Marination Pressure and Phosphate Effects on Broiler Breast Fillet Yield, Tenderness, and Color

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ABSTRACT

In the United States a large percentage of raw poultry meat is marinated prior to cooking. Many products are marinated by vacuum tumbling meat with a mixture of water, salt, and phosphates to increase cook yield and perceived tenderness. This study was designed to determine the effect of 3 pressure treatments (ambient, vacuum, or positive) and phosphate on yield, tenderness, and color on broiler breast meat. In each of 3 replicate trials, 60 broiler breast fillets were randomly assigned to a tumble marination treatment of 1) ambient tumble pressure (101 kPa); 2) vacuum tumble pressure (50 kPa); or 3) positive tumble pressure (204 kPa). Each pressure treatment was conducted with and without phosphate in the marination solution. Marination tumblers were operated at 15 rpm for 20 min at a temperature of 3°C. Broiler breast fillets were weighed (raw, immediately after marination, 1 h postmarination, and after cooking), sheared after cooking with a Warner-Bratzler device, and evaluated for color (CIE L*, a*, and b*) before marination and after cooking. Pressure and phosphate treatment combinations did not significantly affect marinated or drip weights, Warner-Bratzler shear values, cooked b*, or percent drip loss. There was no effect of pressure treatment except for marinade uptake, where ambient tumble uptake was 12.7%, which was significantly higher than positive tumble (11.4%); vacuum tumble uptake (12.0%) was not different from either. Phosphate significantly increased cook weight (from 94.9 to 106.1 g) and cook yield (from 76.6 to 86.1%); L* and a* values were slightly but significantly decreased. Type of pressure during tumble marination had no effect except on marinade uptake, but the effect disappeared with 1 h holding time and cooking. Phosphate improved cook weight and yield. These data show that vacuum pressure during tumbling is not necessary, but phosphate is important to cook yields.

Key words: marination, pressure tumbling, cook yield, tenderness, breast meat quality

INTRODUCTION

Marination of raw poultry meat prior to consumption is a widespread practice in the United States, and up to 50% of the total raw poultry meat production may be marinated (Smith and Acton, 2001). Typical marinades are a mixture of water, salt, and phosphate that are applied to the meat by various methods. Several authors have reviewed the actions of salt and phosphate on meat during and after marination. Briefly, salt and phosphates in the marinade solution increase the water holding capacity of meat (Hamm, 1960). The pH changes and myofibrillar proteins in muscle are extracted and a lattice forms of partially unwound proteins, which allows binding of the phosphate; the meat swells as water is bound in the lattice (Offer and Trinick, 1983; Trout and Schmidt, 1983). Water bound by the action of salt and phosphate is held even through the cooking process (Acton and Jensen, 1994). Although phosphates have been shown to improve meat quality, several countries have banned their use in raw meat production.

Marination mixtures can be applied to the meat through soaking, injection, or vacuum tumbling, depending on the type of meat product. Boneless skinless breast fillets are usually tumble marinated under vacuum pressure. Commercial operations began using vacuum during tumbling many years ago in the belief that negative pressure contributed to a significant increase in the uptake and retention of marinade, resulting in higher cook yields. The vacuum tumbling process has been shown to increase marinade uptake in the meat (Young and Lyon, 1997; Young and Smith, 2004) and improve cook yield (Young and Lyon, 1997; Young et al., 2004). Generally marination of poultry meat increases tenderness as measured by objective shear or texture panels (Landes, 1972; Goodwin and Maness, 1984; Maki and Froning, 1987; Smith et al., 1991). However, the specific
technique of vacuum tumble marination has not been shown to improve tenderness (Young et al., 1996; Young and Smith, 2004) and may increase toughness of early deboned breast meat (Young and Lyon, 1997; Alvarado and Sams, 2004).

Vacuum tumble marination has been shown to increase cooked meat lightness and decrease cooked meat redness (Young et al., 1996; Young and Lyon, 1997). The procedure has also been shown to reduce redness of bruised meat after cooking (Northcutt et al., 2000).

The specific action of vacuum pressure on the muscle that has been reported to improve marination uptake and cook yield has not been identified. Possibly the vacuum pressure provides an environment where the muscle expands slightly, allowing better marination penetration, or allows more extraction of myofibrillar proteins to the surface. Tumbling even without vacuum (at ambient pressure) has been shown to increase marination uptake over still marination (Chen, 1982). A direct comparison between vacuum and ambient pressure tumbling found no improvement for cook yield or shear values (Young and Smith, 2004), so the presence of phosphate and the action of tumbling appear to be more important to the marination process than the application of vacuum pressure.

If vacuum pressure is necessary to maximize the marination process then it should provide obvious benefits to meat yield and quality when compared with ambient pressure tumbling. The use of positive pressure (the opposite of vacuum) during tumbling should produce clearly negative results in regard to uptake, retention, and cook yield of marinated meat. Because vacuum tumbling, although widely used, has not always been clearly shown to have an advantage over ambient pressure, this study was conducted to determine the effects of 3 different pressures applied during tumbling on broiler fillet yield, tenderness, and color, with and without the presence of phosphate in the marination solution.

**MATERIALS AND METHODS**

In each of 3 replicate trials, 30 broiler carcasses were obtained from a commercial processor immediately post-mortem and transported to the laboratory, where fillets were removed annually at 4 h postmortem. Groups of ten fillets each were randomly assigned to 1 of 6 treatments in a 3 × 2 design: 3 pressures during tumbling, ambient tumble (AT) pressure of approximately 101 kPa, vacuum tumble (VT) at a pressure of approximately 50 kPa, or positive tumble pressure of approximately 204 kPa (PT); and 2 marination solutions, one without (P−) and one with phosphate (P+). The P− marination solution was composed of 94% water and 6% NaCl. The P+ solution was composed of 91% water, 6% NaCl, and 3% sodium tripolyphosphate (Brifisol STPNEW, B.K. Giulini Corporation, Simi Valley, CA). Marination solutions were added at 15% (weight to weight) to each group of fillets. The targeted final concentration of NaCl in marinated fillets was 0.9% for both treatments and 0.45% sodium tripolyphosphate for the P+ treatment.

Raw fillets were individually weighed, tagged for identification, and assigned into groups of 10 each. Fillets and the 15% marination solutions were placed into laboratory-scale tumble vessels containing paddles and placed onto a rotating base (model MC II 10/20, Inject Star Inc., Brookfield, CT). The AT tumblers were closed at ambient atmospheric pressure, approximately 101 kPa (29.9 in Hg). The VT tumblers were attached to vacuum pump after closing to reduce pressure to approximately 50 kPa (15 in Hg). The PT tumble vessel was a pressure cooker of similar size, shape, and fitted with the same paddles as the other tumblers (All American Pressure Cooker model 921, Wisconsin Aluminum Foundry Co. Inc., Manitowoc, WI). The PT tumbler was attached to an air compressor to increase pressure to approximately 204 kPa (15 PSI). All tumblers were placed on their side for rotation in a refrigerated room (3°C) and operated at 15 rpm for 20 min. Fillets were reweighed immediately after tumbling to measure marination uptake. Surface color (CIE L* = lightness, a* = redness, and b* = yellowness) was measured in triplicate with a colorimeter (Chroma Meter CR-3000, Minolta Corp., Ramsey, NJ) on the caudal (bone) side of each fillet. The groups of 10 fillets were stored in a plastic bag for 1 h in a 3°C refrigerated room and reweighed to measure drip loss. Individual fillets were placed and sealed into cooking bags and cooked in a steam kettle for 20 min at 95°C to a minimum internal fillet temperature of 80°C. Fillets were removed from bags and reweighed to measure cook weight for yield calculations. After covered storage in a refrigerator for 18 h, a 1.9-cm strip was excised from each fillet parallel to the fiber direction. Strips were sheared twice perpendicular to fiber direction using a Warner-Bratzler (W-B) device (G-R Electrical MFG. Co., Manhattan, KS) to determine kilograms of force to shear, and both shears per fillet were averaged together (Young et al., 2005).

Calculations for percentage marination uptake, percentage drip loss after 1 h, and percentage cook yield were as follows:

\[
\text{% marination uptake} = \frac{\text{marinated weight} - \text{raw weight}}{\text{raw weight}} \times 100;
\]

\[
\text{% drip loss} = \frac{\text{marinated weight} - \text{1 h marinated weight}}{\text{marinated weight}} \times 100; \text{and}
\]

\[
\text{% cook yield} = \frac{\text{cooked weight}}{\text{raw weight}} \times 100.
\]

A 3 × 2 experimental design was used for the main effects of pressure treatment and phosphate presence for the 3 replications of 30 carcasses, 2 fillets per carcass (n = 180). Actual n was 170 due to a calculation error forcing disposal of 1 group of 10 fillets. Data were analyzed using GLM design to test the main effects of pressure treatment and phosphate, with residual error used as the error term (SAS Institute, 1999). Data were pooled for variables
Table 1. Percentage of marinade uptake (mean ± SEM) of broiler breast fillets tumble marinated at ambient, vacuum, or positive pressure

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Marinade uptake, %</th>
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<tbody>
<tr>
<td>Ambient</td>
<td>12.7 ± 0.4</td>
</tr>
<tr>
<td>Vacuum</td>
<td>12.0 ± 0.4</td>
</tr>
<tr>
<td>Positive</td>
<td>11.4 ± 0.3</td>
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</table>

a,bMeans with differing superscripts are significantly different (P < 0.05).

RESULTS AND DISCUSSION

Mean raw weight ± SEM was 123.7 ± 1.6 g and was not significantly different due to assigned groups of pressure or phosphate treatments. Fillets were therefore consistently dispersed among treatment groups with regard to weight. Raw fillet color was also consistent among the assigned treatment groups because there was no significant difference due to group assignment. Mean CIE L* (lightness) values were 43.8; a* (redness) values were 1.6; and b* (yellowness) values were −0.2. Consistency of color among treatment groups was important because meat color extremes have been shown to affect marination uptake, cook yield, and shear (Qiao et al., 2002).

Marinade weight and drip weight were not significantly affected by type of pressure or presence of phosphate during tumbling. Combined mean weights ± SEM for marinade and drip, were, respectively, 138.2 ± 1.7 and 136.7 ± 1.7 g. Marinade uptake was significantly affected by pressure treatment where mean uptake percent was 12.7 ± 0.4% for AT, 12.0 ± 0.4% for VT, and 11.4 ± 0.3% for PT (Table 1). Phosphate presence had no effect on marinade uptake, so data were pooled to report only the effect of pressure treatment. Drip loss was not affected by phosphate or pressure treatments, and the combined drip loss averaged 1.1 ± 0.1%.

Previous reports vary on the efficacy of vacuum pressure to increase uptake and retention. Vacuum tumbling increased marinade uptake of broiler breast meat when compared with tumbling without vacuum (Young and Smith, 2004). The effect of positive pressure on marinade uptake or drip loss has not been previously reported for poultry meat. Lesky et al. (2001) claimed that positive pressure increased uptake of marination for vegetables and pork chops. Young and Lyon (1997) reported that vacuum tumbling increased marinade uptake, but Young et al. (2004) did not find a difference in uptake due to vacuum tumbling for broiler breast meat. Therefore, the previous research on effect of pressure during tumble marination is contradictory for vacuum pressure and absent for positive pressure, and the physical process of tumbling appears to be more important than the pressure applied. This appears true for cut-up parts because Chen (1982) found tumbling without vacuum increased speed of marinade uptake in 8-piece cut-up chicken parts vs. soaking. The tumble process can be maximized by including paddles inside the tumbler, as marinade uptake of broiler fillets was increased compared with tumblers without paddles (Heath and Owens, 1991). Regarding drip loss, Xiong and Kupski (1999), found that tumbling without vacuum but with relatively high salt and phosphate levels resulted in higher moisture retention for broiler fillets after 24 h compared with control samples. That study was not a completely appropriate comparison for results from the current study because holding time was different (1 vs. 24 h) and salt and phosphate levels in the marinade were different.

Phosphate is generally reported to increase marinade uptake of broiler fillets under vacuum pressure (Young and Lyon, 1997; Young et al., 2004). This effect is also evident when broiler fillets are tumbled without vacuum pressure (Xiong and Kupski, 1999). However, breast quarters soaked 12 h in marinade solutions with 6% and without phosphate showed no difference in marinade pickup (Landes, 1972). Results from the current study did not show any increase in marinade uptake by the fillets due to phosphate. This may have been due to variation introduced by the treatments in small tumblers not absorbing all 15% of added marinade.

Cook weight and yield were significantly affected by presence of phosphate, but not by pressure treatment (Table 2). Data were pooled across pressure treatments and reported only by phosphate treatments due to lack of significant interactions or pressure treatment differences. Phosphate increased cook weight from 94.9 to 106.1 g, and cook yield from 76.6 to 86.1%.

In general, phosphate applied to poultry meat by various methods has been shown to increase cook yield. Soaking breast quarters with phosphate marinade prior to cooking increased cooked yields (Landes, 1972). Injection of phosphates into broilers improved cook yield (Farr and May, 1970; Goodwin and Maness, 1984). Chicken carcasses soaked with phosphates had higher cook yields than carcasses soaked in water only (Froning, 1965). Alvarado and Sams (2004) found that vacuum tumbling with phosphate increased cook moisture of broiler breast fillets. Others have reported an increase in cook yield of fillets after vacuum tumbling with phosphates (Young and Lyon, 1997; Young et al., 2004). Smith et al. (1991) reported similar results for duck breast fillets. Additional research has shown that tumbling without vacuum but with phosphates increased cook yield of fillets (Xiong and Kupski, 1999), and a direct comparison of tumbling with phosphates with and without vacuum pressure applied found no difference in cook yield (Young and Smith, 2004). Turkey breasts injected with phosphates and then tumbled without vacuum had higher cook yields than meat not injected with phosphates (Froning and Sackett,
Phosphate decreased $L^*$ from 71.6 by phosphate, but not by pressure treatment (Table 2).

Tender rating for W-B shear based on perceived consumer average W-B value (6.8 kg) corresponds to a slightly minimal effect of early deboning on shear values. The broiler breast. All of the fillets used in this study were uuum tumbling alone increased shear of early deboned followed by vacuum tumbling decreased shear, but vac-

rado and Sams (2004) found injection alone or injection vacuum (Peterson, 1977; Lyon and Hamm, 1986). Alva-

nades introduced by injection or by tumbling without phosphates. Other research has shown a general trend of increasing poultry meat tenderness with use of phosphate marinades. Soaking breast quarters with phosphate marinade prior to cooking increased tenderness of meat as evaluated by a texture panel (Landes, 1972). Turkey breasts injected with phosphates and then tumbled without vacuum had lower shear values than meat not injected with phosphate (Maki and Froning, 1987). The length of time postmortem that poultry meat is aged prior to marinade prior to cooking increased tenderness. These results agree with previous researchers that cook yield is improved with phosphate marinades, but vacuum pressure is not essential to improving yield.

Shear values were not affected by phosphate presence or type of pressure during tumbling. The mean W-B shear value was 6.8 ± 0.4 for the study (n = 170).

These results agree with previous researchers that found no effect of vacuum tumbling with phosphates on decreasing shear (increasing tenderness) of broiler fillets (Young et al., 1996; Alvarado and Sams, 2004). Smith et al. (1991) reported that duck breast fillets were slightly but significantly more tender after vacuum tumbling with phosphates. Other research has shown a general trend of increasing poultry meat tenderness with use of phosphate marinades. Soaking breast quarters with phosphate marinade prior to cooking increased tenderness of meat as evaluated by a texture panel (Landes, 1972). Turkey breasts injected with phosphates and then tumbled without vacuum had lower shear values than meat not injected with phosphate (Maki and Froning, 1987). The length of time postmortem that poultry meat is aged prior to marinade can affect shear values. Shear of early deboned chicken fillets has been decreased by phosphate marinades introduced by injection or by tumbling without vacuum (Peterson, 1977; Lyon and Hamm, 1986). Alvarado and Sams (2004) found injection alone or injection followed by vacuum tumbling decreased shear, but vacuum tumbling alone increased shear of early deboned broiler breast. All of the fillets used in this study were aged 4 h postmortem, so there should have been no or minimal effect of early deboning on shear values. The average W-B value (6.8 kg) corresponds to a slightly tender rating for W-B shear based on perceived consumer tenderness rating compiled by Lyon and Lyon (1990).

The $L^*$ and $a^*$ values of cooked fillets were affected by phosphate, but not by pressure treatment (Table 2). Phosphate decreased $L^*$ from 71.6 ± 0.2 to 70.6 ± 0.2, and $a^*$ from 1.6 ± 0.1 to 0.9 ± 0.1. Although significant, these differences are likely of no practical significance as they are 1 unit or less apart. Cooked $b^*$ values were not affected by phosphate or pressure, and the combined treatments averaged 11.1 ± 0.1.

Cooked $L^*$ (lightness) of broiler breast fillets was slightly (by 1 unit) but significantly increased by phosphates in the marinade during vacuum tumbling, and cooked $a^*$ (redness) was slightly but significantly decreased by less than one-half unit (Young et al., 1996).

Young and Lyon (1997) also reported that vacuum tumbling with phosphate significantly decreased $a^*$ by less than 1 unit. Results from the current study also show slight but significant changes in color of cooked meat after marination. However, although the results agree with previous researchers that redness is decreased with marination, lightness was slightly reduced rather than increased as reported by others. These results are not surprising given the small margin of difference. Also, another report found no difference in lightness values of cooked meat between marinated and nonmarinated fillets (Northcutt et al., 2000).

The lack of difference between VT and either AT or PT for marinade uptake shows that vacuum pressure during tumbling is not important to maximize the marination process. Interestingly, positive pressure applied during tumbling did not negatively affect uptake compared with vacuum as might be supposed, because it is the opposite of vacuum. The same pattern was evident with cook yield and shear values because type of pressure had no effect on these measures.

Variation and efficiency of the marination process used in this study, with small batches of fillets in pilot-size tumblers, could have contributed to a lack of significant results. For example, although 15% of marinade solution was added to each batch none of the treatments absorbed all of the solution. However, the underlying process and mechanisms for marinade uptake and retention through holding and cooking should have been affected somewhat by the wide difference in pressure treatments applied. Relatively small sample size per treatment (n = 30) could have affected the results. The coefficients of variation from each treatment (data not shown) were reviewed, however, and found to be low and consistent within the experiment. The results from this study therefore demonstrate that vacuum pressure during tumbling, as is widely practiced commercially, may not be necessary. The underlying principles for using vacuum pressure may be erroneous and should be examined further, perhaps with larger batches and commercial equipment. The use of phosphate in the marinade was important for improving cook yield, and this practice should continue where practical and legal.

### REFERENCES


<table>
<thead>
<tr>
<th>Phosphate</th>
<th>Cook weight, g</th>
<th>Cook yield, %</th>
<th>$L^*$ cook</th>
<th>$a^*$ cook</th>
</tr>
</thead>
<tbody>
<tr>
<td>No$^1$</td>
<td>94.9± 1.6</td>
<td>76.6± 0.4</td>
<td>71.6± 0.2</td>
<td>1.6± 0.1</td>
</tr>
<tr>
<td>Yes$^2$</td>
<td>106.1± 2.3</td>
<td>86.1± 0.4</td>
<td>70.6± 0.2</td>
<td>0.9± 0.1</td>
</tr>
</tbody>
</table>

$^1$n = 90.

$^2$n = 80.

1985; Maki and Froning, 1987). Results from the current study agree with the previous studies that cook yield is improved with phosphate marinades, but vacuum pressure is not essential to improving yield.


