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The effects of low atmosphere stunning and deboning time on broiler breast meat quality

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THE EFFECTS OF LOW ATMOSPHERE STUNNING AND DEBONING TIME ON BROILER BREAST MEAT QUALITY

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DEBONING TIME ON BROILER BREAST MEAT QUALITY

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A randomized complete block design with three replications (n=432, 72 broilers per treatment) was utilized to evaluate the effects of electrical (ES) and low atmosphere pressure stunning (LAPS) on the quality of broiler breast meat deboned at 0.75, 2, and 4 h postmortem. The L* values were lower ($P<0.05$) for LAPS than ES at 4 h and 2 h deboning times. Shear force did not differ ($P>0.05$) between stun methods but decreased ($P<0.05$) as deboning time increased. Consumers were clustered into 8 groups based on preference and liking of samples. Sixty-five percent of consumers (3 clusters) liked all broiler breast treatments. Within these three clusters, some consumers preferred ($P<0.05$) 4 h deboned samples over those deboned at 2 h (Cluster 7), and other consumers preferred ($P<0.05$) those deboned at 2 h over 4 h samples (Cluster 6). Data

reveals that both stunning methods provide high quality breast meat with minimal product differences.

DEDICATION

I would like to dedicate this thesis to my late brother, Rajanisekhar. Battula, whose discipline, courage and conviction always inspire me.

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CHAPTER I

INTRODUCTION

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

Stunning prior to harvest can be accomplished using chemical, mechanical, low atmosphere pressure (LAPS), or electrical means (Fletcher, 1999). Low atmospheric pressures in the range of 0.2-0.3 atm are created in order to stun broilers when the LAPS system is used. To date, there is minimal information published regarding the effects of LAPS on poultry welfare and meat quality. Purswell *et* al. (2007) recently reported that LAPS appeared to be an effective method for humane stunning and exsanguination of broilers. In addition, it has been reported that low atmosphere pressure stunning has been approved in Europe for use in farmed game species such as partridge, pheasant, and quail (European Commission, 2003), but there is no additional published information regarding this stunning method available. Electrical stunning is the most commonly utilized method for immobilizing poultry prior to harvest in commercial poultry plants (Goksoy *et* al., 1999). The effectiveness of an electrical stunning system is dependent on electrical variables (i.e., current, voltage, wave form, frequency and duration) and biological factors that affect bird impedance (i.e., size, weight, sex, and feather cover; Kettlewell and Hallworth, 1990). Electrical stunning reduces struggle and convulsions during harvest and subsequently reduces carcass damage associated with convulsions (Fletcher, 1999). However, electrical stunning has been shown to cause meat quality defects such as wing hemorrhages, red skin conditions, red wing tips, broken bones, and blood blemishes in breast muscle (Bilgili, 1992; Lambooij *et* al., 1999; Wilkins *et* al., 1999). During electrical stunning, broilers may defecate, fling their claws into the broilers around them, and inhale contaminated water that leads to carcass contamination and carcass down grades (Gregory and Whittington, 1992). To eliminate these problems, controlled atmosphere harvesting systems, such as gas stunning techniques, have been developed. The induction of unconsciousness with gas is rapid and requires less exposure time for broilers. Since the broilers are dead by the time they are shackled, controlled atmosphere stunning can result in improved product quality and yield by eliminating the risk of broken bones, bruising, and hemorrhaging. Researchers have reported that stunning of broilers with a gas mixture improves the quality of broiler breast meat when compared to electrical stunning (Raj, 1998, Raj *et* al., 1997). Research needs to be conducted to determine if similar results are present when low atmosphere pressure stunning is utilized.

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

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

CHAPTER II

LITERATURE REVIEW

Poultry Welfare

Knowles and Broom (1990) have defined welfare as a wide term that embraces both the physical and mental well being of the animal. Humane slaughter laws for food animals are designed to ensure that animals are killed quickly, painlessly, and without suffering (Raj, 1998). The Humane Methods of Slaughter Act (1958) mandates the use of humane methods for pre-slaughter immobilization of all livestock under USDA (United States Department of Agriculture) inspection. The law also dictates that animals must be made insensible to pain prior to bleeding (Bilgili, 1992). The United States Department of Agriculture Poultry Inspection Regulations state that poultry should be slaughtered in accordance with good commercial practices that will result in thorough bleeding of the carcasses and assure that breathing has stopped prior to scalding (Poultry Inspection Regulations, 1984). Studies have reported that as many as one-third of the broilers that pass through electrical stunners in Europe may be improperly stunned, which is of great concern from a welfare point of view (Raj, 1998, Schutt-Abrahm *et* al., 1983). A survey showed that on average, 43% of all broilers received pre stun electric shocks under commercial processing conditions (Wotton and Gregory, 1991). It has also been reported that broilers exposed to CO_2 stunning could experience unpleasant sensations during the inhalation of CO_2 that leads to breathlessness prior to the loss of consciousness (Raj, 1998).

Increased automation of handling procedures may be one way to reduce physical damage and stress in broilers (Mitchell *et* al., 1994, Nicol and Scott, 1990). Bruising, broken bones, dehydration, torn skin, and thermal stress are various poultry welfare concerns that can occur during catching, transportation and unloading (Bremner and Johnston, 1990).

Human contact is a common stressor for broilers, especially during preslaughter activities (Kenan and Fidan, 2006). Handling of broilers prior to slaughter is a stressor, and exposing chickens to an unfamiliar environment is likely to elicit stress reactions (Zulkifli and Sti Nor Azah, 2004; Nicol and Scott, 1990; Kannan and Mench, 1997; Rushen *et* al., 1999). Tonic immobility is a method that has been used to measure the amount of stress in broilers (Benoff and Siegel, 1976; Jones, 1992). Tonic immobility is an anti-predator behavior shown in chickens when caught by a predator (Kenan and Fidan, 2006). The duration of tonic immobility is positively correlated to stress levels that are determined by the serum corticosterone level (Lin *et* al., 2006). Zulkifli and Sti Nor Azah (2004) reported that regular handling reduced tonic immobility reactions in broilers, which indicates reduced stress. These researchers also reported that tactile contact by humans may result in improved growth performance in broilers.

In broilers, approximately 40% of bruises are caused during the catching and crating process, and this process may also lead to broilers that are dead on arrival (DOA) at poultry processing plants (Griffiths, 1985). During commercial poultry processing, up to 0.57% of broilers are dead on arrival (Bingham, 1986; Bayliss and Hinton, 1990;

Gregory and Austin, 1992; Warriss *et* al., 1992; Ekstrand, 1998; Nijdam *et* al., 2004), and up to 25% of broiler carcass are bruised (Farsaie *et* al., 1983; Ekstrand, 1998; Nijdam *et* al., 2004). Ambient temperature, catching company, number of broilers in the flock, mean body weight, mean compartment stocking density, transport time and lairage time are all associated with DOA percentage (Nijdam *et* al., 2004). Season of year, method of transport, and ambient temperature are associated with the percentage of broilers with bruises (Nijdam *et* al., 2004).

Environmental Stress

Elevated concentrations of serum corticosterone functions as an indicator of physiological stress in broiler chickens (Kenan and Fidan, 2006). It has been reported that catching and crating can induce a stress response. The mean plasma corticosterone concentrations increase by 75% at the start of catching and increase by 115% after transport, shackling, and stunning (Nijdam *et* al., 2005). Handling of broilers in an inverted position also leads to increased plasma corticosterone concentrations (Kannan and Mench, 1996) and prolonged tonic immobility (Jones, 1992). Preslaughter stress that occurs due to the handling of broilers can cause increased production, and use of epinephrine and glucocorticoids, which can negatively affect meat quality (Lawrie, 1966). Preslaughter feed withdrawal can lead to metabolic exhaustion, (Nijdam *et* al., 2004), decreased muscle glycogen reserves (Sams and Mills, 1993; Kotula and Wang, 1994; Edwards *et* al., 1999; Nijdam *et* al., 2004) and may also affect meat color (Smith *et* al., 2002). Increased transport times increase broiler stress responses (Freeman *et* al., 1984; Mitchell *et* al., 1992; Warriss *et* al., 1999), decrease breast muscle glycogen levels and decrease the extent of postmortem pH decline in muscle (Lambooij, 1999; Warriss *et* al., 1999; Debut *et* al., 2003). Acute heat stress prior to slaughter induces a lower ultimate pH (Holm and Fletcher, 1997; Sandercock *et* al., 1999), reduces water holding capacity (Sandercock *et* al., 1999; Petracci *et* al., 2001) as well as increases toughness in broiler breast meat (Froning *et* al., 1978; Holm and Fletcher, 1997; Petracci *et* al., 2001).

The broiler's pre-slaughter environment, muscle physiology, and experience at the processing plant all impact the quality of the resulting meat (Sams, 1999). Catching, transportation, unloading, and hanging can reduce quality and yield of broiler breast meat if performed improperly (Sams, 1999). During growth, and especially during transport to processing plants, broilers are exposed to a variety of stressors such as heat, fasting, noise, social disruption, and withdrawal of water (Mitchell and Kettlewell, 1998). These stressors affect the post-mortem metabolism of muscle and subsequent meat quality (Holm and Fletcher, 1997). These stressors can cause adverse effects on the broilers that may range from mild discomfort to death (Knowles and Broom, 1990; Nicol and Scott, 1990; Weeks and Nicol, 2000). Careful bird handling has been reported as a crucial factor that can reduce mortality and carcass defects, such as hemorrhages, bruises, and broken bones (Warris *et* al., 1992; Barbut, 2002; Nijdam *et* al., 2004). Selye (1950) reported that broilers exposed to stressors such as heat, cold, or fatigue always display increased hormone secretion which alters liver and muscle glycogen levels that negatively affects post-mortem muscle quality. Lee *et* al. (1976) reported that meat from broilers that were heat-stressed at 38^{o}C was less tender than meat from broilers in cooler seasons. Wood and Richards (1975) showed that heat stress tends to hasten the rate of post-mortem glycolysis. During summer months, high antemortem temperatures can affect muscle acidification, or rigor development, and subsequent meat quality via adrenal or other physiological responses or simply by fatigue of the broilers (Lambooij, 1999; Warriss *et* al., 1999). Cold stress studies by Wood and Richards (1975) at 2^{o}C showed an increase in shear values of broiler breast meat. Temperature extremes have been proven to be stressors for broilers. When exposed to stress, epinephrine is released from the adrenal medulla causing the passage of potassium from muscle to the blood and the breakdown of liver and muscle glycogen to glucose and lactic acid (Lawrie, 1966). This increased release of epinephrine and glucocorticoids affects the post mortem metabolism and inherent meat quality, which often leads to tougher meat. (Hedrick, 1965; Marple and Cassens, 1973).

There is an increased probability that some broilers will suffer thermal stress during transportation (Bayliss and Hinton, 1990; Mitchell and Kettlewell, 1998; Warriss *et* al., 1999). It has been reported that preslaughter heat stress accelerates rigor mortis development, reduces water holding capacity, and increases the incidence of paleness in poultry meat (Northcutt *et* al., 1994; McKee and Sams, 1997b). Transportation stress has also been reported to reduce tenderness and increase lightness in broiler meat (Ehinger, 1977; Cashman *et* al., 1989). Kannan *et* al. (1997) observed that crating broilers for 1 h produces lighter colored breast meat than crating for 3 h. These authors also reported that providing the broilers a 4 h rest period between transport and slaughter reduced plasma concentrations of corticosterone. This reduction in corticosterone concentration is attributed to holding broilers for 4 h in a dark quite place after transport reduces the stress response. Moran and Bilgili (1995) reported that broilers transported before slaughter had a lower incidence of carcass bruising, because the level of physical activity is reduced due to the fatigue caused by transportation.

Stunning

Stunning was originally performed as a method of animal immobilization to allow easier and safer manipulation of the animal for efficient cutting of blood vessels in the neck (Fletcher, 1999). A good stun instantaneously induces a state of unconsciousness and insensibility to pain that lasts until the death of the animal, immobilizes the animal for easier exsanguination by exsanguination, and does not have a negative effect on meat quality (Savenije *et* al., 2002). Bruising, discolorations, and broken or dislocated bones are the primary defects often attributed to the stunning-exsanguination stage of slaughter (Bilgili, 1992).

Stunning prior to exsanguination can be accomplished using chemical, mechanical, or electrical means (Fletcher, 1999). Chemical stunning can be accomplished through gas stunning with carbon dioxide, argon, or nitrogen. Mechanical stunning is accomplished by brain sticking or concussion (Fletcher, 1999). Electrical stunning prior to slaughter is the most common method used prior to slaughter in commercial poultry plants in the United States (Bilgili, 1999 and 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. Among the five types of electrical stunning systems that are available (Gregory, 1989), the most common system is electrical water bath stunning

(Bilgili, 1992). Electricity is convenient, economical and requires minimal operating space. Electrical stimulation is variable with respect to magnitude (current and voltage), duration (length of water bath and line speed), oscillation frequency, waveform, current direction, and energy (Kranen *et* al., 2000). This method of stunning causes depolarization of neurons in the brain, which results in brain function disturbances in the form of a general epileptiform insult. Upon electrical stunning, the animal may die due to heart attack and loss of oxygen to the brain (Turcsan *et* al., 2003). Insufficient currents may physically immobilize the bird but may not prevent perception of pain, stress or discomfort by the broiler (Bilgili, 1999). From the welfare point of view, the minimum current required per bird in the water bath stunner can be determined using three criteria: 1) Induction of epileptic activity in the brain, 2) abolition of somatosensory evoked potentials (SEP) in the brain, and 3) induction of cardiac arrest at stunning (Raj, 1998).

Electrical stunning is normally used to induce unconsciousness during neck cutting and bleeding for reasons of animal welfare in the European Union (EU) or to induce immobilization to facilitate automatic neck cutting in the U.S. (Lambooij *et* al., 1999). Application of high voltage stunning has been associated with broken bones (Gregory and Wilkins, 1989), exploded or damaged viscera, bruised wing joints and red wing tips (Heath, 1984), hemorrhages on the breast meat (Veerkamp and de Vries, 1983; Veerkamp, 1988), split wishbones and separation of shoulder muscle tendons (Sams, 1996). Although there is no clear relationship between stunning current and traditional whole carcass quality attributes (Griffiths, 1985; Bilgili, 1992), hemorrhages on deep breast muscles of broilers have been shown to increase with high stunning currents (Veerkamp, 1988; Gregory and Wilkins, 1989). High stunning voltages have been linked with an increased incidence of red wing tips and tails (Veerkamp and de Vries, 1983) and broken bones (Walther, 1991). Low voltage electrical stunning systems are an effective method for immobilizing broilers (Bilgili, 1999). Heath *et* al. (1994) reported that low voltage (10 to 25V) and high frequency (500 Hz) systems are used in 77.4% of U.S poultry plants. Low voltage electrical stunning can decrease the incidence of carcass quality damage and hemorrhaging that is associated with high voltage electrical stunning. However, a bird can regain consciousness if not slaughtered within approximately 2 min of stunning. Low voltage electrical stunning has been shown to negatively affect early blood loss but does not affect total blood loss after the 90 to 120 second exsanguination period (Gregory, 1993; Papinaho and Fletcher, 1995). While comparing the results of high and low frequency currents on stunning, Craig and Fletcher (1997) observed that high frequency (500Hz) currents affect the Central Nervous System more than the muscular system as compared to low frequency (50 to 60 Hz), which may have a greater affect on the muscular system. So high frequency current is always associated with low muscular damage. In the European Union, it has been recommended that the minimum stunning current for broilers should be 120 mA, so as to induce cardiac arrest in 90% of broilers, such that they will not regain consciousness during exsanguination (Gregory, 1992). But these high currents can cause muscle contractions that lead to damage to muscle fibers and subsequent hemorrhaging in muscle tissue. (Gregory and Wilkins, 1989; Hillebrand *et* al., 1996a; Kranen *et* al., 1998). Hemorrhaging is due to the sharp increase in blood pressure, especially in the veins (Kranen *et* al., 2000). As a result, blood vessels may rupture and cause bleeding. Poole and Fletcher (1999) reported that Modified Atmosphere Stunning-Killing (MASK) and low voltage (LV) systems are similar in their effects on rigor development and ultimate meat quality but the use of a MASK system may not allow for earlier deboning of broiler breast meat when compared to conventional LV electrical stunning.

However, there are some problems associated with electrical stunning (Raj, 1998): 1) Electrical water bath stunning systems require the uncrating and shackling of live broilers prior to stunning. These handling procedures impose a considerable amount of stress on the broilers 2) Prestunning electric shocks can occur if the broiler’s wings make contact with the water bath before their heads do 3) A practical problem with the conventional electric water bath stunning system is that the electrical impedance varies considerably between broilers so it is not always possible to deliver the current required to induce cardiac arrest in each individual bird using a constant voltage stunner.

Captive bolt stunning, either penetrative or nonpenetrative, has some advantages in poultry processing (Goksoy *et* al, 1999). Concussion (penetrative captive bolt stunning) is induced by rapid acceleration of the head, causing movement of the brain relative to the cranium (commatio cerebri). If acceleration is sufficiently severe, extensive tissue damage will occur, and brain function will be irreversibly impaired (Goksoy *et* al., 1999). A modified captive bolt stunning method for broilers has been developed in which air pressure is used to prevent convulsions. Air pressure stunning reduced post-stun convulsions to less than 15% of the level of convulsions observed after original captive bolt stunning of broilers (Hillebrand *et* al., 1996b). Lambooij *et* al. (1999) reported that the fillets from air pressure stunned broilers were more tender than the fillets from electrically stunned broilers and the incidence of hemorrhaging and pectoral bone fractures were lower in air pressure stunning when compared to electrical stunning. Concussion stunned broilers (penetrative captive bolt stunning) had fewer broken or dislocated bones and fewer hemorrhages than broilers that were stunned with high electrical currents (EU method), resulting in improved carcass and meat quality (Goksoy *et* al., 1999). This occurs because convulsions are mostly mild to moderate and consist of muscle fibrillation with captive needle/air pressure stunning, rather than wing flapping that may occur with electrical stunning (Lambooij *et* al., 1999). Clonic convulsions that were observed after mechanical stunning methods were generated by the brain or spinal cord and may be milder. This may cause less muscle hemorrhaging, than the tonic muscle contractions induced by direct stimulation during electrical whole body stunning (Lambooij *et* al., 1999). Where as Raj *et* al. (1992) observed that tetanic convulsions that occur during EU electrical stunning had a detrimental effect on breast muscle. Super contractions during EU electrical stunning ruptured blood vessels, causing a high incidence of breast muscle hemorrhages (Hillebrand *et* al., 1996b). EU electrical stunning delays post mortem glycolysis or reduces early lactic acid accumulation because of the suppression of perimortem struggle (Papinaho *et* al., 1995). One advantage of captive bolt stunning is an earlier onset of rigor that leads to enhanced meat tenderization, which would allow earlier deboning and decrease the amount of chiller space that is needed (Goksoy *et* al., 1999).

Gas stunning 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 CO_2 (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 CO_2 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 anesthetic response in broilers by reducing the pH of the cerebrospinal fluid (Eisele *et* al., 1967). Several authors have indicated advantages of stunning using gases. These methods affect the central nervous system and do not paralyze the musculature, especially the heart musculature, thus allowing better bleeding (Lindholst, 1991); by using these methods, carcass damage can be reduced due to elimination of muscular contracture. In addition, pain is eliminated, and rigor mortis is accelerated (Raj *et* al., 1990a; Raj *et* al., 1997). Stunning and exsanguination by gas is effective at improving meat quality by reducing bloodspots, especially those on the thighs and breasts, and improving tenderness when compared to electrical stunning (Hoen and Lankhaar, 1999). Other benefits are improved working conditions in the hanging area of the abattoir (Contreras and Beraquet, 2001) and reduction in preslaughter stress (Contreras and Beraquet, 2001) by eliminating the stress that is associated with shackling of live broilers during electrical stunning (Lambooij *et* al., 1999; Gerritzen *et* al., 2000). Gas stunning is also useful in processing a variety of bird types when compared to electrical stunning, since it can be difficult to alter an electrical stunning method for different species (Fanatico, 2003).

A potential problem with gas stunning is that broilers tend to regain consciousness rapidly on exit from the gaseous atmosphere (Raj, 1998). To avoid this problem Raj and Gregory (1990b) recommended that the broilers should be killed during stunning to prevent the broilers from regaining consciousness and to allow for easier handling. Gas stunning, primarily with CO_2, has been successfully used 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 resulted in increased blood loss (Kotula *et* al., 1957), a lower incidence of muscle hemorrhaging and broken bones (Raj *et* al., 1990b), and improved meat tenderness when levels of 40 and 45% of CO_2 were used (Raj *et* al., 1990a; Fleming *et* al., 1991). Raj and Gregory (1991) reported that gas stunning could result in improved meat quality of early deboned carcasses. In one experiment, Raj *et* al. (1990c) concluded that argon stunning resulted in fewer muscle hemorrhages, a more rapid decrease in early post mortem pH and more tender breast meat when compared to electrically stunned broilers. Kang and Sams (1999) reported a lower incidence of carcass damage in broilers that were stunned with CO_2 and attributed this to the broilers being calmer when stunned with a gas. 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 because the convulsions during gas stunning were milder and thus caused less muscle hemorrhaging than the muscle contractions induced by direct stimulation during electrical stunning (Turcsan *et* al., 2001). Sams and Dzuik (1995) reported no difference in shear values for breast fillets from broilers receiving no stun or CO_2 stun.

When compared to electrical stunning, CO_2 stunning has been reported to produce lower breast meat shear values at 1 h post-mortem than electrical stunning (Veeramuthu and Sams, 1993) where as Hirschler and Sams (1993), from the same laboratory, reported that CO_2 stunning resulted in no differences in blood loss, pH, or shear force of the broiler breast meat deboned at 1 or 24 h postmortem when compared to electrical stunning. Carbon dioxide stunning accelerates rigor development, as indicated by a more rapid early postmortem pH decline than that which occurs with electrical stunning, which reduces the length of aging time necessary to ensure meat tenderness (Raj, 1994). This accelerated rigor development could be explained by the increased anoxic convulsions (increased wing flapping) observed in CO_2 stunned broilers, which causes increased utilization of adenosine triphosphate (ATP) by the muscles when compared with electrically stunned broilers. Even though gas stunning has some advantages over electrical stunning in respect to meat quality, 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 is acidic in nature and is pungent to inhale. It is a potent respiratory stimulant that can cause breathlessness before the loss of consciousness (Raj, 1998). 3) Some gases are dangerous to humans. Inhalation of 30% carbon dioxide by humans causes a low level of pungency and breathlessness (Gregory *et* al., 1990). 4) Gas stunning causes a reduction in pluckability and affects meat color (Uijttenboogaart, 1997). 5) Gas stunning is expensive (Fanatico, 2003). The profit gained from the slight improvement in the meat quality does not seem to be enough of an incentive to cover the high price of controlled atmospheric stunners (Turcsan *et* al., 2001). Due to these disadvantages, gas stunning is not commonly used in the poultry industry.

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 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) recently reported that vacuum (low atmospheric) stunning appeared to be an effective method for humane stunning and exsanguination of chickens. These researchers also reported that this method may improve animal welfare by reducing corticosterone levels.

Rigor Mortis

Rigor mortis development is central to the process of muscle death and meat quality (Sams, 1999). Immediately postmortem, muscle cells continue to respire to produce and consume ATP. This ATP acts as a plasticizer to dissociate actin and myosin in order to maintain muscle extensibility. As the cellular oxygen is depleted, the cells depend on anaerobic metabolism for the production of ATP. The muscle will quickly become anaerobic, and glucose will only go through glycolysis to supply ATP. The primary product of anaerobic glycolysis is lactic acid which accumulates and decreases muscle pH. This post mortem decline in pH lowers the activity of the glycolytic enzymes that are sarcoplasmic in origin (Ashgar and Henrickson, 1983). Adenosine triphosphate and other high energy molecules such as creatine phosphate are utilized to maintain the energy supply. Eventually, ATP is exhausted and the energy supply will be compromised. When ATP concentration falls to a critical level [1μM/g (Hamm, 1982)], there is insufficient ATP to dissociate all of the actin and myosin. These proteins remain complexed as actomyosin, and the onset phase of rigor mortis begins. These complexes continue to accumulate until the ATP concentration reaches about 0.1μM/g at which rigor is developed. R-value is a measurement that is used to determine ATP depletion. The R value is the ratio of the concentrations of inosine nucleotides to adenosine nucleotides and indicates the status of very true ATP depletion during rigor mortis development (Calkins *et* al., 1982). The accelerated depletion of ATP is indicated by increased R values. Once rigor mortis is developed, the muscle is not extensible and becomes stiff. The stiffness of a muscle in rigor mortis is a function of the extent of myofibrillar overlap of thick and thin filaments, which is determined by the strength of the opposing muscle groups (Cason *et* al., 1997), the presence of skeletal attachments (Stewart *et* al., 1984) and temperature (Wood and Richards, 1974; Bilgili *et* al., 1989; Dunn *et* al., 1995). Rigor mortis completion is dependent on the energy stores in the muscle at the time of slaughter and the rate of metabolic degradation. The metabolic rate determines the rate of decrease in pH and ultimate pH, which can affect meat color and water holding capacity through protein denaturation (Warris and Brown, 1987).

Exposure to low temperatures when ATP is still present in the muscle cell (such as prior to rigor mortis development) can induce cold shortening and result in tough meat (Hamm, 1982; Smith *et* al., 1969). Carcass aging is the process of storing intact carcasses or breast halves for several hours at refrigerated temperatures prior to deboning to allow for the development of rigor mortis (Sams, 1999). Processors commonly store intact carcasses for at least 4 h after slaughter to allow rigor mortis development prior to deboning (Shelton, 1985; Amey, 1988; Sams, 1994). Removing the muscle prior to this aging time, results in decreased overall tenderness (Stewart *et* al., 1984; Dawson *et* al., 1987; Lyon *et* al., 1989). Increased aging time has been reported to result in reduced meat yield and extra labor, space, equipment and energy requirements (Lyon and Lyon, 1997; Hirschler and Sams, 1998). Electrical current, when applied to the live bird (stunning) before death delays the onset of rigor, whereas electrical stimulation applied immediately postmortem accelerates rigor development (Fletcher, 1999). Electrical stimulation increases the rate of rigor development by a more rapid decrease in pH (Thompson *et* al., 1987) and an increased rate of ATP depletion (Sams *et* al., 1989).

Preslaughter heat stress accelerates rigor mortis development, reduces water holding capacity, and increases the incidence of paleness in poultry meat (Northcutt *et* al., 1994; McKee and Sams, 1997b). Poole and Fletcher (1995) and Kang and Sams (1999) observed that stunning with carbon dioxide slows rigor mortis development when compared to no stunning or electrical stunning. Contrary to this, Raj *et* al. (1997), and Poole and Fletcher (1998) reported that gas stunning accelerates rigor mortis and reduces the necessary aging time prior to deboning, but only when compared to a high amperage (80 to 125 mA) electric stun. Poole and Fletcher (1998) observed that there was no rigor mortis acceleration when gas stunning was compared to a low amperage stun. Papinaho *et* al. (1995) stated that stunning affects early rigor development primarily through a reduction in perimortem struggle, and only indirectly affects the post mortem biochemistry of the breast muscle.

Tenderness

Bourne (1982) noted that meat is one of the foods in which texture is the dominant quality characteristic. According to Szczesniak and Torgeson (1965), texture includes properties of the material related to its structural components which are detectable with physiological senses (mastication, touch etc.). Meat texture is multifaceted and involves more than one attribute (Lyon and Lyon, 1997) and is a dominant quality characteristic in cooked meat (Bourne, 1982). Processing conditions directly affect the finished meat characteristics of broilers. Traditional processing involves chilling carcasses in water from 45 min to 1 h, and then holding them for another 4 to 8 h to achieve maximum tenderness of the breast fillet (Lyon *et* al., 1985; Dawson *et* al, 1987). This aging time is necessary for the completion of post mortem biochemical reactions that are critical in assuring that cooked breast meat is tender (Stewart *et* al., 1984).

Aging fillets prior to deboning allows the development and resolution of rigor mortis which causes meat tenderization (Pool *et* al., 1959; Dodge and Stadleman, 1959; Marion, 1967). During the resolution of rigor mortis and subsequent aging of meat at refrigerated temperatures, several changes occur in skeletal muscle that lead to improved meat tenderness. An important change is the increased ease of fragmentation of myofibrils that results from weakened or degraded Z-disks (Koohmaraie, 1994). Post mortem proteolysis is the primary factor responsible for increased fragility in the Z-disks and the degradation of the other myofibrillar proteins including desmin, titin, nebulin, and Troponin T (Koohmaraie, 1994). Calcium dependent calpains are responsible for cleaving many of these proteins. Ouali *et* al. (1992) suggested that the proportion of calpain and calpastatin in muscle influences the rate of proteolysis of myofibrillar proteins, there by affecting meat tenderness. Koohmaraie (1996) concluded that proteolysis of key myofibrillar proteins by μ-calpain is the underlying mechanism of meat tenderization that occurs during storage of meat at refrigerated temperatures. Considerable weakening of the myofibril lattice results in improved meat tenderness during post mortem storage (McKee *et* al., 1997a). The increase in post mortem muscle ionic strength also contributes to improvements in meat tenderness during post mortem aging. Decreased protein interactions and increased solubility of myofibrillar proteins are associated with increased ionic strength (Wu and Smith, 1987). Cumulatively, post mortem proteolysis and post mortem muscle ionic strength contribute to meat tenderness during aging. Goodwin (1984) noted that many factors influence the ultimate tenderness of broiler breast meat. He specifically identified scalding time and temperature, feather removal, chilling, aging, and prerigor muscle cutting as the important post mortem factors. Where as Lyon and Wilson (1986) and Lyon and Lyon (1990a) concluded that two important variables that influence texture are post mortem deboning time and cooking method. In addition, Fennema (1996) reported that tenderness is influenced by sarcomere length. The contractile state of muscle can be determined by measuring individual sarcomeres, since shorter sarcomeres correlate with tougher meat (Locker, 1960; Herring *et* al., 1967).

Lambooij *et* al. (1999) noted a difference in perceived sensory tenderness for different stunning and restraining treatments. The fillets from the shackled broilers were more tender than the fillets from cone restrained broilers. Restraining broilers in a cone resulted in a slightly slower pH decline than shackling, and resulted in less tender breast meat. Electrical stimulation improves tenderness because of increased activity of proteases (Dutson *et* al., 1980) and physical disruption of myofibrils (Savell *et* al., 1978). In addition, fillets from air pressure stunned broilers were reported to be more tender than the meat from the electrically stunned broilers. Air pressure stunning accelerates muscle glycolysis, which results in more tender breast meat than electrical whole body stunning. In addition, marination is commonly utilized to reduce aging time and enhance meat tenderization (Goodwin and Maness, 1984). Effect of marination on both functional and the textural properties of broiler breast meat were noted by Lyon and Lyon (2000). These researchers stated that a mixture of phosphates, salt and spices are often used to enhance water holding capacity, tenderness and flavor.

Instrumental Tenderness

Instrumental methods such as the Allo-Kramer shear compression system (multiple blades), Warner-Bratzler shear blade, and Texture Profile Analysis are commonly used to evaluate the tenderness of broiler breast meat (Sams *et* al., 1990). Poultry meat researchers have often used the Warner-Bratzler system because it is very fast and allows for rapid analysis of many samples (Sams *et* al., 1990).

Instrumental tenderness methods do not account for the juiciness and other moisture related characteristics, or changes in meat that a panelist may perceive while chewing (Lyon and Lyon, 1997). While using these instruments, sample size, location within the muscle, orientation of the fiber to the shearing blade, and presence or absence of connective tissue must be considered. Shear value is an instrumental unit of measure to determine the force required to cut through samples. It is not a sensory measurement. It is expressed in total kg force or as kg force/mm thickness (Lyon and Lyon, 1998). Simpson and Goodwin (1974) compared Allo-Kramer multiple blade shear values with sensory measurement of tenderness and concluded that values above 8 kg of force per gram of sample corresponded to sensory scores of slightly tough to tough, and values below 8 kg/g corresponds to scores of tender to very tender. For overall texture acceptability, Lyon and Lyon (1990b) indicated that W-B values should be 5.8 kg or less, and A-K values should be 8.1 kg per g or less.

pH

pH is commonly utilized as an indicator of meat quality. The rate and extent of postmortem pH decline are very important factors affecting meat quality (Berri *et* al., 2001). In post mortem muscle, glycogen, glucose, and glucose-6-phosphate are converted to lactate through anaerobic glycolysis. Lactate accumulation and the release of protons from adenosine triphosphate hydrolysis in post mortem muscle induce a pH decline (Bendall, 1973). Post mortem time for muscle to reach its ultimate pH is 4 to 6 h (Papinaho and Fletcher, 1996; Papinaho *et* al., 1996; Stewart *et* al., 1984; Khan, 1974; Smith *et* al., 1992) and varies due to differences in initial glycogen levels, bird strain, sex, body size, fat, stunning procedures, and other physiological factors (Papinaho *et* al., 1996).

In chickens, Kotula and Wang (1994) suggested that the content of glycogen at slaughter modifies meat pH with little change in color and expressible moisture, and only a minimal increase in the shear value of the resultant meat. Olsson and Satlin (1970) reported that glycogen concentration is a potential contributor to the water holding capacity of meat, because the glycogen molecule binds 3 to 4 times its weight in water. Muscular activity during stunning and exsanguination has an accelerating effect on the rate of pH decline (Khan and Nakamura, 1970; Ngoka and Froning 1982; Raj *et* al., 1990a). Acute heat stress prior to slaughter also induces a lower ultimate pH (Holm and Fletcher, 1997; Sandercock *et* al., 1999), reduced water holding capacity (Sandercock *et* al., 1999; Petracci *et* al., 2001) as well as decreased tenderness (Froning *et* al., 1978; Holm and Fletcher, 1997; Petracci *et* al., 2001) in chicken breast meat. It was reported that breast meat pH values decreased post mortem between 2 and 4 h with no difference between 4 and 24 h post mortem times (McNeal and Fletcher, 2003). A significant correlation between muscle pH and color variation was reported by various authors. Breast meat is darker when muscle or meat pH is higher (Livingston and Brown, 1981; Yang and Chen, 1993, Cornforth, 1994). When the pH of the meat is far above the isoelectric point of myofibrillar proteins in the meat, water molecules are tightly bound, causing more light to be absorbed by the muscle, and the meat appears darker in color (Kauffman and Marsh, 1987; Cornforth, 1994). Fletcher and Smith (2006) provided a review of correlation between poultry breast meat lightness (L*) and breast muscle pH. Their research suggested that as muscle pH decreases, the lightness value increases, with a correlation coefficient between -0.6 and -0.8. In addition, redness (a*) decreases and yellowness (b*) increases during storage of meat, probably due to the oxidation of myoglobin. The rate of myoglobin oxidation in muscle increases when the ultimate pH (pH_u) is low. Drip loss and water-holding capacity is also negatively correlated with pH_u. The effect of pH_u on drip loss is a charge effect: as pH decreases, the repulsion forces between the myofibrils decrease since the pH is approaching the isoelectric point of myofibrillar proteins, thus reducing the space available for water in the cell (Hamm, 1986; Judge *et* al., 1989). Dunn *et* al. (1993) reported a negative correlation between shear force and pH_u. Bouton *et* al. (1973) explained that the higher water holding capacity of meat at higher ultimate pH's (>6.0) results in more tender meat.

Pale, Soft, and Exudative Meat

The occurrence of PSE-like meat in broiler breast meat has been reported to be between 0 and 28% by Barbut (1997). The relationship between raw breast meat lightness (L*), or PSE-like meat, with low pH and meat functionality has been reported by several researchers (Boulianne and King, 1998 and Barbut, 1997). Antemortem and postmortem factors such as environmental temperatures (hot or cold), transportation, preslaughter handling practices, stunning methods, and chilling regimes contribute to the development of PSE meat by increasing muscle metabolism, maintaining high temperatures, or both (Cassens *et* al., 1975; Honikel, 1987; Offer, 1991; Backstrom and Kauffman, 1995; D'Souza *et* al.,1998; Maribo *et* al., 1998). A rapid pH decline may induce protein denaturation, resulting in decreased tenderness and juiciness, and less intense (pale) muscle coloration. In the extreme condition, this is known as PSE meat (Solomon *et* al., 1998). Pale, soft, exudative meat develops when the rate of postmortem pH decline is high, leading to a low pH value while the muscle temperature is still high (Rammouz *et* al., 2004). Accelerated onset of rigor mortis is associated with a high muscle temperature, leading to sarcoplasmic and myofibrillar (myosin and actin) protein denaturation. This protein denaturation is associated with decreased functionality and subsequent quality defects such as paleness, poor water binding and soft texture (Fernandez *et* al., 2002).

Pietrzak *et* al. (1997) identified phosphorylase in the myofibrillar fraction of PSE turkey which indicates a loss of protein solubility and functionality.

Characteristics of PSE meat are paleness, low water holding capacity, and formation of soft gels (Ferket and Foegeding, 1994: Barbut, 1997; Owens *et* al., 2000). PSE meat can cause problems during cooking in certain types of further processed turkey products by increasing purge in cook-in bags, which results in a product with decreased cook yield and a dry texture that is unacceptable to the customer (Woelfel *et* al., 2002). The decreased water holding capacity of PSE meat is associated with the denaturation of myofibrillar proteins, whereas pale color is more often associated with the denaturation of sarcoplasmic proteins (Offer, 1991).

Color

Heme pigments are the major contributors to meat color. Studies by Nishida and Nishida (1985) and Kranen *et* al. (1999) reported that there are minimal concentrations of myoglobin in chicken breast muscle, which causes its light color. Other factors include amount of intramuscular fat, moisture content, preslaughter factors, processing variables, age, sex and diet (Mugler *et* al., 1970; Ngoka and Froning, 1982). Bruises, hemorrhages, and poor exsanguination efficiency can negatively affect color of the meat and skin; these are major quality defects and are associated with undesirable discoloration and reduced shelf life (Griffiths and Nairn, 1984). Residual blood in the carcass is often associated with a meaty flavor and decreased shelf life (Alvarado *et* al., 2007). Therefore excessive hemorrhaging caused by different stunning and slaughter techniques can increase hemoglobin content in the muscle that can decrease shelf life by increasing oxidation (Alvarado *et* al., 2007).

Instrumental color is often reported using CIE LAB* color values that represent lightness (L*), redness (a*), and yellowness (b*) and are often used to determine breast meat quality (Qiao *et* al., 2001). Qiao *et* al. (2001, 2002) reported that extreme color variations, from very light to very dark, had significant effects on functional properties and chemical composition of broiler breast meat. Barbut (1993) reported that lightness of raw fillets was negatively correlated with water holding capacity. When broilers are slaughtered during summer months, the color of breast meat is often paler, less red, and more yellow when compared to broilers that are slaughtered during winter months. During summer months, heat stress and excitation just prior to slaughter can affect the postmortem metabolism of muscle and subsequent meat quality characteristics such as color, water holding capacity, and texture (Lambooij, 1999; Warris *et* al., 1999).

Sensory Analysis

The two most important sensory quality attributes for poultry meat are appearance and texture (Fletcher, 2002). Sensory perception of tenderness is more complicated than mechanical measurements because humans measure more than just the force needed to cut or shear meat (Lyon and Lyon, 2000). The sensory description of meat texture is a multi-faceted process that includes meat sample particle size and shape, and other attributes such as the amount of saliva produced, moisture released, ease of swallowing, and mouth coating (Lyon and Lyon, 1997). Other attributes, including flavor and moisture characteristics, are also critical to consumer acceptance or rejection of poultry meat which can be perceived during chewing (Lyon and Lyon, 2000).

Simpson and Goodwin (1974) have reported correlations between taste panel scores and shear values to predict tenderness in broiler breast meat. These authors reported that sensory acceptability scores from a five member untrained panel were correlated with Allo-Kramer shear values and that lower shear values were indicative of more acceptable samples. Lyon and Lyon (1997) found several correlations between individual attributes of sensory perception and instrumental values. These authors reported that Warner-Bratzler and Allo-Kramer shear values were correlated with mechanical and chew down sensory characteristics of broiler breast meat. Lyon and Lyon (1990b) developed sensory descriptors that relate to Warner-Bratzler shear and Lee-Kramer shear values. These researchers provided a detailed description of the sensory characteristics of broiler breast meat. According to these researchers particle size, bolus and wetness characteristics of broiler breast meat interacted with amount of saliva, ease of swallowing, and mouth coating, all of which contributed to an integrated sensory perception of broiler breast meat. Schilling *et* al. (2003) reported a range of shear values that correspond to a consumer sensory tenderness scale. These researchers found significant differences in consumer response among shear value categories. Lyon and Lyon (1990a) examined the effects of various deboning times and cookery methods on the sensory perception of tenderness. They found that microwave cookery produced lower shear values than water submersion cooking and that shear values increased as deboning time decreased.

CHAPTER III

MATERIALS AND METHODS

Sample Procurement

Four hundred and thirty two Ross 708 broilers (mixed sex, and approximately 48 d of age) reared at the Mississippi State University Leveck Animal research Center (LARC) poultry facility, were randomly selected for processing by one of two stunning methods: electrical and low atmosphere pressure (LAPS). Feed was withdrawn 12 h prior to harvest, and broilers were allowed unlimited access to water. Broilers were transported in live haul crates from the LARC poultry facility to the poultry processing plant (less than 0.5 km) at 5:00 am (prior to sunrise) to minimize stress.

Electrical Stunning

Broilers were hung by their feet in steel shackles and were electrically stunned by manually placing their heads in a saturated saline bath (11.5 volts, <0.5 mA AC to DC current for 3 sec). The shackle line speed was constant and set so that approximately 22 broilers were stunned per min. Unilateral neck cutting was manually 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, picked for 35 sec using a rotary drum picker (Baader-Johnson, Kansas City, Kansas) and then mechanically eviscerated.

Low Atmosphere Pressure Stunning

Broilers were stunned using a commercial prototype of a low atmospheric pressure harvest system (Techno catch LLC, Kosciusko, MS). This prototype consisted of a round reinforced mild steel shell 2.3 m in diameter and 3 m long with a gravity roller bed allowing for full cage insertion and retrieval. Low atmospheric pressure was accomplished by means of a series of vacuum rated butterfly valves employed for vacuum application and release. The low atmospheric pressure was achieved 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. Cages with 24 broilers were placed into this air-tight decompression chamber and a low atmospheric pressure of 597 to 632 mm Hg was achieved. All broilers were maintained in the decompression chamber for 2 min. After ataxia (loss of posture, resulting in the inability to maintain a standing position and no neck tension at the onset of unconsciousness), broilers were decapitated manually. Bleeding, scalding, picking, and evisceration steps were identical to the procedures listed in the electrical stunning section.

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

Treatments

Six treatments were utilized in this trial to evaluate the effects of stun method and deboning time on broiler breast meat quality: electrical stunning, deboned at 45 min post mortem (ES 0.75H); electrical stunning, deboned at 2 h post mortem (ES 2H); electrical stunning, deboned at 4 h post mortem (ES 4H); low atmosphere pressure stunning, deboned at 45 min post mortem (LAPS 0.75 H); low atmosphere pressure stunning, deboned at 2 h post mortem (LAPS 2H); low atmosphere pressure stunning, deboned at 4 h post mortem (LAPS 4H).

pH measurement

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

Color Measurement

Instrumental color measurements were taken for each breast within each treatment using a chroma meter (Chroma meter Model CR-400, Minolta Camera Co., Ltd., Osaka, Japan Serial No C8202489) that was calibrated using a standard white calibration plate (Model No 20933026, Japan). Three measurements were taken at three identical locations for each breast on the medial portion of the Pectoralis major muscle. Color for each sample was expressed in terms of CIE values for lightness (L*), redness (a*), and yellowness (b*).

Cooking Loss

Frozen breast samples were thawed (2^{o}C) overnight, trimmed to an approximate weight of 120 g, and vacuum packaged in 15.2 x 20.3 cm, 3 mil cooking bags (Rebel Butcher Supply Co. Inc., Flowood, MS). Samples were cooked by immersing cooking bags in hot water (85^{o}C) for approximately 20 min until an internal temperature of 80^{o}C was reached. A poultry thermometer (beef and poultry thermometer; Chaney instrument

Co; China) was inserted into the middle portion of a breast sample prior to packaging to measure the internal temperature of the sample. The bags were tempered at ambient temperature (20^{o}C) before opening to drain the liquid from each bag. Each breast sample was dried with one paper towel (one ply) and reweighed. Cooking loss was reported as a percentage and calculated as (initial weight–final weight)/(initial weight) X100.

Warner-Bratzler Shear Force Determination

Tenderness was assessed using an objective texture procedure described in Meek *et* al. (2000). Breasts that were used for cooking loss determinations were cooled to room temperature and used for shear force determinations. Four to six adjacent 1 cm (width) x 1 cm (thickness) x 2 cm (length) strips were cut from the cooked breast, parallel to the direction of the muscle fibers. Each strip was sheared once, and the average was calculated for each breast. 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.

Sensory Analysis

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

Statistical Analysis

A randomized complete block design (replications as blocks) with three replications (n=432, 72 broilers per treatment) was utilized to test the treatment effects ($P<0.05$) of stunning method with different deboning times on pH decline, ultimate pH, color, cooking loss, and shear force. When significant differences occurred ($P<0.05$)

among treatments, the Fisher's Least Significant Difference (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 breasts. Agglomerative hierarchical clustering using Wards Method (XL Stat 2006) was performed to group panelists together based on their preference and liking of broiler breast meat. A dendrogram and a dissimilarity plot were used to determine how many clusters should be utilized to group panelists. 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 least significant difference test was utilized to separate treatment means within a cluster when significant differences ($P<0.05$) occurred.

CHAPTER IV

RESULTS AND DISCUSSION

pH and Color

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

All chicken breast samples were darker ($P<0.05$) when deboned at 0.75 h postmortem than samples that were deboned at 4 h postmortem for both stunning methods (Table 1). The L* values were also lower ($P<0.05$) in the low atmosphere pressure stunning treatments at 0.75 h postmortem and 4 h postmortem when compared to electrically stunned broilers deboned at the same time. It appears that use of low atmosphere pressure stunning causes a shift in breast meat color among the broiler population so that a greater proportion of samples have CIE L* values between 50 and 55, and fewer samples have CIE L* values that are greater than 55 when compared to electrically stunned broilers that are deboned at the same time (Figure 2). Differences ($P<0.05$) also occurred among treatments in a* and b*, with ranges of 1.2-1.6 and 1.4-2.1 for a* and b*, respectively (Table 1). Previous studies have used L* values as a measure to estimate the incidence of paleness and/or the PSE condition in broiler breast meat (Van Laack *et* al., 2000; Barbut, 1998; Woelfel *et* al., 2002). Some researchers (Van Laack *et* al., 2000; Woelfel *et* al., 2002) have reported that an average L* value greater than 60 is pale meat while Barbut (1998) indicated that an L* value greater than 55 can be used as a cutoff to indicate the PSE condition in broiler breast meat. Van Laack *et* al. (2000) reported that breasts appearing to be normal had L* values of 55 and those appearing to be pale had CIE L* values of 60, and stated that high L* values and low ultimate pH (<5.7) were indicative of broiler breast meat that was pale in color with low water holding capacity. The L*, a* and mean ultimate pH values from our study (5.8-6.1) are very similar to the values (5.9-6.1) that have been reported by previous researchers as characteristic of normal broiler breast meat at 24 h postmortem for all treatments that were evaluated (Van Laack *et* al., 2000; Barbut, 1998; Woelfel *et* al., 2002; Sams, 1999).

Cooking Loss

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

Instrumental Tenderness

Shear values indicate the maximum force required to cut through the sample and relates to the hardness of the sample. Higher values indicate that more force is required to shear the sample and relates to an overall measurement of sensory “toughness”. Warner-Bratzler shear values (hardness) decreased ($P<0.05$) with increased postmortem deboning times, but no differences ($P>0.05$) existed between electrical stun and low atmosphere pressure stun treatments at any of the three deboning times (Table 1). This reveals that low atmosphere pressure stunning would not positively or negatively affect tenderness, and that it would still be beneficial to age broiler breast meat for at least 4 h prior to removing breast meat from the bone regardless of stunning method. This observation agrees with previous reports (Thielke *et* al., 2005; Lyon *et* al., 2003; Lyon *et* al., 1989) and reemphasizes the importance of an aging period prior to breast meat removal from the carcass. On average, almost all breasts required less than 45 Newtons (N) to shear through the breast meat and would be acceptable in tenderness to a large percentage of consumers (Schilling *et* al., 2003). Several studies have attempted to determine the minimum time of aging that is necessary prior to deboning broiler breast meat. Sams (1999), Stewart *et* al. (1984), Lyon *et* al. (1985), and Dawson *et* al. (1987) reported that between 2 and 4 h postmortem is the critical period after which deboning does not cause decreased tenderness in broiler breast meat. It appears that this phenomenon was also true in this research for both electrical and low atmosphere pressure stunning.

Consumer Acceptability

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

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

A dendrogram was also utilized to group consumers into 6 clusters based on dissimilarity in panelist response to the texture of cooked broiler breast meat. Cluster 6 is the largest cluster (32.9%), and though statistical differences existed (P<0.05), consumers scored all treatments as very acceptable. Cluster 5 (18.9%) liked the texture of all treatments but had higher scores for ES 0.75H, LAPS 2H and ES 4H when compared to LAPS 0.75 H and ES 2H treatments. Cluster 4 (8.5%) liked the texture of all treatments, except the LAPS 0.75 H treatment. On average, Cluster 3 (17.1%) preferred (P<0.05) samples that were deboned at 4 h over those deboned at 2 h and 0.75 h and preferred (P<0.05) samples deboned at 2 h, over those deboned at 0.75 h. This cluster is probably very sensitive to differences in tenderness and prefers very tender samples. No trends were evident in Cluster 2 (12.8%), but these panelists preferred (P<0.05) the ES 0.75 H treatment over all other samples. Cluster 1 (9.8% of panelists) preferred (P<0.05) the texture of samples that were deboned at 2 h and 0.75 h probably because samples that are deboned at 4 h were too tender for their liking.

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

Table 1

The effects of stunning method (low atmosphere pressure and electrical) and deboning time on the color, ultimate pH, shear force and cooking loss of broiler breast meat

Treatment[1]	24 hour pH	CIE L* (Lightness)	CIE a* (Redness)	CIE b* (Yellowness)	Shear Force(N)	Cooking Loss%
4H LAPS	5.99[a]	56.1[b]	1.6[a]	1.8[ab]	19.9[c]	22.6[b]
4H ES	5.95[a]	57.3[a]	1.3[b]	2.1[a]	19.9[c]	22.7[b]
2H LAPS	5.91[a]	55.5[bc]	1.4[a]	1.9[a]	22.7[b]	22.5[ab]
2H ES	5.95[a]	56.3[b]	1.3[b]	1.8[a]	22.6[b]	23.3[ab]
0.75H LAPS	5.94[a]	53.4[d]	1.3[b]	1.4[c]	33.1[a]	23.0[ab]
0.75H ES	5.95[a]	55.1[c]	1.2[b]	1.4[bc]	33.6[a]	24.0[a]
Standard Error	0.01	0.31	0.09	0.13	0.60	0.40

[a-c] Means within a column with the same letter are not significantly different ($P>0.05$).
[1] LAPS–Low atmosphere pressure stunning, ES–Electrical stunning, H–Hours deboned after slaughter

Table 2

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

Treatment[1]	Appearance Acceptability	Texture Acceptability	Flavor Acceptability	Overall Acceptability
4H LAPS	7.0[ab]	7.0[ab]	7.0[a]	7.0[a]
4H ES	7.1[a]	7.1[a]	6.9[ab]	6.9[ab]
2H LAPS	6.9[ab]	6.9[ab]	6.8[abc]	6.9[ab]
2H ES	7.1[ab]	7.0[ab]	6.8[abc]	6.9[ab]
0.75H LAPS	6.8[b]	6.3[c]	6.6[c]	6.5[c]
0.75H ES	7.0[ab]	6.7[b]	6.7[bc]	6.7[bc]
Standard Error	0.10	0.11	0.11	0.11

[a-c] Means with in a column with the same letter are not significantly different (P>0.05).
[1] LAPS–Low atmosphere pressure stunning, ES–Electrical stunning, H–Hours deboned after slaughter.
[2] Hedonic scale was based on a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).

Table 3

Mean Hedonic Scores[2] for overall consumer acceptability of broiler breast meat with different stunning methods and deboning times according to different clusters of consumer segments

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

[a-c] Means within a row with the same letter are not significantly different ($P>0.05$).
[1] LAPS–Low atmosphere pressure stunning, ES–Electrical stunning, H–Hours deboned after slaughter.
[2] Hedonic scale was based on a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely)

Table 4

Mean Hedonic Scores[2] for texture acceptability[3] of broiler breast meat with different stunning methods and deboning times according to different clusters of consumer segments.

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

[a-c] Means within a row with the same letter are not significantly different (P>0.05).
[1] LAPS–Low atmosphere pressure stunning, ES–Electrical stunning, H–Hours deboned after slaughter.
[2] Hedonic scale was based on a 9-point scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely).
[3] Texture acceptability refers to tenderness and was defined as how much the product is liked in respect to tenderness.

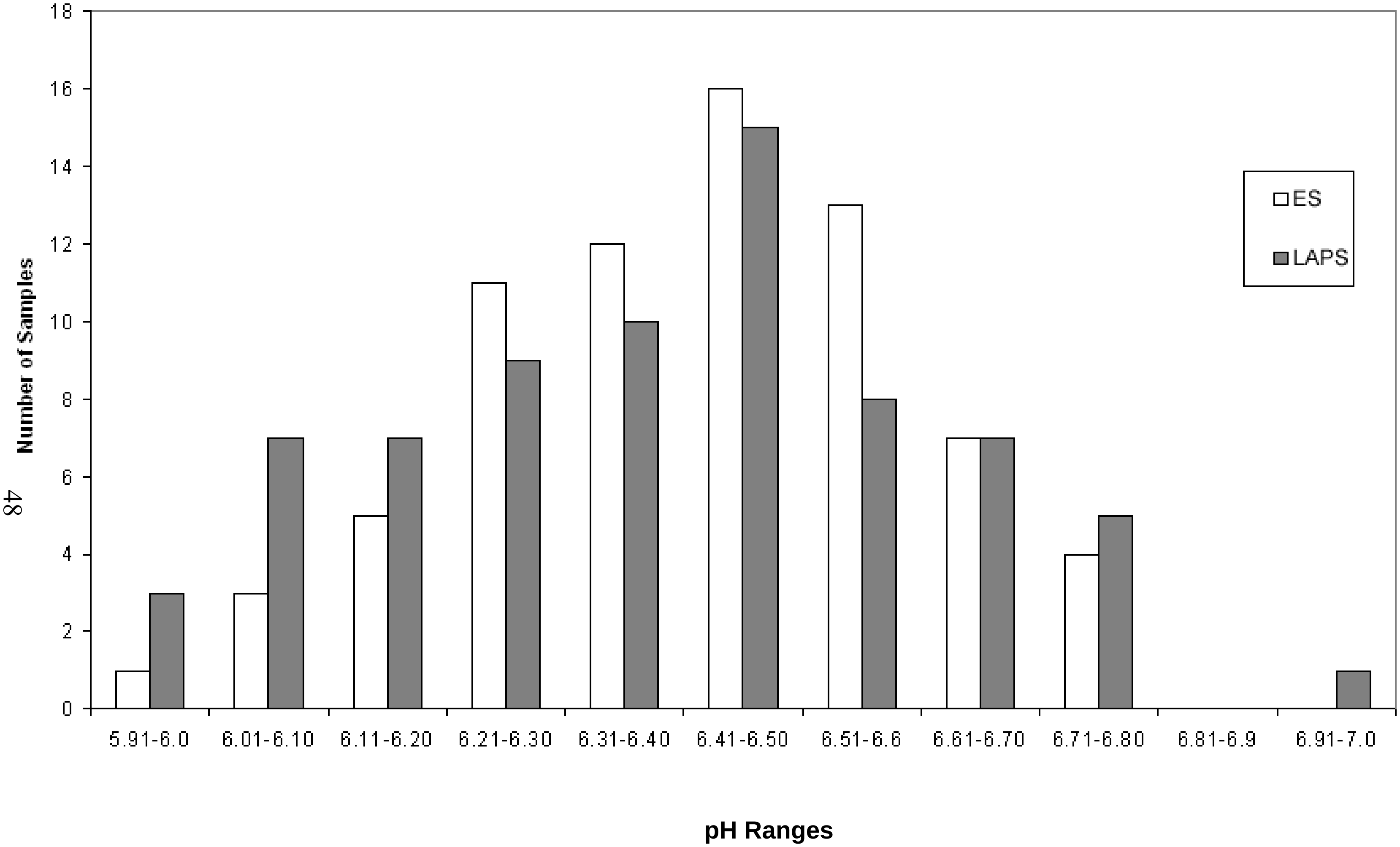

Figure 1: Graph representing the number of samples (n=72) within various pH ranges at 15 min postmortem for breast meat harvested from broilers that were subjected to either electrical stunning(ES) or low atmosphere pressure stunning (LAPS)

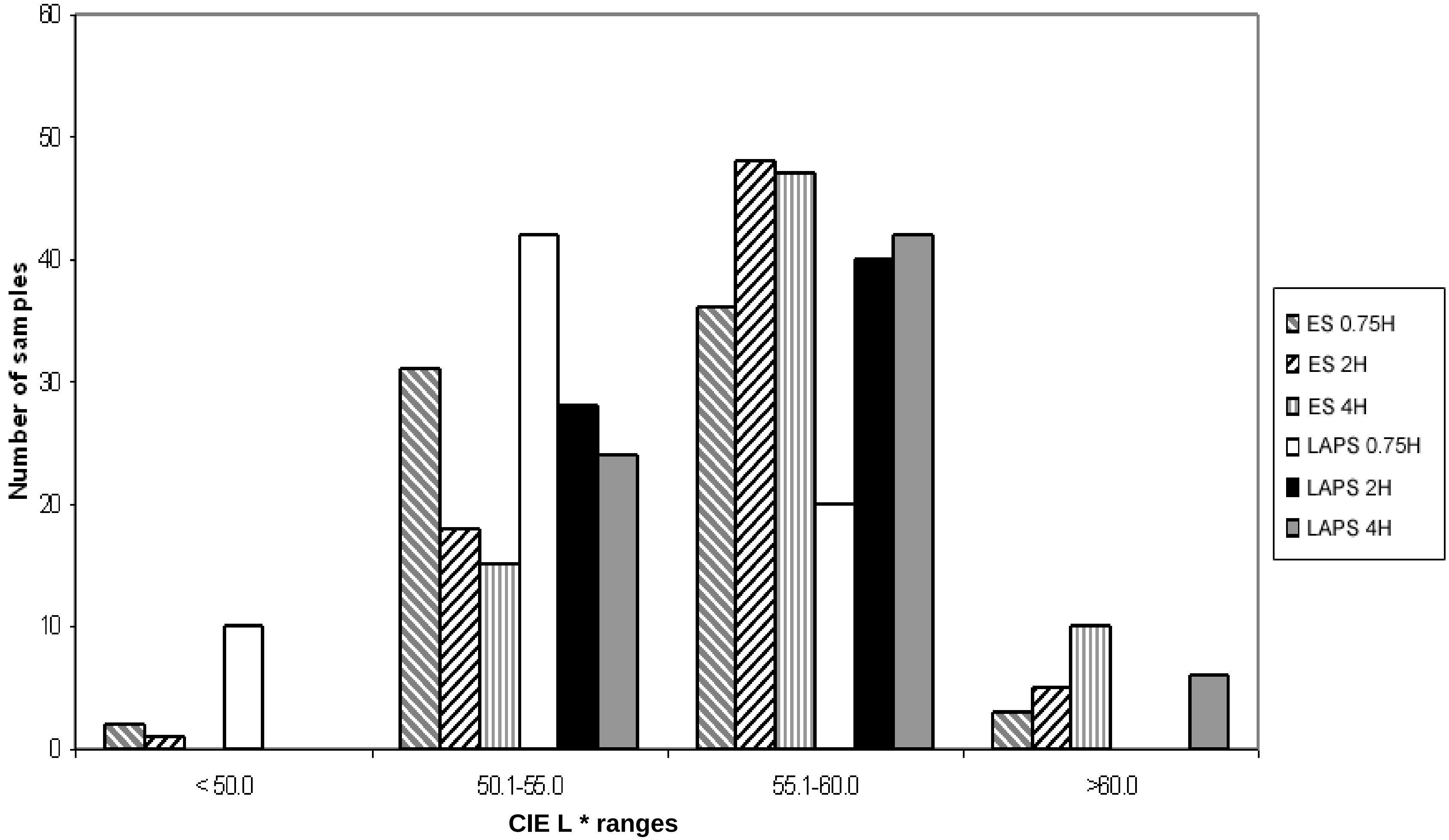

Figure2: Graph representing the number of broiler breast samples (n=72) for each treatment within different ranges for CIE*L. (ES and LAPS represent Electrical stunning and Low atmosphere pressure stunning. 0.75, 2, and 4 h represent postmortem deboning time)

CHAPTER V

SUMMARY AND CONCLUSIONS

In conclusion, minimal quality differences existed among breast meat from electrically and low atmosphere pressure stunned broilers. Deboning at 0.75 h led to decreased tenderness and decreased acceptability in some consumer groups. Results reveal that either stun method should yield high quality breast meat under pristine conditions such as the ones experienced in the study. Further studies need to be performed in which broilers are subjected to stress due to transportation and summer time temperatures that may occur at times in the industrial setting. Additional research should also be performed on the effects of using low atmospheric stunning in large scale poultry processing plants.

REFERENCES

Alvarado, C. Z., Richards, M. P., O'Keefe, S. F., and Wang, H. 2007. The effect of blood removal on oxidation and shelf life of broiler breast meat. Poultry Science. 86:156-161.

Amey, D. 1988. Minimum time process system. Tender meat in 24 minutes. Broiler Industry. 51(2):22-26, 54-56.

Ashgar, A. and Henrickson, R. L. 1983. Post-mortem stimulation of carcasses: Effects on biochemistry, biophysics, microbiology and quality of meat. CRC Critical Rev. Food Sci. Nutr. 18:1-58.

Backstrom, L. and Kauffman, R. 1995. The porcine stress syndrome: A review of genetics, environmental factors, and animal well-being implications. Agri-Practice. 16(8):24-30.

Barbut, S. 1993. Color measurement for evaluating the pale soft exudative (PSE) occurrence in turkey meat. Food Res. Int. 26:39-43.

Barbut, S. 1997. Problem of pale soft exudative meat in broiler chickens. British Poultry Science. 38:355-358.

Barbut, S. 1998. Estimating the magnitude of the PSE problem in poultry. Journal of Muscle Foods. 9:35-49.

Barbut, S. 2002. Catching and hauling live birds. Poultry products processing: An industry guide: CRC Press, New York, NY:61-79.

Bayliss, P. A. and Hinton, M. H. 1990. Transportation of broilers with special reference to mortality rates. Applied Animal Behaviour Science. 28:93-118.

Bendall, J. R. 1973. Postmortem changes. In The structure and function of muscle. G. H. Bourne, ed. New York Academic Press, New York:243-309.

Benoff, F. H. and Siegel, P. B. 1976. Genetic analyses of tonic immobility in young Japanese quail (Coturnix coturnix japonica). Animal Learning Behavior. 4:160-162.

Berri, C., Warcrenier, N., Millet, N. and Le Bihan-Duval, E. 2001. Effect of selection for improved body composition on muscle and meat characteristics of broilers from experimental and commercial lines. Poultry Science. 80:833-838.

Bilgili, S. F., Egbert, W. R. and Huffman, D. L. 1989. Effect of post mortem aging temperature on sarcomere length and tenderness of broiler pectoralis major. Poultry Science. 68:1588-1591.

Bilgili, S. F., 1992. Electrical stunning of broilers – basic concepts and carcass quality implications: A Review. Journal of Applied Poultry Research. 1:135-146.

Bilgili, S. F. 1999. Recent advances in electrical stunning. Poultry Science. 78:282-286.

Bingham, A. N. 1986. Automation of broiler harvesting. Poult. Int. 25:41-42.

Birkhold, S. G., Janky, D. M. and Sams, A. R. 1992. Tenderization of early-harvested broiler breast fillets by high voltage electrical stimulation and muscle tensioning. Poultry Science. 71:2106-2112.

Birkhold, S. G. and Sams, A. R. 1993. Fragmentation, tenderness and post-mortem metabolism of early harvested broiler breast fillets from carcasses treated with electrical stimulation and muscle tensioning. Poultry Science. 72:577-582.

Boulianne, M. and King, A. J. 1998. Meat color and biochemical characteristics of unaccepted dark-colored broiler chicken carcasses. Journal of Food Science. 63:759-762.

Bourne, M. C. 1982. Food texture and viscosity: Concept and Measurement. Academic Press. New York, NY.

Bouton, P. E., Carroll, F. D., Harris, P. V. and Shorthose, W. R. 1973. Influence of pH and fiber contraction state upon factors affecting the tenderness of bovine muscle. Journal of Food Science. 38:404-407.

Bremner, A. and Johnston, M. 1990. Poultry Meat Hygiene and Inspection. London: W.B. Sounders Co. Ltd.

Calkins, C. R., Dutson, T. R., Smith, G. C. and Carpenter, Z. L. 1982. Concentration of creatine phosphate, adenine nucleotides and their derivatives in electrically stimulated and nonstimulated beef muscle. Journal of Food Science. 47:1350-1353.

Cashman, P. J., Nicole, C. J. and Jones, R. B. 1989. Effects of transportation on the tonic immobility fear reactions of broilers. British Poultry Science. 30:211-222.

Cason, J. A., Lyon, C. E. and Papa, C. M. 1997. Effect of muscle opposition during rigor on development of broiler breast meat tenderness. Poultry Science. 76:785-787.

Cassens, R. G., Marple, D. N. and Eikelenboom, G. 1975. Animal physiology and meat quality. Adv. Food Res. 21:71-155.

Contreras, C. C. and Beraquet, N. J. 2001. Electrical stunning, hot boning, and quality of chicken breast meat. Poultry Science. 80:501-507.

Cornforth, D. P. 1994. Color and its importance. In Quality attributes and their measurement in meat, poultry, and fish products. A. M. Pearson, and T. R. Dutson, ed. Chapman and Hall, London, U.K:34-78.

Craig, E. W. and Fletcher, D. L. 1997. A comparison of high current and low voltage electrical stunning effects on broiler breast rigor development and meat quality. Poultry Science. 71:1178-1181.

Dawson, P. L., Janky, D. M., Dukes, M. G., Thompson, L. D. and Woodward, S. A. 1987. Effect of post-mortem boning time during simulated commercial processing on the tenderness of broiler breast meat. Poultry Science. 66:1331-1333.

Debut, M., Berri, C., Baeza, E., Sellier, N., Arnould, C., Guemene, D., Jehl, N., Boutten, B., Jego, Y., Beaumont, S. C. and Le Bihan-Duval, E. 2003. Variation of chicken technological meat quality in relation to genotype and preslaughter stress conditions. Poultry Science. 82:1829-1838.

Dodge, J. W. and Stadleman, W. J. 1959. Post mortem aging of poultry and its effect on the tenderness of breast muscle. Food Technology. 13:81-83.

Drewniak, E. E., Baush, E. R. and Davis, L. L. 1955. Carbon dioxide immobilization of turkeys before slaughter. USDA Circular. USDA, Washington, DC: 958.

D’Souza, D. N., Dunshea, F. R., Warner, R. D. and Leury, B. J. 1998. The effect of pre-slaughter handling and carcass processing rate post-slaughter on pork quality. Meat Science. 50:429-437.

Dunn, A. A., Kilpatrick, D. J. and Gault, N. E. S. 1993. Effect of post mortem temperature on chicken muscle pectoralis major: muscle shortening and cooked meat tenderness. British Poultry Science. 34:689-697.

Dunn, A. A., Kilpatrick, D. J. and Gault, N. E. S. 1995. Contribution of rigor shortening and cold shortening to variability in the texture of pectoralis major muscle from commercially processed broilers. British Poultry Science. 36:401-413.

Dutson, T. R., Smith, G. C. and Carpenter, Z. L. 1980. Lysosomal enzymes distribution in electrically stimulated ovine muscle. Journal of Food Science. 45:1097-1098.

Edwards, M. R., McMurty, J. P. and Vasilatos-Younken, R. 1999. Relative insensitivity of avian skeletal muscle glycogen to nutritive status. Domestic Animal Endocrinology. 16:239-247.

Ehinger, F. 1977. The influence of starvation and transportation on the carcass quality of broilers. In The Quality of Poultry Meat. S. Scholtyssek, ed. European Poultry Federation, Munich, Germany:117-124.

Eisele, J. H., Eger, E. I. and Muallem, M. 1967. Narcotic properties of carbon dioxide in the dog. Anesthesiology. 28:856-865.

Ekstrand, C. 1998. An observational cohort study of the effects of catching method on carcass rejection rates in broilers. Animal Welfare. 7:87-96.

European Commission, Directorate General, Health and Consumer Protection. 2003. Council Directive 93/119/EC. European Commission, Brussels, Belgium.

Fanatico, A. C. 2003. Small scale poultry processing. The national center for appropriate technology publication, May 2003.

Farsaie, A., Carr, L. E. and Wabeck, C. J. 1983. Mechanical harvest of broilers. Trans. ASAE. 26:1650-1653.

Fennema, O. R. 1996. Food chemistry. 3rd edition. New York: Marcel Dekker:880-938.

Ferket, P. R. and Foegeding, E. A. 1994. How nutrition and management influence PSE in poultry meat. In Proceedings from BASF Technical Symposium, Multi-State Poultry Feeding and Nutrition Conference, Indianapolis, IN:64-78.

Fernandez, X., Forslid, A. and Tornberg, E. 1994. The effect of high postmortem temperature on the development of pale, soft, and exudative pork: Interaction with ultimate pH. Meat Science. 37:133-147.

Fernandez, X., Sante, V., Baeza, E., Le-Bihan-Duval, E., Berri, C., Remignon, H., Babale, R., Lepottier, G. and Astruc, T. 2002. Effects of the rate of muscle post mortem pH fall on the technological quality of turkey meat. British Poultry Science. 43:245-252.

Fleming, B. K., Froning, G. W., Beck, M. M. and Sosnicki, A. A. 1991. The effect of carbon dioxide as a pre-slaughter stunning method for turkeys. Poultry Science. 70:2201-2206.

Fletcher D. L. 1999. Recent advances in poultry slaughter technology. Poultry Science. 78:277-281.

Fletcher, D. L. 2002. Poultry meat quality. World's Poultry Science Journal. 58:131-145.

Fletcher D. L. and Smith, D. P. 2006. The relationship between breast muscle color variation and meat functionality. In Proc. XII Eur. Poult. Conf., Verona, Italy. Univ. Bologna, Bologna, Italy:1-4.

Freeman, B. M., Kettlewell, P. J., Manning, A. C. and Berry, P. S. 1984. Stress of transportation for broilers. Veterinary Record. 114:286-287.

Froning, G. W., Babji, A. S. and Mather, F. B. 1978. The effect of preslaughter temperature, stress, struggle and anesthetization on color and textural characteristics of turkey muscle. Poultry Science. 57:630-633.

Gerritzen, M. A., Lambooij, E., Hillebrand, S. J. W., Lankhaar, J. A. C. and Pieterse, C. 2000. Behavioral responses of broilers to different gaseous atmospheres. Poultry Science. 79:928-933.

Goksoy, E. O., Mc Kinstry, L. J., Wilkins, L. J., Parkman, I., Phillips, A., Richardson, R. I. and Anil, M. H. 1999. Broiler stunning and meat quality. Poultry Science. 78:1796-1800.

Goodwin, T. L. 1984. It takes tough discipline to make tender chicken. Broiler Industry. 9:43-44.

Goodwin, T. L. and Maness, J. B. 1984. The influence of marination, weight, and cooking technique on tenderness of broilers. Poultry Science. 63:1925-1929.

Gregory, N. G. 1989. Stunning and slaughter. In Processing of poultry, G. C. Mead, ed. Elsevier Applied Science, London, U.K:31-63.

Gregory, N. G. and Wilkins, L. J. 1989. Effect of stunning current on carcass quality in chickens. Veterinary Record. 124:530-532.

Gregory, N. G., Raj, A. B. M., Audsley, A. R. S. and Daly, C. C. 1990. Effects of carbon dioxide on man. Flieschwirtschaft. 70:1173-1174.

Gregory, N. G. 1992. Stunning of broilers. In Proceedings 19th World's Poultry Congress. Volume 2. Ponsen and Looijen, Wageningen, The Netherlands:345-349.

Gregory, N. G. and Austin, S. D. 1992. Causes of trauma in broilers arriving dead at processing plants. Veterinary Record. 114:286-287.

Gregory, N. G. and Whittington. P. E. 1992. Inhalation of water during electrical stunning in chickens. Res. Vet. Sci. 53:360-362.

Gregory, N. G. 1993. Causes of downgrading in chickens, turkeys and ducks. Broiler Industry. 56:42-45.

Griffiths, G. L. and Nairn, M. E. 1984. Carcass downgrading in broiler chickens. British Poultry Science. 25:441-446.

Griffiths, G. L. 1985. Electrocution, stunning, and chicken carcass appearance. In Proceedings Australian Stock Feed Conference, Adelaide, Australia:282-286.

Hamm, R. 1982. Post mortem changes in muscle with regard to processing of hot boned beef. Food Technology. 36(11):105-115.

Hamm, R. 1986. Functional properties of the myofibrillar system and their measurements. In Muscle as Food. P. J. Bechtel, ed. Academic Press, New York:135-199.

Heath, G. B. S. 1984. The slaughter of broiler chickens. World's Poultry Science Journal. 40:151-159.

Heath G. E., Thaler, A. M. and James, W. O. 1994. A survey of stunning methods currently used during slaughter of poultry in commercial poultry plants. Journal of Applied Poultry Research. 3:297-302.

Hedrick, H. B. 1965. Influence of ante mortem stress on meat palatability. Journal of Animal Science. 24:255-263.

Herring, H. B., Cassens, R. G., Suess, G. G., Brungardt, V. H. and Briskey, E. J. 1967. Tenderness and associated characteristics of stretched and contracted bovine muscles. Journal of Food Science. 32:317-323.

Hillebrand, S. J. W., Lambooij, E. and Veerkamp, C. H. 1996a. The effects of alternative electrical and mechanical stunning methods on hemorrhaging and meat quality of broiler breast and thigh muscles. Poultry Science. 75: 664-671.

Hillebrand, S. J. W., Pieterse, C. and Lambooij, E. 1996b. Air pressure stunning of broilers-changes in the spontaneous electroencephalogram, immobilization and hemorrhaging aspects. In Proceedings of the 42nd International Congress of Meat Science and Technology, Lillehammer, Norway:456-457.

Hirschler, E. M. and Sams, A. R. 1993. Comparison of carbon dioxide and electricity for the preslaughter stunning of broilers. Poultry Science. 72: (Supp. 1):143. (Abstr.)

Hirschler, E. M. and Sams, A. R. 1998. Commercial scale electrical stimulation of poultry: the effects on tenderness, breast meat yield, and production costs. Journal of Applied Poultry Research. 7:99-103.

Hoen, T. and Lankhaar, J. 1999. Controlled atmosphere stunning of poultry. Poultry Science. 78:287-289.

Holm, C. G. P. and Fletcher D. L., 1997. Ante mortem holding temperatures and broiler breast meat quality. Journal of Applied Poultry Research. 6:180-184.

Honikel, K. O. 1987. Influence of chilling on meat quality attributes of fast glycolysing pork muscles. In Evaluation and control of meat quality in pigs. P. V. Tarrant, G. Eikelenboom, and G. Monin, ed. Martinus Nijhoff, Dordrecht, The Netherlands: 273-283.

Jones, B. R. 1992. The nature of handling immediately prior to test affects tonic immobility fear reactions in laying hens and broilers. Applied Animal Behaviour Science. 34:247-254.

Judge, M. D., Aberle, E. D., Forrest, J. C., Hedrick, H. B. and Merkel, R. A. 1989. Properties of fresh meat. In Principles of meat science. Kendall Hunt Publication, Dubuque, IA:109-116.

Kang, I. S. and Sams, A. R. 1999. Bleedout efficiency, carcass damage, and rigor mortis development following electrical stunning or carbon dioxide stunning on shackle line. Poultry Science 78:139-143.

Kauffman, R. G. and Marsh, B. B. 1987. Quality characteristics of muscle as food. In The science of meat and meat products. 3rd ed. J. F. Price and B. S. Schweigert, ed. Food and Nutrition Press, Inc., Westport, CT:356-357.

Kannan, G. and Mench, J. A. 1996. Influence of different handling methods and crating periods on plasma corticosterone concentrations in broilers. British Poultry Science. 37:21-31.

Kannan, G. and Mench, J. A. 1997. Prior handling does not significantly reduce the stress response to preslaughter handling in broiler chickens. Applied Animal Behaviour Science. 51:87-99.

Kannan, G., Heath, J. L., Wabeck, C. J., Souza, M. C. P., Howe, J. C. and Mench, J. A. 1997. Effects of crating and transport on stress and meat quality characteristics in broilers. Poultry Science. 76:523-529.

Kenan, T. M. and Fidan, E. 2006. The effect of physical contact on pre-slaughter stress and fear reactions in broiler chickens. International Journal of Poultry Science. 5(12):1133-1136.

Kettlewell, P. J., and Hallworth, R. N. 1990. Electrical stunning of chickens. J. Agric. Eng. Res. 47:139-151.

Khan, A. W. and Nakamura, R. 1970. Effects of pre and post mortem glycolysis on poultry tenderness. Journal of Food Science. 35:266-267.

Khan, A. W. 1974. Relation between isomeric tension, post mortem pH decline and tenderness of poultry breast meat. Journal of Food Science. 39:393-395.

Knowles, T. G. and Broom, D. M. 1990. The handling and transportation of broilers and spent hens. Applied Animal Behaviour Science. 28:93-118.

Koohmaraie, M. 1994. Muscle proteinases and meat aging. Meat Science. 36:93-104.

Koohmaraie, M. 1996. Biochemical factors regulating the toughening and tenderization processes of meat. Meat Science. 43:S193-S201.

Kotula, A. W., Drewniak, E. E. and Davis, L. L. 1957. Effect of carbon dioxide immobilization on the bleeding of chickens. Poultry Science. 37:585-589.

Kotula, A. W., Drewniak, E. E. and Davis, L. L. 1961. Experimentation with in-line carbon dioxide in immobilization of chickens prior to slaughter. Poultry Science. 40:213-216.

Kotula, K. L. and Wang, Y. 1994. Characterization of broiler meat quality factors influenced by feed withdrawal time. Journal of Applied Poultry Research. 3:103-110.

Kranen, R. W., Scheele, C. W., Veerkamp, C. H., Lambooij, E., Van Kuppevelt, T. H. and Veerkamp, H. 1998. Susceptibility of broiler chickens to hemorrhages in muscles. The effect of stock and rearing temperature regimen. Poultry Science. 77:334-341.

Kranen, R. W., Van Kuppevelt, T. H., Goedhart, H. A., Veerkamp, C. H., Lambooij, E. and Veerkamp, J. H. 1999. Hemoglobin and myoglobin content in muscles of broiler chickens. Poultry Science. 78:467-476.

Kranen, R. W., Lambooij, E., Veerkamp, C. H., Van Kuppevelt, T. H. and Veerkamp, J. H. 2000. Hemorrhages in muscles of broiler chickens. World’s Poultry Science Journal. 56:93-126.

Lambooij, E., 1999. Handling of poultry before slaughter: Some aspect of welfare and meat quality. In Proceedings of the 14th European symposium on the quality of poultry meat, Bologna, Italy:311-323.

Lambooij, E., Pieterse, C., Hillebrand, S. J. W. and Dijksterhuis, G. B. 1999. The effects of captive bolt and electrical stunning, and restraining methods on broiler meat quality. Poultry Science. 78:600-607.

Lawrie, R. A., 1966. Metabolic stress which affect muscle. In The physiology and biochemistry of muscle as a food. E. J. Briskey, R. G. Cassens and J. C. Tautman, ed. The University of Wisconsin Press, Madison, Wisconsin:137-164.

Lee Y. B., Hargus, G. L., Hagberg, E. C. and Forsythe, R. H. 1976. Effect of ante mortem environmental temperatures on post mortem glycolysis and tenderness in excised broiler breast muscle. Journal of Food Science. 41:1466-1469.

Lin, H., Sui, S. J., Jiao, H. C., Buyse, J. and Decuypere, E. 2006. Impaired development of broiler chickens by stress mimicked by corticosterone exposure. Comp. Biochem. Physiol. 143:400-405.

Lindholst, S. 1991. Stunning and meat quality. In Quality of poultry products I. Poultry meat. Uijttenboogaart, T. G. and C. H. Veerkamp, ed. Spelderholt Center for Poultry Research, Beekbergen, The Netherlands:31-32.

Livingston, D. J. and Brown, W. D. 1981. The chemistry of myoglobin and its reactions. Food Technology. 35:244-252.

Locker, R. L. 1960. Degree of muscular contraction as a factor in tenderness of beef. Food Research. 25:304-307.

Lyon, C. E., Hamm, D. M. and Thomson, J. E. 1985. pH and tenderness of broiler breast meat deboned at various times after chilling. Poultry Science. 64:307-310.

Lyon, C. E. and Wilson, R. L. 1986. Effect of sex, rigor condition and heating method on yield and objective texture of broiler breast meat. Poultry Science. 65:907-914.

Lyon, C. E., Davis, C. E., Dickens, J. A. and Papa, C. M. 1989. Effects of electrical stimulation on the postmortem biochemical changes and texture of broiler pectoralis muscle. Poultry Science. 68:249-257.

Lyon, C. E., and Lyon, B. G. 1990a. Texture profile of broiler pectoralis major as influenced by post-mortem deboning time and heat method. Poultry Science. 69:329-340.

Lyon, C. E. and Lyon, B. G. 1990b. The relationship of objective shear values and sensory tests to changes in tenderness of broiler breast meat. Poultry Science. 69:1420-1427.

Lyon, C. E., Lyon, B. G., Papa, C. M. and Robach, M. C. 1992. Broiler tenderness: Effect of post chill deboning time and fillet holding time. Journal of Applied Poultry Research. 1:27-32.

Lyon, B. G. and Lyon, C. E. 1997. Sensory descriptive profile relationships to shear values of deboned poultry. Journal of Food Science. 62:885-888, 897.

Lyon, B. G. and Lyon, C. E. 1998. Assessment of three devices used in shear tests of cooked breast meat. Poultry Science. 77:1585-1590.

Lyon, C. E. and Lyon, B. G. 2000. Sensory differences in broiler breast meat due to electrical stimulation, deboning time, and marination. Journal of Applied Poultry Research. 9:234-241.

Lyon, C. E., Lyon, B. G. and Savage, E. M. 2003. Effect of post chill deboning time on the texture profile of broiler breeder hen breast meat. Journal of Applied Poultry Research. 12:348-355.

Maki, A. and Froning, G. W. 1987. Effect of postmortem electrical stimulation on quality of turkey meat. Poultry Science. 66:1155-1157.

Maribo, H., Olsen, E. V., Barton-Gade, P., Moller, A. J. and Karlsson, A. 1998. Effect of early post mortem cooling on temperature, pH fall and meat quality in pigs. Meat Science. 50:115-129.

Marion, W. W. 1967. Meat tenderness in avian species. World’s Poultry Science Journal. 23:6-15.

Marple, D. N. and Cassens, R. G. 1973. A mechanism for stress susceptibility in swine. Journal of Animal Science. 37:546.

McKee, S. R., Hirschler, E. M. and Sams A. R. 1997a. Physical and biochemical effects of broiler breast tenderization by aging after pre-rigor deboning. Journal of Food Science. 62:959-962.

McKee, S. R. and Sams, A. R. 1997b. The effect of seasonal heat stress on rigor development and the incidence of pale, exudative turkey meat. Poultry Science. 76:1616-1620.

McKee, S. R. and Sams, A. R. 1998. Rigor mortis development at elevated temperatures induces pale exudative turkey meat characteristics. Poultry Science. 77:169-174.

McNeal, W. D. and Fletcher, D. L. 2003. Effects of high frequency electrical stunning and decapitation on early rigor development and meat quality of broiler breast meat. Poultry Science. 82:1352-1355.

Meek, K. I., Claus, J. R., Duncan, S. E., Marriott, N. G., Solomon, M. B., Kathman, S. J. and Marini, M. E. 2000. Quality and sensory characteristics of selected post rigor, early deboned broiler breast meat tenderized using hydrodynamic shock waves. Poultry Science. 79:126-136.

Meilgaard, M., Civille, G. V. and Carr, B. T. 1999. Sensory Evaluation Techniques, 3rd ed. CRC Press, Boca Raton, Florida.

Mitchell, M. A., Kettlewell, P. J. and Maxwell, M. H. 1992. Indicators of physiological stress in broiler chickens during road transportation. Animal Welfare. 1:91-103.

Mitchell, M. A. and Kettlewell, P. J. 1994. Road transportation of broiler chickens: induction of physiologic stress. World's Poultry Science Journal. 50:57-59.

Mitchell, M. A. and Kettlewell, P. J. 1998. Physiological stress and welfare of broiler chickens in transit: Solutions not problems. Poultry Science. 77:1803-1814.

Moran Jr., E. T., and Bilgili, S. F. 1995. Influence of broiler livehaul on carcass quality and further processing yields. Journal of Applied Poultry Research. 4:13-22.

Mugler, D. J., Mitchell, J. D. and Adams, A. W. 1970. Factors affecting turkey meat color. Poultry Science. 49:1510-1513.

Ngoka, D. A. and Froning, G. W. 1982. Effect of free struggle and preslaughter excitement on color of turkey breast muscle. Poultry Science. 61:2291-2293.

Nicol, C. J. and Scott, G. B. 1990. Pre-slaughter handling and transport of broiler chickens. Applied Animal Behaviour Science. 28:57-73.

Nijdam, E., Arens, P., Lambooij, E., Decuypere, E. and Stegeman, J. A. 2004. Factors influencing bruises and mortality of broilers during catching, transport, and lairage. Poultry Science. 83:1610-1615.

Nijdam, E., Delezie, E., Lambooij, E., Nabuurs, M. J. A., Decuypere, E. and Stegeman, J.A. 2005. Comparison of bruises and mortality, stress parameters, and meat quality in manually and mechanically caught broilers. Poultry Science. 84:467-474.

Nishida, J. and Nishida, T. 1985. Relationship between the concentration of myoglobin and parvalbumin in various types of muscle tissues from chickens. British Poultry Science. 26:105-115.

Northcutt, J. K., Foegeding, E. A. and Edens, F. W. 1994. Water-holding properties of thermally preconditioned chicken breast and leg meat. Poultry Science. 73:308-316.

Northcutt, J. K., Buhr, R. J. and Young, L. L. 1998. Influence of preslaughter stunning on turkey breast muscle quality. Poultry Science. 77:487-492.

Offer, G. 1991. Modeling of the formation of pale, soft and exudative meat: Effects of chilling regime and rate and extent of glycolysis. Meat Science. 30:157-184.

Olsson, K. and Saltin, B. 1970. Variation in total body water with muscle glycogen changes in man. Acta Physiol. Scand. 80:97-102.

Ouali, A. 1992. Proteolytic and physiochemical mechanisms involved in meat texture development. Biochemie. 74:251-265.

Owens, C. M., Hirschler, E. M., McKee, S. R., Martinez-Dawson, R. and Sams, A. R. 2000. The characterization and incidence of pale, soft, exudative turkey meat in a commercial plant. Poultry Science. 79:553-558.

Papinaho, P. A. and Fletcher, D. L. 1995. Effect of stunning amperage on broiler breast muscle rigor development and meat quality. Poultry Science. 74:1527-1532.

Papinaho, P. A., Fletcher. D. L. and Buhr, R. J. 1995. Effect of electrical stunning amperage and peri-mortem struggle on broiler breast rigor development and meat quality. Poultry Science. 74:1533-1539.

Papinaho, P. A. and Fletcher. D. L. 1996. The effect of stunning amperage and deboning time on early rigor development and breast meat quality of broilers. Poultry Science. 75:672-676.

Papinaho, P. A., Fletcher. D. L. and Rita, H. J. 1996. Relationship of breast fillet deboning time to shear force, pH, cooking loss and color in broilers stunned by high electrical current. Agricultural Food Science Finland. 5:49-55.

Pearson, A. M. 1987. Muscle function and postmortem changes. In The science of Meat and Meat Products, third edition. J. F. Price, and B. S. Schweigert, ed. Food and Nutrition Press, Inc. Westport, Connecticut:307-327.

Petracci, M., Fletcher, D. L. and Northcutt, J. K. 2001. The effect of holding temperature on live shrink, processing yield and breast meat quality of broiler chickens. Poultry Science. 80:670-675.

Pietrzak, M., Greaser, M. L. and Sosnicki, A. A. 1997. Effect of rapid rigor mortis processes on protein functionality on pectoralis major muscle of domestic turkeys. Journal of Animal Science. 75:2106-2116.

Pool, M. F., De Fremery, D., Campbell, A. A. and Klose, A. A. 1959. Poultry tenderness. II. Influence of processing on tenderness of chicken. Food Technology. 13:25-29.

Poole, G. H. and Fletcher, D. L. 1995. A comparison of argon, carbon dioxide, and nitrogen in a broiler killing system. Poultry Science. 74:1218-1223.

Poole, G. H. and Fletcher, D. L. 1998. Comparison of a modified atmosphere stunning-killing system to conventional electrical stunning and killing on selected broiler breast muscle rigor development and meat quality attributes. Poultry Science. 77:342-347.

Poultry Inspection Regulations, 1984. Subpart I – Operating Procedures. 381.65c.

Purswell, J. L., Thaxton, J. P. and Branton, S. L. 2007. Identifying process variables for a low atmospheric stunning-killing system. Journal of Applied Poultry Research. 16:509-513.

Qiao, M., Fletcher, D. L., Smith, D. P. and Northcutt, J. K. 2001. The effect of broiler breast meat color on pH, moisture, water-holding capacity, and emulsification capacity. Poultry Science. 80:676-680.

Qiao, M., Fletcher, D. L., Smith, D. P. and Northcutt, J. K. 2002. Effects of raw broiler breast meat color variation on marination and cooked meat quality. Poultry Science. 81:276-280.

Raj, A. B. M., Grey, T. C., Audsely, A. R. and Gregory, N. G. 1990a. Effect of electrical and gaseous stunning on the carcass and meat quality of broilers. British Poultry Science. 31:725-733.

Raj, A. B. M., Gregory, N. G. and Austin, S. D. 1990b. Prevalence of broken bones in broilers killed by different stunning methods. Veterinary Record. 127:285-287.

Raj, A. B. M. and Gregory, N. G. 1990c. Investigation into the batch stunning/ killing of chickens using carbon dioxide or argon-induced hypoxia. Res. Vet. Sci. 49:364-366.

Raj, A. B. M. and Gregory, N. G. 1991. Effect of argon stunning, rapid chilling, and early filleting on texture of broiler breast meat. British Poultry Science. 32:741-746.

Raj, A. B. M., Gregory, N. G. and Wilkins, L. G. 1992. Survival rate and carcass downgrading after the stunning of broilers with carbon dioxide-argon mixtures. Veterinary Record. 130:325-328.

Raj, A. B. M. 1994. Effect of stunning method, carcass chilling temperature and filleting time on the texture of broiler pectoralis muscle. British Poultry Science. 35:77-89.

Raj, A. B. M., Wilkins, L. J., Richardson, R. I., Johnson, S. P. and Wotton, S. B. 1997. Carcass and meat quality in broilers either killed with a gas mixture or stunned with an electric current under commercial processing conditions. British Poultry Science. 38:169-174.

Raj, A. B. M. 1998. Welfare during stunning and slaughter of poultry. Poultry Science. 77:1815-1819.

Rammouz, R. E., Babile. R. and Fernandez, X. 2004. Effect of ultimate pH on the physicochemical and biochemical characteristics of turkey breast muscle showing normal rate of post mortem pH fall. Poultry Science. 83:1750-1757.

Rushen, J., Taylor A. A. and Passille, A. M. 1999. Domestic animal's fear of humans and its effect on their welfare. Applied Animal Behaviour Science. 65:285-303.

Sams, A. R., Janky, D. M. and Woodward S. A. 1989. Tenderness and R-Value changes in early harvested broiler breast tissue following post-mortem electrical stimulation. Poultry Science. 68:1232-1235.

Sams, A. R., Janky, D. M. and Woodward, S. A. 1990. Comparison of two shearing methods for objective tenderness evaluation and two sampling times for physical–characteristic analysis of early-harvested broiler breast meat. Poultry Science. 69:348-353.

Sams, A. R. and Mills, A. D. 1993. The effect of feed withdrawal duration on the responsiveness of broiler pectoralis to rigor mortis acceleration. Poultry Science. 72:1789-1796.

Sams, A. R. 1994. Electrical stimulation at commercial line speeds. Broiler Industry. 57(12):36.

Sams, A. R. and Dzuik, C. S. 1995. Gas stunning and post mortem electrical stimulation of broiler chickens. Poultry Meat Quality. In Proceedings of XII European symposium on the Quality of Poultry Meat. Zaragoza, Spain:307-314.

Sams, A. R., 1996. Stunning basics. Broiler Industry. 59:36-38.

Sams, A. R. 1999. Meat quality during processing. Poultry Science. 78:798-803.

Sandercock, D. A., Hunter, R. R., Nute, G. R., Hocking, P. M. and Mitchell, M. A. 1999. Physiological responses to acute heat stress in broilers: implications for meat quality. Proceedings of the 14th European symposium on the quality of poultry meat, Bologna, Italy: 271-276.

Savell, J. W., Smith, G. C. and Carpenter, Z. L. 1978. Effect of electrical stimulation on quality and palatability of light weight beef carcasses. Journal of Animal Science. 46:1221-1228.

Savenije, B., Schreurs, F. J. G., Winkleman-Goedhart, H. A., Gerritzen, M. A., Korf, J. and Lambooij, E. 2002. Effects of feed deprivation and electrical, gas, and captive needle stunning on early post mortem muscle metabolism and subsequent meat quality. Poultry Science. 81:561-571.

Schilling, M. W., Schilling, J. K., Claus, J. R., Marriott, N. G., Duncan, S. E. and Wang, H. 2003. Instrumental texture assessment and consumer acceptability of cooked broiler breasts evaluated using a geometrically uniform-shaped sample. Journal of Muscle Foods. 14:11-23.

Schutt-Abraham, I., Wormuth, H. J. and Fessel, J. 1983. Electrical stunning of poultry in view of animal welfare and meat production. In stunning of animals for slaughter. G. Eikelenboom, ed. Martinus Nijhoff, The Hague, The Netherlands:187-196.

Selye, H., 1950. The physiology and pathology of exposure to stress. Acta Inc., Montreal.

Shelton, T. 1985. Broiler industry in the year 2000. Broiler Industry. 48(11):36.

Simpson, M. D. and Goodwin, T. L. 1974. Comparison between shear values and taste panel scores for predicting tenderness of broilers. Poultry Science. 53:2042-2046.

Smith, M. C., Judge, M. D. and Stadleman, W. J. 1969. A cold shortening effect in avian muscle. Journal of Food Science. 34:42-46.

Smith D. P., Fletcher, D. L. and Papa, C. M. 1992. Post mortem biochemistry of Pekin duckling and broiler chicken pectoralis muscle. Poultry Science. 71:1768-1772.

Smith D. P., Lyon, C. E. and Lyon, B. G. 2002. The effect of age, dietary carbohydrate source, and feed withdrawal on broiler breast fillet color. Poultry Science. 81:1584-1588.

Solomon, M. B., Van Laack, R. L. J. M. and Eastridge, J. S. 1998. Biophysical basis of pale, soft, exudative (PSE) pork and poultry muscle: A review. Journal of Muscle Foods 9:1-11.

Sosnicki, A. A., Greaser, M. L., Pietrzak, M., Pospiech, E. and Sante, V. 1998. PSE-like syndrome in breast muscle of domestic turkeys. A review. Journal of Muscle Foods. 9:13-23.

Stewart, M. K., Fletcher, D. L., Hamm, D. and Thomson, J. E. 1984. The influence of hot boning broiler breast muscle on pH decline and toughening. Poultry Science. 63:1935-1939.

Szczesniak, A. S. and Torgeson, K. W. 1965. Methods of meat texture measurement viewed from the background of factors affecting tenderness. In Advances in Food Research, Vol. 14. Academic press, New York, NY:33-165.

Thielke, S., Lhafi, S. K. and Kuhne, M. 2005. Processing, products, and food safety effects of aging prior to freezing on poultry meat tenderness. Poultry Science. 84:607-612.

Thompson, L. D., Janky, D. M. and Woodward, S. A. 1987. Tenderness and physical characteristics of broiler breast fillets harvested at various times from post mortem electrically stimulated carcasses. Poultry Science. 66:1158-1167.

Turcsan, Zs., Szigeti, J., Varga, L., Farkas, L., Birkas, E. and Turcsan, J. 2001. The effects of electrical and controlled atmosphere stunning methods on meat and liver quality of geese. Poultry Science. 80:1647-1651.

Turcsan, Zs., Varga, L., Szigeti, J., Turcsan, J., Csurak, I. and Szalai, M. 2003. Effects of electrical stunning frequency and voltage combinations on the presence of engorged blood vessels in goose liver. Poultry Science. 82:1816-1819.

Uijttenboogaart, T. G. 1997. Effect of gas and electrical stunning methods on meat quality. In Proceedings of the satellite symposium: Developments of new humane stunning and related processing methods for poultry to improve product quality and consumer acceptability. Lambooij, E. ed. ID-DLO Report 97.026. ID-DLO, Lelystad, The Netherlands:25-33.

Van Laack, R. L. J. M., Liu, C. H., Smith, M. O. and Loveday. H. D. 2000. Characteristics of pale, soft, exudative broiler breast meat. Poultry Science. 79:1057-1061.

Veeramuthu, G. J. and Sams, A. R. 1993. The effects of carbon dioxide and electrical stunning on rigor mortis and toughness development in early-harvested broiler breast fillets. Poultry Science. 72:(Suppl. 1):147. (Abstr.)

Veerkamp, C. H. and de Vries, A. W. 1983. Influence of electrical stunning on quality aspects of broilers. In Stunning animals for slaughter. G. Eikelenboom, ed. Martinus Nijhoff Publishers, Boston, MA:197-212.

Veerkamp, C. H., 1988. What is the right current to stun and kill broilers? Poultry Misset. 4:30-31.

Walther, J. H. 1991. Minimizing product loss in the hang, stun and kill areas. In Proceedings Poultry Health and Condemnation meeting. Ocean City, MD:160-163.

Warris, A. J. and Brown, S. N. 1987. The relationship between pH, reflectance and exudation in pig muscle. Meat Science. 20:65-72.

Warris, P. D., Bevis, E. A., Brown, S. N. and Edwards, J. E. 1992. Longer journeys to processing plants are associated with higher mortality in broiler chickens. British Poultry Science. 33:201-206.

Warris, P. D., Wilkins, L. J. and Knowles, T. G. 1999. The influence of ante-mortem holding on poultry meat. In Richardson, R. I. and G. C. Mead (Eds) Poultry meat science, (Wallingford, CABI Publishing):217-230.

Weeks, C. and Nicol, C. 2000. Live handling and transport. 2nd ed. T. Grandin, ed. CAB International, Wallingford, UK:363-384.

Wilkins, L. J., Gregory, N. G. and Wotton, S. B. 1999. Effectiveness of different electrical stunning regimens for turkeys and consequences for carcass quality. British Poultry Science. 40:478-484.

Woelfel, R. L., Owens, C. M., Hirschler, E. M., Martinez-Dawson, R. and Sams, A. R. 2002. The characterization and incidence of pale, soft and exudative broiler meat in a commercial processing plant. Poultry Science. 81:579-584.

Wood, D. F. and Richards, J. F. 1974. Isometric tension studies on chicken pectoralis major muscle. Journal of Food Science. 39:525-529.

Wood, D. F. and Richards, J. F. 1975. Effect of some antemortem stressors on postmortem aspects of chicken broiler pectoralis muscle. Poultry Science. 54:528-531.

Wotton, S. B. and Gregory, N. G. 1991. How to prevent pre-stun shocks in waterbath stunners. Turkey. 39:15-30.

Wu, F. Y. and Smith, S. B. 1987. Ionic strength and myofibrillar protein solublization. Journal of Animal Science. 65:579-608.

Yang, C. C. and Chen, T. C. 1993. Effects of refrigerated storage, pH adjustment, and marinade on color of raw and microwave cooked chicken meat. Poultry Science. 72:355-362.

Young, L. L. and Lyon, C. E. 1997. Effect of calcium marination on biochemical and textural properties of pre rigor chicken breast meat. Poultry Science. 76:197-201.

Zocchi, C. and Sams, A. R. 1999. Tenderness of broiler breast fillets from carcasses treated with electrical stimulation and extended chilling times. Poultry Science. 78:495-498.

Zulkifli, I. and Sti Nor Azah, A. 2004. Fear and stress reactions and the performance of commercial broiler chickens subjected to regular pleasant and unpleasant contacts with human beings. Applied Animal Behaviour Science. 88: 77-87.

APPENDIX A

IRB APPROVAL LETTER

Mississippi State UNIVERSITY

April 19, 2007

Vamsidhar Battula
22d Wallace Circle
Starkville, Ms 39759

RE: IRB Study #07-103: Effect of Stunning Methods on Chicken Breast Quality

Dear Mr. Battula:

The above referenced project was reviewed and approved via administrative review on 4/18/2007 in accordance with 45 CFR 46.101(b)(6). Continuing review is not necessary for this project. However, any modification to the project must be reviewed and approved by the IRB prior to implementation. Any failure to adhere to the approved protocol could result in suspension or termination of your project. The IRB reserves the right, at anytime during the project period, to observe you and the additional researchers on this project.

Please refer to your IRB number (#07-103) when contacting our office regarding this application.

Thank you for your cooperation and good luck to you in conducting this research project. If you have questions or concerns, please contact me at cwilliams@research.msstate.edu or 325-5220.

Sincerely,

Christine Will

Christine Williams
IRB Compliance Administrator

cc: Mark Wes Schilling

Office for Regulatory Compliance
P. O. Box 6223 • 8A Morgan Street • Mailstop 9563 • Mississippi State, MS 39762 • (662) 325-3294 • FAX (662) 325-8776

APPENDIX B

CONSENT FORM

CONSENT FORM
(You Must Be 18 years Old to Participate)

Title of Study: Effect of Stunning Methods on Chicken Breast Quality.

Study Site: Garrison Sensory Evaluation Laboratory

Name of Researcher(s) & University affiliation:
Vamsidhar Battula. Graduate Student. Mississippi State University. Dept. of Food Science, Nutrition and Health Promotion.
Dr. Mark Wes Schilling. Mississippi Stat University. Dept. of Food Science, Nutrition and Health Promotion.

What is the purpose of this research project?
To measure and compare consumer acceptability of chicken breast meat that is harvested using different stunning methods.

How will the research be conducted?
You will be given samples of product to taste and asked to fill out a questionnaire. After tasting each one, you will be asked to evaluate the products on a score sheet
.

Are there any risks or discomforts to me because of my participation? No.

Does participation in this research provide any benefits to others or myself? This research will provide poultry researchers with information that will help improve the quality of the products.

Will this information be kept confidential? Yes. Personal information, including your name will not be released. Only the data obtained from the testing will be provided to the contracting companies.

Who do I contact with research questions? If you should have any questions about this research project, please feel free to contact Dr. Wes Schilling, 662-325-2666. For additional information regarding your rights as a research subject, please feel free to contact the MSU Regulatory Compliance Office at 662-325-3294.

What do I do if I am injured at a result of this research?
In addition to reporting an injury to Dr. Wes Schilling (662-325-2666) and to the Regulatory Compliance Office (662-325-3294), you may be able to obtain limited compensation from the State of Mississippi if the injury was caused by the negligent act of a state employee where the damage is a result of an act for which payment may be made under §11-46-1, et seq. Mississippi Code Annotated 1972. To obtain a claim form, contact the University Police Department at MSU UNIVERSITY POLICE DEPARTMENT, Stone Building, Mississippi State, MS 39762, (662) 325-2121.

What if I do not want to participate?
Please understand that your participation is voluntary, your refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled, and you may discontinue your participation at any time without penalty or loss of benefits.

You will be given a copy of this form for your records.

___________________________________ ___________
Participant Signature Date

___________________________________ ___________
Investigator Signature Date

APPENDIX C

SCORE SHEET

Product: Chicken Breast **Date:** ____________

1. Please evaluate one sample at a time going from left to right
2. Evaluate all attributes for each sample before evaluating next sample
3. Please evaluate OVERALL last after evaluating the other attributes for each sample
4. Please rinse your mouth before starting.
5. Evaluate the product by looking at it and tasting it

827	449	212	413	760	654	**APPEARANCE**
						Like extremely
						Like very much
						Like moderately
						Like slightly
						Neither like nor dislike
						Dislike slightly
						Dislike moderately
						Dislike very much
						Dislike extremely

827	449	212	413	760	654	**TEXTURE**
						Like extremely
						Like very much
						Like moderately
						Like slightly
						Neither like nor dislike
						Dislike slightly
						Dislike moderately
						Dislike very much
						Dislike extremely

827	449	212	413	760	654	**FLAVOR**
						Like extremely
						Like very much
						Like moderately
						Like slightly
						Neither like nor dislike
						Dislike slightly
						Dislike moderately
						Dislike very much
						Dislike extremely

827	449	212	413	760	654	**OVERALL**
						Like extremely
						Like very much
						Like moderately
						Like slightly
						Neither like nor dislike
						Dislike slightly
						Dislike moderately
						Dislike very much
						Dislike extremely