INTRODUCTION

Marination has been commonly used to improve meat tenderness and flavor (Babji et al., 1982; Xiong and Kupski, 1999), and there are various methods of marination, such as soaking, injection, or vacuum tumbling (Smith and Young, 2007). In the US broiler market in 1962, 2% of broilers sold had been further processed, and this figure has increased to 42% as of 2009 (National Chicken Council, 2012). Among the several processing methods, vacuum tumbling is a useful method to improve meat tenderness as well as the water-holding capacity (WHC; Smith and Young, 2007). The main effects of tumbling accelerate the distribution and absorption of marinade, which contributes to the improvement of protein extraction of poultry meat (Babji et al., 1982). In addition, tumbling in presence of salt has various advantages, including increasing the extraction of myofibrillar proteins associated with binding properties, and increasing the water retention of the poultry meat (Xiong and Kupski, 1999). Thus, tumbling can enhance cooking yields, as well as textural and sensory properties (Froning and Sackett, 1985; Maki and Froning, 1987).

Traditionally, marinades contain water, salt, and acidic components, such as vinegar, wine, or fruit juice. For poultry meat, sodium chloride and phosphates have been generally used to improve quality characteristics (Froning and Sackett, 1985; Young and Lyon, 1997). Meanwhile, acidic marination has been applied to improve tenderness of tough beef (Aktaş et al., 2003). According to Burke and Monahan (2003), marination under acidic conditions reduces the pH value within the meat, resulting in an improvement of meat tenderness due to swelling of the muscle proteins and collagen solubility. Similarly, previous studies reported that acidic marinades including acetic acid, lactic acid, red wine, and sodium lactate improved tenderness of poultry meat (Kijowski and Mast, 1993; Chou et al., 1997; Lin et al., 2000; Smaoui et al., 2012). Although acidic marination is known to have a tenderization effect, there is little information available in literature related to the meat quality of poultry meat tumbled with acidic marinade. For acidic marination with tumbling, the effects of marination have been mainly focused on the microbial properties of the meat, and it had been determined that marination with vacuum tumbling inhibits the contamination of meat by Salmonella spp. in fresh sausages prepared with deboned chicken meat vacuum tumbled with 1% lactic acid for 1 min (Deumier, 2006).

ABSTRACT The objective of this study was to evaluate the effects of soy sauce on the physicochemical and textural properties of tumbled chicken breasts. Chicken breasts marinated with distilled water (Con), 4% NaCl solution, 4% NaCl and lactic acid solution (pH 4.9), and soy sauce solution (4% salt concentration and pH 4.9) were vacuum tumbled at 3°C for 60 min. The chicken breast marinated with soy sauce solution showed lower lightness and higher redness and yellowness due to the color of the soy sauce. The acidic marinades led to a decrease in pH value of tumbled chicken breast. The acidic marinades increased collagen solubility of sample compared with 4% NaCl solution, resulting in decreased shear force. Water-holding capacity, marination and cooking yields, and solubility of myofibrillar proteins were mainly affected by the presence of salt in the marinade, rather than by pH alternation. Our results suggested that soy sauce marination can improve the tenderness of tumbled chicken breast.

Key words: chicken breast, marination, soy sauce
Soy sauce is well known throughout the world has a low pH value due to formation of organic acids derived from the main ingredients (soybean or soybean and wheat) during microbial fermentation (Choi et al., 2000). Also, soy sauce is applied to traditional meat-based cuisines in China, Japan, Korea, and Thailand (Nam et al., 2010). Recently, interest in soy sauce has been increasing steadily in the United States and Europe, as well as Asia (Aoshima and Ooshima, 2009). However, there is very little information available on the combined effects of tumbling and soy sauce.

Therefore, the objectives of this study were (1) to evaluate the physicochemical and textural properties of chicken breast tumbled with soy sauce and (2) to identify the effect of salt, low pH, or both of soy sauce, by comparing soy sauce and sodium chloride marinades under the same pH and salt concentration.

**MATERIALS AND METHODS**

**Sample Preparation**

A total of 96 boneless (deboning after 24 h postmortem), skinless chicken broiler breast fillets (pectoralis major only), 40 d of age, were obtained from commercial processing plants. Chickens were killed by conventional neck cut, bled for 3 min, scaled at 60°C for 2.5 min, plucked in a rotary drum picker, and eviscerated. The pH values of each chicken breast fillet were determined by using portable pH meter equipped with inserting probe (Testo 206-pH2, Testo, Lenzkirch, Germany), and were selected by determining pH value, within a range from 5.95 to 6.05. Thirty-two fillets (16 right fillets and 16 left fillets) were transported to the Konkuk University Meat Science Laboratory (3 replicates of total 96 fillets). First, each chicken breast fillet was weighed (143.14 ± 4.35 g average weight, n = 96), and 32 fillets were randomly selected for 4 treatments (4 left breast and 4 right breast per each treatment).

**Marinade Preparation**

Commercial soy sauce (fermented and heat sterilized soy sauce, Sempio Foods Co., Seoul, South Korea) was purchased from the commercial market. The pH value and NaCl concentration of soy sauce were measured with a pH meter (pH 4.8) and salimeter (16%). A total of 4 marinades were prepared by dissolving the sodium chloride (extra pure grade, Junsei Chemicals Co. Ltd., Tokyo, Japan) and diluting the soy sauce. The characteristics of each marinade were as follows: Con, distilled water; NaCl-I, 4% sodium chloride solution (pH 6.57); NaCl-II, 4% sodium chloride solution (pH 4.9 adjusted with lactic acid); and SS, soy sauce solution (pH 4.9 and NaCl concentration of 4%). The NaCl concentrations of each marinade were confirmed by using a salimeter (TM-30D, Takemura Electric Works Ltd., Tokyo, Japan). All marinades were stored in a 4°C refrigerator for 24 h until marination.

**Marination**

Each fillet was marked with a labeled safety pin to distinguish each individual fillet. Each treatment was vacuum tumbled with each marinade of 20% based on total fillet weight using the tumbler (MKR-150C, Rühle GmbH, Grafenhausen, Germany). The tumbling was carried out the same conditions of 3°C, 60 min, 8 rpm, and 610 mmHg (approximately 80 kPa pressure; Kim et al., 2012). After tumbling, the excessive water on the surface of tumbled sample was removed with paper towels. The each fillet was immediately weighed to determine tumbling yield. The tumbled samples were individually placed in polyethylene bags, and stored at 4°C overnight. Each sample was then weighed again, tempered at 20°C for 30 min to equilibrate temperatures of the samples, and cooked (Young and Lyon, 1997).

**Measurement of Physicochemical and Textural Properties**

Eight fillets of each treatment were used for study of tumbling yield. The left breast was used to evaluate raw and cooked color (n = 4), cooking yields (n = 4), and Warner-Bratzler shear force (2 measurements per each fillet, n = 8). For right breast, the whole muscle was individually chopped with a knife and used to evaluate pH (n = 4), WHC (n = 4), protein solubility (total, myofibrillar, sarcoplasmic proteins, and collagen, n = 4), and SDS-PAGE. This study was carried out in 3 replicates.

The color of raw and cooked samples (left breast of each treatment) was determined with a colorimeter (Minolta Chroma meter CR-210, Osaka, Japan; illuminant C, calibrated with a white plate, CIE L* = +97.83, a* = −0.43, b* = +1.98), equipped with a 50-mm aperture. The setting for the illuminant was C illuminant source and the standard observer was 2°. The CIE L* (lightness), a* (redness), and b* (yellowness) values were recorded. One measurement for the bone side on the surface of each tumbled chicken breast was taken.

The pH values of 5-g samples mixed with 50 mL of distilled water for 60 s in a homogenizer at 8,000 rpm were determined with a pH meter (model 340, Mettler-Toledo GmbH, Schwerzenbach, Switzerland).

Water-holding capacity was determined in triplicate using the filter paper pressed method (Grau and Hamm, 1953). About 0.3 g (±0.02 g) sample was weighed on a Whatman no. 2 filter paper and pressed between 2 plexiglass plates for 3 min. The areas of pressed water and sample were measured using a planimeter (Koi-zumi, Type KP-21, Tokyo, Japan). The WHC was cal-
culated as follows: WHC (%) = 100 × (area of pressed sample/area of pressed water).

Tumbling yield (%) was determined by weighing the meat before and after tumbling. Marinated samples from each treatment were vacuum packed and cooked in a 75°C water bath until internal temperature reached 71.1°C (USDA-FSIS, 1973). The central temperature of samples was monitored with a digital thermometer (Tes-1305, Tes Electrical Corp., Taiwan) equipped with a data logger (RS-232, Tes Electrical Corp.) by inserting an iron constantan thermocouple into the center of the sample. After cooking, the cooked samples were chilled by immersing the bags in an ice water bath for 30 min. The samples were cooled to room temperature for 2 h, and each sample was then removed from the bags and weighed. Cooking yield (%) was determined by weighing the meat before and after cooking.

Protein solubility was determined using the method of Joo et al. (1999) with the following modifications. Sarcoplasmic protein solubility was determined by dissolving 2 g of raw sample in 20 mL of ice-cold 25 mM potassium phosphate buffer (pH 7.2). The samples and buffer were homogenized on ice (model AM-7, Nihonseiki Kaisha Ltd., Tokyo, Japan) and were left to stand on a shaker at 4°C overnight. The mixtures were centrifuged at 1,500 × g for 20 min (4°C) and the protein concentrations of the supernatants determined using the Biuret method (Gornall et al., 1949). Total protein solubility was determined by homogenizing 2 g of raw sample in 20 mL of ice-cold 1.1 mol/L potassium iodide in 100 mol/L phosphate buffer (pH 7.2). The procedures for homogenization, shaking, centrifugation, and protein determinations were as described above. Myofibrillar protein solubility was obtained by determining the difference between total and sarcoplasmic protein solubility.

Total and soluble collagen contents were determined as described in Wattanachant et al. (2004), the hydroxyproline content was determined by the Bergman and Luxley (1963) method. Collagen solubility was calculated as follows: collagen solubility (%) = 100 × (soluble collagen/total collagen; Murphy and Marks, 2000).

Before measurement of Warner-Bratzler shear force (WBSF), cooked samples were kept in a 4°C refrigerator overnight and tempered at 20°C for 30 min. Each sample was cut into a rectangular parallelepiped shape (1 cm wide, 1 cm thick, and 4 cm long) at room temperature (20°C). The WBSF was performed at room temperature with a Warner-Bratzler shear attachment (V-type blade set) on a texture analyzer (TA-XT2i, Stable Micro Systems Ltd., Surrey, UK).

The SDS-PAGE of the raw sample was performed by the method of Laemmli (1970), using 12% running gels. The loaded gel was stained with Coomassie Brilliant Blue R250 (B7920, Sigma, St. Louis, MO), and was destained in methanol: distilled water: lactic acid (50:40:10). The separated protein bands were identified by comparison with those of standard protein marker (Precision Plus Protein Standards, Bio-Rad Laboratories Inc., Hercules, CA), which included 250, 150, 100, 75, 50, 37, 25, 20, 15, and 10 kDa bands.

**Statistical Analysis**

The design of the study was a randomized block with 3 replicates. An ANOVA was performed on all the variables measured using the GLM procedure with the SAS statistical package (2008, SAS Institute Inc., Cary, NC). Marinades were tested as main effects. Duncan’s multiple range test ($P < 0.05$) was used to determine the differences between treatment means.

**RESULTS AND DISCUSSION**

The color parameters of raw and cooked chicken breast were significantly affected by marinades (Table 1). The CIE L* (lightness) values of chicken breast tumbled with sodium chloride solutions and soy sauce solutions were lower than those of the control, and the soy sauce treatment had the lowest lightness in both the raw and cooked chicken breast ($P < 0.05$). According to Lopez et al. (2012), the increase of sodium chloride content in marinade caused the linearly decreased lightness of vacuum-tumbled marinated broiler breast fillets ($P < 0.05$). They explained that the result may be associated with the improvement of water binding ability due to the increase of ionic strength. Also, in Allen et al. (1998), lightness of tumbled broiler breasts correlated negatively ($P < 0.01$, $r = −0.753$) with WHC. In our results, the decreased lightness of NaCl-I and NaCl-II treatment compared with control could be associated with a change in WHC due to addition of salt. There were no differences in CIE a* (redness) and CIE b* (yellowness) among any of the treatments other than the SS treatment. The raw and cooked soy sauce treatments had significantly higher redness and yellowness values than NaCl-II treatment ($P < 0.05$). Soy sauce is dark brown, and a reduction in lightness and increases in redness and yellowness result from staining of the tumbled chicken breast. A similar result was reported by Kim et al. (2011) for prerigor ground beef muscle. According to Choi et al. (1990), melanoidin from Mailard reaction is the main component that affects the dark color of soy sauce.

The effects of soy sauce on the physicochemical properties of tumbled chicken breast are shown in Table 2. As expected, the low pH of marinades decreased in pH value of chicken breasts. The chicken breasts tumbled with low pH marinades (NaCl-II and SS treatments) had a lower pH value than control and NaCl-I treatment, and significant differences in the final pH value of meat treated with NaCl-II and SS were observed ($P < 0.05$), despite the identical pH value of the marinades. Soy sauce contains various organic acids, such as acetic acid, butylic acid, lactic acid, and pyroglutamic acid (Choi et al., 2000), and it is hypothesized that the
differing effects of SS and NaCl-II marinades are due to differences in their overall diffusion capacity.

Water-holding capacity is an important factor affecting textural and sensory attributes. The WHC of meat is greatly associated with pH, and meat shows the poorest WHC around the isoelectric point. The isoelectric point of myosin, one of the main myofibrillar proteins, is about 5.3 (Offer and Knight, 1988). Meat treated with NaCl-II and SS resulted in a higher WHC than the control despite their pH value being around the isoelectric point, due to the salt contained in these marinades ($P < 0.05$). However, there was no difference in the WHC between acidic marinade treatments and NaCl-I. This result shows that the presence of salt in marinades might be more influential to WHC than pH alteration. According to Aktaş et al. (2003), lactic acid marinade improves water binding properties of muscle protein due to shifting pH value away from the isoelectric region. In our study, although the acid marinade caused a small decrease in pH value of tumbled chicken breast, the presence of salt might have mitigated the effect, which was similar to soy sauce-tumbled chicken breast. Cooking yields of chicken breast tumbled with soy sauce were higher than the control, and the yields did not differ in comparison with sodium chloride treatments (NaCl-I and II treatments). Varying results have been reported for the effect of acidic marination on cooking yields of meat. Yusop et al. (2010) reported that the cooking loss of chicken breast fillet was affected by marinade pH. Also, no difference in marination yield and cooking loss of chicken thigh marinated with a combination of sodium lactate and lactic acid was observed by Smaoui et al. (2012), even though the pH value of the chicken thigh was decreased due to treatment with combination marinades. According to Aktaş et al. (2003), the low pH below the isoelectric point in meat marinated with organic acid contributed to an increased WHC, and the effect of acidic marination on WHC could be explained as the protonation of carboxyl groups in muscle protein or as the difference in osmotic pressure. These intramuscular changes may require sufficient time to diffuse the marinade into the muscle. The tumbling technique is thought to speed up the time required for diffusion of the marinade into the meat, compared with immersing or soaking. Our results suggests that tumbling with low pH marinade containing NaCl does not affect water retention factors, including WHC, marination uptake, and cooking yields, although this result may be different if the meat was treated for a longer period of time.

The effects of soy sauce on protein solubility (total, myofibrillar, and sarcoplasmic proteins) of tumbled chicken breast are shown in Figure 1. The solubility of muscle proteins is greatly associated with the tenderizing effect of marination. Especially, increased solubility of myofibrillar proteins and collagen, which is a major protein of meat, contributes to the tenderness of meat (Aktaş et al., 2003). The NaCl-I, NaCl-II, and SS treatments had higher solubility of total, sarcoplasmic, and myofibrillar proteins than the control. However, there

Table 1. Effects of soy sauce on color parameters of tumbled chicken breast

<table>
<thead>
<tr>
<th>Type</th>
<th>Color parameter</th>
<th>Con</th>
<th>NaCl-I</th>
<th>NaCl-II</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CIE L*</td>
<td>64.55 ± 1.26A</td>
<td>60.48 ± 1.12B</td>
<td>60.44 ± 1.32B</td>
<td>48.61 ± 1.34C</td>
</tr>
<tr>
<td></td>
<td>CIE a*</td>
<td>8.18 ± 0.72B</td>
<td>8.08 ± 0.95B</td>
<td>8.08 ± 1.01B</td>
<td>8.97 ± 0.63A</td>
</tr>
<tr>
<td></td>
<td>CIE b*</td>
<td>7.37 ± 1.10B</td>
<td>7.23 ± 1.16B</td>
<td>7.84 ± 1.46B</td>
<td>14.87 ± 1.05B</td>
</tr>
<tr>
<td>Cooked</td>
<td>CIE L*</td>
<td>79.30 ± 0.67A</td>
<td>78.56 ± 1.37AB</td>
<td>78.04 ± 1.07B</td>
<td>68.80 ± 1.42C</td>
</tr>
<tr>
<td></td>
<td>CIE a*</td>
<td>3.13 ± 0.33B</td>
<td>3.00 ± 0.66B</td>
<td>3.08 ± 0.35B</td>
<td>3.63 ± 0.30A</td>
</tr>
<tr>
<td></td>
<td>CIE b*</td>
<td>9.09 ± 0.65B</td>
<td>9.08 ± 0.47B</td>
<td>9.04 ± 0.41B</td>
<td>15.16 ± 0.78A</td>
</tr>
</tbody>
</table>

A–C Different superscripts in the same row indicate values are significantly different ($P < 0.05$).

1All values are the means ± SD of 3 replicates.

2Treatments: the chicken breast tumbled with each marinade. Con, distilled water; NaCl-I, 4% sodium chloride solution; NaCl-II; 4% sodium chloride solution and the pH 4.9 adjusted with lactic acid; SS, soy sauce solution (4% salt concentration and pH 4.9).

3WHC: water-holding capacity was determined by using filter pressed method.

Table 2. Effect of soy sauce on physicochemical properties of tumbled chicken breast

<table>
<thead>
<tr>
<th>Trait</th>
<th>Con</th>
<th>NaCl-I</th>
<th>NaCl-II</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH value after tumbling ($n = 12$)</td>
<td>6.02 ± 0.04A</td>
<td>6.01 ± 0.06A</td>
<td>5.83 ± 0.03B</td>
<td>5.76 ± 0.02C</td>
</tr>
<tr>
<td>WHC (%) ($n = 12$)</td>
<td>40.76 ± 5.05B</td>
<td>48.62 ± 6.23A</td>
<td>48.99 ± 5.09A</td>
<td>48.95 ± 5.42A</td>
</tr>
<tr>
<td>Marination yield (%) ($n = 24$)</td>
<td>107.08 ± 5.79B</td>
<td>113.47 ± 2.84A</td>
<td>114.18 ± 1.98A</td>
<td>114.57 ± 2.50A</td>
</tr>
<tr>
<td>Cooking yield (%) ($n = 12$)</td>
<td>73.83 ± 5.02B</td>
<td>79.73 ± 2.51A</td>
<td>81.86 ± 4.50A</td>
<td>81.99 ± 5.58A</td>
</tr>
</tbody>
</table>

A–C Different superscripts in the same row indicate values are significantly different ($P < 0.05$).

1All values are the means ± SD of 3 replicates.

2Treatments: the chicken breast tumbled with each marinade. Con, distilled water; NaCl-I, 4% sodium chloride solution; NaCl-II; 4% sodium chloride solution and the pH 4.9 adjusted with lactic acid; SS, soy sauce solution (4% salt concentration and pH 4.9).
were no significant differences in the solubility of total, sarcoplasmic, and myofibrillar proteins among NaCl-I, NaCl-II, and SS treatments (P > 0.05). Van Laack and Lane (2000) indicated that the protein solubility of 2 chicken muscles (pectoralis profundus and pubo-ischio femorale) decreased at a lower pH value of 5.4 compared with pH 6.5 due to protein denaturation. Generally, the presence of salt greatly influences salt-soluble proteins, including myosin and actin, and affects the repelling effect between myosin and actin. Thus, the addition of salt improves myofibrillar protein solubility (Feiner, 2006). Our results of protein solubility might be mainly affected by the presence of salt in a marinade.

Weakening of intramuscular connective tissue, including collagen and elastin, is greatly associated with tenderness of chicken (Liu et al., 1994). In previous studies, the solubility of collagen in chicken breast was affected by cooking temperature (Murphy and Marks, 2000) and heating time (Kong et al., 2008). According to Kijowski and Mast (1993), lactic and acetic acid marination reduced shear force of spent hen drumsticks due to swelling of collagen. The effects of soy sauce on collagen solubility of tumbled chicken breast are shown in Figure 2. The chicken breast marinated only sodium chloride solution (NaCl-I treatment) showed lower collagen solubility than the NaCl-II and SS treatments (P < 0.05), although there was no significant difference between the control and NaCl-I treatment. Kijowski (1993) reported that acidic marination contributes to a decrease in the denaturation temperature of collagen from spent hen drumsticks. Chang et al. (2010) indicated that a decreased denaturation temperature of heat-insoluble collagen results in an increased decomposition of connective tissue. Moreover, the combined marination of 2% sodium chloride and 1.5% lactic acid have been shown to result in a rapid decline in heat-insoluble collagen content. Our results suggested that the presence of salt under low pH condition (NaCl-II and SS treatments) might help to increase the solubility of collagen.

As expected, the WBSF of tumbled chicken breast was affected by marinades (Figure 3). The NaCl-II and SS treatments had a significantly lower WBSF than that of the control and NaCl-I (P < 0.05). The NaCl-I treatment had a lower collagen solubility than the control, although WBSF of chicken breast tumbled with NaCl-I decreased compared with the control. This result can be explained by the addition of salt. According to Saha et al. (2009), the tenderness of marinated broiler fillets was improved, depending on salt concentration in marinade. Also, Allen et al. (1998) noted that shear force (Allo-Kramer) of chicken breast fillets had a positively correlation (P < 0.01, r = 0.174) with cooking loss. Thus, the decreased WBSF of NaCl-I treatment compared with the control is due to improvement of cook-
ing loss with the addition of salt. Soy sauce marination reduced the WBSF by 22.7 and 13.2% compared with control and NaCl-I, respectively. Our result suggested that the presence of salt in acidic marinade could be an effective method to improve tenderness. However, there was no difference in the WBSF between NaCl-II and SS treatments. Many previous studies of acidic marination reported positive effects of citrus juice (Burke and Monahan, 2003), weak organic acids (Kijowski and Mast, 1993; Chou et al., 1997; Aktaş et al., 2003; Chang et al., 2010), and wine (Lin et al., 2000) on meat tenderness. In these studies, the evidences for effects of acidic marination could be explained by increases in collagen solubility due to swelling of meat protein. Also, Kong et al. (2008) indicated that the collagen solubility of chicken breast was negatively correlated with shear force ($P < 0.01$, $r = -0.99$).

The SDS-PAGE was determined to identify the effect of soy sauce on proteolysis of tumbled chicken breast (Figure 4). However, no apparent difference in the pattern of protein bands was obtained among all treatments. Chou et al. (1997) observed the postmortem proteolysis of duck breast muscle for 14 d, and reported that 0.1 and 0.2 $M$ lactic acid marination compared with nonmarinated sample accelerates degradation of myofibrils after 14 d. Thus, longer periods of time may be required to identify the effects of acidic marination on proteolysis of muscle.

In conclusion, soy sauce marination led to a decrease in the pH value of tumbled chicken breast. The presence of soy sauce contributed to a decrease in the lightness, as well as an increase in both the redness and yellowness of the chicken breast, due to staining. The decrease in pH did not influence the WHC, marination, or cooking yield compared with marination at an identical salt concentration. The acidic marination may result in the increased solubility of collagen. Our results suggested that the soy sauce marination can improve the tenderness of tumbled chicken breast and the effects may be associated with the presence of salt under acidic conditions within soy sauce.

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