Comparison of a Modified Atmosphere Stunning-Killing System to Conventional Electrical Stunning and Killing on Selected Broiler Breast Muscle Rigor Development and Meat Quality Attributes

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ABSTRACT Two experiments were conducted to compare the effects of a 70:30 argon:carbon dioxide Modified Atmosphere Stun-Kill (MASK) system to both a low voltage (LV) and a high current (HC) electrical stunning and conventional killing system on broiler breast rigor development and meat quality. In Experiment 1, the effects on breast muscle pH and meat tenderness of the MASK system and the LV system were compared. In Experiment 2, the MASK system was compared to both HC and LV stunning for pH, R-value, C.I.E. L*, a*, b*, cooked yield, and tenderness of broiler breast meat. In Experiment 1, there were no significant differences in breast muscle pH between LV and MASK, except at 24 h. Only at 5 h post-mortem did the MASK system result in significantly tougher breast meat. In Experiment 2, there were no significant differences between treatments in breast muscle color or cooked yield at any sampling time. The breast muscle from birds subjected to the HC stun had consistently higher pH values until 5 h post-mortem, at which time the breast meat from birds subjected to the MASK system had higher pH. R-value data showed a similar trend, with the HC stunned birds having the lower R-values until 5 h post-mortem. Breast meat tenderness values for the three treatments were significantly different only at 3 and 5 h post-mortem, when birds stunned with HC had the highest shear values. The MASK system did not exhibit any rigor accelerating benefits when compared to LV stunning and conventional killing, and only minimal rigor acceleration when compared to HC killing.

(Key words: gas stunning, gas killing, breast meat quality, rigor development, slaughter)

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INTRODUCTION

Gas stunning systems have been reported to have advantages over conventional electrical stunning and killing systems. Early research indicated that stunning with carbon dioxide resulted in increased blood loss (Kotula et al., 1957). More recently, when compared to electrical stunning, carbon dioxide stunning has been reported to produce lower breast meat shear values at 1 h post-mortem (Veerramuthu and Sams, 1993). However, the same laboratory has also reported that carbon dioxide stunning resulted in no differences in blood loss, breast muscle pH, or meat shear when compared to electrical stunning (Hirschler and Sams, 1993). In turkeys, carbon dioxide stunning has been shown to result in a lower muscle pH, decreased incidences of hemorrhaging, and lower C.I.E. redness (a*) color value of breast muscles (Flemming et al., 1991), when compared to electrical stunning systems.

The use of carbon dioxide as a stunning agent may be impractical because broilers have been observed to regain consciousness, some within 26 s (Mohan Raj and Gregory, 1990). These authors therefore recommended that when using gas the birds should be killed so as to prevent the birds from regaining consciousness during killing, and to allow for easier handling. Mohan Raj et al. (1990) reported a decrease in carcass damage and a decrease in toughness at 20 min and 24 h post-mortem for birds killed with carbon dioxide when compared to electrical stunning and conventional killing. Other studies on carbon dioxide killing have reported contradicting results. Kang and Sams (1995) reported no difference in 1 h post-mortem breast pH of samples from birds electrically stunned, stunned with carbon dioxide, or killed with carbon dioxide. Dzuik and Sams (1995) reported that killing birds with carbon dioxide had no effect on breast muscle post-mortem pH decline or R-value ascension, but did result in a lower expressible

Abbreviation Key: HC = high current; LV = low voltage; MASK: Modified Atmosphere Stun-Kill system; R-value: the ratio of the absorbances at 250 and 260 nm, indicating the ratio of inosine to adenosine nucleotides.

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moisture content, when compared to breast meat from electrically stimulated birds. The authors also stated that killing with carbon dioxide was less beneficial on ultimate meat quality than electrical stimulation (Dzuik and Sams, 1995).

Argon has also been used as a killing gas, because of its density and ability to displace oxygen in a chamber. The use of argon has been reported to increase the rate of breast muscle pH decline, allowing for early deboning (Mohan Raj et al., 1991). Mohan Raj et al. (1990) reported that using argon in an immersion style gas killing system decreased carcass damage when compared to electrical stunning. Argon has also been reported to improve meat texture when compared to electrical stunning (Raj et al., 1992).

The combination of hypoxia (reduced oxygen supply to the tissues, such as the brain) through displacement with argon, and death by hypercapnia (excess carbon dioxide in the blood) through the use of carbon dioxide has been evaluated. Mohan Raj et al. (1992) reported that exposing birds to a gas mixture of 30% carbon dioxide with less than 5% oxygen achieved by displacement with argon, resulted in less breast muscle hemorrhaging, more broken wing bones, and less broken pectoral bones than killing birds with a 120 mA “stun”. The authors concluded that the stunning of broilers with 30% carbon dioxide with up to 5% residual oxygen in argon would be ideally suited for commercial application, and that stunning with this mixture would improve the quality of breast meat. No textural analysis, however, was reported.

In the European Community it has been recommended that the minimum stunning current for broilers should be 120 mA, so as to induce cardiac arrest in 90% of the birds, such that they will not regain consciousness during exsanguination (Gregory, 1992). The reasoning behind this high current system of “stunning” is to provide for the welfare of the birds; i.e., it guarantees that birds are not subjected to any conscious stresses that can be associated with recovery from stunning. In the U.S. however, the major emphasis of stunning is to render the bird immobile with the least amount of stunner-related carcass damage. Low voltage/low current stunners are commonly used in 65% of U.S. processing plants (Heath et al., 1994).

The purpose of this study was to compare the effects of a 70:30 argon:carbon dioxide Modified Atmosphere Stun-Kill (MASK) system to both a low voltage, constant voltage (LV) and a high current, constant current (HC) electrical stunning system on meat quality attributes. The study was designed to determine whether the advantages reported with the use of MASK in the European Community would be similar when gas killing is compared to a U.S. style electrical stunning and killing system.

**MATERIALS AND METHODS**

**Experiment 1**

In each of four trials, birds were obtained from the live holding area of a commercial processing plant, transported to the laboratory facility, and processed immediately (within 1 h). In each of the trials, the birds were divided equally between a LV treatment and a MASK system. For the LV treatment, each bird was individually stunned with a commercially available constant voltage in-line stunner2 set at 11.5 V and 500 Hz for 10 s. Birds were then bled for 2 min following a unilateral neck cut. The MASK system used was previously described by Foole and Fletcher (1995). Each bird was individually placed in a plexiglass box, after which the gas mixture of 70% argon and 30% carbon dioxide was introduced at a constant pressure of 140 KPa for approximately 2 min. The dead bird was removed from the box, hung on a shackle, and bled immediately as described in the LV treatment. The birds were scalped at 56 C for 2 min in a batch scaler, picked for 30 s in a rotary drum batch picker and hand eviscerated. The birds were then placed into a static ice-water slush until the appropriate deboning time.

For Trial 1, only post-mortem sampling times of 1, 3, and 5 h were used on 52 birds, unequally divided among the three sampling times. For Trials 2 through 4, sampling times of 0.25, 1, 3, 5, and 24 h were used, with 80 birds equally distributed between the treatments and sampling times. From each bird, one breast fillet, consisting of the boneless, skinless Pectoralis major, was sampled for pH determination using the iodoacetate method of Jeacocke (1977). The other breast fillet was excised, placed into a plastic bag, and held at 4 C for 24 h prior to cooking and Allo-Kramer shear determination, as described by Papinaho and Fletcher (1996). Breast filets were cooked for 20 min at 95 C in steam, and a 25-mm diameter core was removed from the thickest part of the muscle. The core was weighed and then sheared using an Allo-Kramer shear cell attached to an Instron Universal Testing Machine.3

**Experiment 2**

In each of three trials, 60 birds were obtained from a local processing plant and handled as described in Experiment 1. The birds were equally distributed among three stunning and killing treatments, and five post-mortem sampling times of 0.25, 1, 3, 5, and 24 h. The three treatments were LV, MASK, both as previously described, and a high current electrical system (HC). For the HC system, birds were individually stunned using a constant current stunner set at 125 mA and 50 Hz for 5 s, to simulate stunning systems recommended for use in the European Community. The birds were then processed as described...
in Experiment 1. At each sampling time, one breast fillet was sampled for pH determination and R-value (the ratio of the absorbances at 250 and 260 nm, indicating the ratio of inosine to adenosine nucleotides) determination, using the method of Honikel and Fisher (1977). The other breast fillet was excised, placed in a plastic bag, and held at 4°C for 24 h. The color of the outside anterior portion of the breast fillet was excised, placed in a plastic bag, and held at 4°C for 24 h. The color of the outside anterior portion of the breast fillet was measured in duplicate with a Minolta Colorimeter II,\(^4\) using the C.I.E.-Lab color scale and illuminant C, and the two measurements were averaged together. The breast fillet was then weighed, cooked, and reweighed to determine cooked yield. Allo-Kramer shear was determined as previously described.

### Statistical Analysis

In Experiment 1, there were two treatments, five sampling times, and four trials. In Trial 1, however, there were 52 birds, which were not evenly distributed among the three sampling times (1, 3, and 5 h post-mortem). The data were analyzed using analysis of variance of the General Linear Models procedure of SAS\(^\text{®}\) (SAS Institute, 1988) and the means separated using a protected Least Significant Difference. Because there were no significant interactions between trial and stunning treatment, the main effects were tested using residual error.

In Experiment 2, there were three treatments, five sampling times, and three trials, with each trial consisting of 60 birds evenly distributed over the treatments and sampling times, for a total of 180 birds. The data were analyzed using analysis of variance of the General Linear Models procedure of SAS\(^\text{®}\) (SAS Institute, 1988) and the means separated using Duncan’s Multiple Range test. Again, there were no significant interactions between the trial and stunning treatment, so main effects were tested using residual error. The pH and R-value data were also subjected to linear regression using the General Linear Models option of SAS\(^\text{®}\) (SAS Institute, 1988) to generate regression coefficients and to test stunning treatment effects from 0.25 to 5 h post-mortem sampling times. Significance of intercept and slope estimates by treatment were determined using the solutions option of the homogeneity-of-slopes model.

### RESULTS AND DISCUSSION

From 0.25 h to 5 h post-mortem, there were no significant pH differences between the LV and MASK treatments (Table 1). At 24 h post-mortem, however, the LV treatment resulted in a significantly higher pH of 5.96, as opposed to the MASK treatment value of 5.89. Nevertheless, this difference was quite small (0.07) and would not be expected to cause any major differences in final meat quality.

Shear values for the two stunning treatments in Experiment 1 are presented in Table 1. No differences were noted among the two treatments except at 5 h post-mortem. The MASK system resulted in breast fillets with a Allo-Kramer shear value of 5.95, which would be considered "slightly to moderately tender", and the LV stun system resulted in breast meat shear value of 5.20, which would be considered "moderately to very tender", based on the work of Lyon and Lyon (1990).

The results for breast muscle pH, R-value, and shear determinations from Experiment 2 are presented in Table 2. At post-mortem sampling times of 0.25, 1, and 3 h, the HC system consistently resulted in significantly higher breast muscle pH values than the LV or MASK treatments. There was no difference at 5 h post-mortem, but there was a significant difference between the LV (5.89) and MASK (5.94) systems at 24 h. For R-value determinations, there were significant differences up to 5 h post-mortem, with the HC system resulting in the lowest values. Only at 3 h post-mortem did the MASK result in a significantly lower R-value (1.059) than the LV system (1.095), with both being significantly higher than the values from the HC system (0.933). For shear determinations, no one treatment mean was significantly different from another, except at 5 h post-mortem, when HC stunning produced significantly tougher samples, with a value of 5.01, as compared to 2.89 and 3.40 for LV and MASK, respectively. By 24 h however, there were no differences in the tenderness of the breast meat.

Cooked yield values of the breast fillets are not presented, because there were no significant differences between treatments at any sampling time (72.33 ±

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\(^4\)Minolta Corp., Ramsey, NJ 07446.
0.26%). Also, Lightness (L*) and yellowness (b*) values were not significantly different between treatments at any sampling time (46.7 ± 0.2 and 2.8 ± 0.1, respectively). At 1 h post-mortem however, there was a significantly higher redness (a*) value of the breast fillets from the LV birds (4.0 ± 0.3) compared to the breast fillets from the other two treatments (HC = 3.0 ± 0.2 and MASK = 3.2 ± 0.2).

The regression results for the breast muscle pH and R-value for the first 5 h post-mortem are presented in Table 3. The breast muscles from the HC birds exhibited the significantly highest intercept value for pH (6.67), and a significantly greater negative slope (−0.135 vs −0.090 and −0.088 for the LV and MASK systems, respectively). The higher intercept is indicative of delayed rigor development whereas the stunner used in Experiment 1 of this study recommended for use in the European Community, used low voltage (11V, 500 Hz for 10 s), as is widely used in the U.S. The difference in electrical stunning

### Table 2. Effects (± SEM) of low voltage stunning (LV), high current killing (HC) and modified atmosphere stunning/killing (MASK) on time post-mortem on pH, R-value, and Allo-Kramer shear, Experiment 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>0.25 h</th>
<th>1 h</th>
<th>3 h</th>
<th>5 h</th>
<th>24 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>HC</td>
<td>6.62 ± 0.03b</td>
<td>6.56 ± 0.04a</td>
<td>6.34 ± 0.06b</td>
<td>5.94 ± 0.05</td>
<td>5.88 ± 0.04b</td>
</tr>
<tr>
<td></td>
<td>LV</td>
<td>6.31 ± 0.05b</td>
<td>6.09 ± 0.05b</td>
<td>5.89 ± 0.04</td>
<td>5.84 ± 0.05</td>
<td>5.77 ± 0.04b</td>
</tr>
<tr>
<td></td>
<td>MASK</td>
<td>6.40 ± 0.04b</td>
<td>6.31 ± 0.05b</td>
<td>6.11 ± 0.04b</td>
<td>5.96 ± 0.05</td>
<td>5.94 ± 0.06b</td>
</tr>
<tr>
<td>R-value</td>
<td>HC</td>
<td>0.905 ± 0.009b</td>
<td>0.909 ± 0.009b</td>
<td>0.933 ± 0.022c</td>
<td>1.144 ± 0.040b</td>
<td>1.341 ± 0.015</td>
</tr>
<tr>
<td></td>
<td>LV</td>
<td>0.986 ± 0.029a</td>
<td>1.022 ± 0.029a</td>
<td>1.195 ± 0.035a</td>
<td>1.264 ± 0.032b</td>
<td>1.357 ± 0.020</td>
</tr>
<tr>
<td></td>
<td>MASK</td>
<td>0.945 ± 0.015ab</td>
<td>0.991 ± 0.026a</td>
<td>1.059 ± 0.030b</td>
<td>1.261 ± 0.026b</td>
<td>1.340 ± 0.016</td>
</tr>
<tr>
<td>Shear, kg</td>
<td>HC</td>
<td>4.94 ± 0.41</td>
<td>8.73 ± 0.78</td>
<td>8.01 ± 0.83a</td>
<td>5.01 ± 0.76a</td>
<td>3.10 ± 0.34</td>
</tr>
<tr>
<td></td>
<td>LV</td>
<td>6.52 ± 1.20</td>
<td>6.66 ± 0.80</td>
<td>4.32 ± 0.52b</td>
<td>2.89 ± 0.24b</td>
<td>3.22 ± 0.14</td>
</tr>
<tr>
<td></td>
<td>MASK</td>
<td>4.85 ± 0.52</td>
<td>8.56 ± 1.36</td>
<td>5.64 ± 1.07ab</td>
<td>3.40 ± 0.15b</td>
<td>3.06 ± 0.16</td>
</tr>
<tr>
<td>P</td>
<td>HC</td>
<td>0.0010</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.2186</td>
<td>0.0618</td>
</tr>
<tr>
<td></td>
<td>LV</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0002</td>
<td>0.2186</td>
<td>0.0618</td>
</tr>
<tr>
<td></td>
<td>MASK</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.2186</td>
<td>0.0618</td>
</tr>
</tbody>
</table>

### Table 3. Regression coefficients for the effects of low voltage stunning (LV), high current killing (HC), and modified atmosphere stunning/killing (MASK) on time post-mortem from 0.25 to 5 h for pH and R-value data, Experiment 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>Intercept</th>
<th>Slope</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>HC</td>
<td>6.67 ± 0.04a</td>
<td>−0.135 ± 0.013b</td>
<td>0.707</td>
</tr>
<tr>
<td></td>
<td>LV</td>
<td>6.24 ± 0.04a</td>
<td>−0.090 ± 0.013b</td>
<td>0.512</td>
</tr>
<tr>
<td></td>
<td>MASK</td>
<td>6.39 ± 0.03b</td>
<td>−0.088 ± 0.012a</td>
<td>0.550</td>
</tr>
<tr>
<td>R-value</td>
<td>HC</td>
<td>0.870 ± 0.021b</td>
<td>0.046 ± 0.007</td>
<td>0.478</td>
</tr>
<tr>
<td></td>
<td>LV</td>
<td>0.983 ± 0.024a</td>
<td>0.059 ± 0.008</td>
<td>0.537</td>
</tr>
<tr>
<td></td>
<td>MASK</td>
<td>0.927 ± 0.020ab</td>
<td>0.061 ± 0.007</td>
<td>0.638</td>
</tr>
</tbody>
</table>

a,b,cMeans within a column and measurement with no common superscript differ significantly (P ≤ 0.05); n = 12 per mean.

For example, HC pH = [time in h] × (−0.135) + 6.67.

Mean ± SEE.
systems (i.e., high vs low current) has been suggested as a possible reason why there are differences between the HC and gas, and no difference between the LV and gas stunning/killing (Raj and Fletcher, 1995). Experiment 2 was conducted to determine whether previous differences seen in meat quality from birds subjected to gas stunning were due more to the method of electrical stunning rather than the gas itself.


REFERENCES


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