared to the control. In soy sauce marinated pork, the surface of the 15.2-T samples was significantly paler than that of the control or 7.4-T samples (58.21 vs. 54.52, p<0.001). In the case of yellowness, no significant differences were observed between the control and 7.4-T samples (p>0.05). Similarly, all SC-CO_2 treated hot-pepper paste marinated pork samples appeared significantly lighter than the controls (p<0.001). It has been reported that pressure and temperature combinations in high pressure treatments can influence the extent of protein denaturation (Jimenez Colmenero, 2002). When SC-CO_2 was applied to fresh pork, an increase in denatured proteins was detected by Choi *et al*. (2008), especially the sarcoplasmic proteins including fructose-6-phosphate kinase, creatine kinase, and triosephosphate isomerase, as well as one unknown protein. These denatured sarcoplasmic proteins can influence the color of fresh pork in terms of lightness and redness, and the SC-CO_2 treatment groups showed the paler surface than the control group (Choi *et al*., 2008).

Among several reports on meat storage or treatment under various CO_2 conditions, Jakonsen and Bertelsen (2002) reported no change in meat pH following CO_2 treatment, while others showed that the pH decreased with CO_2 treatment. In this study, both soy sauce and hot-pepper marinated products did not have significantly different pH values after the SC-CO_2 treatment from those of the controls (p>0.05). For soy sauce marinated pork, weight losses following SC-CO_2 treatment and cooking were similar in the control samples and in any of the SC-CO_2 treated samples (p>0.05), and no difference was observed in the weight loss following SC-CO_2 treatment at 7.4 MPa and 15.2 MPa for 10 min (17.29 vs. 18.97%, p>0.05). Similar results were observed for hot-pepper paste marinated pork. The technological aspects and sensory quality traits of a meat depend on the pH decline: a rapid decline and low pH causes the denaturation of muscle proteins, especially the extent of myofibrillar protein denaturation affects water-holding capacity (Offer, 1991; Choi and Kim, 2009). For this reason, fresh meat with lower muscle pH is associated with higher drip and cooking losses (Kang *et al*., 2011). However, the extents of myofibrillar protein denaturation as well as muscle pH of fresh pork were not affected by the SC-CO_2 treatment (Choi *et al*., 2008). In this study, the SC-CO_2 treatment had no effect on the pH of soy sauce or hot-pepper marinated pork as well as cooking loss.

Previous studies have reported effects of pressurization on tenderness attributes. The majority of studies showed that the high pressurization is associated with the tenderizing of meat due to structural changes of the myofibrils (Cheftel and Culioli, 1997; MacFarlane, 1973; Schumann *et al*., 1982; Suzuki *et al*., 1992). For example, when bovine semitendinosus muscle pressurized to 300 MPa at 10°C, a decrease in hardness was reported by Suzuki *et al*. (1992). In other studies examining beef tenderness, however, the application of high pressure at low temperatures (< 30°C) did not have any beneficial effects on cold-shortened *biceps femoris* muscle (Bouton *et al*., 1977) or on normal or cold-shortened *semimembranosus* and *longissimus* muscles (MacFarlane *et al*., 1981). The SC-CO_2 treatment improved meat tenderness when the samples were treated at a relatively low pressure and temperature (15 MPa and 31.1°C) with the comparison in the high pressurization treatment (300 MPa). A significantly higher WBS value (less tender) was observed in control samples compared to the 15.2-T soy sauce marinated pork (37.57 vs. 24.47 N, p<.05). For the hot-pepper paste marinated pork, all treated samples were significantly tender than those in the control group (p<0.05).

Sensory evaluations

Table 4 and 5 present the effects of SC-CO_2 treatment on the sensory traits of soy sauce and hot-pepper paste marinated pork products. Several studies have reported that the application of pressure causes a gradual change in the surface color of meats, including pork, beef, and tuna (Cheftel and Culioli, 1997; Choi *et al*., 2008; Hong *et al*., 2005). The discoloration observed with regard to high pressure processing is related to globin denaturation and the oxidation of ferrous myoglobin to ferric metmyoglobin (Cheftel and Culioli, 1997). Nevertheless, the total color difference due to pressure processing is greatly reduced after cooking. The panelists could not distinguish any surface color differences between the control and SC-CO_2 treated samples after cooking (p<0.05).

Of all the attributes of palatability of meat and meat products, tenderness is one of the most important traits of

Table 4. Effects of supercritical carbon dioxide (SC-CO_2) treatment at 31.1°C for 10 min on sensory evaluation of soy sauce marinated pork products

	Control	SC-CO_2 Pressure			Level of significance
		7.4 MPa	12.2 MPa	15.2 MPa	
Color acceptability[1]	3.96±0.72	5.04±0.97	4.77±0.99	5.04±0.51	NS
Tenderness[2]	4.38±0.61[b]	5.04±1.80[ab]	5.56 ±1.24[ab]	6.18±1.03[a]	*
Juiciness[3]	3.69±1.19	4.41±0.74	4.32±2.42	3.60±1.47	NS
Flavor intensity[4]	5.13±1.77	4.59±0.80	4.86±1.70	3.78±1.51	NS
Overall acceptability[1]	3.69±1.33	5.40±0.29	4.68±1.71	4.23±0.85	NS

Results are expressed as the mean±SD.
Levels of significance: NS = not significant; *p<0.05.
[a-b]Means within a row with different superscripts differ significantly (p<0.05).
[1]Scale: 1 = very unacceptable; 9 = very acceptable.
[2]Scale: 1 = very tough; 9 = very tender.
[3]Scale: 1 = very dry; 9 = very juicy.
[4]Scale: 1 = very weak; 9 = very strong.

Table 5. Effects of supercritical carbon dioxide (SC-CO_2) treatment at 31.1°C for 10 min on sensory evaluation of hot-pepper marinated pork products

	Control	SC-CO_2 Pressure			Level of significance
		7.4 MPa	12.2 MPa	15.2 MPa	
Color acceptability[1]	3.96±1.53	3.87±1.54	2.70±1.19	4.32±0.83	NS
Tenderness[2]	4.80±0.62	5.00±1.51	5.16±0.99	6.38±1.60	NS
Juiciness[3]	4.23±0.85	4.32±1.79	2.61±0.80	3.96±1.88	NS
Flavor intensity[4]	4.77±0.99	4.23±0.85	4.32±1.02	3.78±0.36	NS
Overall acceptability[1]	4.59±0.80	4.14±1.62	2.79±0.74	4.59±0.80	NS

Results are expressed as the mean±SD.
Level of significance: NS = not significant.
[1]Scale: 1 = very unacceptable; 9 = very acceptable.
[2]Scale: 1 = very tough; 9 = very tender.
[3]Scale: 1 = very dry; 9 = very juicy.
[4]Scale: 1 = very weak; 9 = very strong.

meat and meat products (Maltin *et al*., 1998). Generally, the WBS or hardness of texture-profile analysis is positively correlated with the subjective tenderness scores of sensory panelists (Nam *et al*., 2009). In the case of the soy sauce marinated pork, when SC-CO_2 applied at 15.2 MPa and 31.1°C for 10 min, the tenderness score was higher than the control samples (6.18 vs. 4.38, p<0.05). However, tenderness scores did not differ between control and SC-CO_2 treated hot-pepper paste marinated pork (p<0.05), even though the WBS values of SC-CO_2 treated samples were significantly lower than those of the control. In case of other eating quality attributes including juiciness and flavor intensity, there were no significant differences between the control and the treatments.

Conclusion

In this study, SC-CO_2 treatment did not have adverse effects on the meat quality traits of soy sauce or hot-pepper paste marinated pork products, with the exception of lightening the color of the meat. However, panelists did not distinguish color changes or differences in the overall acceptability of the soy sauce or hot-pepper paste marinated products after SC-CO_2 treatment and cooking. In the case of soy sauce marinated pork, when SC-CO_2 applied at 15.2 MPa and 31.1°C for 10 min, treatment samples showed a tenderer meat than the control samples. Overall, these results suggested that SC-CO_2 treatment is useful in the meat industry to increase the microbial safety of marinated meat products without defects of meat quality.

Acknowledgements

This research was funded by the Korea Institute of Planning and Evaluation for Technology of Food, Agriculture, Forestry, and Fisheries. The authors thank the Korea University Food Safety Center for use of their equipment and facilities.

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(Received 2013.6.5/Revised 2013.8.29/Accepted 2013.9.4)