The Effects of Low-Atmosphere Stunning and Deboning Time on Broiler Breast Meat Quality

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ABSTRACT A randomized complete block design with 3 replications (n = 432, 72 broilers per treatment) was used to evaluate the effects of electrical (ES) and vacuum stunning (VS) on broiler breast meat quality. Electrical stunning was performed by applying 11.5 V, <0.05 mA, AC to DC current for 3 s for each broiler. Vacuum stunning was accomplished by exposing the birds to a low atmospheric pressure of 597 to 632 mmHg in an airtight decompression chamber. Breast removal was then performed at 0.75, 2, and 4 h postmortem for each stunning method. Color, pH, cook loss, and shear force values were measured on breasts that were removed from the right side of the carcass. Breasts removed from the left side of the carcass were used for consumer acceptability testing. The L* values were lower ($P < 0.05$) for VS than ES at 4- and 2-h deboning times. On average, 15-min and 24-h postmortem pH values were not different ($P > 0.05$) for both stunning method and deboning time. Shear force did not differ ($P > 0.05$) between stunning methods but decreased ($P < 0.05$) as deboning time increased. On average, no differences ($P > 0.05$) existed in consumer acceptability (appearance, texture, flavor, overall) among breast meat from ES or VS birds that were deboned at 2 or 4 h. However, consumers could be clustered into 8 groups based on preference and liking of samples regarding overall and texture acceptability. Sixty-five percent of consumers (3 clusters) liked all broiler breast treatments. Within these 3 clusters, some consumers preferred ($P < 0.05$) 4-h deboned samples over those deboned at 2 h (cluster 7), and other consumers preferred ($P < 0.05$) those deboned at 2 h over 4-h samples (cluster 6). Data revealed that both stunning methods provided high-quality breast meat with minimal product differences.

Key words: electrical stunning, vacuum stunning, deboning time, breast meat quality

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INTRODUCTION

In recent years, animal stunning has been primarily viewed from an animal welfare perspective as a means of minimizing the pain and suffering associated with slaughter, which should produce a rapid onset of stress-free insensibility of sufficient duration to keep the animal unconscious until harvested (Fletcher, 1999). Poultry stunning includes methods that immobilize the birds for the harvesting machine, provide a uniform heartbeat for efficient exsanguination, and relax the feather follicles for easier picking. (Fanatico, 2003). Stunning, neck cutting (killing), and bleeding operations are inseparable and interrelated steps in the harvesting process (Bilgili, 1999), and relationships exist between stunning method, killing, muscle metabolism, and broiler meat quality (Fanatico, 2003).

Stunning before harvest can be accomplished by using chemical, mechanical, vacuum, or electrical means (Fletcher, 1999). Low atmospheric pressures in the range of 0.2 to 0.3 atm are created in vacuum stunning to stun broilers. To date, minimal information has been published regarding the effects of vacuum stunning on poultry welfare and meat quality. Purswell et al. (2007) recently reported that vacuum (low-atmospheric) stunning appeared to be an effective method for humanely stunning and killing chickens. In addition, it has been reported that vacuum stunning has been approved in Europe for use in farmed game species such as the partridge, pheasant, and quail (European Commission, 2003), but there is no other published information regarding this stunning method. Electrical stunning is the most commonly used method for immobilizing poultry before harvest in commercial poultry plants (Goksoy et al., 1999). The effectiveness of an electrical stunning system is dependent on electrical variables (i.e., current, voltage, wave form, frequency, and duration) and biological factors that affect bird impedance (i.e., size, weight, sex, and feather cover; Kettlewell and Hallworth, 1990). Electrical stunning reduces struggle and convulsions during harvest and subse-

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quently reduces carcass damage associated with convulsions (Fletcher, 1999). However, electrical stunning has been shown to cause meat quality defects such as wing hemorrhages, red skin conditions, red wing tips, broken bones, and blood blemishes in breast muscle (Bilgili, 1992; Lambooij et al., 1999; Wilkins et al., 1999). During electrical stunning, broilers may defecate, fling their claws into the broilers around them, and inhale contaminated water, which leads to carcass contamination and carcass downgrades (Gregory and Whittington, 1992). To eliminate these problems, controlled-atmosphere harvesting systems (gas-stunning techniques) have been developed. The induction of unconsciousness with gas is rapid and requires less exposure time for broilers. Because the broilers are dead by the time they are shackled, controlled-atmosphere stunning can result in improved product quality and yield by eliminating the risk of broken bones, bruising, and hemorrhaging. Researchers have reported that stunning of broilers with a gas mixture improves the quality of broiler breast meat when compared with electrical stunning (Raj et al., 1997; Raj, 1998). Research needs to be conducted to determine whether similar results are present when vacuum stunning is used.

Researchers have reported significant relationships between ultimate pH and poultry meat quality (Fletcher, 1999; Van Laack et al., 2000). The rate and extent of postmortem pH decline are 2 major factors that affect many properties of meat, including objective color, water-holding capacity (**WHC**), protein solubility, and rate of microbial spoilage (Bendall, 1973; Cornforth, 1994). Antemortem stress and postmortem lactic acid production, along with protein denaturation while the muscle temperature is still elevated, result in meat quality defects such as poor texture, decreased WHC, decreased juiciness, and increased incidence of pale, soft, and exudative (**PSE**) meat (McKee and Sams, 1997; Solomon et al., 1998; Sosnicki et al., 1998).

Two approaches have been developed to avoid meat quality problems associated with color, WHC, and tenderness: accelerated processing based on electrical stimulation of the carcasses (Zocchi and Sams, 1999) and the introduction of aging times into the process. The period of time between harvest and deboning (aging) in broiler processing is important because it contributes to meat tenderness (Schilling et al., 2003). Short aging, such as early deboning, results in an increase in toughness, which is a highly undesirable trait for broiler meat (Lyon et al., 1985). Poultry processing plants currently age broilers for 4 to 7 h to ensure that broiler breast meat is tender (Lyon and Lyon, 1990; Sams, 1999; Schilling et al., 2003). Many technologies, including electrical stimulation (Maki and Froning, 1987; Sams et al., 1989), wing restraints, or tensioning (Birkhold et al., 1992; Birkhold and Sams, 1993), marination (Young and Lyon, 1997), postchill flattening, or extended holding of deboned breasts (Lyon et al., 1992), have been devised to minimize the need for postmortem aging. Because limited research has been conducted regarding the effects of vacuum stunning on meat quality, this study was designed to determine whether electrical and vacuum stunning varied in their effects on the tenderness, color, pH, pH decline, and sensory acceptability of broiler breast meat deboned at various times postmortem.

MATERIALS AND METHODS

Sample Procurement

A total of 432 Ross 708 birds (mixed sex, and approximately 48 d of age) reared at the Mississippi State University Leveck Animal Research Center poultry facility were randomly selected for processing by 1 of 2 stunning methods: electrical and vacuum. Feed was withdrawn 12 h before harvest, and broilers were allowed unlimited access to water. Broilers were transported in live-haul crates from the Leveck Animal Research Center poultry facility to the poultry processing plant (less than 0.5 km) at 0500 h (before sunrise) to minimize stress.

Electrical Stunning

Broilers were hung by their feet in steel shackles and were electrically stunned by manually placing their heads in a saturated saline bath (11.5 V, <0.5 mA, AC to DC current for 3 s). The shackle line speed was constant and set so that approximately 22 broilers were stunned per minute. Unilateral neck cutting was manually performed immediately after stunning, and bleeding lasted for 140 s. Upon completion of exsanguination, the broilers were scalded at 53.3°C for 191 s, picked for 35 s by using a rotary drum picker (Baader-Johnson, Kansas City, KS), and then mechanically eviscerated.

Vacuum Stunning

Broilers were stunned by using a commercial prototype of a low atmospheric pressure harvest system (Technocatch LLC, Kosciusko, MS). This prototype consisted of a round reinforced mild steel shell 2.3 m in diameter and 3 m long, with a gravity roller bed allowing for full cage insertion and retrieval. Low atmospheric pressure was accomplished by means of a series of vacuum-rated butterfly valves used for vacuum application and release. The low atmospheric pressure was achieved by using 2 vane-type vacuum pumps, each rated at 14 m^3/min. These pumps were connected to the chamber through 2 separate pipes, each with its own control valve. An additional valve was connected via piping to the tank for vacuum release. A computer-based data acquisition and control system (USB-1208FS, Measurement Computing Corp., Norton, MA) was used to monitor tank pressure and control pump action. Cages with 24 broilers were placed into this airtight decompression chamber and a low atmospheric pressure of 597 to 632 mmHg was achieved. All broilers were maintained in the decompression chamber for 2 min. After ataxia (loss of posture, resulting in the inability to maintain a standing position and no neck tension at the onset of unconsciousness), broilers were decapitated manually. Bleeding, scalding, picking, and evisceration steps were identical to the procedures listed in the electrical stunning section.

After harvest, broiler carcasses were stored in ice water in metal (173 cm in length, 85 cm in width, and 68.5 cm in depth) and rubber containers (142 cm in length, 81 cm in width, and 50.8 cm in depth) to mimic the chilling process in a poultry plant. Twenty-four birds per replication for each stunning method were randomly selected for whole breast removal and deboning at 0.75, 2, and 4 h postmortem. Each whole breast was placed into a labeled Ziploc bag (S. C. Johnson & Son Inc., Racine, WI) and cooled (2°C) overnight. At 24 h postmortem, the whole breast was separated into right and left halves. Color and pH were measured on the breast samples (right side of carcass) and then individually vacuum packaged (Turbovac 320-ST-S, Inject Star of the Americas Inc., Brookfield, CT) in 15.2 × 20.3 cm, 3-mil vacuum pouches (Rebel Butcher Supply Co. Inc., Flowood, MS), labeled, and stored frozen (–23°C) in a walk-in freezer until cook loss and shear force determinations could be performed. The breasts from the left side of the carcass were bagged (6 breasts per bag), vacuum packaged (40.64 × 50.8 cm, 4-mil vacuum pouch; Rebel Butcher Supply Co. Inc.), and frozen (–23°C) until consumer sensory acceptability tests could be performed.

Treatment Effects

Six treatments were used in this trial to evaluate the effects of stun method and deboning time on broiler breast meat quality: electrical stunning, deboned at 45 min postmortem (ES 0.75H); electrical stunning, deboned at 2 h postmortem (ES 2H); electrical stunning, deboned at 4 h postmortem (ES 4H); vacuum stunning, deboned at 45 min postmortem (VS 0.75H); vacuum stunning, deboned at 2 h postmortem (VS 2H); vacuum stunning, deboned at 4 h postmortem (VS 4H).

pH Measurement

A pH meter (Model Accumet 61a, Fisher Scientific, Hampton, NH) was used to measure the pH of 24 broilers per replication at 15 min postmortem (pH_{15}) by inserting a pH probe (Model FlexipHet SS Penetration tip, Cole Palmer, Vernon Hills, IL) 2.5 cm below the pectoralis major muscle at approximately 2.5 cm from the top of the breast and 2.5 cm from the breast bone. At 24 h postmortem, ultimate pH (pH_u) measurements for each sample were taken by using the same pH meter in the same anatomical location as the 15-min pH measurements.

Color Measurement

Instrumental color measurements were taken for each breast within each treatment by using a chromameter (Chromameter Model CR-200, Minolta Camera Co. Ltd., Osaka, Japan) that was calibrated by using a standard white calibration plate (Model 20933026, Minolta Camera Co. Ltd.). Three measurements were taken at 3 identical locations for each breast on the medial portion of the pectoralis major muscle. Color for each sample was expressed in terms of CIE values for lightness (L*), redness (a*), and yellowness (b*).

Cooking Loss

Frozen breast samples were thawed (2°C) overnight, trimmed to an approximate weight of 120 g, and vacuum packaged in 15.2 × 20.3 cm, 3-mil cooking bags (Rebel Butcher Supply Co. Inc.). Samples were cooked by immersing cooking bags in hot water (85°C) for approximately 20 min until an internal temperature of 80°C was reached. A poultry thermometer (beef and poultry thermometer; Chaney Instrument Co., Lake Geneva, WI) was inserted into the middle portion of a breast sample before packaging to measure the internal temperature of the sample. The bags were tempered at ambient temperature (20°C) before opening to drain the liquid from each bag. Each breast sample was patted dry with one paper towel (one ply) and reweighed. Cooking loss was reported as a percentage and calculated as (initial weight – final weight)/(initial weight) × 100.

Warner-Bratzler Shear Force Determination

Tenderness was assessed by using an objective texture procedure described in Meek et al. (2000). Breasts that were used for cooking loss determinations were cooled to room temperature and used for shear force determinations. Four to 6 adjacent 1-cm (width) × 1-cm (thickness) × 2-cm (length) strips were cut from the cooked breast, parallel to the direction of the muscle fibers. Each strip was sheared once, and the mean was calculated for each breast. Samples were sheared perpendicular to the muscle fibers by using a Warner-Bratzler shear attachment mounted on an Instron Universal Testing Center (Model 3300, Instron, Norwood, MA) with a 50-kg load transducer and a crosshead speed of 200 mm/min.

Sensory Analysis

Three consumer-based sensory panels (n = 50 to 55 panelists per replication) were conducted to evaluate the acceptability of broiler breast meat harvested with different stunning methods at various deboning times. Each panel consisted of students, staff, and faculty at Mississippi State University. Participants were recruited with an advertising sign and by word of mouth for participation, and samples were cooked as described for the cooking loss and tenderness evaluations. Breast meat samples were cooked to an internal temperature of 80°C, cooled for 15 min to rest the meat, cut into 1-cm cubes, and placed into labeled plastic bags. The breast meat samples were then kept in a warm water bath (60 to 70°C) until panelists evaluated the samples. Random 3-digit numbers were used to identify the samples, and each participant evaluated 6 treatment samples. Participants were asked to evaluate the sample's overall acceptability, and the sample's acceptability with respect to appearance, texture, and flavor on a 9-point hedonic scale. The category definitions were as follows: 9 = like extremely; 8 = like very much; 7 = like moderately; 6 = like slightly; 5 = neither like nor dislike; 4 = dislike slightly; 3 = dislike moderately; 2 = dislike very much; 1 = dislike extremely (Meilgaard et al.,1999). Acceptability of texture was defined as product liking with respect to tenderness. Acceptability of appearance was defined as product liking with respect to color and moisture, and acceptability of flavor was defined as product liking with respect to chicken flavor (taste). Panelists were asked to evaluate all attributes for each sample before evaluating the next sample and to evaluate one sample at a time, going from left to right. Sample order was also randomized to account for sampling order bias. Water and unsalted crackers were provided, and panelists were asked to expectorate and rinse their mouths between each sample.

Statistical Analysis

A randomized complete block design (replications as blocks) with 3 replications (n = 432, 72 broilers per treatment) was used to test the treatment effects ($P < 0.05$) of stunning method with different deboning times on pH decline, ultimate pH, color, cooking loss, and shear force. When significant differences occurred ($P < 0.05$) among treatments, the Fisher's least significant difference test was used to separate treatment means. A randomized complete block design (replications and panelists as blocks) with 3 replications was used to test the treatment effects ($P < 0.05$) of stunning method and deboning time on the sensory acceptability (appearance, texture, and flavor) and overall acceptability of the chicken breasts. Agglomerative hierarchical clustering using Ward's method (XL Stat 2006, Addinsoft USA, New York, NY) was performed to group panelists together based on their preference and liking of broiler breast meat. A dendrogram and a dissimilarity plot were used to determine how many clusters should be used to group panelists. After separating the data into clusters, the entire data set was evaluated to confirm that the data for each panelist were relatively close to the means of the treatments that were within the cluster into which they were grouped. After conducting agglomerative hierarchical clustering, randomized complete block designs (panelists as blocks) were performed within each cluster, and the least significant difference test was used to separate treatment means within a cluster when significant differences ($P < 0.05$) occurred.

RESULTS AND DISCUSSION

pH and Color

At 15 min postmortem, the mean pH of breast meat did not differ ($P > 0.05$) between electrical (6.39) and vacuum (6.42) stunning methods. However, 15-min pH from vacuum-stunned birds had a higher number of samples between 5.9 and 6.2 than 15-min pH from electrically stunned birds. Electrically stunned birds had a higher number of samples between 6.2 and 6.5 than vacuum-stunned birds at 15 min (Figure 1). This suggests that vacuum stunning may cause rigor development to occur slightly more rapidly than electrical stunning in some broilers. However, neither stunning method had a large number of 15-min pH samples with pH below 6.0, with a 4.2% incidence in vacuum-stunned birds and a 1.4% incidence in electrically stunned birds. Results from this study are similar to those of Debut et al. (2003), who reported that pH at 15 min postmortem was between 6.3 and 6.6 for broiler breast meat from electrically stunned carcasses. At 24 h postmortem, pH did not differ ($P > 0.05$) among deboning times or between stunning methods (Table 1). The pH is an indicator of meat quality, and a low pH (<5.7) at 24 h postmortem is indicative of poor meat quality (Fernandez et al., 1994; Alvarado et al., 2007). Papinaho and Fletcher (1995) reported no differences in 24-h postmortem pH values between stunned and non-stunned broilers, and Alvarado et al. (2007) reported no difference in ultimate pH of breast meat from broilers that were CO_2- and electrically stunned. The reported mean ultimate pH values of 5.7 and 5.76 for pale meat and 5.96 and 6.07 for normal meat (Van Laack et al., 2000; Woelfel et al., 2002) were similar to the mean values in the present study, in which the majority of broiler breast samples were in the pH range of 5.8 to 6.1. This reveals that use of vacuum stunning should not have a major impact on broiler breast meat quality because pH decline was similar. On average, occurrence of rapid pH decline was minimal, and pH decline is one of the factors that affects the onset and rate of rigor development and breast meat quality (Pearson, 1987; Sams et al., 1990; Fleming et al., 1991; McKee and Sams 1997).

All chicken breast samples were darker ($P < 0.05$) when deboned at 0.75 h postmortem than samples that were deboned at 4 h postmortem for both stunning methods (Table 1). The L* values were also lower ($P < 0.05$) in the vacuum-stunning treatments at 0.75 h postmortem and 4 h postmortem when compared with electrically stunned birds deboned at the same time. It appears that the use of vacuum stunning causes a shift in breast meat color in the broiler population so that a greater proportion of samples have CIE L* values between 50 and 55, and fewer samples have CIE L* values that are greater than 55 when compared with electrically stunned birds that are deboned at the same time (Figure 2). Differences ($P < 0.05$) also occurred among treatments in redness and yellowness, with ranges of 1.2 to 1.6 and 1.4 to 2.1 for a* and b*, respectively (Table 1). Previous studies have used L* values as a measure to estimate the incidence of paleness or the PSE condition in broiler breast meat, or both (Barbut, 1998; Van Laack et al., 2000; Woelfel et al., 2002). Some researchers (Van Laack et al., 2000; Woelfel et al., 2002) have reported that an average L* value greater than 60 is pale meat, whereas Barbut (1998) indicated that an L* value greater than 55 can be used as a cutoff to indicate the PSE condition in broiler breast meat. Van Laack et al.

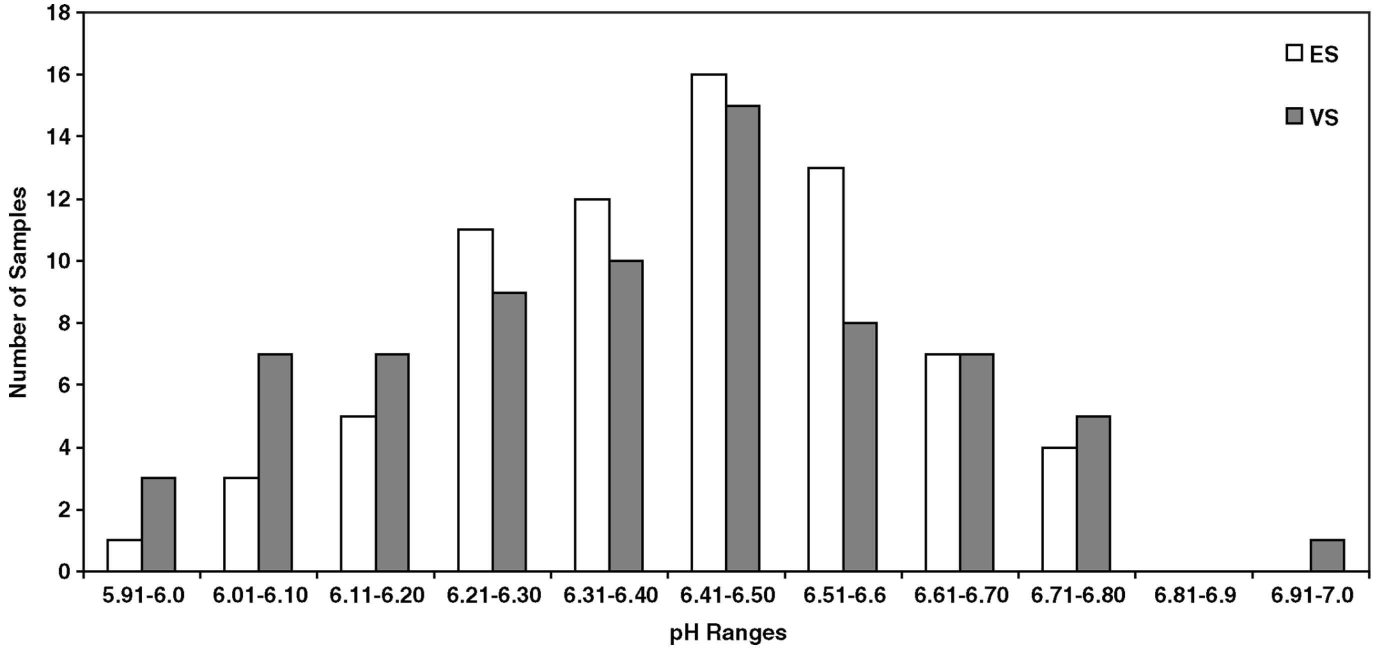

Figure 1. Graph representing the number of samples (n = 72) within various pH at 15 min postmortem for breast meat harvested from broilers that were either electrically stunned (ES) or vacuum stunned (VS).

(2000) reported that breasts appearing to be normal had L* values of 55 and those appearing to be pale had CIE L* values of 60; they stated that high L* values and low ultimate pH (<5.7) were indicative of broiler breast meat that was pale in color with low WHC. The L*, a*, and mean ultimate pH values from our study (5.8 to 6.1) were very similar to the values (5.9 to 6.1) that have been reported by previous researchers as characteristic of normal broiler breast meat at 24 h postmortem for all treatments that were evaluated (Barbut, 1998; Sams, 1999; Van Laack et al., 2000; Woelfel et al., 2002).

Cooking Loss

There were no significant differences ($P > 0.05$) in cooking loss percentages between the 2 stunning methods at any of the deboning times (Table 1). However, the ES 0.75H (24.0) treatment had greater ($P < 0.05$) cooking loss than the VS 4H (22.6) and ES 4H (22.7) treatments, but no other differences existed ($P > 0.05$). These results suggest that implementing vacuum stunning should not cause any difference in cooking loss and juiciness when compared with electrical stunning. The data are in agreement with previous studies by Raj et al. (1990) and Lambooij et al. (1999), in which stunning method did not result in cooking loss differences. Raj et al. (1990) reported that gaseous stunning did not affect the cooking loss compared with electrical stunning. Northcutt et al. (1998) observed no cook loss effect caused by stunning method in turkey meat.

Instrumental Tenderness

Shear values indicate the maximum force required to cut through the sample and relate to the hardness of the sample. Higher values indicate that more force is required to shear the sample, and these relate to an overall measurement of sensory "toughness." Warner-Bratzler shear values (hardness) decreased ($P < 0.05$) with increased postmortem deboning times, but no differences ($P > 0.05$)

Table 1. The effects of stunning method (vacuum or electrical) and deboning time on the color, ultimate pH, shear force, and cooking loss of broiler breast meat

Treatment[1]	24-h pH	CIE L* (lightness)	CIE a* (redness)	CIE b* (yellowness)	Shear force (N)	Cooking loss (%)
VS 4H	5.99^{a}	56.1^{b}	1.6^{a}	1.8^{ab}	19.9^{c}	22.6^{b}
ES 4H	5.95^{a}	57.3^{a}	1.3^{b}	2.1^{a}	20.6^{c}	22.7^{b}
VS 2H	5.91^{a}	55.5^{bc}	1.4^{a}	1.9^{a}	22.7^{b}	22.5^{ab}
ES 2H	5.95^{a}	56.3^{b}	1.3^{b}	1.8^{a}	22.6^{b}	23.3^{ab}
VS 0.75H	5.94^{a}	53.4^{d}	1.3^{b}	1.4^{c}	33.1^{a}	23.0^{ab}
ES 0.75H	5.95^{a}	55.1^{c}	1.2^{b}	1.4^{bc}	33.6^{a}	24.0^{a}
SE	0.01	0.31	0.09	0.13	0.60	0.40

[a–c]Means within a column with the same letter are not significantly different ($P > 0.05$).

[1]VS = vacuum stunning; ES = electrical stunning; H = hours deboned after slaughter.

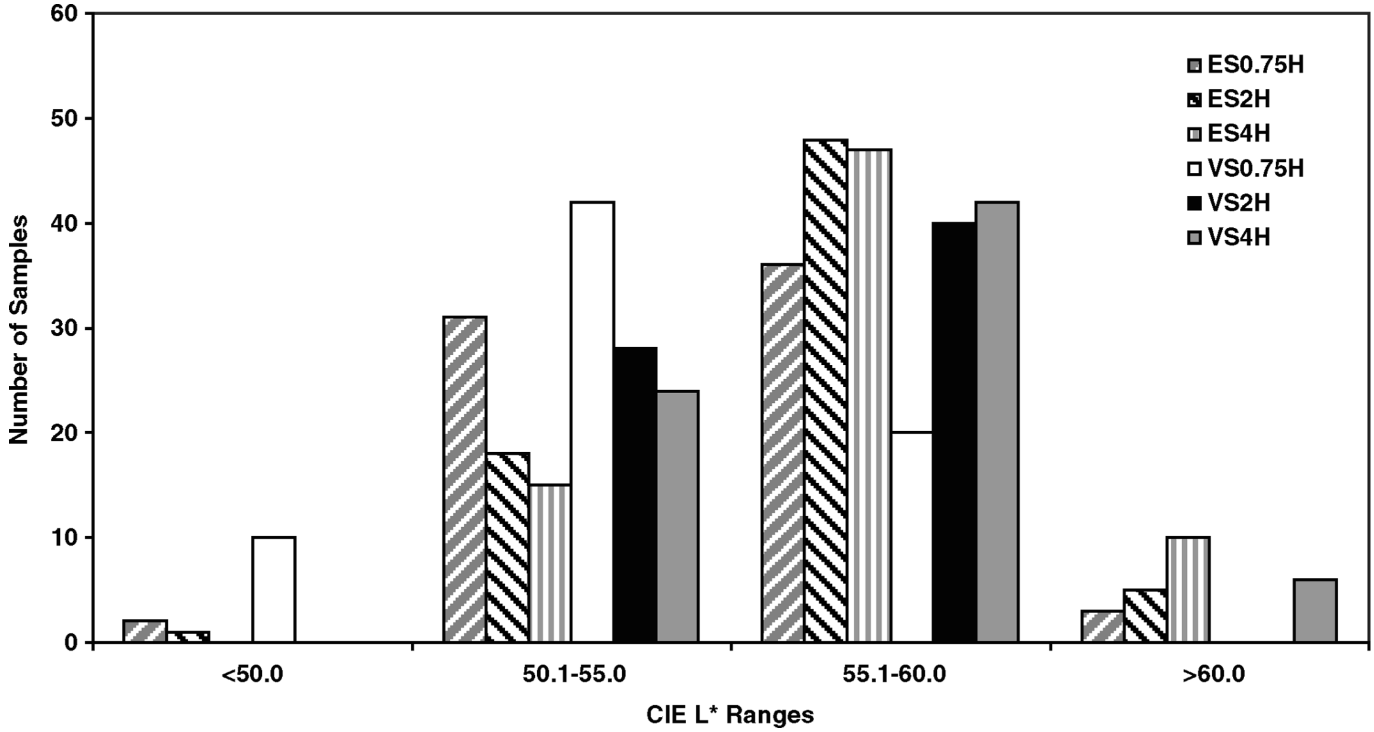

Figure 2. Graph representing the number of broiler breast samples (n = 72) for each treatment within different ranges for CIE L*. ES and VS represent electrical stunning and vacuum stunning; 0.75, 2, and 4 represent postmortem deboning time.

existed between electrical-stunning and vacuum-stunning treatments at any of the 3 deboning times (Table 1). This reveals that vacuum stunning would not improve or would negatively affect tenderness, and that it would still be beneficial to age broiler breast meat for at least 4 h before removing breast meat from the bone, regardless of the stunning method. This observation agrees with previous reports (Lyon et al., 1989, 2003; Thielke et al., 2005) and reemphasizes the importance of an aging period before breast meat removal from the carcass. On average, almost all breasts required less than 45 N to shear through the breast meat and would be acceptable in tenderness to a large percentage of consumers (Schilling et al., 2003). Several studies have attempted to determine the minimum time of aging that is necessary before deboning broiler breast meat. Sams (1999), Stewart et al. (1984), Lyon et al. (1985), and Dawson et al. (1987) reported that some time between 2 and 4 h postmortem was the critical period after which deboning did not cause toughening of meat. This phenomenon also appeared to be true in this research for both electrical and vacuum stunning.

Consumer Acceptability

Consumer acceptability scores for the appearance, texture, flavor, and overall acceptability of breast meat were affected ($P < 0.05$) by postmortem deboning time, but not by stunning method. However, consumer acceptability scores for texture of broiler breast meat were different ($P < 0.05$) between stunning methods at the 0.75-h postmortem deboning time (Table 2). The mean scores for all sensory attributes were increased with deboning time for both stunning methods. This reveals that postmortem deboning had a greater impact than stunning method on sensory characteristics and consumer acceptability. It is apparent from the data that, on average, breast meat that was deboned at either 2 or 4 h postmortem was very acceptable to consumers regardless of the stunning method that was used.

Because consumers vary so much in their perception of acceptability, cluster analysis was performed, and a dissimilarity plot was used to group the panelists into 8 clusters based on their preference and overall liking of cooked broiler breast meat (Table 3). It was apparent from these data that clusters 6, 7, and 8 liked the chicken breast treatments very much. Cluster 8 (24.4% of the panelists) rated all samples at a score of like very much. Cluster 7 (15.9%) preferred samples that were deboned for 4 h over other samples. Cluster 6 (26%) liked all samples but preferred the 2-h samples over the 4-h samples, probably because they liked tender meat but found the 4-h deboned meat to be too tender. There was no clear trend for clusters 1, 2, 4, and 5 (21.3% of all panelists). Cluster 3 (12.8%) liked chicken breast slightly to moderately, but preferred VS 4H, ES 4H, and ES 2H over all other treatments.

A dendrogram was also used to group consumers into 6 clusters based on dissimilarity in panelist response to the texture of cooked broiler breast meat (Table 4). Cluster 6 was the largest cluster (32.9%), and although statistical differences existed ($P < 0.05$), consumers scored all treatments as very acceptable. Cluster 5 (18.9%) liked the tex-

Table 2. The effects of stunning method and deboning time on the consumer acceptability[1] of appearance, texture, and flavor, and overall consumer acceptability of broiler breast meat determined by using consumer panels (n = 155)

Treatment[2]	Appearance acceptability	Texture acceptability	Flavor acceptability	Overall acceptability
VS 4H	7.0[ab]	7.0[ab]	7.0[a]	7.0[a]
ES 4H	7.1[a]	7.1[a]	6.9[ab]	6.9[ab]
VS 2H	6.9[ab]	6.9[ab]	6.8[abc]	6.9[ab]
ES 2H	7.1[ab]	7.0[ab]	6.8[abc]	6.9[ab]
VS 0.75H	6.8[b]	6.3[c]	6.6[c]	6.5[c]
ES 0.75H	7.0[ab]	6.7[b]	6.7[bc]	6.7[bc]
SE	0.10	0.11	0.11	0.11

[a–c]Means within a column with the same letter are not significantly different ($P > 0.05$).

[1]Hedonic scale was based on a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

[2]VS = vacuum stunning; ES = electrical stunning; H = hours deboned after slaughter.

ture of all treatments but had higher scores for ES 0.75H, VS 2H, and ES 4H when compared with the VS 0.75 H and ES 2H treatments. Cluster 4 (8.5%) liked the texture of all treatments except the VS 0.75 H treatment. On average, cluster 3 (17.1%) preferred ($P < 0.05$) samples that were deboned at 4 h over those deboned at 2 and 0.75 h and preferred ($P < 0.05$) samples deboned at 2 h over those deboned at 0.75 h. This cluster was probably very sensitive to differences in tenderness and preferred very tender samples. No trends were evident in cluster 2 (12.8%), but these panelists preferred ($P < 0.05$) the ES 0.75H treatment over all other samples. Cluster 1 (9.8% of panelists) preferred ($P < 0.05$) the texture of samples that were deboned at 2 and 0.75 h, probably because samples that were deboned at 4 h were too tender for their liking.

Tenderness or texture results for consumer acceptability varied slightly from Warner-Bratzler shear determinations. For the Warner-Bratzler shear values, differences ($P < 0.05$) were apparent only among deboning times and did not exist ($P > 0.05$) between stunning methods. For the tenderness or texture acceptability scores, there were slight differences ($P < 0.05$) among treatments within clusters. This may have occurred because consumers are highly variable in their perception of what it means for a sample to be acceptable or optimal in regard to tenderness. For example, Schilling et al. (2003) reported that there was not a direct relationship between Warner-Bratzler shear values and consumer liking of tenderness, and that some consumers preferred samples with shear values that were either between 20 and 30 N or 30 and 40 N over samples with shear values between 10 and 20 N. Minimal variation was apparent in cluster 1 and cluster 2, with the exception that panelists did not rate the acceptability of tenderness extremely high and did not like the tenderness or texture of the 0.75-h vacuum-stunned treatment. Clusters 3, 4, 5, and 6 consisted of 76% of the consumers and all liked chicken breasts very much. Cluster 3 appeared to be the cluster that was very sensitive to tenderness because there were slight variations ($P < 0.05$) between some vacuum-stunned and electrically stunned samples, but differences were greater between deboning times than stunning methods. Minimal differences existed among treatments for cluster 4, with the exception that panelists did not like the texture of the VS 0.75H treatment. From the results of this study, it is not possible to pinpoint why this occurred. Even though slight differences ($P < 0.05$) occurred in tenderness acceptability between stunning methods (within treatments) for clusters 5 and 6 (greater than 50% of the panelists), all of these consumers scored these treatments between like moderately and like very much on the hedonic scale, with the exception of the ES 2H treatment.

In conclusion, minimal quality differences existed among electrically and vacuum-stunned broiler breasts.

Table 3. Mean hedonic scores[1] for overall consumer acceptability of broiler breast meat with different stunning methods[2] and deboning times according to different clusters of consumer segments

Cluster	Panelists (%)	VS 4H	ES 4H	VS 2H	ES 2H	VS 0.75H	ES 0.75H
1	7.9	5.0[bc]	6.2[a]	5.8[ab]	4.2[c]	6.0[ab]	5.9[ab]
2	6.7	6.3[a]	4.5[b]	4.5[b]	6.5[a]	4.9[b]	6.7[a]
3	12.8	6.6[a]	6.4[a]	5.1[bc]	6.4[a]	5.6[b]	4.5[c]
4	2.4	7.8[a]	8.3[a]	8.3[a]	5.5[b]	8.0[a]	2.5[c]
5	4.3	7.9[a]	6.4[b]	7.9[a]	8.0[a]	3.0[c]	7.0[b]
6	25.6	6.5[cd]	6.5[cd]	7.5[a]	7.0[b]	6.9[bc]	7.0[b]
7	15.9	7.7[a]	7.5[a]	6.8[b]	6.6[bc]	6.3[c]	6.9[b]
8	24.4	8.0[a]	8.2[a]	7.8[a]	8.1[a]	7.9[a]	8.0[a]

[a–d]Means within a row with the same letter are not significantly different ($P > 0.05$).

[1]Hedonic scale was based on a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

[2]VS = vacuum stunning; ES = electrical stunning; H = hours deboned after slaughter.

Table 4. Mean hedonic scores[1] for texture acceptability[2] of broiler breast meat with different stunning methods[3] and deboning times according to different clusters of consumer segments

Cluster	Panelists (%)	VS 4H	ES 4H	VS 2H	ES 2H	VS 0.75H	ES 0.75H
1	9.8	5.9^{b}	4.8^{c}	7.1^{a}	6.4^{ab}	7.0^{a}	6.6^{ab}
2	12.8	5.9^{b}	5.9^{b}	5.6^{b}	6.2^{b}	4.0^{c}	7.0^{a}
3	17.1	6.7^{ab}	7.3^{a}	5.6^{c}	6.5^{b}	5.4^{c}	4.3^{d}
4	8.5	7.5^{ab}	6.9^{b}	8.0^{a}	7.9^{a}	4.4^{c}	7.1^{b}
5	18.9	6.8^{bc}	7.7^{a}	7.3^{ab}	5.9^{d}	6.6^{c}	7.3^{ab}
6	32.9	7.9^{ab}	7.7^{bc}	7.6^{bc}	8.1^{a}	7.9^{ab}	7.5^{c}

[a–c]Means within a row with the same letter are not significantly different ($P > 0.05$).

[1]Hedonic scale was based on a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

[2]Texture acceptability refers to tenderness and was defined as how much the product is liked with respect to tenderness.

[3]VS = vacuum stunning; ES = electrical stunning; H = hours deboned after slaughter.

Deboning at 0.75 h led to decreased tenderness and decreased acceptability in some consumer groups. Results revealed that either stunning method should yield high-quality breast meat under pristine conditions such as the ones used in the study. Further studies need to be performed in which broilers are subjected to stress caused by transportation and summertime temperatures that may occur at times in the industrial setting. Additional research is also needed on the effects of using low atmospheric pressure stunning in large-scale poultry processing plants.

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