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The Effects of Low Atmospheric Pressure and Electrical Stunning on the Instrumental and Sensory Quality of Broiler Breast Meat Deboned at 45 Minutes and 4 Hours Postmortem

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Low Atmospheric Pressure Stunning (LAPS) has recently become available to the broiler industry. Therefore, research was conducted to determine the effect of stunning method (LAPS and Electrical Stunning(ES)) and postmortem deboning time (0.75 hr and 4 hr) on the instrumental and sensory acceptability (3 replications) of breast meat (n=576, 144 birds per treatment) prepared using different cooking methods (fried, baked, sous vide). Breast meat was evaluated for pH, CIE L*a*b*, yields, shear force, and consumer acceptability. Postmortem pH decline was more rapid ($P<0.05$) in the breast meat of LAPS stunned birds when compared to ES stunned birds, but no differences existed ($P>0.05$) among treatments with respect to final pH. On average, no differences ($P > 0.05$) existed in the sensory acceptability of fried and sous vide cooked broiler breast treatments. However, for the baked cooking method, the LAPS treatment that was deboned at 4 hr was more acceptable ($P<0.05$) than other treatments and the ES and LAPS 4 hr postmortem treatments had more acceptable ($P<0.05$) texture than the ES and LAPS 0.75 hr treatments. Since consumers were highly variable in their liking of

chicken breast treatments, consumers were grouped into 6 clusters for each cooking method based on liking and preference. Cluster analysis data revealed that the greatest number of consumers liked all chicken breast treatments, but a larger proportion of consumers liked the 4 hour LAPS and ES treatments when compared to the 0.75 hr LAPS and ES treatments for all cooking methods. In addition, the consumers that indicated that baked chicken breast was highly acceptable preferred ($P<0.05$) breast meat from the 4 hr LAPS treatment over chicken breast meat from the 4 hr ES treatment. Based on sensory results, chicken breast meat from all stunning and deboning method combinations was highly acceptable to the majority of consumers, but the LAPS 4 hr treatment was slightly more acceptable than other treatments when baked.

DEDICATION

I dedicate this manuscript to my loving wife Rev Anbalagan, my dear parents, Mangala Gowri Radhakrishnan and Radhakrishnan Santhanakrishnan, my loving sister Shanthi Radhakrishnan and my advisor Dr. Wes Schilling.

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CHAPTER I

INTRODUCTION

Methods of handling and stunning of broilers have seen technological advancement that is primarily due to increased efficiency which has been implemented due to increased product demand, improved animal care, and an emphasis on meat quality (Fletcher, 1999). The most commonly used stunning method within the United States broiler industry is electrical stunning (ES) (Goksoy et al., 1999). Broiler processors utilize low voltage stunning which results in unconsciousness but not death. In contrast, European broiler processors use high current electrical stunning, also called electrocution, which results in death. However, some European poultry researchers have reported that high current stunning results in muscle hemorrhages, broken bones and damaged wings (Gregory et al., 1989). Most broiler processing plants utilize water bath electrical stunning in which the shackled broilers are lowered such that the head is submerged in water with electrical current passing through the water (Raj et al., 1998). Electrical stunning is an acceptable method of stunning, but some researchers have reported concerns with respect to animal welfare since broilers are hand caught by humans as well as inverted during shackling (Lambooij et al., 1999; Gerritzen et al., 2000). Low Atmosphere Pressure Stunning (LAPS) may be a more humane method of stunning. This is because the corticosterone levels in electrically stunned broilers are greater than the corticosterone levels in LAPS birds, which indicates a lower stress response (Vizzier Thaxton et al., 2010).

Modified atmospheric stunning (MASK) involves controlled changes in the atmosphere surrounding a broiler such that the broiler loses consciousness due to lack of oxygen (hypoxia), excess CO2 (hypercapnic hypoxia), a combination of these two methods (hypercapnic anoxia) (Hoen and Lankhaar, 1999), or use of oxygen with inert gases such as nitrogen or argon (Hypercapnic hyper oxygenation). Benefits of MASK include reduction of pre-harvest stress due to eliminating added excitement that is associated with shackling of live broilers during electrical stunning (Lambooij et al., 1999; Gerritzen et al., 2000). Carbon dioxide induces unconsciousness by reducing the pH of the cerebrospinal fluid (Eisele et al., 1967). When the pH of blood falls below the normal level (7.4) to 7.1, it induces unconsciousness by influencing vital enzyme reactions, membrane permeability, and electrolyte imbalance. Even though these methods are effective and yield acceptable quality meat, an increased concentration of CO2 in combination with a lack of oxygen leads to a death struggle (Turcsan et al., 2001).

Inhalation of elevated concentrations of inert gases (argon and nitrogen) causes hypoxia which eventually leads to anoxia (complete absence of oxygen). The brain is the most sensitive organ to a physiologic reduction in blood oxygen concentration and when the oxygen supply is insufficient for normal brain functioning, it will lead to unconsciousness and subsequent death (Guyton and Hall, 2010). LAPS reduces the atmospheric partial pressure of oxygen by evacuating air from an air tight chamber. Broilers are placed in an air tight decompression chamber, and pressures of 0.20 to 0.29 atm are used to stun broilers (U.S. Process Patent 7662030, 2010). The brain is minimally capable of anaerobic metabolism since neurons have only a minimal reserve of glycogen. The metabolic rate of neurons is much higher than most other tissues, thus glucose is continuously being metabolized and storage does not occur. Therefore, most neuronal activity depends on second-to-second delivery of glucose and oxygen from the blood. Thus, a sudden cessation of blood flow to the brain or a sudden drastic decrease in oxygen in the blood will result in unconsciousness in 5 to 10 sec (Guyton and Hall, 2010).

To date there is minimal information published regarding the effects of LAPS on poultry welfare and meat quality. Purswell et al. (2007) reported that LAPS appeared to be an effective method for humanely stunning and slaughtering chickens. In a pilot plant study, Battula et al. (2008) demonstrated that there were minimal differences in meat quality when broilers were raised at the University, transported 200 meters to the processing location and held for 2 h prior to stunning with ES or LAPS. In that study, it appeared that LAPS provided some advantages over ES such as breast meat with decreased average lightness in color and a quicker onset of rigor mortis. Van Laack et al., (2000) previously reported that lighter meat color (CIE $L^* \geq$ to 60) was generally associated with lower water-holding capacity and pH when compared to meat that was not as light (CIE $L^* \approx 55$). This quicker onset of rigor mortis may lead to increased tenderness and juiciness in early deboned breast fillets since an earlier onset of rigor may prevent the muscle from contracting after deboning (Aberle et al., 2001).

A shorter aging time would be possible with LAPS if rigor mortis was complete prior to 4-6 hr postmortem, the current industry standard for aging time on the carcass. Since the meat quality research listed above (Battula et al., 2008) was conducted under controlled research conditions, research needs to be conducted under commercial conditions (commercial broilers, commercial LAPS system) to determine if differences in broiler breast fillet meat quality exists between ES and LAPS for various deboning times under industrial conditions. In addition, postmortem pH decline needs to be evaluated to determine if the onset of rigor mortis is different between ES and LAPS stunned birds. Therefore, the objectives of the first part of this research were: 1) to determine if differences exist in breast fillet meat quality among broilers that are subjected to electrical stunning (ES) and low atmosphere pressure stunning (LAPS) at two deboning times (0.75 h and 4 h) through measuring pH, CIE L*a*b*, cooking yield, shear force, and consumer acceptability; 2) to evaluate the pH decline of breast meat from ES and LAPS broilers as an indicator of variability in the onset of rigor for ES and LAPS broilers.

Most consumer based sensory tests for broiler breast meat are conducted using baked or sous vide cooking methods. However, most consumers prepare their chicken breast in various ways including use of spices, breading and other recipes and then either baked, broiled or fried. Since no research has been conducted pertaining to how these common cooking methods impact sensory acceptability, an additional objective of this research was to evaluate if stunning methods has an impact in consumer acceptability using commonly used cooking methods in comparison to methods commonly used in research. The previous investigations addressed the effect of stunning on meat quality while evaluating the sensory acceptance of baked breast samples.

The consumer demand for chicken meat/meat products has experienced a tremendous growth, and accordingly, broiler breasts could be processed/cooked using different methods such as baking or frying. Sous vide cooking, a method popular in retail and the catering industry, refers to minimally processed foods under vacuum conditions and offers the advantages of convenience in preparation, yields, unique flavor and uniform texture (Armstrong and McIlveen, 2000, Wang et al., 2004; Narciso-Gaytan et al., 2010). However, limited investigations have been undertaken to evaluate the sensory acceptance of broiler meat from LAPS and ES birds deboned at various postmortem durations and prepared by different cooking methods.

Therefore, the objectives of the second component of this research were to determine if differences exist in consumer acceptance and descriptive sensory characteristics of breast meat from broilers that are subjected to electrical (ES) and low atmosphere pressure stunning (LAPS) at various deboning times (0.75 hr and 4 hr) and prepared by different cooking methods (baking, frying, sous vide).

CHAPTER II

LITERATURE REVIEW

Introduction

Broiler welfare is essential in broiler production and harvest and should be taken into account from the time that the chicks are hatched on the farm to when the broilers are harvested at the commercial processing plant. Broiler welfare is important because it gives value to the life of the animal and maximizes the quality of the resulting meat. The stunning and harvesting procedures are also key factors that contribute to animal welfare and meat quality. For a stunning/harvesting method to be humane, it must produce insensibility as rapidly and painlessly as possible. In addition, the stunning method should ensure that the animals are desensitized throughout the entire slaughter process.

Animal welfare during slaughter was one of the major criteria that led to legislative regulations for stunning across the world. In the United States, The Humane Methods of Slaughter Act (1978) mandated humane handling and immobilization of livestock prior to exsanguination. Nevertheless, poultry is not covered under this Act, and thereby stunning conditions for poultry are not mandatory as originally dictated in the Poultry Products Inspection Act of 1957 (Poultry Products Inspection Act, 1957). In 1993, The European Union Council established a directive to ensure pre-harvest welfare of livestock, including poultry species, and mandates stunning to ensure that birds are rendered insensible to pain, until death by exsanguination (Official Journal of the European Union, 2009).

Various stunning methods have been utilized in the poultry industry. An effective stunning procedure instantaneously induces a state of unconsciousness and insensibility to pain that lasts until the death of the animal, immobilizes the animal for automated exsanguination, and does not have a negative effect on meat quality (Savenije et al., 2002). Bruising, discolorations (Bilgili, 1992), and broken bones (Gregory and Wilkins, 1989) are the primary defects often attributed to the stunning-exsanguination stage of harvest. Stunning prior to exsanguination can be accomplished by passing an electrical current through the broiler, modification of the atmosphere by altering the composition of the air, or by decreasing atmospheric pressure. Electrical stunning has conventionally been used in processing facilities which has resulted in automation and rapid processing. Modified atmosphere stun-kill methods have been researched as an alternative to electrical stunning as a means to potentially improve animal welfare, and can be accomplished through gas stunning with carbon dioxide, argon, or nitrogen. Recently, low-atmosphere pressure has been utilized successfully to induce insensibility in broilers without any detrimental effect on meat quality (Thaxton et al., 2010).

Electrical Stunning

Commercial Application

Electrical stunning is the most common stunning method used prior to slaughter in commercial poultry plants in both the United States and Europe (Bilgili, 1999; Goksoy et al., 1999). Electrical stunning is accomplished by passing a sufficient amount of electrical current through the central nervous system of broilers for a given amount of time (Bilgili, 1992). Heath et al. (1994) reported that more than 97% of all poultry were subjected to electrical stunning in the United States in the early 1990s. There are two main types of electrical stunning, whole-body stunning and head-only stunning. Among the different types of electrical stunning systems that are available (Gregory, 1989), the most common system is electrical water bath stunning (Bilgili, 1992). Electrical stunning is most often conducted in a water bath stunner that is maintained at constant voltage. The electrical current flows through the brain of the broiler until a seizure like state occurs. This epileptic state could be measured through depolarization of the membrane potential using an electro encephalogram.

Electricity is convenient, economical and requires minimal operating space. With respect to industrial practices, commercial stunners vary in magnitude (current and voltage), duration (length of water bath and line speed), oscillation frequency, waveform, current direction, and energy (Kranen et al., 2000). Nevertheless, research has led to significant advances in electrical stunning techniques such as low voltage pulsed direct current stunning system (Bilgili, 1998), where the total resistance in the stunner has been reduced.

Mechanism and physiology of stunning

Electrical stunning is relatively simple, inexpensive, takes up minimal space, and is easy to operate (Bilgili; 1999). Electrical stunning is performed by passing sufficient electrical current through the central nervous system for a given amount of time (Bilgili; 1998). In the United States, electrical stunning is commercially performed using high frequency pulse (500Hz) direct current at low amperage (12 to 24 mA) for 7 to 12 seconds. However, commercial electrical stunning systems can vary from direct current to alternating current using high to low frequency from 50 to 500 Hz (Bilgili; 1992). The European Union commonly uses electrical stun-kill systems by applying alternating current levels from 100 to 125 mA. This stun-kill or electrocution system stimulates ventricular fibrillation and causes cardiac arrest that results in blocking the blood flow to the brain, which leads to anoxia and rapid death.

Ventricular fibrillation is an abnormal, uncoordinated fluttering contraction of the lower chamber of the heart. Researchers (Gregory and Wotton, 1986; Gregory, 1989) have reported that there are some welfare advantages in achieving ventricular fibrillation during broiler stunning. The application of high current helps induce ventricular fibrillation before the broiler's neck is cut that prevents broilers from regaining consciousness during the slaughter process.

During electrical stunning, a sufficient amount of electrical current is passed through the broilers' central nervous system for a known amount of time, which causes depolarization of neurons in the brain and leads to epileptic seizure. This process leads to unconsciousness that is induced by electricity that causes the inhibition of impulses from reticular activating and somatosensory systems (Heath et al., 1994). The loss of somatosensory evoked potentials (SEP) and spontaneous electroencephalograms (EEG) may be related to brain failure and absence of pain. Stunning broilers with insufficient current may immobilize broilers physically but may not prevent broilers from pain, stress, or discomfort.

Effect on carcass characteristics

Broiler meat quality is essential to the economic viability of broiler processors. Discoloration, bruising, broken bones, bruised wings, or any visual damage downgrades the meat quality and therefore lowers the economic value. These issues are often related to poor stunning (Bilgili, 1992). Some researchers have reported that high voltage stunning can increase the incidence of broken bones (Gregory and Wilkins, 1989), bruised wings, red wing tips and exploded or damaged viscera (Heath, 1984), hemorrhages in the breast meat (Veerkamp and de vries, 1983) and separation of the shoulder muscle tendons (Sams, 1996). The European Union recommends a minimum stunning current of 120mA (EU) that induces unconsciousness and cardiac arrest, and assures an onset to an unrecoverable death by hypoxia leading to anoxia (Gregory, 1992). But these high amperages can cause muscle contractions that lead to muscle fiber damage and subsequent hemorrhaging in muscle tissue. (Gregory and Wilkins, 1989; Hillebrand et al., 1996; Kranen et al., 1998). Hemorrhaging is due to a sharp increase in intravascular pressure (Kranen et al., 2000), as a result of which blood capillaries may rupture and cause bleeding.

When comparing electrical stunning (EU, 100 V, 80 mA) with concussion stunning in a research trial, Goksoy et al. (1999) observed a higher incidence of broken bones, and bone (coracoid, furculum)- and muscle-hemorrhages in electrically stunned birds when compared to their counterparts stunned by concussion stunning. In contrast, electrically stunned birds exhibited a lower incidence of red wing tips and shoulder hemorrhages when compared to birds that were stunned by concussion. Nevertheless, the authors reported a rapid rate of blood loss in electrically stunned (non-fibrillated) birds when compared to concussion stunning. In a recent investigation, Lambooij et al. (2010) observed that in birds subjected to head-only electrical stunning, the percentage of fillets free of blood splashes was 80%, compared to 16% in conventional electrical stunning.

However, the authors reported that head-only stunning resulted in wing flapping which could be a disadvantage as it may lead to broken bones and subsequent hemorrhages. Recent advances in electrical stunning systems focus on “tailor-made” head-only stunning, which delivers the stunning current based on individual head resistance, and offers minimal carcass and meat defects (Ad Bal, 2011). Such systems utilize a restrainer cone to minimize carcass movements. However, additional research needs to be conducted on “tailor made” head-only stunning since the above mentioned research was a small scale study with limited sample size. Such stunning would need to be conducted in commercial applications to verify the advantages that have been reported for this method.

Effect on rigor mortis and meat quality

Some researchers have reported that high amperage stunning delays rigor development for approximately 6 hours (Papinaho and Fletcher; 1996) when compared to low amperage stunning. Broilers stunned using 50mA had lower pH values and higher R-values in broiler breast meat than broilers stunned with 125mA (Papinaho et al., 1995). Poole and Fletcher (1998) reported no difference in pH and shear value of broiler breast meat using low voltage (11.5V and 500Hz for 10 sec) stunning and modified atmospheric stun-kill methods (70% argon and 30% carbon dioxide). Craig and Fletcher (1997) reported no differences between high voltage stunning (125mA, 50 Hz DC for 5 sec) and low voltage stunning (10.5V, 500 Hz, AC for 10 sec) for 24 h pH, raw breast meat color, and Allo-Kramer shear value. However, high current stunning delayed early rigor development and reduced initial blood loss. Raj et al. (1992) reported higher incidence of pectoral bone damage and hemorrhaging in the broiler breast muscle due to the occurrence of titanic convulsions using high voltage stunning (120mA, 50 Hz for 4 sec).

A potential problem associated with electrical stunning is that broilers can get pre-stunned if the wings make contact with the water bath before their head makes contact (Raj., 1997). This can lead to variability in electrical impedance and prevent cardiac arrest.

Gas stunning

Commercial application and physiology of stunning

Modified atmospheric stunning (MASK) or gas stunning has been researched since the 1950s (Kotula et al., 1957). MASK or controlled atmospheric stunning involves controlled changes in the gaseous atmosphere surrounding a broiler such that the broiler loses consciousness due to lack of oxygen (anoxia), excess of CO2 (hypercapnic hypoxia), a combination of these two methods (hypercapnic anoxia) (Hoen and Lankhaar, 1999), use of oxygen with inert gases such as nitrogen or argon (Hypercapnic hyper oxygenation) or by atmospheric depressurization (low atmosphere pressure stunning).

Even though these methods are effective and yield good quality meat, an increased level of CO2 in combination with a lack of oxygen may cause excitation or convulsions in the broilers (Turcsan et al., 2001). The stunning gas or gas mixture should not be aversive to the broilers, and the induction of anesthesia should be rapid (Raj, 1998). Carbon dioxide causes an anesthetic response in broilers by reducing the pH of the cerebrospinal fluid (Eisele et al., 1967). When the pH of blood falls below the normal level (7.4 to 7.1), it induces unconsciousness by influencing vital enzyme reactions, membrane permeability, and electrolyte balance.

Several researchers have indicated that there are advantages to stunning with gases. One particular advantage includes the acceleration of rigor mortis (Raj et al., 1990a; Raj et al., 1997). Stunning by gas is effective at improving carcass quality by reducing bloodspots, especially on the thighs and breasts, when compared to electrical stunning (EU electrocution) (Hoen and Lankhaar, 1999). Other benefits include reduction in pre-harvest stress due to eliminating added excitement that is associated with shackling of live broilers during electrical stunning (Lambooij et al., 1999; Gerritzen et al., 2000). However, minimal research data could be found on blood corticosterone levels from broilers subjected to MASK and compared to broilers that were electrically stunned (US and EU). Small scale studies (Xu et al., 2011a, b) indicated that plasma corticosterone levels were comparable between MASK and ES stunned broilers. However, these were small scale pilot studies and further research under commercial conditions needs to be conducted to verify if the use of MASK could lead to decreased corticosterone concentration, thus indicating lower stress. The results from the pilot studies above indicate that the death struggle from MASK may be equally as stressful to broilers as the shackling that occurs during ES stunning. One potential limitation with modified atmosphere stunning is that broilers may regain consciousness rapidly on exit from the gaseous atmosphere (Raj, 1998). To avoid this problem, Raj and Gregory (1990) recommended that the broilers should be killed during stunning to prevent the broilers from regaining consciousness and to allow for easier handling.

Effect on carcass characteristics

Modified atmosphere stunning with CO_2 has been successfully utilized in pork slaughter for many years and has been investigated for possible uses in the poultry industry since the 1950s (Drewniak et al., 1955; Kotula et al., 1957). Kotula et al. (1961) developed an inline CO_2 immobilization system for chickens by using 33 to 36% CO_2.

Researchers have reported that stunning with CO_2 increased initial blood loss when compared to non-stunned birds (Kotula et al., 1957), resulted in less muscle hemorrhaging and broken bones when compared to electrocution (Raj et al., 1990b), and increased breast meat tenderness when compared to electrocution when stunning was conducted at levels of 40 or 45% CO_2 (Raj et al., 1990a; Fleming et al., 1991). Kang and Sams (1999) observed a lower incidence of carcass damage in broilers that were stunned with CO_2 when compared to those subjected to water-bath electrical stunning (35 mA, US), and attributed this to the broilers being calmer when stunned using modified atmosphere stunning. Poole and Fletcher (1998) concluded that stunning of broilers with 30% carbon dioxide and up to 5% residual oxygen in argon improved the quality of breast meat when compared to electrical stunned broilers, which was attributed to milder convulsions during gas stunning (Turcsan et al., 2001).

Effect on rigor mortis and meat quality

With respect to tenderness, no differences were observed in shear values for breast fillets from broilers receiving no stun vs. CO_2 stun (Sams and Dzuik, 1995). When compared to electrical stunning, CO_2 stunning has been reported to produce lower breast meat shear values at 1 h post-mortem than United States (US) electrical stunning (Veeramuthu and Sams, 1993). The death struggle induced by carbon dioxide stunning accelerates rigor development as indicated by a more rapid onset of postmortem pH decline than occurs with US electrical stunning. This reduces the length of aging time (4 h vs 7 h) required to ensure meat tenderness (Raj, 1994). Although the exact mechanism is not known, the increased anoxic convulsions (increased wing flapping) that have been observed in CO_2 stunned broilers accelerates rigor development which leads to a more rapid utilization of adenosine triphosphate (ATP) by the muscles when compared to muscles from electrically stunned broilers (Raj et al., 1997). In addition, Kang and Sams (1999) reported that even though breast meat pH decline did not differ between ES (US) and CO2 stunned broilers, the R-value was greater in CO2 stunned birds, thus indicating that the onset of rigor mortis was quicker.

Even though gas stunning has some advantages over electrical stunning with respect to avoiding bird handling stress and allowing earlier deboning, there are some distinct disadvantages: 1) Gaseous stunning involves an induction phase that can be stressful to the broilers (Lambooij et al., 1999). 2) Carbon dioxide can cause breathlessness prior to the loss of consciousness (Raj, 1998). 3) Gases used in MASK are dangerous to humans. Inhalation of 30% carbon dioxide by humans causes a low level of pungency and breathlessness (Gregory et al., 1990). These limitations hinder the broad acceptance of gas stunning in the poultry industry.

Inert gas stunning

Commercial application and physiology of stunning

The use of a mixture of inert gases in combination with oxygen or carbon dioxide is an alternative approach for controlled atmosphere stunning. Oxygen deprivation in the body is termed hypoxia or anoxia. Inhalation of high concentrations of the inert gases (argon and nitrogen) causes hypoxia or anoxia. The brain is the most sensitive organ to a physiologic reduction in blood oxygen levels and when the oxygen supply is insufficient for normal brain functioning, it will lead to unconsciousness and subsequent death (Guyton and Hall, 2010). In poultry, unconsciousness was observed when the concentration of oxygen was reduced below 5% O2 by volume (Wooley and Gentle, 1988), whereas for anoxic stun-to-kill systems, less than 2% O2 by volume could be used (Raj, 1991). The commonly used gases are nitrogen and argon with/without CO2 for broilers and nitrogen with CO2 for turkey, which results in anoxic loss of sensibility.

In a commercial situation, Hoen and Lankhaar (1999) reported that a few plants use 90% argon in air, 60% argon in air with 30% carbon dioxide, or a mixture of 40% carbon dioxide, 30% oxygen, and 30% nitrogen. Argon is heavier than air and also tasteless and odorless, which makes it easier to administer during gas stunning. A combination of argon with carbon dioxide in gas stunning resulted in rapid cessation of brain functions in poultry species (Raj and Gregory, 1991, 1994). In practical situations, gas stunning minimizes the handling of birds (uncrating/shackling) prior to stunning as done in electrical stunning, thereby reducing pre-slaughter stress. On the other hand, gas stunning also lead to some distress in birds as exhibited by wing flapping, gasp, and head shakes (Lambooij et al., 1999). In addition, the oxygen-replacers like Argon demonstrate lower efficacy in young animals (Wooley and Gentle, 1988).

Effect on carcass characteristics

Raj et al. (1990) reported no broiler breast muscle meat bruising and fewer muscle hemorrhages when argon gas (2% oxygen and remaining oxygen displaced by argon for 120 sec) was used when compared to CO2 and electrical stunning. Moreover, stunning broilers using argon resulted in rapid early postmortem pH decline and tender broiler breast meat when compared to electrical stunning. This indicates that deboning may be possible prior to 4 hours postmortem. Mckeegan et al. (2007) reported that a 2-phase inert gas stunning method could be used to enhance animal welfare. The anesthetic phase (1st phase) consisted of 40% CO2, 30 % O2, and 30% N2 followed by a euthanasia phase

(2nd phase) with 80% CO_2, 5 % O_2, and 15% N_2. Raj et al. (1998) reported that broilers lose consciousness quicker when exposed to 90% argon in air or a mixture of 30% CO_2 and 60% argon in air when compared to 40% CO_2, 30 % O_2, and 30 % N_2. Raj et al. (1992) reported a higher incidence of hemorrhaging in broiler breast meat stunned electrically (120 mA, 50 Hz for 4 sec) than gas mixture stunning (10%, 20, 30% CO_2 and 70% 80% and 90% argon with 5% O_2).

Effect on rigor mortis and meat quality

Savenije et al. (2002), in a small-scale research trial, investigated the effect of stunning methods on muscle metabolism and reported that head-only stunning (electrocution) resulted in the greatest metabolic rate, which was indicated by a faster decrease in muscle pH, glycogen, and ATP and an increase in R-value and lactate concentration at 2 h postmortem. Stunning with argon/ CO_2 yielded intermediate rates, while the lowest rate was reported for birds subjected to water bath-electrocution and modified atmosphere stunning with $CO_2/O_2/N_2$. The authors reported differences for hemorrhage scores, water holding capacity (up to 8 h postmortem), and meat color (L*, a*, b* values) with respect to different stunning systems. Gas stunning (inert and CO_2) and captive needle stunning resulted in fillets with the lowest hemorrhage scores (1.8), while water bath stunned birds had the highest scores (3.6). Nevertheless, the authors utilized restraining funnels (bleeding cones) in head-only and captive-needle stunned broilers, while the gas-stunned carcasses were not restrained and the water-bath stunned birds were in shackles. L* value (lightness) for breast meat was similar for fillets from gas stunned birds (60.5), captive needle stunning (59.7), and electrical stunning (58.7). Electrical stunning in water bath exhibited breast meat with similar a* values (redness)

(4.5), when compared to captive needle stunning (3.3), and stunning by gas (3.5 in argon/ CO_2, 3.2 in $CO_2/O_2/N_2$). Considering yellowness, b* values were 11.7, 11.3, 11.1, and 10.9 respectively for gas stunning ($CO_2/O_2/N_2$), captive needle stunning, electrical stunning and argon stunning. In addition, no differences were observed in tenderness and water holding capacity for breast meat after 24 h postmortem among the stunning systems.

Poole and Fletcher (1998) utilized 70:30 argon/CO_2 in a modified atmosphere stunning-killing system and reported that this system produced comparable effects on meat quality and rigor development with respect to low voltage electrical stunning, while the benefit of accelerated rigor development could be minimal when compared to high current electrical stunning. Modified atmosphere inert gas stunning could result in broken wing bones caused by severe convulsions during stunning. In addition, availability and expense of the inert gases make it difficult for processors to adopt this technology. However, researchers (Raj, 1998; McKeegan et al., 2007; Coenen et al., 2009) concluded that modified atmosphere stunning with CO_2 or inert gases could improve broiler welfare by minimizing handling of live birds when compared to electrical stunning (EU).

Low Atmospheric Pressure Slaughter

Commercial application and physiology of stunning

Unlike other methods of modified atmosphere stunning, vacuum (low atmosphere) stunning does not displace oxygen with another gas or use CO_2 to produce anesthesia. Low atmosphere pressure stunning (LAPS) or atmospheric depressurization reduces atmospheric partial pressure of oxygen by evacuating air from an air tight chamber. Broilers are placed in an air tight decompression chamber and pressures of 0.70

to 0.20 atmospheres are utilized to stun the broilers. Though minimal research has been performed on low atmospheric stunning, Purswell et al. (2007) reported that vacuum (low atmospheric) stunning appeared to be an effective method for humane stunning and exsanguination of chickens.

Low atmospheric pressure slaughter has been in the development and implementation stages in commercial broiler plants since 2005. This technology controls the atmosphere through anoxia by using a vacuum pump to reduce oxygen tension in the atmosphere. Italy allows the use of a vacuum chamber for slaughter of farmed game species (European Commission, 2003). In the U.S., decompression as a method of euthanasia has been ruled unacceptable by the American Veterinary Medical Association for multiple reasons such as improper equipment design and operation as agents of pain (AVMA, 2007). The question of when chickens lose consciousness during the process of reducing atmospheric pressure is addressed by Guyton and Hall in Textbook of Medical Physiology (2006). They explain that most tissues of the body can go without oxygen for several minutes and some for as long as 30 minutes. During which, the cells obtain energy through anaerobic metabolism.

The brain is minimally capable of anaerobic metabolism since neurons have only a minimal reserve of glycogen. The metabolic rate of neurons is much higher than most other tissues, thus glucose is continuously being metabolized and storage simply does not occur. Additionally, storage of oxygen in neurons is also very minimal. Therefore, most neuronal activity depends on second-to-second delivery of glucose and oxygen from the blood. Thus, a sudden cessation of blood flow to the brain or a sudden drastic decrease in oxygen in the blood will result in unconsciousness in 5 to 10 seconds.

Effect on carcass characteristics and meat quality

Since limited data could be obtained from a single bird unit, Thaxton et al. (2010) utilized a research model (TechnoCatch LLC, Kosciusko, MS) that held one commercial cage unit and later a two cage system with automatic controls. After test runs were completed at both a University and commercial processing plant setting, the authors reported that the research prototype provided satisfactory results on poultry welfare. LAPS-stunned birds demonstrated significantly lower blood corticosterone levels (755 pg/ml) when compared to electrically stunned birds (1642 pg/ml), thus indicating lower stress in broilers that were stunned using the LAPS system, likely through minimized handling of the live birds in comparison to shackling with electrical stunning (Kannan and Mench, 1996). The authors suggested that decreased corticosterone levels could minimize meat quality defects under stressful conditions, such as elevated temperature in the summer. On the other hand, LAPS-stunned birds demonstrated 3.2% greater wing damage than electrically stunned birds. The authors also verified the absence of recovery in birds subjected to low atmosphere pressure stunning through behavioral evaluation (absence of bill-breathing and mandibulation), blood analysis and histopathological examination (absence of hemorrhagic lesions in tissues) Using these criteria, these authors concluded that LAPS is a humane system of stunning with potential application in the poultry industry.

In another investigation, Battula et al. (2008) compared the effect of LAPS and electrical stunning (US) on broiler breast meat quality and consumer acceptability. The birds were stunned by exposing them to a low atmospheric pressure (proprietary information with patent pending) in an airtight decompression chamber. Meat quality parameters including color, pH, cook loss, and shear force values were measured on breasts at different deboning times. The authors reported similar L* values (56.1) in breast meat from LAPS birds deboned after 4 h postmortem, compared to those from electrically stunned (US) birds (L* value = 57.3). The a* value (redness) was 1.6 and 1.3 in LAPS and electrically stunned (US) carcasses respectively, while the b* value (yellowness) was 1.8 and 2.1. No differences were observed in shear force (19.9N - 20.6N), pH 24 h postmortem (5.99 – 5.95), and consumer acceptability among breast meat from electrically stunned (US) or LAPS birds and the authors concluded that both stunning methods yield high-quality breast meat with minimal product differences. Even though 24 h pH was similar between breast meat from ES and LAPS stunned birds, the rate of rigor mortis was more rapid in LAPS stunned broilers when compared to ES stunned broilers (Battula et al., 2008, Radhakrishnan, et al., 2010). Radhakrishnan et al. (2010) also reported that even though final product pH was similar between breast meat from ES and LAPS stunned broilers, the pH at 15 minutes postmortem was between 6.1 and 6.2 for breast meat from LAPS stunned broilers and approximately 6.5 for ES stunned broilers. In addition, these researchers reported that the pH from LAPS stunned broilers was approximately 6.0 by 30 min postmortem, but the pH did not reach 6.0 until 4 h postmortem for ES stunned broilers. However, pH of breast meat from both ES and LAPS stunned broilers was approximately 5.8 at 24 h postmortem (Radhakrishnan et al., 2010). These differences in pH early postmortem could either be due to a death struggle during LAPS and/or a different pattern of postmortem muscle metabolism since blood corticosterone levels are low in the LAPS stunned broilers when compared to ES stunned broilers. More research is necessary to make conclusive remarks about whether pH differences are due to a death struggle and/or rigor mortis. With respect to deboning time, the authors recommended an aging period of 4 h, regardless of the stunning method, as it contributes to meat tenderness. On the other hand, poultry processing plants with electrical stunning usually age broilers for 4 to 7 h to ensure that the product is tender (Lyon and Lyon, 1990; Schilling et al., 2003) and to meet customer specifications.

Conclusions

The goal of stunning is to render birds/animals insensible to pain rapidly, thereby ensuring humane slaughter. Each method varies in its mode of operation and offers distinct merits and disadvantages. The selection of method depends on factors such as animal welfare, cost and ease of operation, effect on meat quality, and safety of operators. Animal welfare should be considered while designing and implementing poultry stunning systems. Electrical, controlled atmosphere, and low atmosphere pressure stunning all produce high quality broiler meat, but controlled atmosphere and low atmosphere pressure stunning also potentially reduce stress due to minimizing broiler handling prior to slaughter. Although electrical, controlled atmosphere and low atmosphere stunning are all appropriate methods for slaughter if conducted correctly, low atmosphere pressure stunning is currently utilized in the broiler industry and may provide benefits with respect to animal welfare.

CHAPTER III

MATERIALS AND METHODS

Sample Procurement

Ross 708 birds (mixed sex, and approximately 48 d of age) were reared at farms in West Central AR and slaughtered at a commercial broiler processing facility (OK Foods, Fort Smith, AR). Feed was withdrawn 10 h prior to slaughter, and broilers were allowed ad libitum access to water. Five hundred and seventy-six broilers were randomly selected for processing by one of two stunning methods (ES and LAPS) in two separate trials (n=288 per trial). Half of the broilers from each stunning treatment were deboned at 0.75 hr postmortem (n=144) and half were deboned at 4 h postmortem. Broilers were deboned at 45 min postmortem to determine if LAPS and ES would produce meat that is tender, juicy, and acceptable to consumers. To account for variability in broilers, 12 live haul cage compartments containing 24 broilers each were selected for each of the two trials from the same house within a poultry farm. Six crates were randomly selected for each of the ES and LAPS treatments within each trial. Using the same criteria, an additional 144 Ross 708 broilers were randomly selected (n=72 per treatment) for processing to evaluate pH decline postmortem for both ES and LAPS broilers in each of three separate trials. Broilers were transported approximately 75 km in the summer in live haul modules from the poultry farm to the poultry processing plant. In addition, broilers were removed from their crates, tagged with unique wing badges that varied in color for different treatments and individual broilers differed in number so that they could be tracked throughout the process. After broilers were tagged, they were placed back in their crates for approximately 2 h prior to stunning.

Electrical Stunning

Broilers were shackled and electrically stunned in a commercial stunner using a saturated saline bath (Dapec stunner, Meyn, Oostzaan, The Netherlands) using the following electrical settings: 31-33 volts, 500 Hz, <0.5 mA AC/DC current for 10 sec. AC to pulsed DC current was used in the stunning process. The shackle line speed was constant and set so that approximately 160 broilers were stunned per min. Decapitation was performed immediately after stunning, and bleeding lasted for 140 sec. Upon completion of exsanguination, the broilers were scalded at 53.3^o C for 191 sec and picked for 35 sec (JM64 Meyn Pickers, Meyn, Oostzaan, The Netherlands) prior to mechanical evisceration.

Low Atmosphere Pressure Stunning

Broilers were stunned using a commercial low atmospheric pressure slaughter system (Technocatch LLC, Kosciusko, MS). This system consists of a cylindrical reinforced mild steel shell that was 2.1 meter in diameter and 6 meters long with a roller bed run by an electric motor which allowed for insertion of two full broiler cages at one end with post-stun removal at the other end. Low atmospheric pressure was accomplished by means of a series of vacuum rated butterfly valves utilized for vacuum application and release. The low atmospheric pressure was achieved by using two vane type vacuum pumps each rated at 14 cubic m per min. These pumps were connected to the chamber through two 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. Live haul cages with 250 commercial broilers were placed into this chamber where the pressure was reduced to an approximate elevation of 10,000 m. The exact pressure and rate of change from sea level is described in the United States process patent number 7662030. All broilers were maintained in the LAPS chamber for 2 min after loss of posture for a total time of 2.5 min in the container. Bleeding, scalding, picking, and evisceration steps were completed and were identical to the procedures listed in the electrical stunning section.

Treatment Effects

Four treatments were used in this study to evaluate the effects of stunning method and deboning time on broiler breast meat quality: electrical stunning deboned at 0.75 hr (ES 0.75 hr); electrical stunning deboned at 4 hours (ES 4hours); low atmospheric pressure stunning deboned at 0.75 hr (LAPS 0.75 hr); low atmospheric pressure stunning deboned at 4 hours (LAPS 4hours). The breast meat samples deboned at 0.75 hr for ES and LAPS were stored and chilled with ice slush in a stainless steel combo treated with antimicrobial (chlorine 400-ppm approx). The 4 hrs deboned treatment for ES and LAPS breast meat samples were chilled in a commercial chiller. The right side of each breast sample was analyzed for pH, L*,a* and b* values, cook loss, brine absorption and shear force . The left side of each breast sample was utilized to conduct sensory analysis, including consumer testing and sensory descriptive analysis.

pH measurements

For the 144 broilers that were designated for the pH decline portion of the study (n=72 for each treatment), pH meters (Model Accumet 61a, Fisher Scientific, Hampton, NH) were used to measure the pH of the breast fillet meat. pH was evaluated by inserting the pH probe (Model FlexipHet SS Penetration tip, Cole Palmer, Vernon Hills, IL) 2.5 cm below the top of the Pectoralis major muscle at approximately 2.5 cm from the cranial end of the fillet and 2.5 cm from the keel on the sternum at 0.25, 0.50, 0.75, 1, 4, and 24 h postmortem. Samples were stored in Ziploc bags in coolers on ice to chill breast meat and deboned at 4 h postmortem, immediately after the pH was measured at 4 hr postmortem.

All pH measurements were taken within 3 min of the target evaluation times of at 0.25, 0.50, 0.75, 1, 4 h postmortem. At 24 h postmortem, ultimate pH (pHu) measurements for each sample were taken using the same pH meters in the same anatomical location as was used for the pH decline measurements for the 576 broilers that were used in the experiment. Four identical pH meters were used to evaluate pH at each deboning time. Two pH meters were used for LAPS treatments and two were used for ES treatments to ensure that ES and LAPS broilers were both evaluated at the correct deboning time.

Color Measurements

Color measurements were taken on each breast within each treatment using a Chroma meter (Chroma meter Model CR-200, Minolta Camera Co., Ltd., Osaka, Japan Serial No C8202489, illuminant D65, 8 mm aperture) that was calibrated using a white standard calibration plate (Model 20933026, Minolta Camera Co. Ltd.). Measurements were taken at three identical locations for each fillet on the medial side of the Pectoralis major muscle. Color for each sample was expressed as L* (lightness), a* (redness) and b* (yellowness).

Brine Absorbtion/Marination

At 168-240 h postmortem, chicken breasts from each treatment were randomly selected and divided into four 0.908 kg portions for brine absorbtion measurements. Each treatment (n=4) was tumbled (Model -10 G, Hollymatic Corp. Countryside, IL) at 20 mmHg with 1 % NaCl [Finished Product Basis, FPB], 0.5 % sodium tripolyphosphate [FPB] and 15 % water [FPB] for 30 min stopping every 15 min for 10 min to increase brine absorbtion.

Cooking Loss

Frozen breast samples were thawed (2^{o}C) overnight and trimmed to an approximate weight of 120 g from an identical location for each fillet and vacuum packaged in 15.2 x 20.3 cm, 3-mil cooking bags (Rebel Butcher Supply Co. Inc.). Breast samples were cooked in vacuum packed bags by immersing them in hot water at 85^{0}C for 20 min to an internal temperature of 80^{o}C. A temperature probe was inserted (beef & poultry thermometer; Chaney Instrument Co., Lake Geneva, WI) into the middle portion of a breast sample prior to packaging to measure the internal temperature of the sample. Once the internal temperature was reached, the bags were removed from the hot water and left at room temperature for cooling. Once the internal temperature reached 20^{0}C, the bags were opened and the liquid was drained out. Each breast fillet was patted dry with a paper towel (one ply) and reweighed. Cook loss was reported as a percentage and calculated as

$$\frac{\text{(Initial weight of breast fillet before cooking – final weight of breast fillet after cooking)}}{\text{(Initial weight of breast fillet before cooking)}} \times 100 \qquad (3.1)$$

Warner-Bratzler and Allo-Kramer Shear Force Determination

Shear force was assessed using a Warner-Bratzler Shear force procedure described in Meek et al. (2000). Half of the breast fillets (n=36) that were used for cooking loss determinations were used for shear force determinations. Four to six adjacent 1 cm (width) x 1 cm (thickness) x 2 cm (length, parallel to the orientation of the muscle fibers) strips were cut from the cooked breast fillet, parallel to the direction of the muscle fibers. Each strip was sheared once, and the mean was calculated for each fillet. Samples were sheared perpendicular to the muscle fibers using a Warner-Bratzler shear attachment mounted on an Instron Universal Testing Center (Model 3300, Instron, Norwood, MA) using a 50 kg load transducer and a cross head speed of 200 mm/min.

Shear force was also assessed for both marinated and non-marinated samples using an Instron Universal Testing Center (Model 3300, Instron, Norwood, MA) that was equipped with an Allo-Kramer shear compression cell (CS-2) set at a chart and crosshead speed of 100 mm/min (Smith et al., 1988; Lyon & Lyon, 1990). For each test, a 25 g cubed piece (1 cm thick) from the center of the cooked 120 g fillet portion (n=36 per treatment) was placed in the Kramer cell and sheared once. Shear force (N/g) was reported as the highest peak in the texturegram and total energy (J/g) as the area under the texturegram.

Sensory Acceptability Testing

Three consumer based sensory panels (n=50-55 panelists per replication) were conducted for each cooking method to evaluate the acceptability of broiler breast meat from birds subjected to LAPS or ES and deboned at 0.75 hr or 4 hr postmortem. Each panel consisted of students, staff, and faculty at Mississippi State University. Participants were recruited with an advertising sign and word of mouth for participation, and samples were cooked as described earlier. A total of 9 consumer panels (n>55) were conducted, 3 for each cooking method.

For sous vide cookery, the breast samples were cooked in vacuum packaged bags by immersing them in water at 85°C to an internal temperature of 80°C. A temperature probe was inserted (beef & poultry thermometer; Chaney Instrument Co., Lake Geneva, WI) into the middle portion of a breast sample prior to packaging to measure the internal temperature of the sample. Prior to cooking, 2 tbsp. of McCormick Grill Mates Chicken Rub (Onion, Spices & Herbs (Black pepper, Red pepper and Sage), Salt, Garlic, Brown Sugar, Lemon peel, Paprika, Silicon Dioxide (added to make free flowing), Malto-dextrin, Sugar, Natural flavoring, Corn syrup solids and Sulfiting agents) was added for every 0.454 kg of chicken breast by placing the chicken and the spices in a bag and shaking the bag for 1 min to evenly distribute spices on the surface..

For baked breast meat, Kraft Shake and Bake Original Chicken formulation (Enriched wheat flour (wheat flour, Niacin, Iron, Thiamin, Mononitrate (vitamin B1), Riboflavin (Vitamin B2), Folic acid), wheat flour, Malt dextrin, Bleached wheat flour, salt, partially hydrogenated soy bean & Cotton seed oils, Canola oil, Spices contain less than 2% of mustard flour, Dextrose, Yeast, Caramel color, Extractives of paprika (Color), Dried Onions, Natural Flavor, Oleoresin Paprika &Ascorbic Acid) was added based on manufacturer instructions and baked at 400°F to an internal temperature of 77°C.

For fried breast meat treatments, Best yet Plain Bread Crumbs (Whole egg, Enriched Wheat flour, Malted Barley, Niacin, Ferrous Sulfate, Thiamine Mononitrate, Riboflavin, Folic acid, Water, High Fructose Corn syrup, partially Hydrogenated vegetable oil, Soybean oil, Cotton seed oil and Canola oil, Salt, Yeast, Sugar, Honey, Sesame & Poppy seeds, Molasses, Wheat Gluten, Whey, Soy Flour, Whole wheat flour, Rye flour, Oat bran, Corn flour, Rice flour, Potato Flour, Butter, Skim milk, Buttermilk, Lactic acid, Distilled vinegar, Soy Lecithin, Dough conditioner (Mono & Diglycerides, Sodium & Calcium Stearoyl Lactylate), Yeast nutrients (Contains one or more of the following: Monocalcium Phosphate, calcium sulfate, Amonium sulfate), Calcium propionate & Potassium Sorbate for preservation) was used to bread the chicken breast meat prior to frying at 177˚C to an internal temperature of 77˚C. Bread crumbs were added by placing greater than 0.1 kg of bread crumbs in a bag and mixing them with 0.454 kg of chicken through shaking for 1 min.

For each panel, cooked breast fillets were cooled at room temperature for 15 min, cut into 2.5 × 2.5 × 2.5 cm cubes, and kept warm (60 to 70˚C) in 7.6 L chafing dishes (53042, Polarware Co., Kiel, WI) until panelists evaluated the samples. Random three digit numbers were utilized to identify the samples and each participant evaluated 4 treatment samples (LAPS0.75 hr, LAPS4hr, ES0.75 hr, ES4hr) within a cooking method. 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.,2007).

Acceptability of texture was defined as product liking in respect to tenderness. Acceptability of appearance was defined as product liking in respect to color and moisture, and acceptability of flavor was defined as product liking in respect to chicken flavor (taste). Panelists were asked to evaluate all attributes for each sample before evaluating the next sample, and evaluate one sample at a time going from left to right as numbered on evaluation forms. 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.

Descriptive Sensory Analysis

The descriptive panel consisted of 8 members with previous experience in sensory evaluation of muscle foods. Panelists were trained for 18-20 h in evaluating attributes related to aroma, flavor, and texture of chicken breasts that were cooked and served as described previously. The descriptive analysis was replicated three times and the panelists evaluated the attributes related to appearance, aroma, flavor, and texture on a 15 cm line scale, with '0' as the least score for the descriptors and '15' as the highest score for the descriptors (Garner, 2002).

Statistical Analysis

A randomized complete block design (replications as blocks) with two replications (n=576, 72 broilers per treatment) was utilized to test the treatment effects ($P<0.05$) of stunning method with different deboning times on ultimate pH, color, cooking loss, and shear force. When significant differences occurred ($P<0.05$) among treatments, the Fisher's Protected Least Significant Difference (LSD) test was used to separate treatment means. A randomized complete block design (replications and panelists as blocks) with three replications was utilized 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 breast fillets. For each cooking method, agglomerative hierarchical clustering using Wards Method (XL Stat 2006) was performed to group consumer panelists 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 utilized to group panelists for each cooking method. After separating the data into clusters, the entire data set was evaluated to confirm that the data for each panelist was relatively close to the means of the treatments that were within the cluster that they were grouped into. After conducting agglomerative hierarchical clustering, randomized complete block designs (panelists as blocks) were performed within each cluster, and the LSD test was utilized to separate treatment means within a cluster when significant differences ($P<0.05$) occurred.

In a separate experiment, a randomized complete block design with 3 replications (n= 144, n=24 per treatment within each replication) was used to evaluate postmortem pH decline over time and determine if differences were present in pH at each time postmortem.

For the third experiment, a randomized complete block design (replications and panelists as blocks) with three replications was utilized to test the treatment effects ($P<0.05$) on the consumer sensory acceptability and descriptive sensory characteristics of the chicken breasts. The data were analyzed using the PROC GLM procedure (SAS, 2009). Principal Component Analysis (PCA) was conducted for three descriptive sensory data gets to determine the variability in attributes among treatments (SAS, 2009).

CHAPTER IV

RESULTS AND DISCUSSION

Postmortem pH Decline

The pH of breast meat was lower (P<0.05) from LAPS broilers when compared to breast meat from ES broilers at 0.25 hr, 0.5 hr, 0.75 hr, 1 h, and 4 h postmortem, but did not differ in pH (P>0.05) at 24 h postmortem (Figure 4.1). This indicates that the onset of rigor mortis was more rapid in the LAPS broiler carcasses when compared to the ES broiler carcasses. In addition, the lack of difference in pH at 24 h postmortem indicates that the breast meat is similar in its distance from the isoelectric point when rigor mortis is complete and should therefore have similar quality characteristics such as color and water-holding capacity (Strasburg et al., 2008). The pH of breast meat from LAPS stunned broilers at 4 h postmortem and 24 h postmortem was 5.85 and 5.78, respectively, which indicates that rigor mortis was closer to complete in LAPS stunned broilers at 4 h postmortem but was not yet complete in the ES stunned broilers, since the pH was 6.08 at 4 h, in comparison to 5.79 at 24 h postmortem. At 0.25 hr postmortem, 32 % of LAPS samples had a pH below 6.0, in comparison to 0 % for ES Samples (Figure 4.2). In addition, 65 % of LAPS samples had a pH below 6.3 at 0.25 hr postmortem in comparison to only 21 % for ES samples. Previous investigations by Battula et al. (2008) in a pilot study also documented that the number of breast meat samples with a pH less than 6.2 at 0.25 hr postmortem was greater in LAPS birds than in ES stunned birds.

Furthermore, these observations for meat pH at 0.25 hr postmortem in ES birds are in agreement with that of Debut et al. (2003), who reported a corresponding pH range of 6.3 to 6.6 for ES birds. The more rapid pH drop in breast meat from LAPS stunned broilers in the present study indicates that the onset of rigor mortis is very rapid for a large proportion of samples when compared to samples from ES stunned broilers. This is evident from the observations at 4 h postmortem wherein 88 % of the LAPS samples had a pH of 5.6-6.0, while this proportion was only 39 % for the ES treatment. On the other hand, 89 % of LAPS and 93 % of ES breast meat samples had a final pH in the range of 5.6 to 6.0, indicating that both LAPS and ES systems have a similar effect on ultimate/final meat pH at 24 h postmortem (Alvarado et al., 2007; Papinaho and Fletcher, 1995). Low voltage electrical stunning delays post mortem glycolysis or reduces early lactic acid accumulation due to the suppression of perimortem struggle (Papinaho et al., 1995). On the other hand, Goksoy et al. (1999) documented that captive bolt stunning led to lower pH at 10 min postmortem and lower shear when deboned at 3 h postmortem which indicates a death struggle and the potential for an earlier onset of rigor mortis. The toughness in broiler meat if deboned before the development of rigor mortis is attributed to physical stimulation during processing, cold shortening, and the absence of skeletal framework to limit shortening (Sams, 1999).

Instrumental Color

With respect to the color of broiler breast meat that was deboned at 4 hr postmortem, there was no difference (P>0.05) in lightness (L* value) between LAPS and ES stunned broilers (Table 4.1). This indicates that LAPS can be utilized in the broiler stunning industry without impacting meat color. When comparing the L values for ES and LAPS breast samples that were deboned at 0.75 h postmortem, the L* value was less for breast fillets from ES broilers. Our results differ with the data from the pilot study (Battula et al., 2008) which reported lower L* values in LAPS birds when compared to ES samples, and could be attributed to the difference in sample size, environment (summer), as well as experimental settings (commercial scaling) in the present study. Both LAPS- and ES- samples exhibited lower ($P<0.05$) L* values at 0.75 h postmortem indicating that). These samples have a greater pH since they have not completed rigor. This causes water molecules that are tightly bound to myofibrillar proteins to scatter less light and make the meat appear darker (Cornforth, 1994). There were significant differences among treatments in a* values and b* values (Table 4.1) with values ranging from 0.6 to 1.8, and 4.6 to 6.2, respectively, albeit negligible practical relevance. Furthermore, all samples demonstrated L* values less than 60 which are considered within the normal range for broiler breast fillet meat (Van Laack et al., 2000; Woelfel et al., 2002). Greater L* value (above 60) together with low ultimate pH indicates pale meat with lower water holding capacity (Van Laack et al., 2000; Woelfel et al., 2002).

Brine Absorption and Cooking Loss

There were no differences ($P>0.05$) between LAPS and ES with respect to brine absorption at both deboning times (Table 4.1). Though no statistical comparison was made, marinated breast fillets for both LAPS and ES stunned broilers had less cooking loss at each deboning time when compared to their non-marinated counterpart. This is expected since salt and phosphate in the marinating solution improve the water holding capacity of the meat. Marinated ES samples had less ($P<0.05$) cooking loss at both deboning times than their LAPS counterparts. However, cooking loss was similar

(P>0.05) in all non-marinated treatments, with the exception of the LAPS 0.75 h samples, which had a slightly greater (P<0.05) cooking loss than all other treatments and could be attributed to a more rapid decline in pH which leads to biochemical conditions that may result in reduced water-holding capacity by proteins in the meat. Moreover, Raj et al (1990) and Lambooij et al. (1999) have also reported no difference in cooking loss between breast meat from electrical stunned broilers and carbon dioxide and argon gas stunning.

Instrumental Shear Force Determination

There was no difference (P>0.05) in Allo-Kramer shear force between LAPS and ES treatments for control samples (non-marinated) at each deboning time, but both 4 hr deboned treatments required less (P<0.05) shear force to cut through the meat than breast meat from the LAPS and ES 0.75 h postmortem treatments (Table 4.2). For marinated samples, the ES breast meat that was deboned at 0.75 hr required less (P<0.05) shear force to cut through the breast meat than the marinated breast meat from the 0.75 h deboned LAPS treatment. In addition, there was no difference (P>0.05) in Allo-Kramer shear force of breast meat between LAPS and ES 4 hr treatments, and both 4 hr treatments required less force (P<0.05) to shear through the samples than both ES and LAPS 0.75 hr treatments for both marinated and non-marinated samples. This confirms that deboning breast meat at 4 hr postmortem provides greater assurance that the breast meat will be tender. These shear values were fairly similar to values reported by Cavitt et al. (2004), who reported Allo-Kramer Shear values of approximately 90 (N/g) and 60 (N/g) at 1.25 and 4 hr postmortem, respectively. In contrast to our results using the Allo-Kramer Shear Cells, Warner-Bratzler shear force values indicated that there was no difference in tenderness between breast meat from LAPS and ES treatments in marinated and non-marinated samples, with the exception of the non-marinated ES 0.75 hr treatment. Allo-Kramer shear force accounts for the force required to penetrate through a sample (25 g), while Warner-Bratzler shear force utilizes uniform sample strips, which could be attributed to the difference in data between the two measuring devices. Schilling et al. (2003) reported that shear force values of less than 45 N would be considered tender to the majority of consumers. Therefore, our results indicate that aging for 4 h results in tender meat in both LAPS and ES systems which is also supported by previous investigations (Lyon et al., 1989; Thielke et al., 2005; Battula et al., 2008). Even though 0.75 hr postmortem samples had greater Allo-Kramer shear force values than samples deboned at 4 h, Warner-Bratzler shear force results indicate that ES 0.75 hr and LAPS 0.75 hr samples were both tender and would be acceptable to a large percentage of consumers (Schilling et al., 2003).

Consumer Acceptability of Baked Broiler Breast Meat

Consumers rated breast fillet meat from all treatments between like slightly and like moderately for all aspects measured (Table 4.3). The appearance acceptability of all treatment combinations was between like moderately and like very much. The only difference in appearance among treatments was that on average, the samples from the LAPS 4 hr treatment were preferred ($P<0.05$) over samples from the ES 4 hr treatment. However, this difference is very small numerically and does not likely have practical significance. No other differences in the acceptability of appearance existed among treatments ($P>0.05$). On average, the aroma of breast meat from the LAPS 4 hr treatment was liked ($P<0.05$) slightly more than the ES 0.75 hr and ES 4 hr treatments, but no other differences (P>0.05) occurred among treatments. The texture of the LAPS 4 hr treatment was preferred (P<0.05) over the texture of the ES and LAPS 0.75 hr treatments, but the acceptability of texture for the LAPS 4 hr and ES 4 hr treatments were not different (p<0.05). With respect to overall acceptability and flavor, the broiler breast meat from the LAPS 4 hr treatment was more acceptable (P<0.05) than breast meat from the other treatments. This shows that even though consumers indicated that breast meat from all treatments were acceptable (liked slightly or better), the LAPS 4 hr treatment may possibly produce breast meat with slightly better flavor and overall acceptability when the product is prepared as listed in the methods and baked in an oven.

To analyze the variability in the overall consumer acceptability scores of the panelists, cluster analysis was performed. Consumers were separated into six separate groups based on a dissimilarity plot and a dendrogram (Table 4.4). Cluster 1 (37.8% of panelists) and Cluster 2 (24% of panelists) liked all samples at least like slightly and panelists in Cluster 1 preferred (P<0.05) breast meat from the ES 0.75 hr and LAPS 4 hr treatment over the breast meat from the LAPS 0.75 hr and ES 4 hr treatments, but all samples were rated between like slightly and like very much. This indicates minimal practical differences among treatments. Panelists that were grouped into Cluster 2 preferred (P<0.05) breast meat from the LAPS treatments when compared to breast meat from the ES treatments, but the degree of liking was very high for all samples (7.7 to 8.3). Panelists preferred (P<0.05) breast meat from the LAPS 4 hr over ES 4 hr treatments in both cluster 1 and 2, even though the scores were numerically close. Panelists in cluster 3 (13 %) rated breast meat from the LAPS 0.75 hr, ES 4 hr and LAPS 4 hr treatments like slightly and moderately and preferred (P<0.05) these samples over breast meat from over the ES 0.75 hr treatment. Cluster 4 (3.2% of panelists) preferred (P<0.05) breast meat from treatment ES 0.75 hr over the rest of the treatments. In addition, panelists in cluster 3 preferred (P<0.05) the ES 4 hr and LAPS 0.75 hr treatments over samples from the LAPS 4 hr treatment. This potentially indicates two things. First, these 5 panelists (3.2 %) did not like breast meat from LAPS treatments and preferred meat from ES treatment that required more shear force to cut through the breast meat. The 10.3% of the panelists that were in cluster 5 did not like any of the samples and indicates that these panelists did not like baked chicken samples and should not have been included in the study. The remaining 9.7 % of the panelists cluster 6 did not differ in their liking scores for ES 0.75 hr, ES 4 hr, and LAPS 4 hr samples, but they preferred (P<0.05) these samples over breast meat samples from the LAPS 0.75 hr treatment. The results from cluster analysis demonstrate that with the exception of cluster 5, all panelists liked at least one treatment. After the removal of cluster 5, 100 % of panelists liked breast meat from the ES 4 hr treatment, 96% of the panelists like samples from the LAPS 4 hr treatments, and 86% liked the ES 0.75 hr and LAPS 0.75 hr treatments. Cluster analysis data indicates that all samples were acceptable, but that a larger number of consumers preferred samples that were deboned at 4 h for both stunning methods (ES and LAPS). In addition, data indicates that 72 % of consumers preferred (P<0.05) the LAPS 4 hr treatment over the ES 4 hr treatment, even though the differences were very small. These findings were further validated by using Allo-Kramer shear force data from this experiment, which indicated that samples that were deboned at 4 h had lesser (P<0.05) shear force values than 0.75 h deboned samples. The current study that was performed by using commercial settings revealed that the LAPS system could be successfully used in broiler harvesting plants without affecting their breast meat quality with respect to color, texture, and overall consumer acceptance when compared to commercial electrical stunning.

Consumer Acceptability of Fried Broiler Breast Meat

The acceptability of appearance was greater ($P<0.05$) for breast meat from the LAPS 0.75 hr treatment than breast meat from the ES 0.75 hr and ES 4 hr treatments, and the appearance of the LAPS 4 hr samples was preferred ($P<0.05$) over the appearance of the ES 4 hr samples (Table 4.5). No other differences existed ($P>0.05$) among treatments. However, the mean values for appearance acceptability were between 7.4 and 7.8, which indicates minimal practical differences among treatments. On average, the aroma acceptability was greater ($P<0.05$) in samples from the ES 0.75 hr when compared to the ES 4 hr and LAPS 0.75 hr treatments, but no other differences ($P>0.05$) existed between treatments for breast meat aroma acceptability. Similar to the acceptability of appearance, minimal practical differences existed since values ranged from 7.1 to 7.4 (like moderately) on a 9 point hedonic scale that ranges from 1 to 9. No differences existed ($P>0.05$) among breast meat from the various treatments with respect to texture, flavor, and overall acceptability with average ratings close to like moderately (7.0). This indicates that chicken breast meat from each treatment could effectively be used for frying without impacting acceptability. This is in contrast to the baking method, where the cooking method is not as forgiving to less tender raw material and it would be important to have breast meat that was deboned at 4 hr postmortem from either the LAPS or ES treatment.

Cluster analysis was conducted to account for the variability among individual panelists (Table 4.6). Cluster 1 (44.2 % of consumers) liked all samples between like moderately and like very much, and on average preferred ($P<0.05$) breast meat from the ES 0.75 hr treatment over breast meat from the LAPS 0.75 hr treatment (Table 4.6). However, these values are 7.2 and 7.5, which are very close to each other on the hedonic scale. Cluster 2 (12.8 % of consumers) preferred ($P<0.05$) breast meat from the ES treatments over the LAPS treatments. These consumers liked both ES treatments moderately and neither liked nor disliked the LAPS treatments. Cluster 3 (19.8 % of consumers) preferred ($P<0.05$) the LAPS 0.75 hr, LAPS 4 hr, and ES 4 hr treatment samples over breast meat from the ES 0.75 hr samples. These panelists liked the former 3 treatments between like slightly and like moderately and neither liked nor disliked the ES 0.75 hr treatment samples. Cluster 4 (18.0 % of consumers) liked all samples between like moderately and like extremely. These panelists preferred the LAPS 0.75 hr treatment over all other treatments and preferred the ES 4 hr treatment over the ES 0.75 hr treatment. No other differences existed ($P>0.05$) among treatments. Results indicate that although all samples would be very acceptable to consumers, they would prefer to consume the LAPS 0.75 hr samples. Cluster 5 (6.4 % of panelists) preferred the ES 0.75 hr treatment over the ES 4 hr treatment and preferred the LAPS 0.75 hr treatment over the LAPS 4 hr and ES 4 hr treatments. This indicated that these panelists prefer the earlier deboned samples, which is likely due to more texture or bite. In addition, this cluster preferred ($P<0.05$) the LAPS 4 hr treatment over the ES 4 hr treatment. Cluster analysis also indicates that 80.2 % of panelists like (score greater than 6) the ES 0.75 hr samples, 87.2 % of panelists like the LAPS 0.75 hr and LAPS 4 hr samples, and 93.6 % of panelists liked the ES 4 hr treatment.

Consumer Acceptability of Sous Vide-Cooked Broiler Breast Meat

The only differences among treatments that were prepared sous vide were in texture acceptability (Table 4.7). The texture of the breast meat from the ES 4 hr treatment was preferred ($P<0.05$) over breast meat from all other treatments. In addition these values correlate with overall acceptability, even though no differences existed ($P>0.05$) among breast samples from any treatment for overall acceptability. Results indicate that the texture of the ES 4 hr treatment is slightly preferred over other treatments, but that all samples were on average, liked moderately.

Cluster analysis demonstrates that Cluster 1 (17.5 % of panelists) preferred ($P<0.05$) the LAPS 0.75 hr, ES 4 hr, and LAPS 4 hr treatments over the ES 0.75 hr samples (Table 4.8). Cluster 2 (31.2 %) was the largest cluster and liked all samples very much, with no differences ($P>0.05$) among treatments. Cluster 3 (10.0 % of panelists) preferred ($P<0.05$) breast meat samples from the ES 4 hr treatment over all other treatments, preferred the LAPS 0.75 hr samples over the ES 0.75 hr samples and the LAPS 4 hr treatment samples, and preferred ($P<0.05$) the ES 0.75 hr treatment over the LAPS 4 hr treatment. Cluster 4 (15.6 % of panelists) did not rate samples very high in general, but preferred both ES treatments over the LAPS treatments. Cluster 5 (13.1 % of panelists) liked all treatments at least moderately, with the exception of the LAPS 0.75 hr treatment. In addition, samples from the ES 4 hr treatment were preferred ($P<0.05$) over all other treatments, and the LAPS 4 hr and ES 0.75 hr treatments were preferred ($P<0.05$) over the LAPS 0.75 hr treatment. Cluster 6 (12.5 % of panelists) preferred

(P<0.05) the ES 0.75 hr and LAPS 4 hr treatments over the LAPS 0.75 hr treatment, and preferred samples from the LAPS 0.75 hr treatments when compared to samples from the ES 4 hr treatment. Eight-four % of the panelists liked at least one sous vide treated sample moderately. Of these 84 % of panelists, 67, 70, 85, and 88 % liked breast meat samples from ES 0.75 hr, LAPS 0.75 hr, ES 4 hr, and LAPS 4 hr moderately or greater.

Descriptive Sensory Analysis

Sensory descriptive analysis was conducted to determine the sensory descriptors that describe each cooking method as well as differentiate between stunning and deboning time treatment combinations. For baked samples, the only aroma and flavor descriptors that differed between treatments included metallic flavor and spice intensity (flavor). Breast meat from the ES 4 hr had a slightly lower (P<0.05) rating than the ES 0.75 hr and LAPS 4 hr treatment but did not differ (P>0.05) from the LAPS 0.75 hr treatment for metallic flavor (Table 4.10). In addition, the spice intensity was slightly greater (P<0.05) for breast meat from the LAPS 0.75 hr treatment when compared to the ES 0.75 hr and LAPS 4 hr samples. The ES 4 hr and LAPS 4 hr treatments were more tender (P<0.05) than samples from the ES 0.75 hr treatment, and the ES 4 hr treatment was juicier (P<0.05) than the ES 0.75 hr treatment (Table 4.9). The lower tenderness and juiciness rating of samples from the ES0.75 hr treatment in comparison to ES 4 hr (control, industry standard), may have led to it being rated lower than samples from other treatments in Cluster 3 (Table 4.4). However, these same differences may have also contributed to the ES 0.75 hr treatment being preferred by cluster 4 (3.2% of panelists). This small group of panelists may have preferred less tender and harder chicken breast meat. The ES 0.75 hr samples were also harder (p<0.05) than samples from other treatments, with the exception of the LAPS 0.75 hr treatment, and the LAPS 0.75 hr treatment was more cohesive than the LAPS 4 hr samples. It is not possible to know for sure, but breast meat from the LAPS 0.75 hr treatment may have been liked less than breast meat samples from other treatments because it was harder (Table 4.9) than the ES 4 hr (control, industry standard) and spicier than the ES 0.75 hr and LAPS 4 hr treatment (Table 4.10).

There were minimal differences in sensory descriptors among treatments when the chicken breasts were fried (Tables 4.9 and 4.10). There were some differences ($P<0.05$) in bitterness but all samples ranged between 0.3 and 0.4, so these differences were not of practical significance. The ES 0.75 hr treatment yielded fried breast meat that was juicier ($P<0.05$) than breast meat from the ES 4 hr treatment, but no other treatment differences existed for juiciness. Cluster 2 (12.8 % of panelists) may not have liked the LAPS 0.75 hr treatment because it had a higher numerical score for spice intensity. Consumers may not have liked the heavier spice flavor. Cluster 3 (19.8 % of panelists) may not have liked the ES 0.75 hr samples because it was juicier than the other treatments. Cluster 5 (6.4 % of panelists) may not have liked the ES 4 hr treatment because it was slightly dryer than the other samples.

More differences existed between treatments for sous vide samples than the other cooking methods (Tables 4.12 and 4.13). Breast meat from the LAPS 4 hr treatment had slightly more chicken flavor ($P<0.05$) than breast meat from the ES 0.75 hr treatment, but no other differences existed ($P>0.05$) among treatments for this flavor component. In addition, breast meat from the LAPS 0.75 hr treatment had more ($P<0.05$) spice flavor than breast meat from the ES 4 hr and LAPS 4 hr treatments. In addition, the LAPS 0.75

hr treatment produced more sour meat than the ES 4 hr and LAPS 4 hr treatments, and the ES 0.75 hr treatment produced meat that was more sour than the LAPS 4 hr treatment. These results are logical since the 0.75 hr deboned samples also had more lemon flavor than samples deboned at 4 hours. Cluster 2 did not like either LAPS treatment. If they had only not liked the LAPS 0.75 hr treatment, it would have been logical that this group did not like the enhanced sour and lemony taste of that sample. However, there is no logical explanation for these results based on sensory descriptive analysis. Cluster 3 did not like the ES 0.75 hr treatment which may be due to a combination of variability in chicken flavor, spice flavor, lemon flavor, sour flavor, and juiciness. Cluster 5 may have preferred the LAPS 0.75 hr samples over the 4 hr deboned samples because these panelists liked the increased sour and lemony flavor.

Principal Components Analysis and biplots (Figures 4.3, 4.4, 4.5)) were used to differentiate between cooking methods and treatments based on sensory descriptors. In Figure 4.3, the two axes (eigen values) explain 92 % of the variability in the data. The fried chicken breast samples are described by the fatty aroma when compared to the baked and sous vide samples. The 0.75 hr min deboned samples have slightly more aroma in general than the 4 hour deboned samples. The baked samples are described by chicken aroma and broth compared to the other cooking methods and by having slightly less spice aroma than the sous vide cooked samples. In addition, there are minimal differences between baked samples, but the ES 4 hr samples had slightly less roasted aroma, chicken aroma, and spice aroma than the other baked treatments. For the sous vide samples, there are only minor differences between samples, but the 4 hr deboned samples are slightly more brothy than the 4 hour deboned treatments, The LAPS samples have slightly more chicken flavor than the ES samples, and the ES 4 hr treatment has more spice aroma than the other treatments.

In Figure 4.4, the two axes (eigen values) explain 89 % of the variability in the data. The fried chicken breasts were oilier than all other cooking methods, and there were minimal differences between fried treatments with respect to flavor. The baked treatments were described more by chicken flavor and metallic than the other cooking methods. The baked treatments were very similar in flavor, but the LAPS samples were slightly more bitter than the ES Samples. The ES 0.75 hr samples were more metallic than the ES 4 hr samples, and the LAPS 0.75 hr had a greater spice intensity than other samples. The sous vide samples were differentiated from other cooking methods by having higher relative intensities for chemical, spice flavor, sour, and umami. The sous vide treatments were the easiest to differentiate from each other with respect to flavor when compared to the other cooking methods. The LAPS 0.75 hr samples were defined by being more lemony, spicy, and sour when compared to other treatments. The ES 0.75 hr sample was slightly more lemony, spicy, and sour than the 4 hr deboned treatments, which indicates that deboning at 0.75 hr min leads to small increases in these descriptors and that combining LAPS with deboning at 0.75 hr accentuates these differences. The LAPS 4 hr treatment could be further differentiated from ES 4 hr treatment because it was less intense in chemical, sour, salty, bitter, and umami than the ES 4 hr treatment, which may help explain why cluster 3 in the consumer testing did not like this treatment.

In Figure 4.5, the two axes (eigen values) explain 87 % of the variability in the data. This figure indicates that the texture for all fried treatments were very similar and the texture of all sous vide treatments were very similar to each other. The only descriptor separating the fried treatments is juiciness, in which the ES 0.75 hr treatment is juicier than the ES 4 hr treatment. For the sous vide samples, the graph shows the LAPS treatments grouped together and the ES treatments grouped together, but the numerical differences in texture were very small between treatments. Baking accentuated textural differences between treatments that were not seen with other cooking methods. The ES and LAPS 4 hr deboned treatments, were more tender, less cohesive, and less hard than the ES and LAPS 0.75 hr deboned treatments with tenderness being the primary differentiator. However, the ES 4 hr treatment was slightly juicier than the LAPS 4 hr treatment. In addition, the LAPS 0.75 hr treatment was slightly more tender and juicier than breast meat from the ES 0.75 hr treatment. These results reveal that any of these stunning and deboning combinations could be used if the end use of the product is frying or sous vide cookery. However, if the product is going to be baked, only ES 4 hr and LAPS 4 hr treatments should be used to prevent texture variability.

Table 4.1 The effects of stunning method and deboning time on the pH, color, brine absorption, and cooking loss of broiler breast meat.

Treatment[1]	Ultimate pH	CIE L* (Lightness)	CIE a* (Redness)	CIE b* (Yellowness)	Brine Absorption (%)	Cooking Loss (%) Marinated	Cooking Loss (%) Non-Marinated
LAPS 0.75 hr	5.9^{a}	58.2^{b}	1.8^{a}	6.2^{a}	14.6	19.6^{ab}	24.6^{a}
ES 0.75 hr	5.9^{a}	56.6^{c}	0.6^{c}	4.6^{c}	14.3	17.1^{c}	22.5^{b}
LAPS 4 hr	5.8^{a}	59.7^{a}	1.6^{a}	4.9^{bc}	13.5	19.9^{a}	22.5^{b}
ES 4 hr	5.9^{a}	59.9^{a}	1.0^{b}	5.2^{b}	13.4	18.3^{bc}	22.0^{b}
S.E.	0.03	0.73	0.23	0.66	0.63	0.58	0.65

a-c Means within a column with the same letter are not significantly different ($P>0.05$)
[1] LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

Table 4.2 The effects of stunning method and deboning time on the shear force of broiler breast meat.

Treatment[1]	Allo-Kramer Shear Force Control (N/g)	Allo-Kramer Shear Force Brine (N/g)	Warner-Bratzler Shear Force Control (N)	Warner-Bratzler Shear Force Brine (N)
LAPS 0.75 hr	93.2[a]	80.9[a]	19.8[b]	13.0[a]
ES 0.75 hr	95.9[a]	61.1[b]	23.9[a]	13.7[a]
LAPS 4 hr	41.6[b]	35.2[c]	19.7[b]	13.1[a]
ES 4 hr	40.5[b]	32.1[c]	20.1[b]	12.6[a]
S.E.	2.13	3.19	0.43	0.32

a-c Means within a column with the same letter are not significantly different ($P>0.05$).
[1]LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

Table 4.3 The effects of stunning methods and deboning time on the consumer acceptability

Treatment[2]	Appearance Acceptability	Aroma Acceptability	Texture Acceptability	Flavor Acceptability	Overall Acceptability
LAPS 0.75 hr	7.3^{ab}	7.0^{ab}	6.3^{c}	6.6^{b}	6.6^{b}
ES 0.75 hr	7.3^{ab}	6.8^{b}	6.6^{bc}	6.7^{b}	6.6^{b}
ES 4 hr	7.2^{b}	6.8^{b}	6.9^{ab}	6.6^{b}	6.7^{b}
LAPS 4 hr	7.5^{a}	7.1^{a}	7.1^{a}	7.0^{a}	7.0^{a}
S.E.	0.08	0.08	0.11	0.10	0.10

Mean hedonic score representing appearance, aroma, texture, flavor and overall consumer acceptability, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of broiler breast meat (n=185). Samples were baked with different stunning methods (ES=electrical stunning; LAP=low atmospheric pressure stunning), and deboning time (hr=hours) according to different consumer groups (clusters). $^{a\text{-}c}$ Means within a row with the same letter are not significantly different ($P>0.05$).

Table 4.4 Overall Consumer acceptability of baked broiler breast meat.

Cluster	Panelist (%)	ES0.75hr	LAPS0.75hr	ES4hr	LAPS4hr
1	37.8	7.1[a]	6.6[b]	6.6[b]	7.2[a]
2	24.0	7.9[b]	8.2[a]	7.7[b]	8.3[a]
3	13.0	4.3[b]	6.8[a]	6.9[a]	6.6[a]
4	3.2	8.7[a]	5.5[b]	6.8[b]	2.8[c]
5	10.3	4.3[ab]	5.3[a]	3.3[b]	5.0[a]
6	9.7	6.6[a]	3.6[b]	6.9[a]	7.0[a]

Mean hedonic scores representing overall consumer acceptability, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of broiler breast meat (n=185). Samples were baked with different stunning methods (ES=electrical stunning; LAP=low atmospheric pressure stunning), and deboning time (hr=hours) according to different consumer groups (clusters). [a-c] Means within a row with the same letter are not significantly different ($P>0.05$).

Table 4.5 The effects of stunning methods and deboning time on appearance, aroma, texture, flavor and overall consumer acceptability of fried broiler breast meat.

Treatment[2]	Appearance Acceptability	Aroma Acceptability	Texture Acceptability	Flavor Acceptability	Overall Acceptability
ES 0.75 hr	7.5^{bc}	7.4^{a}	7.1^{a}	6.9^{a}	7.0^{a}
LAPS 0.75 hr	7.8^{a}	7.2^{b}	7.3^{a}	7.0^{a}	7.1^{a}
ES 4 hr	7.4^{c}	7.1^{b}	7.1^{a}	6.9^{a}	7.0^{a}
LAPS 4 hr	7.6^{ab}	7.2^{ab}	7.0^{a}	6.7^{a}	6.9^{a}
S.E	0.09	0.07	0.11	0.08	0.07

Mean hedonic scores representing appearance, aroma, texture, flavor and overall consumer acceptability, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of fried broiler breast meat (n=185).$^{a-c}$ 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]LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

Table 4.6 Overall consumer acceptability of fried broiler breast meat.

Cluster	Panelist (%)	ES0.75 hr	LAPS0.75 hr	ES4 hr	LAPS4 hr
1	44.2	7.5^{a}	7.2^{b}	7.3^{ab}	7.3^{ab}
2	12.8	7.0^{a}	4.9^{b}	7.0^{a}	4.7^{b}
3	19.8	4.9^{b}	6.6^{a}	6.3^{a}	6.1^{a}
4	18.0	7.9^{c}	8.7^{a}	8.3^{b}	8.2^{bc}
5	6.4	7.4^{ab}	7.8^{a}	3.9^{c}	6.5^{b}

Mean hedonic scores representing overall consumer acceptability, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of broiler breast meat (n=185). Samples were fried with different stunning methods (ES=electrical stunning; LAP=low atmospheric pressure stunning), and deboning time (hr=hours) according to different consumer groups (clusters). $^{a-c}$ Means within a row with the same letter are not significantly different (P>0.05).

Table 4.7 The effects of stunning methods and deboning time on sous vide cooked broiler breast meat.

Treatment[2]	Appearance Acceptability	Aroma Acceptability	Texture Acceptability	Flavor Acceptability	Overall Acceptability
ES 0.75 hr	7.1[a]	7.0[a]	6.9[b]	6.7[a]	6.9[a]
LAPS 0.75 hr	7.1[a]	7.3[a]	7.0[b]	6.8[a]	6.9[a]
ES 4 hr	7.3[a]	7.2[a]	7.3[a]	7.0[a]	7.2[a]
LAPS 4 hr	7.1[a]	7.1[a]	7.0[b]	6.9[a]	6.9[a]
S.E	0.08	0.08	0.1	0.1	0.09

Mean hedonic scores representing appearance, aroma, texture, flavor and overall consumer acceptability, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of sous vide cooked broiler breast meat (n=185).[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]LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

Table 4.8 Overall consumer acceptability of sous vide cooked broiler breast meat.

Cluster	Panelist (%)	ES0.75 hr	LAPS0.75 hr	ES4 hr	LAPS4 hr
1	17.5	5.9^{b}	7.0^{a}	7.1^{a}	7.3^{a}
2	31.2	7.8^{a}	7.8^{a}	7.9^{a}	8.0^{a}
3	10.0	6.0^{c}	7.3^{b}	8.0^{a}	5.3^{d}
4	15.6	6.0^{a}	4.9^{b}	6.1^{a}	5.2^{b}
5	13.1	7.4^{b}	5.8^{b}	8.0^{c}	7.4^{b}
6	12.5	7.4^{a}	6.3^{b}	5.4^{c}	7.4^{a}

Mean hedonic scores representing overall consumer acceptability, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of broiler breast meat (n=185). Samples were cooked sous vide with different stunning methods (ES=electrical stunning; LAP=low atmospheric pressure stunning), and deboning time (hr=hours) according to different consumer groups (clusters).[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]LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

Table 4.9 Sensory descriptive scores for oven-baked broiler breast meat from different stunning methods and deboning times.

Aroma and Flavor	ES0.75 hr	LAPS0.75 hr	ES4 hr	LAPS4 hr
Brothy	3.9^{a}	3.7^{a}	3.8^{a}	3.6^{a}
Sweet	2.1^{a}	2.1^{a}	2.0^{a}	2.0^{a}
Chickeny	3.6^{a}	3.6^{a}	3.4^{a}	3.7^{a}
Roasted	1.9^{a}	1.9^{a}	1.7^{a}	1.9^{a}
Spice	4.2^{a}	4.5^{a}	4.1^{a}	4.4^{a}
Chemical	1.8^{a}	1.8^{a}	1.7^{a}	1.7^{a}
Chicken Flavor	4.0^{a}	4.0^{a}	3.9^{a}	4.1^{a}
Metallic	1.9^{a}	1.8^{ab}	1.6^{b}	1.9^{a}
Spice Intensity	3.8^{b}	4.3^{a}	4.0^{ab}	3.8^{b}

Mean hedonic scores representing brothy, sweet, chickeny, roasted, spice, chemical, chicken flavor, metallic and spice intensity, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of oven-baked broiler breast meat (n=185).[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]LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

Table 4.10 Sensory descriptive scores for oven-baked broiler breast meat from different stunning methods and deboning times.

Basic taste and	ES0.75 hr	LAPS0.75 hr	ES4 hr	LAPS4 hr

Oral Texture				
Sour	1.1[a]	1.3[a]	1.2[a]	1.1[a]
Salty	1.8[a]	2.1[a]	2.0[a]	1.7[a]
Bitter	0.9[a]	1.3[a]	0.9[a]	1.4[a]
Umami	2.1[a]	2.3[a]	2.2[a]	2.3[a]
Sweet	1.3[a]	1.5[a]	1.2[a]	1.4[a]
Tenderness	8.1[b]	8.6[ab]	9.2[a]	9.2[a]
Juiciness	7.1[b]	7.5[ab]	8.2[a]	7.7[ab]
Hardness	4.2[a]	4.0[ab]	3.5[c]	3.6[bc]
Cohesiveness	3.7[ab]	3.8[a]	3.4[ab]	3.3[b]

Mean hedonic scores representing sour, salty, bitter, umami, sweet, tenderness, juiciness, hardness and cohesiveness, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of oven-baked broiler breast meat (n=185).[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]LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

Table 4.11 Sensory descriptive scores for fried broiler breast meat from different stunning methods and deboning times.

Appearance, Aroma and Flavor	ES0.75 hr	LAPS0.75 hr	ES4 hr	LAPS4 hr

Color	9.2[a]	8.7[a]	9.0[a]	8.7[a]
Greasiness	3.1[a]	3.3[a]	2.9[a]	3.1[a]
Sweet	2.2[a]	2.2[a]	2.1[a]	2.0[a]
Chickeny	3.2[a]	3.3[a]	3.1[a]	3.2[a]
Roasted	1.7[a]	1.6[a]	1.6[a]	1.6[a]
Spice Intensity	0.8[a]	1.9[a]	0.8[a]	0.8[a]
Fatty	2.5[a]	2.4[a]	2.4[a]	2.5[a]
Brown	2.7[a]	2.6[a]	2.9[a]	2.9[a]
Chemical	1.4[a]	1.5[a]	1.4[a]	1.3[a]
Oily	2.7[a]	2.6[a]	2.7[a]	2.6[a]
Chicken Flavor	3.8[a]	3.7[a]	3.6[a]	3.6[a]
Metallic	1.4[a]	1.3[a]	1.4[a]	1.2[a]
Spice	0.8[a]	0.8[a]	0.8[a]	0.7[a]

Mean hedonic scores representing color, greasiness, sweet, chickeny, roasted, spice intensity, fatty, brown, chemical, oily, chicken flavor, metallic and spice, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of fried broiler breast meat (n=185).[a]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]LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

Table 4.12 Sensory descriptive scores for fried broiler breast meat from different stunning methods and deboning times.

Basic Taste and	ES0.75 hr	LAPS0.75 hr	ES4 hrs	LAPS4 hrs

Oral Texture				
Sour	0.6^{a}	0.5^{a}	0.5^{a}	0.5^{a}
Salty	1.3^{a}	1.3^{a}	1.2^{a}	1.2^{a}
Bitter	0.4^{ab}	0.3^{ab}	0.4^{a}	0.3^{b}
Umami	2.4^{a}	2.3^{a}	2.3^{a}	2.2^{a}
Sweet	2.0^{a}	1.9^{a}	2.0^{a}	2.0^{a}
Tenderness	9.2^{a}	9.1^{a}	8.9^{a}	9.0^{a}
Juiciness	8.0^{a}	7.6^{ab}	7.2^{b}	7.5^{ab}
Hardness	4.0^{a}	4.0^{a}	4.1^{a}	4.1^{a}
Crunchiness	3.7^{a}	3.7^{a}	4.0^{a}	3.8^{a}
Cohesiveness	3.9^{a}	4.2^{a}	4.0^{a}	4.0^{a}

Mean hedonic scores representing sour, salty, bitter, umami, sweet, tenderness, juiciness, hardness and cohesiveness, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of fried broiler breast meat (n=185).[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]LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

Table 4.13 Sensory descriptive scores for sous vide cooked broiler breast meat from different stunning methods and deboning times.

Appearance,

Aroma and Flavor	ES0.75 hr	LAPS0.75 hr	ES4 hr	LAPS4 hr
Moisture	6.0^{a}	6.3^{a}	6.1^{a}	6.0^{a}
Brothy	3.9^{a}	3.9^{a}	4.1^{a}	4.2^{a}
Chickeny	3.4^{b}	3.7^{ab}	3.6^{ab}	3.8^{a}
Sweet	1.7^{a}	1.9^{a}	1.9^{a}	2.0^{a}
Spice (Aroma)	5.4^{a}	5.4^{a}	5.8^{a}	5.1^{a}
Brown Caramelized	1.3^{ab}	1.1^{b}	1.4^{a}	1.2^{ab}
Lemony	4.3^{b}	5.1^{a}	3.9^{b}	4.0^{b}
Metallic	1.5^{a}	1.5^{a}	1.4^{a}	1.4^{a}
Spice (flavor)	5.8^{ab}	6.0^{a}	5.2^{b}	5.1^{b}
Chemical	1.9^{a}	1.9^{a}	1.8^{ab}	1.6^{b}

Mean hedonic scores representing moisture, brothy, chickeny, sweet, spice (aroma), caramelized, lemony, metallic, spice (flavor) and chemical, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of sous vide cooked broiler breast meat (n=185).[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]LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

Table 4.14 Sensory descriptive scores for sous vide cooked broiler breast meat from different stunning methods.

Basic Taste and Oral Texture	ES 0.75 hr	LAPS 0.75 hr	ES 4 hr	LAPS 4 hr
Sour	2.0[ab]	2.2[a]	1.7[bc]	1.5[c]
Salty	2.0[a]	1.9[a]	1.9[a]	1.6[a]
Bitter	1.1[a]	1.0[a]	0.9[ab]	0.7[b]
Umami	2.4[a]	2.5[a]	2.5[a]	2.2[a]
Tenderness	9.0[a]	9.2[a]	8.6[a]	9.0[a]
Juiciness	7.7[a]	7.6[a]	8.0[a]	8.0[a]
Chewiness	3.3[a]	3.4[a]	3.4[a]	3.1[a]

Mean hedonic scores representing sour, salty, bitter, umami, juiciness and chewiness, based on a 9-point scale (1=dislike extremely, 5= neither like nor dislike, and 9= like extremely), of sous vide cooked broiler breast meat (n=185).[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]LAPS = Low Atmospheric pressure stunning; ES = electrical stunning; hr = hours deboned after slaughter.

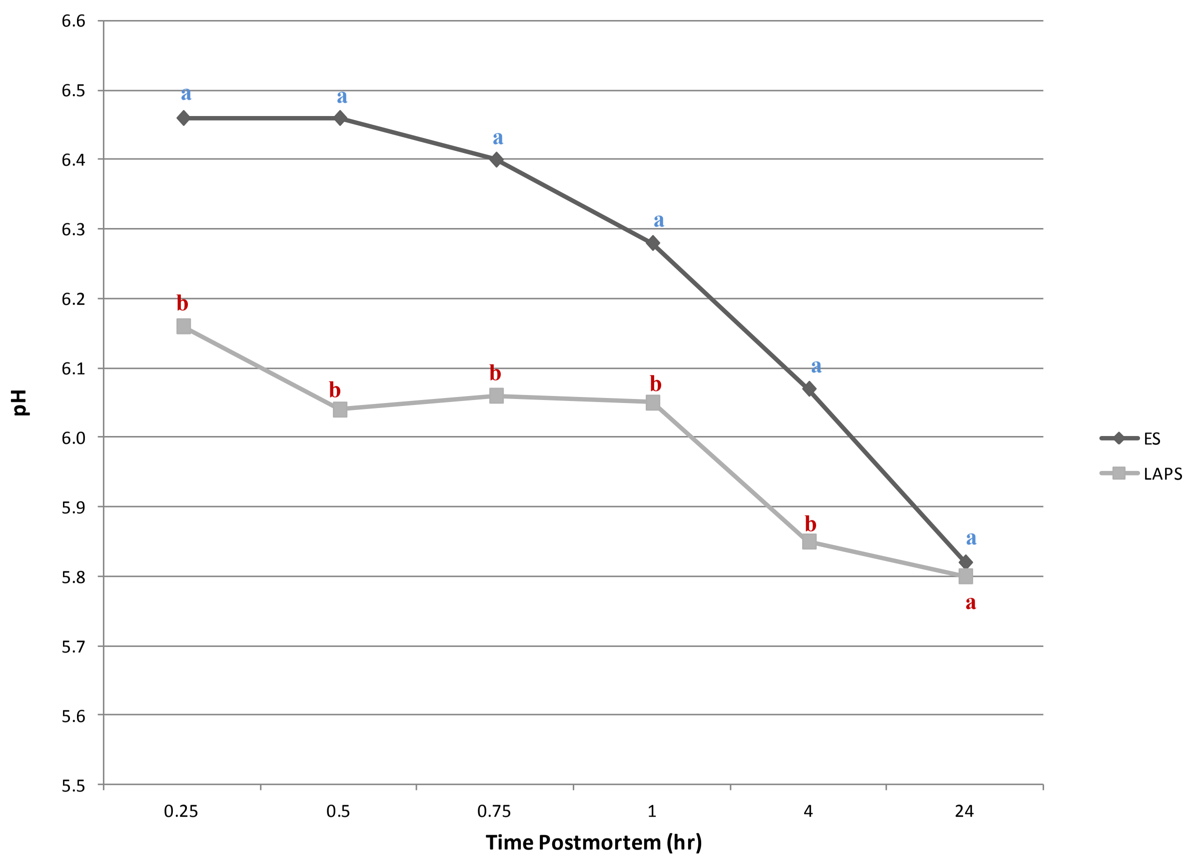

Figure 4.1 pH Decline of broiler breast meat (n=144) over time postmortem from broilers that were stunned through Electrical Stunning (ES) and Low Atmosphere Pressure Stunning (LAPS). Different letters at each postmortem indicate a difference ($P<0.05$).

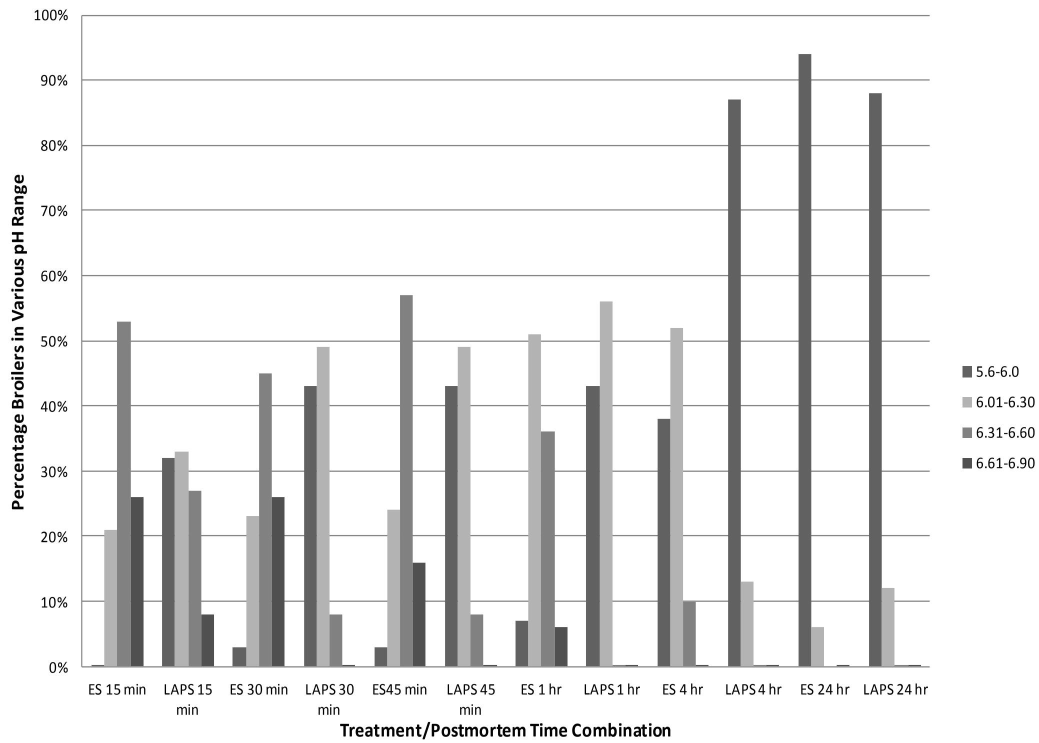

Fig. 2: The percentage of broilers (n=144) that had breast meat in different pH ranges at different times postmorten for electrically stunned (ES) and Low Atmosphere Pressure Stunning (LAPS).

Figure 4.2 The percentage of broilers (n=144) that had breast meat in different pH ranges at different times postmortem for Electrically Stunned (ES) and Low Atmosphere Pressure Stunning (LAPS)

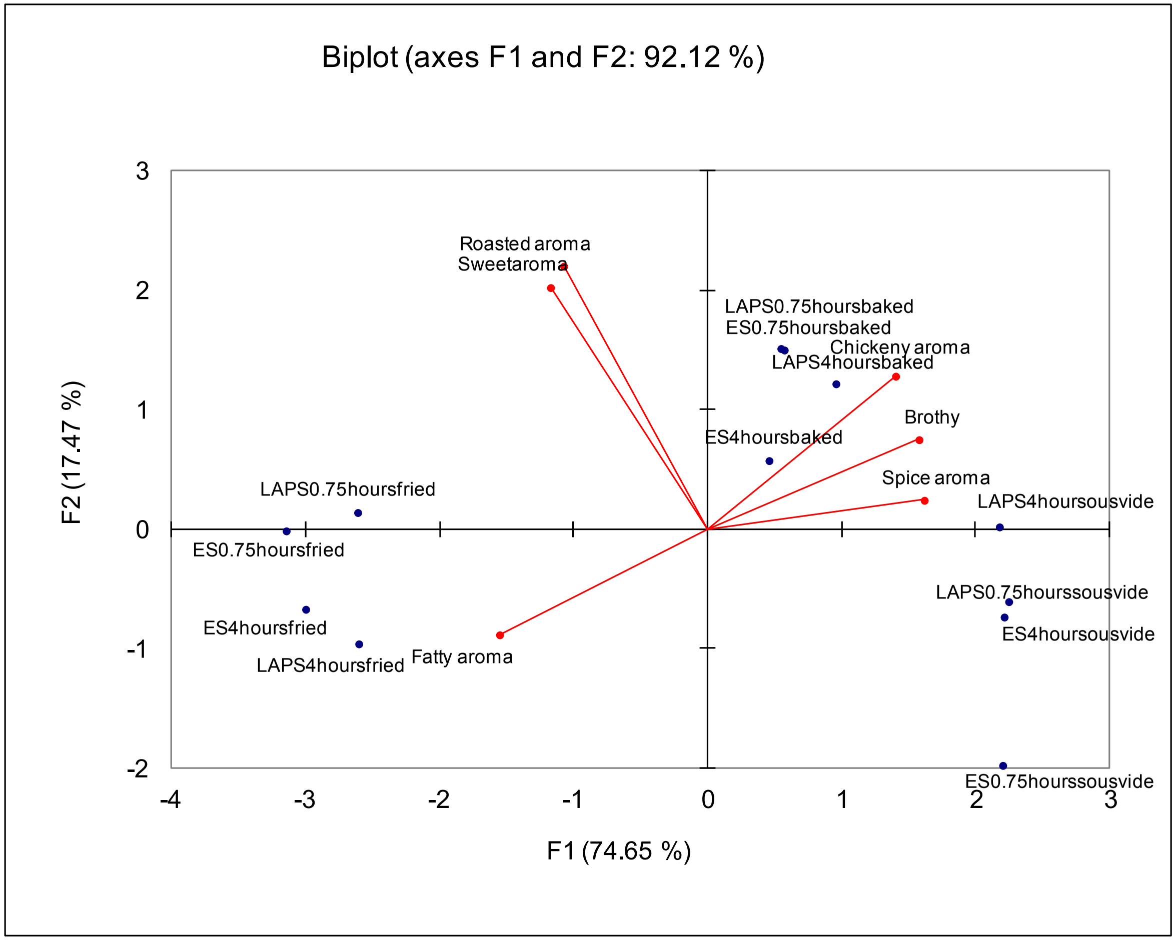

Figure 4.3 Principal component analysis biplot for the aroma of broiler breast meat with corresponding stunning method (ES, electrical stunning; LAPS, low atmospheric pressure stunning), deboning time (0.75 hours; 4 hours), and cooking method (baking, frying, sous vide).

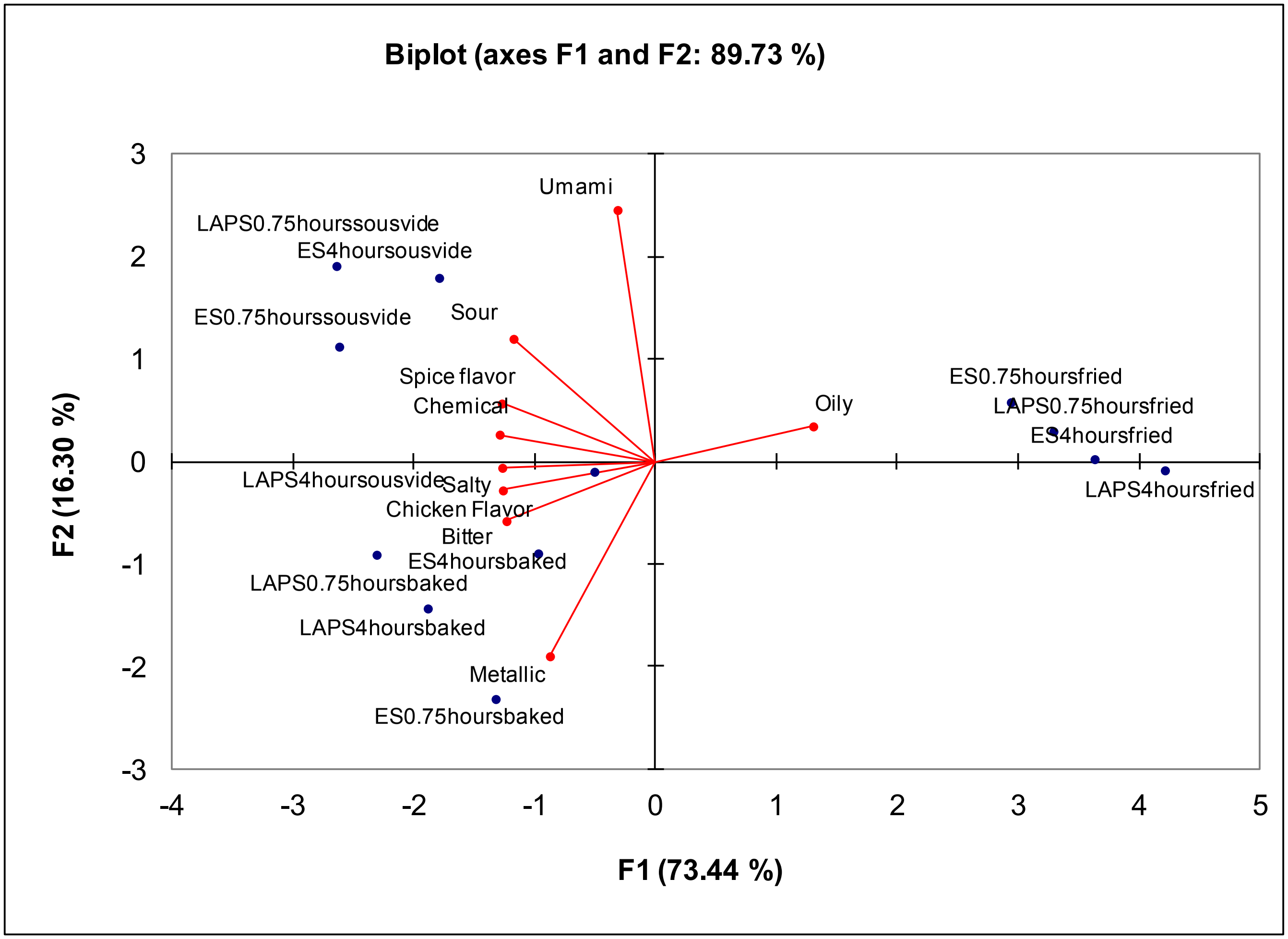

Figure 4.4 Principal component analysis biplot for the flavor of broiler breast meat with corresponding stunning method (ES, electrical stunning; LAPS, low atmospheric pressure stunning), deboning time (0.75 hours; 4 hours), and cooking method (baking, frying, sous vide).

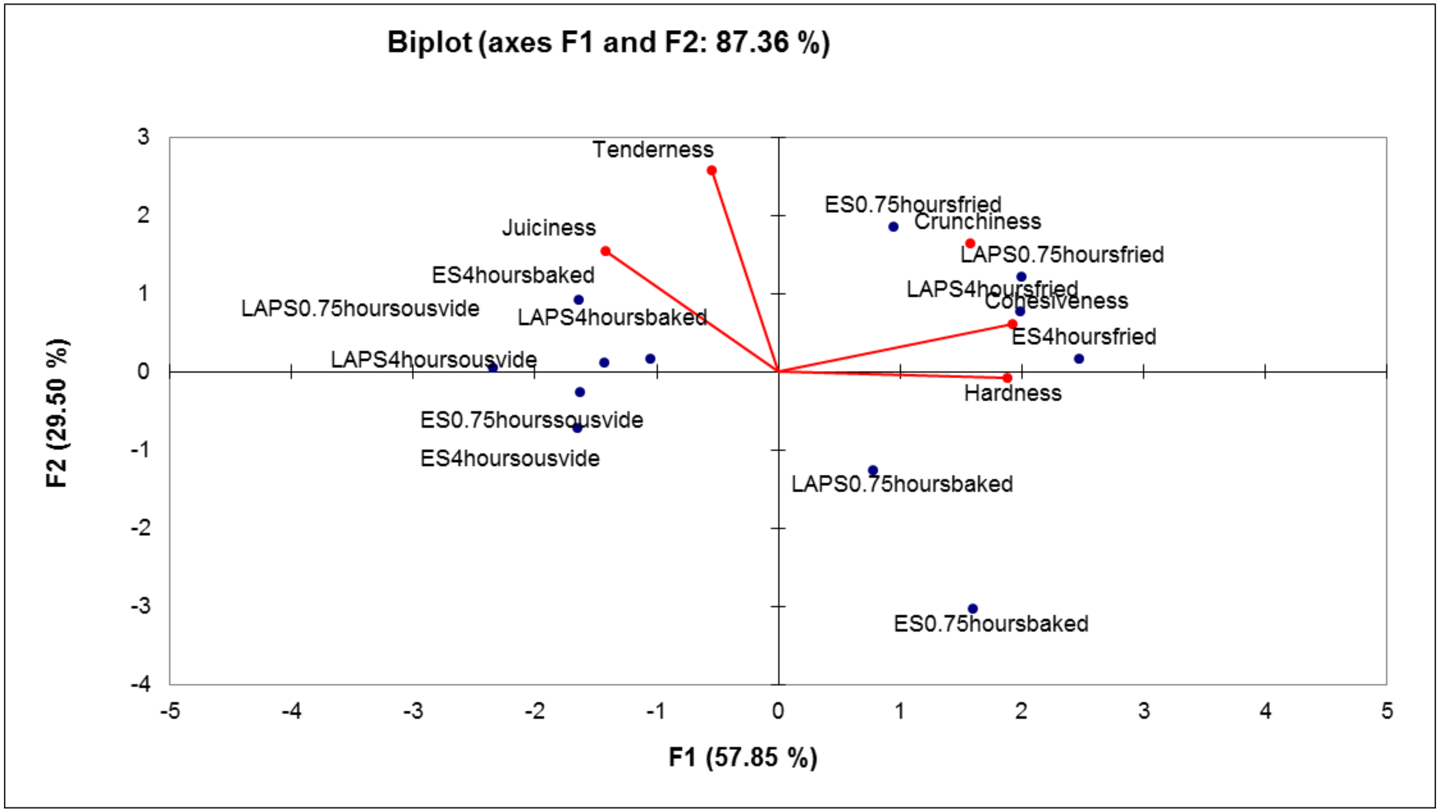

Figure 4.5 Principal component analysis biplot for the texture of broiler breast meat with corresponding stunning method (ES, electrical stunning; LAPS, low atmospheric pressure stunning), deboning time (0.75 hours; 4 hours), and cooking method (baking, frying, sous vide).

CHAPTER V

CONCLUSIONS

The present study that was conducted in a commercial setting revealed that the LAPS system could be successfully utilized in poultry plants without detrimental breast fillet quality problems with respect to color, texture, and consumer acceptance in comparison with electrical stunning. LAPS and ES yielded broiler breast meat with acceptable quality when prepared by different cooking methods. Chicken breast meat from all stunning and deboning method combinations was highly acceptable to the majority of consumers. Consumer preference was similar for the breast meat samples when prepared by frying or sous vide. LAPS samples deboned at 4hrs were preferred by consumers over the others, when baked. Sous-vide cooking yielded a tender and juicy product with unique flavor characteristics. Furthermore, deboning at 4 hrs would be beneficial for texture of broiler breast meat in oven-baking, irrespective of the stunning method.

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