INTRODUCTION

Marination is a process that is widely used in the poultry industry to add moisture to meat before cooking (Fletcher, 2004; Smith and Acton, 2010). Marination not only improves the flavor and functionality of meat, but also improves product yield for the poultry processors by adding water into the muscle (Smith and Acton, 2010). Salt and sodium tripolyphosphate are common ingredients in most marinades. Salt functions to enhance flavor, acts in conjunction with phosphate to extract salt-soluble proteins, increases marinade uptake, and increases overall moisture retention during storage, further processing, or both, of marinated products (Fletcher, 2004; Smith and Acton, 2010). Phosphates improve the water-binding characteristics of marinated poultry products by increasing meat pH and by unfolding muscle proteins.

Experiments have been conducted to understand the relationship between processing variables and marination performance of chicken meat. Heath and Owens (1991) showed that an in-bag method of marination of broiler breast muscle was also measured using the swelling/centrifuging method. Marinade uptake, marinade retention, raw product yield, and cooked product yield were determined after tumbbling, following storage for 24 and 48 h after marination and after cooking. Salt-induced water gain was greater \( (P < 0.05) \) in nonmarinated fillets at 24 h postmortem compared with 6 h postmortem. Compared with unmarinated fillets, marination enhanced finished product yield significantly \( (P < 0.05) \) regardless of postmortem aging and color lightness. Marinade retention and product yield were different \( (P < 0.05) \) in fillets categorized by \( L^* \) (lightness) values. There were no differences \( (P > 0.05) \) between 2 postmortem aging times for marination uptake, overall product yield, cooking loss, final cooked product yield, or meat shear force regardless of initial fillet \( L^* \) values. However, marinade retention of 6-h samples was significantly better than 24-h samples \( (P < 0.05) \). These results demonstrate that with a targeted 15% marinade uptake, postmortem aging of 2-h deboned fillets before marination does not affect marinade uptake and product yield, but significantly affects marinade retention by boneless skinless chicken breast.

Key words: marination, aging, marinade uptake, marinade retention, chicken breast meat

http://dx.doi.org/10.3382/ps.2013-03650

© 2014 Poultry Science Association Inc.

Received September 24, 2013.
Accepted August 19, 2014.

1Mention of a product or specific equipment does not constitute a guarantee or warranty by the US Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable.

2Corresponding author: hong.zhuang@ars.usda.gov
tumbling marination significantly influences marina
date uptake (Young and Smith, 2004; Smith and Young,
2007). Overall, these results demonstrate that marina
tion performance of chicken breast meat can be affected
by the various parameters of the marination process.

In addition to processing variables, the intrinsic char-
acteristics of the raw chicken meat also influence mari-
nation performance. Allen et al. (1998) and Qiao et al.
(2002) showed that marina date uptake, marina date re-
tention, and cook loss after vacuum tumbling marination
were influenced by color lightness of raw chicken breast
meat. It is well-established that differences in breast fil-
let color are closely associated with variations in meat
pH and water-holding capacity (WHC). The ability of
meat to bind water is not a static property; WHC
changes with time postmortem. Using a salt-induced
swelling/centrifugation assay that simulated water up-
take in moisture-enhanced products, Zhuang and Sav-
age (2012) found that postmortem aging for either 24 h
or cold storage for 7 d increased WHC in boneless
skinless chicken breast meat compared with the fillets
aged for only 2 h. Thus, it was hypothesized that aging
broiler breast fillets for a longer period of time before
marination would result in enhanced marination per-
formance, including marina date uptake and marina date
retention of a salt/phosphate-based marina date and overall
product yield, cook loss, and overall cooked product
yield. Therefore, the objective of the present study was
to assess the marination performance of whole bone-
less skinless broiler breast fillets that were marinated
at 6 and 24 h postmortem. Because color lightness of
chicken breast fillets influences marination performance
(Allen et al., 1998; Qiao et al., 2002), the results in
the current study were analyzed based on breast fillets
categorized as pale, normal, and dark color according
to the CIELAB L* (lightness) values of the raw meat
before marination.

MATERIALS AND METHODS

Broiler Breast Fillets

On 3 separate days (March 28, April 11, and May
9, 2012), broiler breast butterfly fillets (removed from
carcasses at 2 h postmortem) were collected from the
deboning line of a commercial processing plant. Brook-
ers used for processing were approximately 6 wk old
and slaughtered using common broiler processing prac-
tices for the US food service market, including electrical
stunning, prescake electrical stimulation, and immer-
sion chilling. For each replication, more than 30 but-
terfly fillets were used to measure salt-induced wa-
ter gain at 6 and 24 h postmortem, respectively. Five
grams of minced meat and 7.5 mL of 0.6 M NaCl
solution were added to a 20-mL centrifuge tube
and mixed with a Vortex mixer for 1 min. The tube
was then incubated at 4°C for 15 min before being vor-
texed and centrifuged at 4°C at 3,000 × g for 15 min.
The salt-induced water gain (%) was determined by the
formula:

\[
\% \text{ salt-induced water gain} = 100 \times \frac{W_{\text{pellet}} - W_{\text{sample}}}{W_{\text{sample}}},
\]

where \(W_{\text{pellet}}\) represents the weight of the swollen pel-
let at the bottom of the tube after centrifugation, and
\(W_{\text{sample}}\) represents the initial weight of the minced muscle
sample. The left and right sides of the nonmarinated
butterfly fillets were used to measure salt-induced wa-
ter gain at 6 and 24 h postmortem, respectively.

Marination

Fillets were tagged and weighed individually before
they were vacuum-tumbled (model: DVTS 30 V.S,
Daniels Food Equipment, Parkers Prairie, MN) for 20
min at 16 rpm and −0.6 atm in marina date (20% of ini-
tial fillet weight) at 4°C. Marinade contained 5% NaCl
and 3% sodium tripolyphosphate and was formulated
with a targeted final concentration of 0.75% NaCl and
0.45% phosphate in the final product. More than the
needed marina date (20%) was added in the marina
tank to get 15% pickup target in 20-min vacuum tum-
bling. After marination, individual fillets were drained

Color and pH Measurements

Color (medial side) and pH (with a piercing probe at
the cranial end) of the fillets were measured by using
Minolta Spectrophotometer CM700d and Hach H280
GB pH meter with a Cole Parmer spear tip probe (EW-
5998–20), respectively, according to the methods of
Zhuang and Savage (2009) at approximately 4 h post-
mortem.
and weighed to determine the percentage of uptake and then reweighed at 24 h postmarination and 48 h postmortem to determine marination retention and overall product yield. The formulas used for the calculations were as follows:

\[
\text{marinade uptake} \, (\%) = 100 \\
\times \left( \frac{W_{\text{marinated}} - W_{\text{green}}}{W_{\text{green}}} \right); \\
\text{marinade retention} \, (\%) = 100 \\
\times \left[ 1 - \left( \frac{W_{\text{marinated}} - W_{\text{final}}}{W_{\text{marinated}} - W_{\text{green}}} \right) \right]; \\
\text{overall product yield} \, (\%) = 100 \times \frac{W_{\text{final}}}{W_{\text{initial}}},
\]

where \(W_{\text{initial}}\) represents fillet weight at 2 to 4 h postmortem, \(W_{\text{green}}\) represents fillet weight immediately before marination at either 6 or 24 h postmortem, \(W_{\text{marinated}}\) represents fillet weight immediately following marination, \(W_{\text{final}}\) represents fillet weight following storage for 24 h postmarination, and \(W_{\text{24h}}\) represents fillet weight at 48 h postmortem. For the fillets marinated at 6 h postmortem, the \(W_{\text{24h}}\) was determined at approximately 30 h postmortem. For fillets marinated at 24 h postmortem, the \(W_{\text{24h}}\) was determined at approximately 48 h postmortem. Nonmarinated controls were weighed at similar postmortem times to marinated fillets. Our previously published data showed significant differences in salt-induced weight gain between 2-h samples and 24-h samples. Further study (unpublished results) on changes in salt-induced water gain during 24 h of postmortem aging demonstrated that the differences could well extend to 8 h and beyond postmortem. Selection of 6 h postmortem as a treatment could provide the differences in the meat properties, which was further confirmed by salt-induced weight gain analysis (Table 1) in the present study, as well as giving us enough time to prepare the samples for experiments.

Before the marination experiments, a preliminary test was conducted to evaluate the effect of fillet sides on marinade uptake and retention. Results showed that there were no significant differences between the left side and the right side fillets from the same butterfly fillets, indicating the differences between the 6- and 24-h treatments would have resulted from the aging effect.

**Cooking and Warner-Bratzler Shear Force Determination**

Fillets were cooked in bags to the endpoint temperature of 80°C using a combi oven at 48 h postmortem and sampled following the procedures reported in Zhuang and Savage (2008). Cooking loss was calculated based on fillet weights pre- and postcooking. The overall cooked product yield was calculated as the percentage of cooked weight divided by the initial fillet weight

<table>
<thead>
<tr>
<th>Postmortem time (h)</th>
<th>Light</th>
<th>Dark</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>25.0 ± 7.1b</td>
<td>74.9 ± 46.8a</td>
<td>49.9 ± 41.2b</td>
</tr>
<tr>
<td>24</td>
<td>57.6 ± 23.3a</td>
<td>88.9 ± 44.8a</td>
<td>73.3 ± 37.8a</td>
</tr>
</tbody>
</table>

\(^{a,b}\text{Mean values with no common superscript within a column are significantly different} \, (P < 0.05).\)

**RESULTS AND DISCUSSION**

Salt-induced water gain increased significantly \((P < 0.05)\) with postmortem aging in the overall combined results (Table 1). The observed increase in the salt-
induced water gain from 6 to 24 h postmortem in the nonmarinated fillets is in line with previously published data (Zhuang and Savage, 2012), indicating that the fillets used for our marination study had expected WHC for 2 different marination groups. In addition, these data further demonstrate that postmortem aging enhances WHC in the fillets across 6- and 24-h postmortem time points. A large increase in the WHC was found with the pale samples than the dark samples, indicating that the aging effect on the salt-induced water gain depends on raw fillet color lightness. The mean and SD for salt-induced water gain were higher in dark fillets compared with pale fillets at both 6 and 24 h postmortem. This aging-depending enhancement in meat WHC has been ascribed to the weakening or breakage of muscle structure restraints (myosin-actin cross-bridge, M- and Z-line structures) by enzymes during the meat aging process, which allows water to move into myofibrils and results in protein swelling and, therefore, enhanced water holding of added salt water by meat (Offer and Trinick, 1983; Wilding et al., 1986).

Table 2 shows the color and pH characteristics of the broiler breast fillets categorized by their color lightness. These measurements were taken on the fillets at approximately 2 h postmortem before marination (4 h postmortem). There were significant differences (P < 0.05) in pH, L*, a*, and b* values between the 3 groups of fillets. As expected, dark fillets had the highest pH and a* values and the lowest L* and b* values, followed by normal fillets. Pale fillets had the lowest pH and a* values and the highest L* and b* values. These data are well in agreement with the data published in literature for the 3 color categories (Qiao et al., 2001; Zhang and Barbut, 2005; Zhuang and Savage, 2010) and indicate that the raw materials used in the current study were typical for each color group, different from each other, and adequate to meet the objectives of this study.

The effects of postmortem aging on marinade uptake, marinade retention, overall product yield, cook loss, and final cooked product yield of broiler fillets with different color lightness are shown in Table 3. Marinade uptake (targeted at 0.75% NaCl and 0.45% phosphate in the final product) was not influenced (P > 0.05) by the time postmortem at which the fillets were marinated or by the color classification of the fillets (Table 3). These data indicate that with targeted 15% of marinade uptake, meat WHC has no effect on marinade uptake by boneless skinless chicken fillets or there is either no or very weak relationship between meat WHC and marinade uptake. This conclusion becomes more evident as more and more studies are published on chicken meat marination. For example, the literature has consistently reported that darker fillets have significantly higher WHC compared with paler fillets regardless of the WHC indicator used (Barbut, 1993; Woelfel and Sams, 2001; Qiao et al., 2002; Barbut et al., 2005), but the reports on the effect of fillet color on marination properties have been inconsistent. Allen et al. (1998) found that moisture pick-up by dark breast fillets was significantly higher (P < 0.05) than light fillets and there was no significant correlation (P > 0.05) between meat WHC and the pick-up. However, Qiao et al. (2002) reported that marinade uptake by normal and light fillets was significantly higher than dark fillets and there was a significantly but positive relationship between raw breast meat L* value and the uptake. Woelfel and Sams (2001) and Gorsuch and Alvarado (2010) showed that regardless of marinade pH and phosphate type, marinade uptakes were similar to each other between pale and normal fillets. It is generally accepted that the ratio of surface versus volume or surface physical properties (or both) of meat have more effects on marinade uptake than the intrinsic properties of meat (Heath and Owens, 1991). Our preliminary results (unpublished data) show that there were no significant correlation between marinade uptake and either raw fillet color lightness (indicted by L* values) or pH, but there was a significantly negative relationship between fillet weight and marinade uptake after fillets were marinated for 20 min, indicating that meat weight has more effects on marination uptake than meat pH and color or WHC.

Aging time before marination (6 or 24 h) did not significantly affect marinade retention within each fillet color lightness group (P > 0.05). However, when data were pooled, 6-h samples retained marinade significantly better (P < 0.05) than 24-h samples (data are not shown). This result is contrasted to our hypothesis that aging would enhance marinade retention in poultry breast meat by increasing meat WHC. However, our results are in accordance with what was reported by Heath and Owens (1991). In the study on variation in marinade retention, Heath and Owens (1991) found that regardless of tumbler type (with or without

<table>
<thead>
<tr>
<th>Fillet color lightness</th>
<th>pH</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pale</td>
<td>5.72 ± 0.32&lt;sup&gt;a&lt;/sup&gt;</td>
<td>62.1 ± 2.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>−0.41 ± 0.94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.1 ± 2.2&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Normal</td>
<td>5.94 ± 0.30&lt;sup&gt;b&lt;/sup&gt;</td>
<td>33.3 ± 1.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.27 ± 0.62&lt;sup&gt;b&lt;/sup&gt;</td>
<td>11.5 ± 1.6&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Dark</td>
<td>6.08 ± 0.34&lt;sup&gt;c&lt;/sup&gt;</td>
<td>46.3 ± 2.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1.36 ± 0.67&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10.0 ± 1.7&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b</sup>Mean values with no common superscript within a column are significantly different (P < 0.05).
baffles), fresh chicken breast meat that was removed from carcasses 4 h postmortem retained significantly more marinade ($P < 0.05$) than the meat removed 24 h postmortem. In the same experiment, they also demonstrated that when the breast pieces were marinated in a common bath in a tumbling drum, fresh meat had better marinade retention compared with the aged pieces; however, when each breast piece was packed in an individual bag with marinade, there was no difference in marinade retention between fresh and aged samples. When the tumbling time was more than 4 min (8 or 12 min), more marinade was retained in fresh meat than that in aged meat. However, no difference between the fresh and aged samples was noticed when the tumbling time was 4 min. In our study, 20 min was used for marination duration, which is much longer than 4 min. Lee et al. (2011) found that marinade retention in the fillets marinated for 30 min was consistently higher than those for 15 min. These results suggest that in addition to meat WHC, other factors, such as meat surface conditions, the depth of marinade penetration in meat, or both, can also significantly affect marinade retention (Heath and Owens, 1991). During postmortem aging, proteolysis of myofibrillar proteins results in myofibril fragmentation and loss of muscle integrity (Taylor et al., 1995; Huff Lonergan et al., 2010). These changes in muscle structures might significantly affect meat surface condition, depth of marinade penetration after tumbling, or both, which ultimately affects the marinade retention.

Marination significantly enhanced the overall product yields, cook loss, and final cooked product yield of breast fillets compared with nonmarinated controls ($P < 0.05$) regardless of color group. However, there were no differences ($P > 0.05$) for any of these 3 measurements between 6- and 24-h treatments, even though the data of measurements were pooled over color group. These results suggest that marination can significantly increase finished product yields of chicken breast meat but postmortem aging may have no effect on them. Perumalla et al. (2011) found that marination significantly reduced cook loss of chicken breast meat regardless of carcass chilling method. Xiong and Kupski (1999) noticed that cook yield of marinated chicken fillets was significantly higher than no salt control regardless of phosphate type, tumbling time, and breading. The marination-enhanced chicken meat product yield has been attributed to increased ionic strength and pH of

### Table 3. Postmortem aging effect on the marinade uptake (%), marinade retention (%), overall product yield (%), cook loss (%), and final cooked product yield (%) of broiler breast fillets with different color lightness (mean ± SD)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pale</th>
<th>Normal</th>
<th>Dark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marinade uptake&lt;sup&gt;1&lt;/sup&gt; (%)</td>
<td>14.66 ± 3.31</td>
<td>13.93 ± 3.07</td>
<td>14.65 ± 2.85</td>
</tr>
<tr>
<td>Marinade retention&lt;sup&gt;2&lt;/sup&gt; (%)</td>
<td>87.0 ± 6.5&lt;sup&gt;a,y&lt;/sup&gt;</td>
<td>84.2 ± 3.4&lt;sup&gt;a,y&lt;/sup&gt;</td>
<td>92.0 ± 2.7&lt;sup&gt;a,x&lt;/sup&gt;</td>
</tr>
<tr>
<td>Overall product yield&lt;sup&gt;3&lt;/sup&gt; (%)</td>
<td>96.4 ± 4.5&lt;sup&gt;b,x&lt;/sup&gt;</td>
<td>99.1 ± 0.4&lt;sup&gt;b,x&lt;/sup&gt;</td>
<td>99.7 ± 0.3&lt;sup&gt;b,x&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cook loss&lt;sup&gt;4&lt;/sup&gt; (%)</td>
<td>24.0 ± 2.4&lt;sup&gt;b,x&lt;/sup&gt;</td>
<td>21.3 ± 2.4&lt;sup&gt;b,x&lt;/sup&gt;</td>
<td>16.2 ± 3.2&lt;sup&gt;b,y&lt;/sup&gt;</td>
</tr>
<tr>
<td>Final cooked product yield&lt;sup&gt;5&lt;/sup&gt; (%)</td>
<td>73.2 ± 4.1&lt;sup&gt;b,y&lt;/sup&gt;</td>
<td>77.9 ± 2.3&lt;sup&gt;b,y&lt;/sup&gt;</td>
<td>83.5 ± 3.4&lt;sup&gt;b,x&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b</sup>Mean values with no common superscript within a column are significantly different ($P < 0.05$).

<sup>x,y</sup>Mean values with no common superscript within a row are significantly different ($P < 0.05$).

<sup>1</sup>Marinade uptake (%) = 100 × (W<sub>marinated</sub> – W<sub>green</sub>) / W<sub>green</sub>; n = 14, where W<sub>marinated</sub> represents fillet weight immediately following marination, and W<sub>green</sub> represents fillet weight immediately before marination at either 6 or 24 h postmortem.

<sup>2</sup>Marinade retention (%) = 100 × [1 – (W<sub>24h</sub> – W<sub>green</sub>) / (W<sub>marinated</sub> – W<sub>green</sub>)]; n = 14, where W<sub>marinated</sub> represents fillet weight immediately following marination, W<sub>24h</sub> represents fillet weight following storage for 24 h postmarination, and W<sub>green</sub> represents fillet weight immediately before marination at either 6 or 24 h postmortem.

<sup>3</sup>Overall product yield was calculated based on the initial fillet weight at 2 h postmortem and the weight of the marinated fillets at 48 h postmortem; n = 14.

<sup>4</sup>Cooking loss was calculated based on fillet weights pre- and postcooking, n = 6 for control, and n = 8 for marinated samples.

<sup>5</sup>Final cooked product yield was calculated based on cooked fillet weight and the initial raw fillet weight at 2 h postmortem; n = 6 for control, and n = 8 for marinated samples.
meat by salt and phosphate, which thereafter increases the ability of muscle to retain water and marinated product yield (Hamm, 1975).

Raw meat color lightness significantly (P < 0.05) affected marinade retention, overall product yield (pooled data), cook loss, and final cooked product yield (Table 3). For example, for marinade retention, the dark fillets marinated at 6 h postmortem retained marinade better (P < 0.05) than both pale and normal fillets. Regardless of marination treatment, cooking loss of dark fillets was significantly lower (P < 0.05) than the pale fillets. For 24-h samples, dark fillets exhibited a higher (P < 0.05) cooked product yield than either light or normal fillets. Allen et al. (1998) reported that marinated dark fillets showed significantly lower cook loss and drip loss compared with marinated light fillets. Qiao et al. (2002) found that marinated dark and normal meat exhibited better cooked yield than lighter meat. Barbut et al. (2005) showed both marinated yield and final yield of dark fillets were significantly higher than pale fillets. Similar to these findings, our results further demonstrate that finished product yields of marinated chicken fillets vary with raw meat color lightness.

There were no differences in shear force values between the 2 marination treatments regardless of raw fillet color lightness (P > 0.05), and there were no differences (P > 0.05) between the 3 color groups for the marinated fillets (Table 4). Qiao et al. (2002) found a significant difference in shear force of marinated chicken fillets among the 3 color groups; however, they concluded that the differences are not likely to be significant under practical conditions. Our results, in agreement with their conclusion, suggest that tenderness of marinated chicken breast fillets is not affected by postmortem aging and raw meat color lightness.

In summary, although postmortem aging enhanced saline water gain by chicken breast fillets, postmortem aging shows no significant effect on marination performances, marinade uptake, overall product yield, cook loss, and overall cooked product yield, and Warner-Bratzler shear force of early-deboned fillets regardless of the color lightness. However, there were significantly different differences in marinade retention between the 2 aging times. There were significant differences in marination performance, including marinade retention, overall product yield, cook loss, and overall cooked product yield between color lightness groups of broiler fillets before marination. These data suggest that with marination for 20 min with target 15% yield, postmortem aging, and raw material color lightness may affect marination performance of chicken breast meat.

### ACKNOWLEDGMENTS

The authors express their sincere thanks to Elizabeth Barton, Andrew Ross, Taylor Kronn, Matthew Eady, and Patrick Hogan (the Quality and Safety Assessment Research Unit, USDA-Agricultural Research Service, Athens, GA) for their technical assistance in this research.

### REFERENCES


### Table 4. Warner-Bratzler shear force of marinated broiler breast fillets with different color lightness (mean ± SD, n = 8)

<table>
<thead>
<tr>
<th>Marination treatment</th>
<th>Pale</th>
<th>Normal</th>
<th>Dark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marinated 6 h postmortem</td>
<td>2.40 ± 0.54</td>
<td>3.42 ± 1.19</td>
<td>3.12 ± 0.97</td>
</tr>
<tr>
<td>Marinated 24 h postmortem</td>
<td>2.42 ± 0.52</td>
<td>3.14 ± 0.99</td>
<td>2.60 ± 1.03</td>
</tr>
</tbody>
</table>


