ABSTRACT The effects of hydrodynamic pressure processing (HDP) on marination and meat quality characteristics of turkey breasts were investigated. Breast muscles from 45 turkey hens were removed from the carcasses within 30 min postmortem. From each bird, the breast from one side was treated with HDP and the other side served as a nontreated control. Breasts were then marinated in either 15 or 30% brine (water, salt, and phosphate) based on muscle weight with vacuum tumbling for 30 min or nonmarinated. The control and HDP-treated breasts from each bird received the same marination treatment. Brine uptake, processing yield, and cooking loss were measured as processing characteristics and texture, color, and expressible moisture were measured to document changes in meat quality. Hydrodynamic pressure processing increased ($P < 0.001$) brine uptake after 10 and 30 min of marination and increased ($P < 0.001$) processing yield compared with controls. The HDP-induced improvements in these processing characteristics were augmented at 30% brine levels compared with 15% brine. Cooking loss was lower ($P < 0.001$) in marinated breasts compared with nonmarinated samples. Hydrodynamic pressure processing decreased ($P < 0.0001$) Warner-Bratzler shear force and significantly influenced texture profile parameters, resulting in reduced hardness but increased cohesiveness and springiness compared with controls at both marination levels. Hydrodynamic pressure processing did not influence color ($L^*$, $a^*$, and $b^*$) or expressible moisture values compared with controls at either marination level. Marinated samples (15 and 30% brine levels) had lower ($P < 0.001$) Warner-Bratzler shear force values and lower ($P < 0.05$) hardness, cohesiveness, and chewiness values compared with nonmarinated samples. Data from this study suggest that HDP enhances brine absorption, increases processing yield, and improves texture characteristics in marinated turkey breasts.

Key words: turkey breast, hydrodynamic pressure processing, marination, meat quality

INTRODUCTION

Consumer assessment of the eating quality of poultry products is influenced by meat quality attributes such as tenderness, juiciness, color, and flavor. Developing processing techniques to enhance these characteristics is vital to improving consumer acceptance of poultry products. Marination is a widely used method for improving the tenderness, juiciness, and flavor of poultry (Lemos et al., 1999). Some estimates indicate that up to 50% of the total production of raw poultry meat in the United States is marinated before consumption (Smith and Acton, 2001). The brine used for marination usually consists of water, salt, phosphate, and sometimes flavoring ingredients. The incorporation of phosphates and salt into poultry muscle has been shown to improve tenderness (Palladino and Ball, 1979; Goodwin and Maness, 1984), water-holding capacity (WHC) and cooking yield (Farr and May, 1970; Carpenter et al., 1979; Young et al., 1991; Young and Lyon, 1997), and oxidative stability (Ang and Young, 1987). Vacuum tumbling is often used during the marination process to enhance brine absorption and distribution within the muscle. The improved eating quality, increased product yield, and extended shelf life of marinated poultry products benefits both consumers and processors.

High-pressure treatment has also been shown to improve the quality attributes of meat. Hydrodynamic pressure processing (HDP) is a postharvest processing technology that uses high energy, high-pressure shock-waves through water to improve meat quality (Solomon et al., 1997). It has been well established that HDP treatment of beef, pork, and lamb improves cooked meat tenderness (Solomon et al., 1997, 1998; Moeller et al., 1999). In poultry, the few studies that have been
conducted indicate that HDP shockwaves improve the tenderness of early deboned chicken and turkey breasts (Meek et al., 2000; Claus et al., 2001a,b). These studies were all conducted on fresh, nonmarinated muscle products. In beef strip loins, HDP treatment before injection with a solution of salt and phosphate improved tenderness, moisture uptake, and moisture retention (Claus et al., 2002). Similarly, HDP treatment of beef strip loins after brine injection has been shown to improve tenderness (Sagili and Claus, 2003). The effects of HDP on the marination process and meat quality characteristics of moisture-enhanced poultry products are relatively unknown. It is hypothesized that the impact HDP has on muscle ultrastructure enhances the processing and meat quality attributes in marinated poultry muscle. Thus, the objective of this study was to evaluate the effect that HDP treatment has on the marination process, product yield, and final meat quality characteristics of turkey breasts.

MATERIALS AND METHODS

Sample Preparation and Treatments

Forty-five turkey hens (9 to 11 kg, live weight) were harvested at the Henry A. Wallace Beltsville Agricultural Research Center. Both breast muscles (pectoralis major) were removed from each carcass within 30 min postmortem and placed in an ice bath for 2.5 h. Individual breast muscles were then vacuum-packaged, stored at 1.5°C until 24 h, and then frozen at −20°C until use. Breast muscles were thawed at 1.5°C for 48 h before processing.

On each of 5 separate processing days, paired breast muscles from 9 birds were used. One breast from each bird was randomly assigned to receive HDP treatment, whereas the paired muscle served as a nontreated control. Samples assigned HDP treatment were vacuum-packaged in groups of 3 in boneguard bags (Cryovac/Sealed Air Corp., Duncan, SC) and placed on a 40-cm-diameter × 1.3-cm-thick metal reflector plate fitted on the bottom of a 98-L plastic container filled with water (4 to 6°C). A 100-g cylindrical-shaped binary explosive was detonated 31 cm above the meat to generate a high-pressure shockwave. Paired breast muscles from each bird were then assigned to 1 of 3 marination levels: 1) nonmarinated, 2) marinated in 15% brine based on muscle weight, and 3) marinated in 30% brine based on muscle weight. The brine was formulated to contain 2.5% phosphate (Curafos STPP, Innophos, Cranberry, NJ) and 5.0% NaCl (Alberger Fine Flake Salt, Cargill Salt, Minneapolis, MN) in 2°C water. In the 15% marinated breasts, the targeted final concentrations of phosphate and NaCl were 0.375 and 0.75%, respectively. In the 30% marinated breasts, the targeted final concentrations of phosphate and NaCl were 0.75 and 1.5%, respectively. Breasts were marinated in a vacuum tumbler (model ET-3, Sipromac, Quebec, Canada) at 4 rpm for 30 min in a 2°C room. After 10 min of marination, vacuum tumbling was stopped and breasts were removed from the tumbler, rested for 5 min, and then weighed. Vacuum-tumbling marination was then continued for an additional 20 min. After marination, breasts were reweighed and then individually vacuum-packaged and stored overnight at 1.5°C.

After the overnight storage period, breasts were weighed and one 2.5-cm-thick slice was removed from each raw breast for color and WHC measurements. Breasts were then reweighed and steam-cooked to an internal temperature of 74°C in an Alkar Processing Oven (model 700 HP, Alkar, Lodi, WI). Cooked samples were then weighed and stored overnight at 1.5°C. After overnight storage, the breasts were reweighed and two 2.5-cm-thick slices were then removed from each breast muscle for texture measurements.

Processing Characteristics

For calculation of processing characteristics, individual breast weights were recorded before marination (w1), after 10 min of marination (w2), after 30 min of marination (w3), after overnight storage (w4), immediately before cooking (w5), and immediately after cooking (w6). Processing characteristics were calculated as follows:

\[
\text{Brine uptake at 10 min} \% = \left( \frac{w_2 - w_1}{w_1} \right) \times 100
\]

\[
\text{Brine uptake at 30 min} \% = \left( \frac{w_3 - w_1}{w_1} \right) \times 100
\]

\[
\text{Moisture loss after storage} \% = \left( \frac{w_3 - w_4}{w_3} \right) \times 100
\]

\[
\text{Processing yield} \% = \left( \frac{w_4}{w_1} \right) \times 100
\]

\[
\text{Cooking loss} \% = \left( \frac{w_5 - w_6}{w_5} \right) \times 100.
\]

To visualize brine penetration into the muscle, breasts from 6 additional birds were processed similar to above but with dye included in the brine (Figure 1). One breast from each bird was HDP-treated and the other side was used as a nontreated control. Breasts were vacuum-tumbled and marinated in either 15 or 30% brine based on muscle weight. Brine was formulated similar to above with the addition of FD&C Blue No. 1 added at 0.20% of the final brine concentration. Processing characteristics for the dye samples were analyzed and determined to be similar to those of the other samples. Meat quality characteristics were not measured on the dye samples.

Meat Quality Characteristics

Texture of cooked breasts was determined using Warner-Bratzler shear force (WBSF) and texture profile analysis (TPA). Warner-Bratzler shear force was determined on a 2.5-cm-thick slice using a minimum of 6
cores removed parallel to the direction of the muscle fibers using a 1.3-cm-diameter corer. Cores were sheared perpendicular to the muscle fibers using a Warner-Bratzler meat shear fixture on a Universal Testing Machine (model 1122, Instron Corporation, Canton, MA). For TPA, at least three 2.5-cm-diameter cores were removed perpendicular to the slice surface and then compressed twice to 50% of the original height on the Universal Testing Machine at crosshead speed 50 mm/min using a 7.5-cm-diameter compression plate. The TPA parameters calculated were hardness, cohesiveness, springiness, and chewiness (Bourne, 1978). Color measurements based on the CIE color values (L*, lightness; a*, redness; and b*, yellowness) were determined using a Chroma Meter (model CR-200, Minolta Camera Co. Ltd., Osaka, Japan) calibrated to a white tile standard. Color values were recorded as the average of 3 locations on the cut surface of the breast slice. As a measure of WHC, expressible moisture (EM) was measured according to a modified procedure of Boles and Shand (2001). Three 1.5 ± 0.2 g samples were removed from the slice parallel to the muscle fibers. The samples were placed on filter paper in a 50-mL tube and centrifuged parallel to fiber orientation at 2,400 × g for 20 min at 4°C. Expressible moisture was calculated as the percentage of moisture removed from the sample: [(initial wt − centrifuge wt)/initial wt] × 100.

Statistical Analysis

Data were analyzed using the PROC MIXED procedure of SAS (Version 9.2, SAS Institute Inc., Cary, NC). The effects of treatment (control and HDP) and marination level (nonmarinated, 15%, and 30%) were analyzed as a 2 × 3 factorial in a randomized complete block design, with block representing the 5 separate processing days. The model included treatment, marination level, and the treatment × marination level interaction as fixed effects. Processing day and bird were included as random effects. The LSMEANS and PDIFF options of SAS were used to identify significant differences (P < 0.05).

RESULTS AND DISCUSSION

Processing Characteristics

The effect of HDP on brine uptake was dependent upon the marination level, as indicated by significant interactions between the treatments when measured after 10 and 30 min of vacuum tumbling. Compared with controls, HDP-treated breasts took up significantly more brine after 10 and 30 min of vacuum tumbling (Table 1). The HDP-induced increase in brine uptake compared with controls was higher at 30% marination levels than 15% for both measurement times. Furthermore, the increase in brine uptake from 15 to 30% marination levels was enhanced with HDP treatment of turkey breasts. Final brine uptake (measured at 30 min) was about 5% higher in HDP-treated breasts at 15% brine levels and about 9% higher in HDP-treated breasts at 30% brine levels compared with controls. In fact, final brine uptake in HDP-treated breasts marinated with only 15% brine was the same as control breasts marinated with 30% brine. The amount of moisture that was lost after overnight storage was similar between control and HDP-treated samples (Table 2). With lower moisture losses after overnight storage, breasts marinated at the 15% level seemed to retain more moisture than nonmarinated breasts or those that were marinated at the 30% level (Table 2). Processing yield exhibited a significant treatment × marination interaction effect (Table 1). In nonmarinated breasts, control and HDP samples did not differ in processing yield. Similar to final brine uptake, HDP-treated breasts had a 5% greater yield at 15% marination and a 9% greater yield at 30% marination than non-treated controls (Table 1). Cooking loss was lower in marinated versus nonmarinated breasts but was slightly higher in HDP-treated breasts compared with controls (Table 2). The amount of purge exudate during storage of cooked product was not influenced by HDP or marinate level (data not shown).

Data from the current study clearly demonstrate that HDP-treated turkey breasts have quicker brine absorption and higher total brine uptake during vacuum tumbling than controls. The ability of muscle to bind and hold water is a function of the myofibrils and myofilament spacing (Offer and Trinick, 1983; Hamm 1986). In moisture-enhanced pork and chicken, Xiong (2005) demonstrated that phosphates cause transverse expansion of myofibrils and extraction of myosin from the ends of the A bands, which cause swelling of the muscle fibers. This expansion results in increased water up-
Table 1. Interaction effects of hydrodynamic pressure processing (HDP) treatment and marination level (0, 15, and 30%) on processing characteristics of turkey breasts

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th>HDP</th>
<th>Treatment × marination interaction (P-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>15%</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>0%</td>
<td>15%</td>
<td>30%</td>
</tr>
<tr>
<td>Brine uptake at 10 min (%)</td>
<td>7.57b</td>
<td>13.12a</td>
<td>0.34</td>
</tr>
<tr>
<td>Brine uptake at 30 min (%)</td>
<td>11.61b</td>
<td>18.63a</td>
<td>0.31</td>
</tr>
<tr>
<td>Processing yield (%)</td>
<td>97.82a</td>
<td>107.55c</td>
<td>121.44b</td>
</tr>
<tr>
<td>n</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

a–dMeans within a row lacking a common superscript differ ($P < 0.05$).

**P** < 0.001; ***P** < 0.001.

Table 2. Main effects of hydrodynamic pressure processing (HDP) treatment and marination level (0, 15, and 30%) on processing characteristics of turkey breasts

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th>HDP</th>
<th>SEM</th>
<th>P-value</th>
<th>Marination level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>15%</td>
<td>30%</td>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>Brine uptake at 10 min (%)</td>
<td>7.57b</td>
<td>13.12a</td>
<td>0.34</td>
<td>***</td>
<td>30</td>
</tr>
<tr>
<td>Brine uptake at 30 min (%)</td>
<td>11.61b</td>
<td>18.63a</td>
<td>0.31</td>
<td>***</td>
<td>8.81a</td>
</tr>
<tr>
<td>Moisture loss after storage (%)</td>
<td>1.47</td>
<td>1.59</td>
<td>0.07</td>
<td>NS</td>
<td>1.84y</td>
</tr>
<tr>
<td>Processing yield (%)</td>
<td>105.94b</td>
<td>110.53a</td>
<td>0.36</td>
<td>***</td>
<td>97.49y</td>
</tr>
<tr>
<td>Cook loss (%)</td>
<td>18.66b</td>
<td>20.04a</td>
<td>0.22</td>
<td>***</td>
<td>20.44y</td>
</tr>
</tbody>
</table>

a–bTreatment main effect means within a row lacking a common superscript differ ($P < 0.05$).

**P** < 0.05; ***P** < 0.001.

This experiment was conducted with dye incorporated into the brine (Figure 1). Because the dye included in the brine was highly water-soluble, it was assumed that the diffusion of the dye would occur simultaneously with the brine absorption into the muscle. Consistent with the increase in brine uptake that was observed in HDP samples based on weight (Table 1), dye samples show that there was deeper and more profuse brine penetration in HDP samples compared with non-HDP controls (Figure 1). The dispersion pattern of the brine was similar in both treatments and it is likely that brine distribution would have been more homogeneous throughout the breast muscle with additional vacuum tumbling. The visual differences in shape and size between the control and HDP-treated samples in Figure 1 are likely the result of the high-pressure shockwaves compressing the muscle and the increased brine absorption with HDP treatment. This was consistently observed in most HDP-treated samples throughout this experiment.

Although HDP quickened brine absorption and increased total brine uptake, the results from the current study suggest that HDP had minimal effect on brine retention before cooking the product. The amount of moisture that was lost with storage and the EM of the raw product were not different between HDP and control samples. The increase in the cooking loss that was observed in HDP samples was offset by the dramatically enhanced brine uptake of the HDP samples. This suggests that HDP would have a net positive effect on the moisture enhancement and perceived juiciness of turkey.
the cooked turkey breasts. The decreased cooking loss with marination and vacuum tumbling is likely the result of adding phosphate to the muscle and is consistent with past research (Brotsky, 1976; Babdji et al., 1982; Froning and Sackett, 1985; Young and Lyon, 1997).

Meat Quality Characteristics

Measurements of meat texture, color, and EM exhibited nonsignificant interaction effects \((P > 0.05)\) between HDP and marination treatments. The independent effects of HDP and marination level on meat quality measurements are shown in Table 3. Hydrodynamic pressure processing treatment decreased WBSF values in both nonmarinated and marinated breasts. When compared with nonmarinated breasts, marination at both the 15 and 30% levels decreased WBSF values. Texture profile analysis revealed that HDP decreased hardness, increased cohesiveness, increased springiness, and had no effect on chewiness compared with controls (Table 3). Compared with nonmarinated breasts, marination at 15 and 30% decreased TPA measures of hardness, cohesiveness, and chewiness. Samples marinated in 30% brine had higher TPA springiness measurements than samples marinated at 15% and nonmarinated samples. Neither \(L^*\) (lightness) nor \(b^*\) (yellowness) measurements were influenced by HDP or marination treatments (Table 3). Measurements of \(a^*\) (redness) were lower \((P < 0.05)\) in samples marinated in 30% brine compared with nonmarinated samples and samples marinated in 15% brine but were not influenced by HDP (Table 3). As a measure of WHC, EM was not influenced by HDP but was numerically lower in marinated turkey breasts.

The improvements in WBSF and TPA texture characteristics observed with HDP treatment in the current study are likely due to the effect that HDP has on myofibril ultrastructure (Zuckerman and Solomon, 1998). This is consistent with previous research showing that HDP improves the tenderness of early deboned chicken and turkey breasts (Meek et al., 2000; Claus et al., 2001a,b). The lack of a significant treatment interaction effect on WBSF in the current study suggests that the marination process does not further enhance the tenderization effects of HDP. The tenderizing effect of marination is similar to what has previously been observed in poultry muscle (Schults and Wierbicki, 1973; Goodwin and Maness, 1984). Although the HDP and marination treatments in this study decreased shear force measurements, the magnitude of the improvements averaged less than 1.0 kg. The smaller than expected tenderness improvement was likely the result of the turkey breasts being fairly tender initially. Similar to observations in nonmarinated poultry (Meek et al., 2000; Claus et al., 2001b), HDP treatment in this study improved texture characteristics with no deleterious effects on muscle color or WHC, as measured by expressible moisture. The trend toward an improvement in the WHC of turkey breasts with marination supports the well-established observation that phosphate and salt cause myofibril swelling and improve WHC (Offer and Trinick, 1983; Xiong, 2005).

In conclusion, HDP treatment of muscles before marination had a positive impact on turkey breast processing and quality attributes. Hydrodynamic pressure processing treatment enhanced brine absorption, increased processing yield, and improved the tenderness of the final cooked product. Thus, data from this study suggest that HDP has the potential of adding value to moisture-enhanced poultry products for both processors and consumers through its beneficial effects on marination and meat tenderness.

**ACKNOWLEDGMENTS**

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ville Agricultural Research Center, for their technical assistance in conducting this study.

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