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Effects of electrical stimulation on tenderness of chicken processed by the chill-pack method

Donald Keith Moore

To the Graduate Council:

I am submitting herewith a thesis written by Donald Keith Moore entitled "Effects of electrical stimulation on tenderness of chicken processed by the chill-pack method." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

Curtis C. Melton, Major Professor

We have read this thesis and recommend its acceptance:

H. Dwight Loveday, Herschel V. Shirley

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Date August 15, 1985

EFFECTS OF ELECTRICAL STIMULATION ON TENDERNESS OF CHICKEN PROCESSED BY THE CHILL-PACK METHOD

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Donald Keith Moore, Jr.

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ABSTRACT

Ninety chickens were assigned at random to 1 of 8 treatment groups or to a control group in each replication. The 8 treatment groups received electrical stimulation (ES) of 50 or 100 volts for a duration of 25 pulses (25p) or until no response (NS) was detected at a point in the slaughter sequence of either pre-stick (PS) or pre-chill (PC); the control group received no electrical stimulation other than stunning. The treatment groups were arranged in a 2 x 2 x 2 factorial design. Two hundred seventy-nine birds were analyzed in three replications to study the possibility of improving the tenderness, or at least preventing the toughening, of "chill-pack" processed chickens. Measurements made included Warner-Bratzler shear force, an objective measure of tenderness; sarcomere length; and expressible moisture index (EMI), an indication of water holding capacity (WHC) which is positively correlated with tenderness.

Warner-Bratzler shear values were significantly different between replications ($P<.01$) and between the PS and PC treatments as groups ($P<.05$), although neither group was different from the control ($P>.10$). The interaction between replication and treatment was significant ($P<.05$).

There was no difference in sarcomere lengths among any of the individual treatments or due to any of the factors studied.

EMI was significantly different between replications ($P<.01$) and between PS and PC stimulation groups ($P<.01$), but neither group differed significantly from the control ($P>.10$).

Results indicate that electrical stimulation applied prior to chilling may be a feasible way to reduce toughening in chill-pack chicken.

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CHAPTER I

INTRODUCTION

For many years chicken has been processed by the "ice-pack" method. The birds are slaughtered, dressed and chilled following standard industry practices. The chilled carcasses are then placed in wire-bound boxes and covered with ice. The boxes are bound and held in a cooler at 32-36°F until ready to ship (Brant et al., 1982).

In recent years some of the larger processors have changed to the "chill-pack" method to process their birds. This method involves slaughtering, dressing and chilling the birds in the conventional manner, but then cutting the birds immediately, packaging them, and crust-freezing the packages in a blast freezer at -20 to -40°F for about 1 hour, after which they are held in a 26 to 32°F cooler until shipping (Brant et al., 1982).

Chicken processed by the chill-pack method has some tenderness problems which did not exist with the ice-pack method that it replaced. However, the chill-pack method has several advantages over the ice-pack method. These advantages are:

1. Less handling due to prepackaging before reaching the retail outlet,
2. Longer shelf-life due to less handling,
3. Less weepage,
4. More uniform skin color, and
5. More ease in handling (Brant et al., 1982).

It is believed that the decrease in tenderness in the chill-pack process may be the result of a deviation in the normal rigor process that the birds pass through. In the ice-pack method the birds are stored at normal cooler temperatures right after chilling so that rigor proceeds in a "normal" manner, while in the chill-pack method the birds are cut and placed in a blast freezer at a very low temperature before rigor has been completed. Pre-rigor cutting and storage at very low temperatures causes a phenomenon known as "cold shortening" in red meat animals (Locker and Hagyard, 1963) and may be the causative factor in the chicken tenderness problem described here.

Electrical stimulation after slaughter has proven to be an effective way of reducing the effects of cold shortening in beef carcasses, although it seems to be of no value or to actually have negative effects (decrease tenderness) on pork carcasses (Johnson et al., 1982; Wiley et al., 1983; and Crenwelge et al., 1984).

The objective of this study was to determine if the chicken slaughtering process can be altered with electrical stimulation to reduce muscle tenderness problems associated with the chill-pack method without reducing the other advantages of this method.

The breast only was used in this study since the consumers' complaints of toughness seem to be associated most often with this part of the chicken.

CHAPTER II

REVIEW OF LITERATURE

1. EFFECTS OF NON-RIGOR FACTORS ON CHICKEN TENDERNESS

Several factors that have no influence or are related only indirectly to the rigor process may have an effect on the tenderness of chicken muscle.

Strain

Strain is a factor that may influence tenderness (Marion, 1967). Shrimpton and Miller (1960) reported a difference in tenderness between two strains, with White Rocks being more tender than Brown Leghorns. Goodwin et al. (1969) in a later study found no difference in tenderness that could be attributed to differences in strain.

Age

Age is a factor in poultry tenderness, as it is with tenderness in almost all species of meat animals. May et al. (1962) found that 72-week-old chickens were less tender than 10-week-old chickens. Broilers are usually slaughtered at 8 weeks of age or less, so toughness associated with age should be minimal. Evans et al. (1976) compared the tenderness of 6, 7 and 8-week-old broilers and reported that 7-week-old birds had the highest and 8-week-old birds had the lowest shear values.

Sex

Most of the literature reports little influence of sex on tenderness (Shrimpton and Miller, 1960; Gilpen et al., 1960; Carlson et al., 1966). Goodwin et al. (1969) found that males had a slight but significant advantage in tenderness when compared to females. Simpson and Goodwin (1975) found that males had a significantly lower shear value than females for breast muscle, while females had a significantly lower shear value for thighs. Treat and Goodwin (1973) found that large male birds (1800-1900g) had a higher shear value than small females (1400-1500g).

Size

Cantrell (1974) reported that heavy fowl were generally more tender than light fowl. Simpson and Goodwin (1975) stated that larger birds are usually produced in the fall and winter, and that birds processed in the fall had lower shear values than birds processed in other seasons.

Ration

Marion (1967) stated that ration, as long as it is adequate for optimum growth, has no effect on tenderness.

Season

Hargus and Lee (1973) sampled birds processed in each month of the year and found that broilers processed in the summer showed the highest shear values. Their findings agreed with the work done by Simpson and Goodwin (1975).

Stress

Lee et al. (1976) stated that heat stress in the live birds has an adverse effect on tenderness, which might explain the toughness of the summer-processed birds. They also found that birds subjected to cold temperatures (4°C and -20°C) before slaughter were consistently, but not significantly, tougher than control birds held at 20°C.

Shirley (1985) has found that birds raised under continuous light suffer from a stressed condition (light-stress) brought about by the constant exposure to light. These birds exhibit morphological changes in almost every body system due to being subjected to this constant stressor. Work is currently underway to determine what effect this light-stress has on the tenderness of the birds.

Simpson and Goodwin (1975) found that birds processed at four different processing plants had significantly different shear values.

This discussion illustrates the variability that is found in poultry research. One study will find that a certain factor does not have an effect on tenderness, and the next study will find that it does. Perhaps this ambiguity is inherent in the species itself. Mellor et al. (1958) stated, "Great variations in tenderness exist among carcasses of animals of the same age and reared under the same conditions." Paul (1959) compared the tenderness of chickens hatched from eggs laid by the same hen with different hens in the flock, and found that the use of half-siblings did not decrease the bird-to-bird variation. deFremery and Streeter (1969) stated the tenderness variation between birds is much higher than between paired muscles

in the same bird. Stadelman (1967) reported that even with the best available controls shear values have varied by 50 percent. It is evident from these findings that there is a large variation in the chicken population, and that this variation will likely have an effect on most experiments conducted on this species.

2. EFFECTS OF FACTORS RELATED TO RIGOR, GLYCOLYSIS, pH, AND AGING ON CHICKEN TENDERNESS

Rigor

Rigor mortis--literally "stiffness of death"--is a physical event that all animals exhibit at some point after death and is characterized by the loss of extensibility of the muscle fibers (Forrest et al., 1975). The rigor process has a large influence on meat tenderness and is so interconnected with glycolysis and post-mortem pH that a discussion of rigor necessitates a discussion of all three. Many processes that a bird undergoes immediately before slaughter and almost every process that occurs afterward have some effect on rigor. Shrimpton (1960) stated that none of the factors known to be associated with the onset of rigor can be expected to have any substantial effect on the tenderness of the meat from young chickens. The discussion that follows indicates that his observation is far from correct.

Post-mortem glycolysis, ATP breakdown and reduction in pH are three events that are associated with a normal rigor process. Oxygen transport to the muscle tissue stops after bleeding. When this occurs,

respiration in the muscle can continue only anaerobically. Thus post-mortem glycolysis is responsible for depleting the energy reserves (glycogen) in the body. Since no oxygen is available lactic acid is the end product of post-mortem glycolysis, and as the glycogen stores are depleted, lactic acid accumulates in the muscle tissue and pH drops (Bate-Smith, 1948). Muscle is still a "living" tissue at this point, and the anaerobic reactions that occur in the live animal are still occurring in the carcass; these include muscle contraction and relaxation and the breakdown of ATP (Forrest et al., 1975). ATP is being produced via glycolysis, but when glycolysis stops due to depletion of glycogen, ATP production stops, and ATP is irreversibly broken down by muscle contraction (Bate-Smith, 1948). When the ATP concentration decreases to a certain level, permanent crossbridges are formed between actin and myosin which lock the muscle in contraction, and rigor develops (Forrest et al., 1975).

It has been reported that the onset of rigor occurs when ATP levels decrease to one-half to one-third of the initial concentration (Bate-Smith, 1948; deFremery and Pool, 1960; Khan, 1975). Using this assumption, deFremery and Pool (1960) stated that the time to onset of rigor in chicken muscle is 2 to 4.5 hours post-mortem. Khan (1975) determined that rigor began to develop 5 to 6 hours post-mortem in untreated birds. Other researchers have stated that chicken muscle goes into rigor in as little as 30 (Kijowski et al., 1982) or 40 minutes (Shrimpton, 1960). Dawson et al. (1958) stated that rigor may occur between 1 and 2 hours after slaughter, but that with some

birds rigor occurs in a very short time, while in others it takes considerably longer. This large variation in the literature for the time of rigor onset may be related to a difference in the initial post-mortem glycogen levels of muscle (Mellor et al., 1958 and Grey et al., 1974), since the more glycogen present in the muscle at death the longer the time for depletion, therefore, the slower the onset of rigor.

Glycolysis and pH

Mellor et al. (1958) postulated, "The glycogen level of the tissues at the time of death may be one of the basic factors influencing tenderness." They found that birds with a high glycogen content at death (3500 g/g Pectoralis major) had significantly lower shear values (4.12 kg) than birds with a low initial glycogen content (643 g/g Pectoralis major and 5.62 kg). Grey et al. (1974) killed chickens with an overdose of anaesthetic and reported that, even in the resting muscle with no death struggle, there was a large variation in glycogen content (42 to 62 μmol/g muscle), but they did not conduct shear tests to determine if this caused a difference in tenderness. The findings of Khan and Nakamura (1970) supported this theory. They found that accelerated glycolysis immediately before slaughter, which would lower the initial glycogen content, caused increased accumulation of lactic acid in the muscle tissue at the time of slaughter and gave less tender meat. Accelerated glycolysis followed by resting before slaughter, which allows time for the lactic acid to be transported

from the muscle to the liver, increased the ultimate pH of the meat and increased tenderness. They concluded that minimizing pre-slaughter glycolysis in well-fed and well-rested birds would increase tenderness. The tenderizing effect of depleting glycogen with resting before slaughter has been reported by other researchers (deFremery, 1966 and Khan, 1975), who administered epinephrine 12 or more hours before slaughter to deplete the glycogen stores in the muscle tissue.

Struggling of the birds before slaughter might cause a decrease in tenderness, because this would deplete glycogen reserves. Dodge and Stadelman (1960), using birds fed tyzine, a tranquilizer, at a rate of 4 grams per ton of feed, found that as struggling before slaughter increased, the tenderness of the birds decreased. However, as struggling during slaughter increased, tenderness also increased. The more struggling observed during slaughter, the more tender the meat after 2 hours of aging. They reported that struggling had no effect on birds fed a control diet (no tranquilizer).

Klose et al. (1972) reported that laboratory birds that had been electrically stunned were somewhat more tender than birds allowed to struggle. Lee et al. (1979) found that although the shear values of electrically stunned birds were higher than those of no-stun birds upon leaving the chiller, after aging for 2 hours at 2°C the stunned birds had significantly lower shear values than the no-stun birds and there was less variability in the stunned birds as indicated by a lower standard error of the mean.

Scalding

The effects of scalding temperature and scalding time on tenderness have been widely studied. deFremery (1966) stated that increasing the severity of scalding by either raising the scalding temperature or increasing the scalding time will increase the toughness of the meat. He found that increasing the severity of scalding hastened the onset of rigor. These findings support the earlier work done by Pool et al. (1959) and deFremery and Pool (1959). Pool et al. (1959) found that increasing the scalding temperature and/or time caused an increase in shear values that was very evident at 2 to 3 hours and persisted to the 24-hour aged groups. Wise and Stadelman (1959) studied the effects of scalding at 130, 140, or 150°F for 20, 40, or 80 seconds on the tenderness of the breast muscle at depths of 2, 4, and 6 mm. They found that as scald temperature or scald time increased, the shear value of each layer of the breast increased. The shear value decreased as the distance from the exterior surface of the breast increased in all treatments. They concluded that the toughening effect of a high temperature-long time scald is related to the depth to which the scald heat penetrates the tissue.

Picking

Picking is another processing step that can influence tenderness. Pool et al. (1959) found that machine-picked birds were very significantly tougher than hand-picked birds and that increasing the duration or severity of the picking made the toughening worse.

Klose et al. (1972) reported similar findings. deFremery and Pool (1959, 1960) and deFremery (1966) reported similar findings and found that mechanical stimulation (machine-picking) hastened the onset of rigor. Sayre (1970) experimented with chicken muscle that had been beaten in a mechanical picker and concluded that beating accelerated the onset of rigor, but he found no ultimate (after 24 hours aging) differences in the tenderness of the meat as a result of the beating.

Cutting Effects

Pool et al. (1959) stated that there appeared to be a small toughening effect produced by cutting up the carcass before chilling. deFremery and Pool (1960) found that pre-rigor excision of the Pectoralis major (P. major) muscle followed by aging for 24 hours increased the shear value from 5.8 to 12.6 pounds. Klose et al. (1971) found that 10-week-old birds cut at the joints at 20, 60 and 120 minutes post-mortem had significantly higher shear values for the breast than birds cut after 22 hours of aging. They found no difference in the shear values of the thighs. In 8-week-old birds with the wings removed at 20 minutes post-mortem, those birds in which the wing was removed with a distal humerus cut were significantly more tender than those which had the wing removed at the joint. The birds with distal cuts at 20 minutes also had lower shear values than birds with wings removed at the joint after 24 hours, although the difference was not significant. They reported that breaking the ribs and flattening the breast increased toughness, too, even though it was not cut. Webb

and Brunson (1972) reported similar results experimenting with distal and joint cuts. They stated that the severity of the effect of hot-cutting on tenderness depends on the size of the cuts and the number of muscle fibers that are cut. Other researchers (Klose et al., 1972; Treat and Goodwin, 1973; Cantrell et al., 1974; Grey et al., 1974; Lyon et al., 1985) reported similar findings with respect to hot-cutting on tenderness.

Lee et al. (1976) found that excised muscle with a low ultimate pH is tough. They stated that a low pH at death, indicating fast glycolysis immediately before death, would produce more tender meat. They concluded that for excised muscle a low initial glycogen level, low initial pH, and high ultimate pH are desirable for best tenderness.

The authors cited above (Pool et al., 1959; deFremery and Pool, 1960; Klose et al., 1971; Webb and Brunson, 1972; Klose et al., 1972; Treat and Goodwin, 1973; Cantrell et al., 1974; Grey et al., 1974; Lee et al., 1976; Lyon et al., 1985) have stated that muscle excised pre-rigor is tough, but they do not give a reason. Cutting muscle frees it from the attachments which hold it together (tendons) and to the bone (ligaments). When these attachments are severed, the muscle becomes an individual entity with no restrictions on its contractile ability. Muscle that is thus cut undergoes more severe contraction (Forrest et al., 1975), and when rigor occurs the muscle is locked in a "super-contracted" state. This super-contraction is aided by holding the muscle at temperatures above 15 to 18°C (heat-shortening) or below 0°C (cold-shortening) (deFremery and Pool, 1960;

Smith et al., 1969; Khan, 1971; Forrest et al., 1975; Lee and Rickansrud, 1978; Heath, 1979). Cold-shortening can also be induced by chilling the carcass too rapidly (Forrest et al., 1975). This may be an explanation for the findings of Wyche et al. (1972) that the shear values of breasts with the skin removed were higher than those of breasts with the skin intact since the skin serves as an insulator to prevent the body heat from dissipating too quickly.

Peterson and Lilyblade (1979) studied the prevention of toughening. They killed 8-week-old birds, excised the P. major immediately, and treated it with sodium carbonate buffer. These muscles maintained a high pH (>6.5) for the duration of aging and were through the onset and resolution of rigor, with tenderization, by 24 hours post-mortem. They concluded that shortening (toughening) of excised muscle can be retarded by limiting the pH drop.

Freezing Effects

Thaw rigor is a phenomenon closely related to cold shortening and occurs when pre-rigor muscle is frozen and then thawed (Forrest et al., 1975). Freezing renders the enzyme systems and the transport systems inactive, so that, chemically, frozen muscle is relatively inert. Koonz et al. (1954) observed that freezing muscle during the early post-mortem period altered the tenderness pattern and "fixed" the tenderness of the muscle by apparently arresting the chemical actions promoting tenderness. When this muscle is thawed, however, rigor proceeds almost immediately (deFremery, 1966) and the muscle

may shorten by up to 80 percent from its original length (Forrest et al., 1975). It is thought that this severe shortening occurs as a result of concentrating the salts in the muscle as it freezes (Bendall, 1973). As the muscle thaws this concentration of salts, especially calcium salts, causes very rapid and sustained muscle contraction, resulting in severe shortening that is only partially relieved by resolution and aging. deFremery (1966) found that shear values in muscle that had undergone thaw rigor were twice as high (16 lbs) as those for muscle that was frozen after aging (8 lbs). deFremery and Pool (1960) and Hale and Stadelman (1973) reported similar findings in their studies.

Chilling Effects

Chilling is another stage in processing where tenderness may be adversely affected. If the meat is chilled too quickly, it cold-shortens; if it is not chilled quickly enough, it may heat-shorten and there may be microbial problems. Chilling is usually a two-stage operation in modern plants with the pre-chill water temperature at 50 to 65°F (10 to 18°C) and the final chiller at 32 to 34°F (0 to 1°C). The birds generally stay in each chiller for 20 to 30 minutes and exit the final chiller at a body temperature of 36 to 40°F (2 to 4°C) (Brant et al., 1982). Cold air was once a common method of chilling (dry-chilling). Dodge and Stadelman (1967) found that water-chilled poultry was significantly more tender than air-chilled poultry. Cantrell and Hale (1974) reported that the topmost layer of breast

muscle had a higher shear value when dry-chilled, which could be due to dehydration and/or cold-shortening of the muscle. Klose et al. (1960) found that using tap water, ice slush or combinations of the two, either with or without agitation, had no effect on tenderness during a 20-minute chilling period. Khan (1971) studied the effects of temperature during post-mortem glycolysis on tenderness and determined that lowering the temperature of the meat to 15°C before the pH had dropped to 6.3 minimized the loss of tenderness. This would have to be accomplished by the chilling operation since the birds pass into rigor at a pH of about 6.2 (Grey et al., 1974; Khan, 1975) and this pH is attained within an hour or so after slaughter (deFremery and Pool, 1960; Grey et al., 1974) if not sooner (Khan and Nakamura, 1970; Khan, 1971).

By the time the birds exit the chiller they have probably been in the plant from 75 to 100 minutes, depending on the chilling time. Some of the birds will be in rigor by this time (Grey et al., 1974; Kijowski et al., 1982), while others will not (Dawson et al., 1958; deFremery and Pool, 1960; deFremery, 1966; Khan, 1975).

deFremery and Pool (1959, 1960) and deFremery (1966) conducted studies on the effects of the above-mentioned processing steps as well as exhaustive electrical stimulation (ES) and electron irradiation on the onset of rigor and tenderness. They concluded that anything that accelerates the onset of rigor, the rate of post-mortem glycolysis, the breakdown of ATP, and the drop in pH will also increase muscle toughness. deFremery (1966) found that in birds with glycogen depleted

long before slaughter (18 hours) post-mortem glycolysis was virtually eliminated and these birds were more tender at 1, 2 and 3 hours post-mortem than control birds were after aging 24 hours. He concluded that the toughening due to rapid onset of rigor was caused by rapid post-mortem glycolysis and not to rapid ATP depletion. Khan (1975) reported similar findings. He found that fast onset of rigor and isometric tension decreased tenderness, except when the pH was high. He stated that muscle with a high pH value 1 hour post-mortem and a low ultimate pH, which indicates very little ante-mortem glycolysis and slow post-mortem glycolysis, would be tender; muscle having a low pH 1 hour post-mortem and a low ultimate pH, which indicates rapid glycolysis just before and after death, would be tough; and muscle with a high pH 1 hour post-mortem and a high ultimate pH, which indicates glycogen depletion long before slaughter, would be tender. Sayre (1970), however, stated that treatments that delayed the onset of rigor--both ante-mortem injection of sodium pentobarbitol and electrical stunning--delayed the onset of maximum toughness and subsequently delayed tenderization. He stated that the end result (tenderness) was the same as for normal birds.

Aging Effects

Aging of muscle after chilling allows time for the resolution of rigor during which the muscle again becomes pliable and tenderness increases. Koonz et al. (1954) reported that muscles were less tender during the early post-mortem period and assumed that this was associated

with rigor. They found that muscles became tender and presumably rigor was resolved within 24 hours. Pool et al. (1959) observed that most of the possible change in tenderness, as measured by decreasing shear value, took place in 4 hours, with little or no change after 12 hours. deFremery and Streeter (1969) reported that tenderization in chicken breast muscle follows a rapid rise to a maximum shear value at 3 to 4 hours, a rapid decrease to a low shear value at about 9 hours, with very little change thereafter, and no change beyond 24 hours. Nakamura (1972) reported that tensile strength of muscle fibers increased during the first 4 to 6 hours post-mortem and decreased thereafter. Muscles showing the highest tensile strength at 6 hours were the toughest at that time. He reported that toughness abated but that differences still existed at 24 hours. The findings of maximum tenderness in the breast by 12 hours with no change after 24 hours were substantiated by van den Berg (1964) and deFremery (1966). Pool et al. (1959) performed cooking studies starting immediately after slaughter and continuing for 3-1/2 hours and concluded that there is no evidence of a lesser degree of toughness preceeding maximum toughness. Unless the meat was cooked very rapidly, however, heat-shortening would have masked any differences that existed. May et al. (1962) even found that tenderness started to increase almost immediately after slaughter.

Dodge and Stadelman (1960) found that aging for 5 hours produced significantly lower shear values than aging for 2 hours. Dawson et al. (1958) found a direct relationship between the holding

time prior to freezing and the tenderness of muscle and concluded chicken should be aged at least 3 to 6 hours before freezing. Lyon et al. (1985) observed that deboning at 6 hours or later seemed to be the best for maximum tenderness. Smith et al. (1969) held birds for 4 hours at 16°C and then held them at 0°C for 20 hours and concluded that cold-shortening was prevented by holding the muscle at the higher temperature until rigor was completed.

It has even been postulated that aging may reverse the effects of cold shortening (Hale and Stadelman, 1973). May et al. (1962) reported no significant difference in aging at 19°C or 0°C, although 0°C had a definite trend to give a more tender product. deFremery and Pool (1960) reported that freezing and thawing muscle after aging has negligible effect, and Khan (1971) stated that holding muscle at a high temperature after completion of rigor had no deleterious effect on tenderness.

The mechanism whereby tenderness is re-established in muscle by the resolution of rigor and post-rigor aging has not been elucidated (deFremery and Pool, 1960; Sayre, 1970). deFremery and Pool (1960) reported that resolution of rigor does not involve changes in the elastic properties of the muscle. They found that the loss of extensibility that occurred during rigor was not reversed during resolution. Bandack-Yuri and Rose (1961) reported that at least two, and probably three, proteolytic enzymes are present in chicken breast muscle even though all are present in small amounts or are weakly proteolytic. They found that the release of amino acids or low

molecular weight polypeptides does not occur during tenderization of chicken and concluded that proteolytic activity is not predominantly responsible for the increase in tenderness of breast muscle during aging. deFremery and Streeter (1969) tested for a decrease in the level of alkali-insoluble connective tissues (stromal proteins--collagen and elastin) during post-mortem aging. Their results were negative and they concluded that the development of tenderness should be attributed to some other fraction of the muscle tissue.

Chajuns and Spencer (1962) conducted an experiment using an oxidizing agent, potassium iodate, and a reducing agent, sodium sulfite, to age excised muscle. They found when the muscles were excised pre-rigor that aging in potassium iodate made them much tougher while aging in sodium hydrosulfite gave the same shear results as aging in water. When the muscles were excised 2 hours post-mortem (post-rigor) the sodium sulfite greatly increased the tenderness over aging in water. They concluded that the reduction of disulfide bonds may play a role in the tenderization of muscle during aging.

3. COMPARISON OF TENDERNESS IN BREAST AND THIGH MUSCLE

In view of the fact that consumer complaints of toughness seem to be associated with the breast and not the thigh, a brief review of the tenderness differences between these two parts as reported in the literature is included.

Goodwin et al. (1969) reported that thigh muscle was much more tender (shear value 6 to 7 kg/g) than breast muscle (shear value 9 to 11 kg/g). Cunningham and Lee (1975) froze birds and cooked them either from the frozen state or after thawing and found that, in both cases, dark meat (thigh) had a significantly lower shear value and received higher sensory ratings for juiciness and tenderness than light meat (breast).

Although shear values for breast muscle often may be higher than for leg muscle, the opposite is suggested by the aging pattern of the two types of muscles (Marion, 1967). Hanson (1942), van den Berg et al. (1964), and deFremery and Streeter (1969) stated that thigh muscle tenderizes more slowly than breast muscle. van den Berg et al. (1964) found that tenderness of breast muscle increased rapidly in the first 24 hours post-mortem, but changed little between 2 and 7 days of storage. They found that leg muscle reacted very similarly to breast muscle for 24 hours, but then underwent a second phase of tenderization at 4 to 8 days. Organoleptic testing indicated extensive tenderization during this period accompanied by a small, but significant, decrease in shear values. Shear testing measures the toughness of the muscle fibers while organoleptic testing also takes into account the strength of the connections between fibers. They concluded that the second phase of tenderizing in leg muscle was due to weakening of transverse connections between fibers. deFremery and Streeter (1969) reported maximum shear resistance for breast muscle at 3 hours post-mortem followed by a rapid decrease

to low resistance at 9 hours with very little change thereafter and no change after 24 hours. Maximum shear resistance for thigh muscle seemed to be attained at 3 hours with a rapid decrease to 24 hours, and a slower but continuous decrease up to 8 days. They also analyzed changes in connective tissue and found no decrease in alkali-insoluble connective tissue during post-mortem aging.

There are varying reports on the effect of sex on the tenderness of the parts (Goodwin et al., 1969; Simpson and Goodwin, 1975). Simpson and Goodwin (1975) found that both thighs and breasts from birds processed in the fall and winter were more tender than those from birds processed in the spring and summer.

Hot-cutting seems to have an adverse effect on the thigh as well as the breast (Klose et al., 1971; Klose et al., 1972). Klose et al. (1971) found that thighs were more tender when cut at 5 days than at 20 minutes post-mortem. They found that cutting breast muscle before 2 hours post-mortem resulted in higher shear values. Comparisons between breast and thigh could not be made in this study due to the different sample sizes that were sheared. The same researchers (Klose et al., 1972) later found that aging for 6 hours resulted in better sensory scores for tenderness than cutting 25 minutes after evisceration. Scores for breast samples were less desirable than scores for thigh samples in all cases.

Dawson et al. (1958) found that thighs received higher ratings for tenderness than breasts when frozen at 40 minutes and 3 hours post-mortem. They reported no difference in tenderness ratings when frozen at 6 and 24 hours.

4. EFFECT OF ELECTRICAL STIMULATION ON MUSCLE AND MEAT

The idea of using electricity to alter the normal post-mortem changes in meat is not a new idea. Benjamin Franklin, in 1749, determined that electrical shocking of turkeys enhanced tenderness (Lopez and Herbert, 1975). Harsham and Deatherage (1951) patented a process for using electrical stimulation (ES) to improve the tenderness of meat 34 years ago. These findings were neglected by meat scientists and the meat industry until the 1970's.

Many research projects have been conducted in the past 10 years to study the effects of ES on the ultimate quality and palatability characteristics of meat from different species of meat animals. Since the current project concentrates on the effects of ES on tenderness in chickens, this review will concentrate on the reported effects of ES on tenderness with brief discussions of its effects on other properties of meat.

Beef

Much of the work done with ES in beef has been aimed at accelerating the rigor process before the carcass temperature drops appreciably in order to prevent cold-shortening, thereby "increasing" the tenderness of the meat.

Calkins et al. (1983) stated that ES sides have a faster metabolic rate than non-stimulated sides. Will et al. (1979) found that ES caused a more rapid ATP depletion in semimembranosus (SM),

longissimus dorsi (LD), and supraspinatus (SS) muscles. The increase in rate of ATP depletion was quantified by Bendall et al. (1976). They stated that 50 percent of the ATP is gone when a pH of 6 is reached and that 95 percent is depleted when the ultimate pH of 5.6 to 5.7 is attained. The time required to reach these pH levels was 8.5 and 10.5 hours, respectively, in unstimulated carcasses, while ES carcasses reached these values in 1.0 and 1.5 to 2.0 hours, respectively.

ES seems to have a two-fold effect on the drop in pH. Davey et al. (1976) and George et al. (1980) found that there was a very pronounced drop in pH (about 0.5 units) during the time in which ES was applied and that there was an acceleration of the rate of pH fall after stimulation. Schroeder et al. (1982) reported that the pH dropped faster in ES sides than in unstimulated sides from the same animals.

Davey et al. (1976) reported that LD muscle, if stimulated for 1 minute or more, would have a pH below 6 at 5 hours post-mortem, while unstimulated LD would not reach this pH for at least 24 hours. Similar findings were reported by Gilbert and Davey (1976). George et al. (1980) stated that pH falls faster in the LD than in the semitendinosus (ST) in both ES and unstimulated carcasses.

Shaw and Walker (1977) and Taylor and Marshall (1980) found that ES at very low voltages--20 to 110 V and 32V, respectively--resulted in a significantly faster pH drop that was equivalent to that attained in other studies using much higher voltages.

Shaw and Walker (1977) stimulated sides for 1, 2, and 4 minutes using different voltages (110V maximum) and positioning of electrodes and concluded that the acceleration of pH decline was not greatly affected by any of these factors. Bendall et al. (1976) reported that ES at 100 volts did not increase the rate of pH fall in LD muscle, but did in others. There was no difference in the results of ES on dressed and undressed carcasses.

Many researchers have found that ES improves objective and/or subjective tenderness values in beef (Bouton et al., 1978; Calkins et al., 1983; Davey et al., 1976; George et al., 1980; Gilbert and Davey, 1976; Martin et al., 1983; McKeith et al., 1981; Savell et al., 1977; Savell et al., 1978a; Savell et al., 1978b; Savell et al., 1981; Schroeder et al., 1982; Smith et al., 1977; Taylor and Marshall, 1980; Will et al., 1979). ES has also been shown to decrease the variability in tenderness between animals (Davey et al., 1976; George et al., 1980; Savell et al., 1977; Smith et al., 1977). Davey et al. (1976) reported that ES increased the number of muscles that were rated as tender (tenderometer reading less than 40) in unaged sides and found there was a 63 percent increase in the number of LD's alone. They also found that ES increased the number of muscles that fell into the tender group with aging.

Smith et al. (1977) and Schroeder et al. (1982) experimented with ES in both forage and grain-fed cattle. ES improved tenderness in both groups, but the improvement in forage-fed cattle was much greater than in grain-fed cattle. They concluded that ES is of greater

benefit when used on carcasses that would produce less tender meat if untreated. Tenderness scores in ES forage-fed carcasses were not as high as in grain-fed unstimulated carcasses. Calkins et al. (1983) reported that the increased metabolic rate in ES beef appears to overcome the detrimental effects of little finish, light weight, and/or rapid chilling (reaching a relatively cool muscle temperature at 2 hours post-mortem).

Davey et al. (1976) concluded that ES speeds glycolysis throughout the carcass and rigor is reached before the temperature falls to levels inducing cold shortening. Using much lower voltages (110V as opposed to 3600V), Bouton et al. (1978) reached basically the same conclusion. Gilbert and Davey (1976) found that ES reduced the need for conventional chilling to achieve rigor from 25 to 5 hours, overcame cold and thaw shortening, and still permitted tenderization during aging. ES appears to be a less costly and a more acceptable solution to preventing cold shortening in beef than the other alternatives of delay chilling, high-temperature conditioning, and hanging by the obturator foramen (Smith et al., 1977).

George et al. (1980) concluded that ES accelerates the "conditioning process" in beef mucles, but that ES, per se, does not accelerate the aging of meat. Meat chilled rapidly or deboned after ES had no resultant increase in tenderness over control muscles. Martin et al. (1983) also found that faster cooling rates had detrimental effects on tenderness in ES carcasses.

George et al. (1980) reported that ES muscles had significantly greater sarcomere lengths than unstimulated controls; however, other researchers (Smith et al., 1977; Savell et al., 1978a; Will et al., 1979; Schroeder et al., 1982) have reported that there is no difference in sarcomere lengths between ES samples and controls. This suggests that the tenderness improvement associated with ES can be achieved by means other than the prevention of cold shortening (Savell et al., 1978a).

Two other mechanisms have been proposed for the tenderizing effect of ES on meat, including beef and other species as well. These are: (1) increased activity of acid proteases; and (2) the physical disruption of myofibrils (Cross, 1979).

Will et al. (1980) stated that ES, through accelerating pH decline, appeared to increase the free activity of the lysosomal enzymes. Kang et al. (1983), working with rabbit muscle, found evidence to support this theory. Low pH and high temperature in muscle in the early post-mortem period disrupts lysosomal membranes freeing lysosomal enzymes into the cytoplasm (Moeller et al., 1976, 1977). This is precisely what happens in ES muscle. Dutson et al. (1980) found that ES muscle from sheep had a significantly higher percentage free activity for both cathepsin C and β-glucuronidase at 1 hour post-mortem than unstimulated muscle, indicating that more of these enzymes had been released from the lysosomes in the ES samples. The ES sides had lower activity in the sedimentable fraction, which contained the lysosomal membranes, suggesting that more of the enzymes

were still membrane-bound in the control than in the ES samples. The specific activity was not different for ES and control samples in the supernatant. This showed that although the ES muscle had more enzymes released, these enzymes also degraded faster due to the higher temperature of the system at a given pH (these autolytic proteases are also subject to autolysis).

Savell et al. (1978a) found contracture bands and stretched sarcomeres in ES beef muscle. They reported that ES samples had less-well-defined I-bands and Z-lines through the contracture bands with stretched or broken sarcomeres on either side of these bands. Will et al. (1980) stated that in beef ES 30 minutes after slaughter the contraction bands appeared 1 hour post-mortem and cellular swelling was detected 6 hours post-mortem. Areas of disruption of the sarcomere integrity apparently due to Z-line disintegration were also detected at 1 hour post-mortem. The control samples showed cellular swelling and swollen and ruptured mitochondria at 24 hours post-mortem, but there was excessive tissue damage in the ES muscle that was not found in the control muscle at that time. George et al. (1980) reported that ES resulted in extensive denaturation of sarcoplasmic proteins. They stated that degradation of troponin-T, which has been shown to decay during conditioning of meat, was not responsible for increasing tenderness, because ES muscles were more tender than control muscles with the same troponin-T content. Marsh et al. (1980) stated that ES produces its tenderizing effect primarily, and maybe solely, by tissue disruption. They stimulated beef sides using a

frequency of 2 Hertz (Hz) to accelerate pH decline without causing tissue disruption. ES and unstimulated sides were chilled so that the carcass temperatures between the two groups were constant, and the researchers found that control sides with a pH greater than 6.1 were more tender than ES sides with a pH of less than 5.7 at 3 hours post-mortem. There was no difference in tenderness between ES sides and rapidly glycolysing control sides (pH less than 6.1).

Other researchers have explored different reasons for the beneficial effects of ES on meat tenderness. Forrest and Briskey (1967), working with pork, found that the initial lactate level in the muscle was not important in determining the response to ES, as had been previously believed. They also found no difference in the response of red and white fibers to ES on the time course of rigor. Kang et al. (1983) reported that ES inhibits the increase in actin-myosin interaction during post-mortem storage of rabbit muscle.

Aging of meat in conjunction with ES results in additional tenderization (Bouton et al., 1978; Martin et al., 1983). Savell et al. (1978b) stated that ES and 7 days cooler aging may be sufficient to increase the tenderness of beef loins without storing for 10 to 21 days. Savell et al. (1981) later stated that ES will accelerate the aging time of beef, but that the actual aging time reduction and extent of ultimate tenderness appears to be affected by the inherent tenderness of the beef.

ES affects many characteristics of beef other than tenderness. One of the other beneficial aspects is the effect of ES on color.

Smith et al. (1977) stated that ES beef may exhibit a brighter red color at 24 hours, but that there was no difference at 72 hours. Savell et al. (1978b) found that ES improved lean color and reduced the appearance and severity of "heat-ring" in the loin. These findings were also reported by Calkins et al. (1982) and Martin et al. (1983). Savell et al. (1978b), McKeith et al. (1981), and Martin et al. (1983) reported that ES significantly increased marbling scores. Smith et al. (1977), Savell et al. (1978b), and McKeith et al. (1981) found that ES improves the texture and/or firmness of lean.

Savell et al. (1977), Savell et al. (1978a), and Savell et al. (1981) found that ES muscles had significantly higher flavor ratings. Gilbert and Davey (1976) reported no difference in general acceptability of ES and control samples, while Savell et al. (1981) found ES samples had higher overall palatability ratings. Savell et al. (1978a) and Savell et al. (1981) reported lower juiciness ratings with ES, but other researchers (Davey et al., 1976; Gilbert and Davey, 1976; Savell et al., 1977; Schroeder et al., 1982) reported no difference in juiciness between ES and control samples. George et al. (1980) and Schroeder et al. (1982) found that there was no increase in drip loss of ES muscles, but Martin et al. (1983) stated that ES sides had a lower water holding capacity. Schroeder et al. (1982) reported no difference in cooking traits due to ES, while Savell et al. (1978a) and Savell et al. (1978b) found greater cooking losses in ES meat.

Gilbert and Davey (1976) found that ES did not contribute to bacterial growth. Schroeder et al. (1982) reported that ES had no

effect on the shelf life of beef. Ockerman and Szczawinski (1983) stated that ES lowers aerobic plate counts for at least 7 days. From their results they concluded that bacterial cells are damaged directly during the process of ES.

Lamb

Carse (1973) found that ES reduced the time needed for lamb carcasses to reach a pH of 6 from 15.4 hours to 3 hours. Muscles excised from both groups at 5 hours and tested on a tenderometer had ratings of 36 and 65 for the ES and control groups, respectively. He found no difference in the tenderness of muscles held 20 hours before freezing. There was no visual evidence of a pale, soft, and exudative (PSE) condition as a result of ES.

Crystall and Hagyard (1976) studied ES in lambs using 3600V of electricity. They found that ES caused a marked acceleration in glycolysis. If ES was delayed beyond 5 minutes, though, the effect of hastening conditioning was diminished. The ES lamb in their studies did not suffer from cold or thaw shortening when frozen 60 minutes post-mortem. Tenderometer readings were similar to those obtained by Carse (1973), with a 77 for controls and a 37 for ES lambs. All of the major muscles in the loin and leg had improved tenderness when ES was used. No quality defects were found that could be attributed to ES. They concluded, as did Carse (1973), that there was no evidence that rapid post-mortem glycolysis and rigor at high temperature causes toughness in meat.

Bendall (1976) found that ES with a 250V alternating current source was more effective in speeding pH decline than ES with a 1200V direct current source. This demonstrated that large voltages (>1000V) are not necessary. He also found that ES had a two-fold effect on pH decline.

Savell et al. (1977) found that ES lambs had higher overall tenderness ratings, higher overall palatability ratings and lower shear force values than unstimulated controls. No differences in flavor, juiciness or sarcomere length between control and ES lambs was observed.

Rashid et al. (1983) studied the qualitative effects of the electricity itself on lambs. There seemed to be a positive relationship between the output energy/pulse and the extent of post-mortem glycolysis. The highest energy output/pulse was obtained at 350V with a frequency of 10Hz and caused a pH drop to 6.0 in the least amount of time. They reported that a low voltage with a higher frequency seemed to be less effective and less consistent in influencing post-mortem glycolysis than a high voltage with a lower frequency. High voltage and low frequency had the greatest effect in reducing calcium-induced shortening in muscle excised immediately after evisceration. There seemed to be a linear increase in the rate of glycolysis with a decrease in frequency from 250 to 10Hz.

Pork

Johnson et al. (1982) studied the effects of ES on stress-susceptible and non-susceptible pigs, and found that ES did not

affect the 24 hour pH of any of the animals. ES had a variable effect on lean color and firmness scores. There was no difference in the weight loss of lean cuts held under refrigerated conditions or in thawing or cooking losses associated with ES. They reported no difference in Warner-Bratzler shear values between ES and unstimulated carcasses, but the carcasses were aged for 5 days before freezing and thawing. Palatability attributes were influenced very little, if at all, after aging 5 days. They concluded that ES has a minimal--or no--effect on carcass quality characteristics, weight loss and cooking characteristics of pork.

Swasdee et al. (1983) reported that ES caused a lower pH in pork carcasses and seemed to cause softer muscles with more separation in the shoulder. ES lowered the level of salt-soluble proteins (SSP). They stated that ES does not appear to enhance the visual properties of pork muscles as it does for beef and may decrease the percentage of SSP; therefore, there is no apparent advantage of using ES with pork.

Crenwelge et al. (1984) found that ES of pork carcasses, especially early post-mortem, detrimentally affected quality by producing lean muscle with lighter color, reduced firmness and more extensive muscle separation. This could be lessened somewhat either by rapid chilling or by ES after 30 minutes instead of after 5 to 15 minutes. They reported that cooking loss, shear force and palatability traits were not affected.

Wiley et al. (1983) found that subjective and objective tenderness measurements of loin chops from ES carcasses were significantly less desirable than those of chops from non-stimulated carcasses and that the sensory traits of chops from ES carcasses were only marginally acceptable.

Goats

Savell et al. (1977) found that the loins from ES goats had higher overall tenderness and overall palatability ratings, longer sarcomere lengths and lower shear values than loins from unstimulated goats. ES had only a small effect on the leg.

McKeith et al. (1979) reported that ES goats had significantly lower shear values for LD, SM, and BF muscles at 1 and 7 days post-mortem than control goats. The ES goats also had significantly higher sensory tenderness ratings and higher overall palatability ratings for loin chops. They stated that the tenderness advantage observed for ES meat on the first day post-mortem did not diminish with additional aging. No difference in sarcomere lengths between ES and unstimulated goats was observed in this study. There were no advantages in ES from one site to another in the slaughter line (post-sticking, post-pelt removal, post-evisceration, or after splitting).

CHAPTER III

MATERIALS AND METHODS

This experiment involved a total of 279 6- to 8-week-old broilers of a commercial hybrid strain. Ninety of the broilers were raised for the experimenter at the University of Tennessee poultry farm in Knoxville. One hundred eighty-nine of the broilers were donated by the Tyson Foods Corporation.

All of the birds were killed at the Tyson Foods poultry processing plant in Shelbyville, TN in order to have the birds killed under modern in-plant conditions. The 90 birds raised at the UT poultry farm were killed in March, 1984, with 91 of the Tyson's birds being slaughtered in July, 1984, and the other 98 in September, 1984.

1. SLAUGHTER AND CHILLING PROCEDURE

The birds were slaughtered utilizing the standard procedure of stunning, sticking, exsanguination, scalding, picking, evisceration and chilling. The birds were then processed in what is commonly called the chill-pack method and samples were collected for testing. After leaving the chiller, carcasses were cut by removing the wings at the attachment to the breast, removing the legs, separating the breast from the back leaving the ribs with the breast, and splitting the breast by splitting the keel bone. The paired breasts from each bird were packaged and labeled for identification. The packages were then placed in a blast freezer at -14 to -30°F for 1 hour or until

the meat had developed a firm, frozen crust on the surface. When all of the samples were satisfactorily chilled the packages were boxed in waxed cardboard boxes and transported to the University of Tennessee Food Technology Department where they were stored in a meat cooler at 36°F for 2 days before testing.

The live birds were divided into groups of 10 and subjected to electrical stimulation (ES) of either 50 (50V) or 100 volts (100V) which was applied either immediately before sticking (PS) or immediately after evisceration and before chilling (PC). ES was applied in pulses of 1 second on, 1 second off with each bird in a given group receiving either 25 pulses (25p) or being stimulated to no response (NR). This design gave 8 stimulation treatments with the ninth group serving as a non-stimulated control. This experiment was conducted 2 times. In a third replication a second control group was added. This group of birds was conventionally slaughtered, but after chilling they were packed whole in ice and stored in a 28°F cooler until transported back to UT. This group sreved as an ice-pack control to compare directly with the chill-pack control to determine if there was any inherent difference in the two post-chilling handling methods.

The low voltages were used for two reasons:

1. Because it was believed that over 100 volts would cause hemorrhaging in the PS treatments and extensive bone breaking, as well as possibly rupturing the intestinal tract due to excessive muscle contraction during stimulation, resulting in a greater condemnation rate during inspection, and

2. Because lower voltages are less of a safety hazard in the processing plant.

Duration of stimulation was set at 25p and NR in order to either partially or totally deplete the energy reserves of the birds, thereby allowing a determination to be made as to which should give the more beneficial effects on tenderness.

The points at which stimulation was applied, PS and PC, have been used in research on other species and would be the two most likely places for the incorporation on an ES system into the high-speed processing lines of modern poultry plants.

Each experimental bird was tagged with a numbered plastic tag attached to the thigh with a rubber band before being placed in the chiller in order to maintain identification.

2. MEASUREMENTS

Warner-Bratzler Shear Test

The left half of each breast was cooked on a broiler pan in a rotary oven at 425°F for 1 hour. The meat was then cooled to room temperature and 3 strips measuring 1.3 cm wide by 0.6 cm thick and running the length of the muscle fibers were cut from the Pectoralis major (P. major) muscle in a direction parallel to the muscle fibers. These strips were objectively evaluated for tenderness with the Warner-Bratzler shear attachment on the Instron Universal Testing Machine (Model 1132) using a 50 kg load cell. Each strip of P. major was sheared twice for a total of 6 shear values per bird. The values are reported as average shear values in kilograms (kg).

Sarcomere Length

A sample of raw muscle was removed from the P. major in the right half of the breast and fixed in 4.0 percent neutral formalin. After the muscle had hardened the fixed sample was blended for 2 minutes with 0.02M potassium chloride. A slide was prepared from the myofibrillar suspension and examined using a Wild M20 phase contrast microscope. Sarcomere lengths were measured using a Wild 15x compensating filar micrometer. Fifteen groups of 5 sarcomeres (75 total) from each sample were measured. Values are reported as average sarcomere length in microns (μm).

Expressible Moisture Index

The water holding capacity of the samples was determined using the method reported by Miller and Harrison (1965). A raw sample from the P. major in the right half of the breast weighing approximately 0.3 grams was placed on a piece of Whatman No. 1 filter paper (18.5 cm diameter), stacked between two pieces of 15.2 cm by 15.2 cm plexiglass and subjected to 10,000 psi of pressure for 5 minutes. Samples were analyzed in duplicate and 6 samples were pressed at a time. After pressing, the bottom plexiglass plate was carefully removed and the circles of the meat and expressed moisture areas that appeared on the filter paper were traced to preserve their integrity. The filter paper and pressed meat sample were removed from the upper piece of plexiglass to which they had adhered, were dried, and the areas of the two circles were measured with a compensating polar

planimeter. The area of the pressed meat sample was subtracted from the area of the expressed moisture + pressed sample to calculate the area of the expressed moisture. The result is given as the ratio of the area of the pressed meat sample to the area of the expressed moisture, which is the expressible moisture index (EMI).

Experimental Design and Analysis

The Warner-Bratzler shear test was run on samples from all three replications while analyses for sarcomere length and EMI were run on the first and second replications only.

The eight ES treatments were arranged in a 2 x 2 x 2 factorial design. The ninth treatment was an unstimulated control group. An illustration of the experimental design is shown in Figure 1. All data were analyzed using analysis of variance with replicate, treatment, and individual bird as independent variables. Individual bird was nested within treatment (Sokal and Rohlf, 1981). Duncan's Multiple Range test (Duncan, 1955) was used to separate means where appropriate.

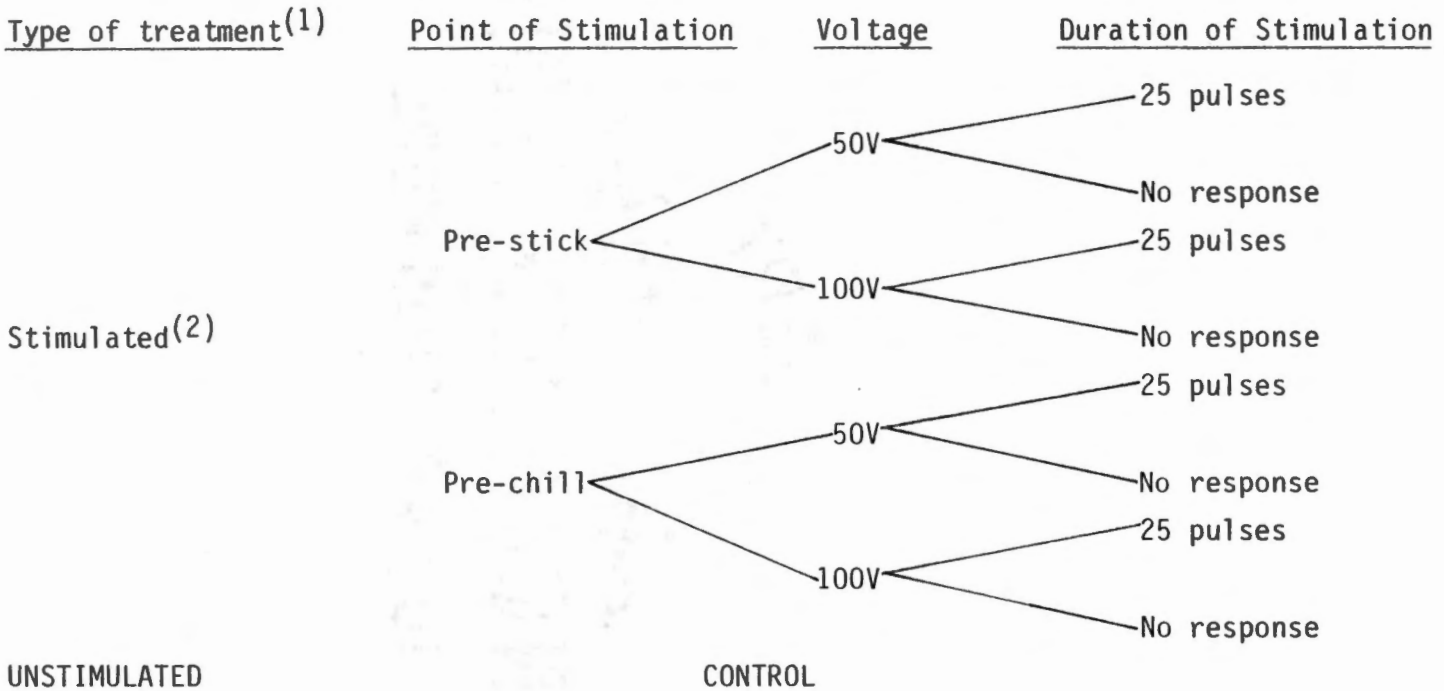

Figure 1. Diagram of experimental design. (1) Each treatment contained 10 birds, (2) Birds were stimulated with a rheostat (Type 2PF1010, STACO, Inc., Dayton, Ohio) with electrodes attached to the neck and the tail.

CHAPTER IV

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) of the Warner-Bratzler shear values for the Pectoralis major (P. major) is presented in Table 1 and the means and standard errors for shear data are listed in Table 2. The highly significant difference ($P<.01$) in mean shear values between replications was not expected and cannot easily be explained. Although the weights of the birds were not recorded, it was observed that the birds from the second and third replications were somewhat larger than the birds from the first replication, which may be responsible for some of the difference. The three replications were all slaughtered in different seasons of the year, with the first replication being slaughtered in spring (March), the second in summer (July), and the third in fall (September). Simpson and Goodwin (1975) reported that birds killed in the fall and winter were more tender than birds killed in the spring and summer. The data from this experiment conflict somewhat with their findings, but the unusually hot weather in September may have had an adverse effect on the tenderness of these birds due to heat stress (Lee et al., 1976).

The ANOVA for the shear data (Table 1) showed that there was no difference ($P>.05$) in tenderness between treatments. However, the interaction between replication and treatment was significant ($P<.05$). This suggests that the birds within the various treatments did not respond equally to electrical stimulation (ES) from replication

Table 1. Analysis of Variance for Shear Values of Chicken Pectoralis major

Source	Degree of Freedom	Mean Square
Replication	2	30.4926**
Treatment	8	4.7980
Replication x treatment (Error A)	16	2.9580*
Bird (replication x treatment) (Error B)	241	1.7004

*Significant at P<.05.

**Significant at P<.01.

Table 2. Mean Shear Values[1] of Pectoralis major Muscle by Replication, Treatment, and Treatment Within Replication

Treatment[2]	Replication 1	2	3	Average by Treatment
PS, 50V, 25p	5.06^{b}	4.74^{abc}	4.84	4.88
S.E.	±0.47	±0.33	±0.59	±0.26
PS, 50V, NR	4.42^{ab}	5.76^{c}	5.64	5.28
S.E.	±0.41	±0.62	±0.52	±0.31
PS, 100V, 25p	3.98^{a}	5.19^{bc}	5.05	4.74
S.E.	±0.33	±0.40	±0.49	±0.25
PS, 100V, NR	4.34^{ab}	5.88^{c}	5.44	5.22
S.E.	±0.38	±0.70	±0.58	±0.33
PC, 50V, 25p	4.22^{ab}	3.84^{a}	5.19	4.42
S.E.	±0.35	±0.32	±0.45	±0.24
PC, 50V, NR	3.74^{a}	3.44^{a}	5.02	4.06
S.E.	±0.20	±0.22	±0.35	±0.20
PC, 100V, 25p	3.80^{a}	4.31^{ab}	4.87	4.31
S.E.	±0.29	±0.27	±0.48	±0.21
PC, 100V, NR	3.83^{a}	4.41^{ab}	5.82	4.53
S.E.	±0.17	±0.36	±0.39	±0.26
Control	4.10^{ab}	4.05^{ab}	5.69	4.60
S.E.	±0.27	±0.29	±0.49	±0.24
Average by replication	4.10^{x}	4.62^{y}	5.29^{z}	
S.E.	±0.11	±0.16	±0.16	

[1]Shear value reported as kilograms of force required to shear a 0.6 cm x 1.3 cm sample.

[2]PS = Pre-stick, PC = Pre-chill, 25p = 25 pulses of electricity, NR = stimulated to no response.

^{abc}Means in the same column with different superscripts are significantly different ($P<.05$).

^{xyz}Means in the same row with different superscripts are significantly different ($P<.05$).

to replication. There was a difference among treatment within the first and second replications, but when the three replications were analyzed together, there was an averaging effect that negated these differences (Table 2). There was no difference between the ice-pack and chill-pack control groups (third replication). The variation in individual birds within a treatment group may have contributed to the averaging effect with the resultant lack of significance among treatments. The raw data even show a considerable amount of variation between shear values within a single P. major muscle, an effect that was reported by Webb and Brunson (1972), who found that points closest to the wing were significantly less tender than points near the attachment to the sternum in half-carcasses with the wing removed.

A series of orthogonal contrasts was used to partition the treatment sum of squares using the same error term (Error A) used to test the main effect. The four treatments stimulated after evisceration and before chilling (PC) were significantly more tender ($P<.01$) than the group of treatments stimulated before sticking (PS). The PC treatments were all more tender and the PS treatments all less tender than the control (Table 2), although these differences were not significant ($P>.05$). Neither voltage, duration of stimulation, nor any of the interactions were significant (Table 3).

The ANOVA for sarcomere length measurements is given in Table 4. Sarcomere lengths were measured in replications 1 and 2 only. There were no differences in sarcomere length due to replication, treatment, or the replication x treatment interaction. This agrees with the findings reported in turkeys by Welbourn et al. (1968) and

Table 3. Orthogonal Contrasts for Shear Data

Contrast	Mean Square
ES[1] treatments vs. control	0.1213
PS[2] treatments vs. PC[3] treatments	28.3893**
50 volts vs. 100 volts	0.1206
25 pulses vs. no response	1.9904
Point of stimulation x voltage	1.2432
Point of stimulation x duration	3.8527
Voltage x duration	1.5437
Point of stimulation x voltage x duration	0.8140

[1]ES = electrical stimulation.

[2]PS = Pre-stick.

[3]PC = Pre-chill.

**Significant at P<.01.

Table 4. Analysis of Variance for Sarcomere Length Measurements of Chicken *Pectoralis major*

Source	Degrees of Freedom	Mean Square
Replication	1	0.0114
Treatment	8	0.0136
Replication x treatment (Error A)	8	0.0151
Bird (replication x treatment) (Error B)	160	0.0139

in chickens by Sayre (1970); there is little variability in sarcomere length after the onset of rigor and sarcomere length is not closely related to shear values. Several researchers have also found no difference in sarcomere lengths of ES beef. The samples for sarcomere length in this study were excised and fixed 5 days post-mortem, which, in all likelihood, negated any differences which would have existed in the early post-mortem period. However, since the author was concerned with the ultimate tenderness of the meat, comparable to that experienced by the consumer, he felt that an adequate delay period--an approximation of the expected holding time in a retail case and the home refrigerator before cooking--was justified. The author had great difficulty with this analysis. The aging process was complete, the meat having been stored in a cooler for 5 days, and the sarcomeres were very hard to measure. Often an educated guess had to be made as to where sarcomeres began and ended, and this created a situation with ample room for experimental error.

Tables 5 and 6 present the ANOVA and means, respectively, for expressible moisture index (EMI). Replication 3 was not included in the EMI analysis. The samples from the first replication had a significantly higher ($P<.01$) EMI than samples from the second replication. EMI is reported as the ratio of the area of the pressed meat sample to the area of the expressed liquid. The greater the area of meat sample in relation to expressed liquid, the higher the water holding capacity (WHC) of the sample, since it retains more of the liquid, thus the relationship between WHC and EMI is directly

Table 5. Analysis of Variance for Expressible Moisture Index Determinations from Chicken Pectoralis major

Source	Degrees of Freedom	Mean Square
Replication	1	2.3195**
Treatment	8	0.2839
Replication x treatment (Error A)	8	0.1184
Bird (replication x treatment) (Error B)	159	0.1332

**Significant at P<.01.

Table 6. Mean Values for Expressible Moisture Index[1] by Replication, Treatment, and Treatment Within Replication

Treatment[2]	Replication 1	Replication 2	Average by Treatment
PS, 50V, 25p	1.14	0.85	1.00
S.E.	±0.14	±0.10	±0.09
PS, 50V, NR	1.08	1.09	1.09
S.E.	±0.10	±0.14	±0.08
PS, 100V, 25p	1.37	0.87	1.12
S.E.	±0.21	±0.11	±0.13
PS, 100V, NR	1.13	0.82	0.98
S.E.	±0.12	±0.04	±0.07
PC, 50V, 25p	1.15	1.11	1.13
S.E.	±0.11	±0.09	±0.07
PC, 50V, NR	1.42	1.26	1.34
S.E.	±0.17	±0.10	±0.10
PC, 100V, 25p	1.43	1.14	1.29
S.E.	±0.13	±0.06	±0.08
PC, 100V, NR	1.20	1.00	1.10
S.E.	±0.09	±0.07	±0.06
Control	1.24	0.94	1.06
S.E.	±0.10	±0.09	±0.07
Average by replication	1.24[a]	1.01[b]	
S.E.	±0.04	±0.03	

[1]Expressible moisture index expressed as meat area/expressed liquid area (Miller and Harrison, 1965).

[2]PS = Pre-stick, PC = Pre-chill, 25p = 25 pulses of electricity, NR = stimulated to no response.

[ab]Means with different superscripts are significantly different ($P<.05$).

proportional--as WHC increases, EMI increases. The data show that the samples from the first replication had a greater overall WHC than the samples from the second replication. This may help to explain the lower overall shear value of replication 1, since an increase in the amount of bound water in a meat sample is related to an increase in tenderness.

The ANOVA, again, indicated no difference among treatments, and, again, this was believed to be due to the variation within treatment groups. Orthogonal contrasts (Table 7) showed that the PC treatments had a higher ($P<.05$) EMI than the PS treatments, although neither group differed significantly from the control. Thus ES had the same effect on the WHC's of the treatment groups as it did on the shear values, which strengthens the evidence supporting a relationship between higher WHC and increased tenderness.

Table 7. Orthogonal Contrasts for Expressible Moisture Index Data

Contrast	Mean Square
ES[1] treatments vs. control	0.0328
PS[2] treatments vs. PC[3] treatments	1.1496*
50 volts vs. 100 volts	0.0121
25 pulses vs. no response	0.0021
Point of stimulation x voltage	0.0219
Point of stimulation x duration	0.0138
Voltage x duration	0.9609
Point of stimulation x voltage x duration	0.0649

[1]ES = electrical stimulation.

[2]PS = Pre-stick.

[3]PC = Pre-chill.

*Significant at P<.05.

CHAPTER V

CONCLUSION

Three replications involving a total of 279 chickens of a commercial hybrid strain were divided into 8 treatment groups which received electrical stimulation (ES) of 50 or 100 volts either pre-stick (PS) or pre-chill (PC) for a duration of 25 pulses (25p) or until no response (NR) was detected and an unstimulated control group. Measurements made were Warner-Bratzler shear force (WBS), sarcomere length (SL), and expressible moisture index (EMI).

WBS values were significantly different between all three replications, which was probably caused by the environmental conditions--mainly temperature--at the times of slaughter. There was no significant improvement in shear force values with any one treatment. The PC treatments as a group had a significantly lower shear value than the PS treatments, but they were not different from the control.

There was no difference in sarcomere lengths attributable to any of the factors studied.

EMI was significantly different between replications. The PC treatments had a higher EMI than the PS treatments, but there was no difference among any of the individual treatments. The higher EMI's, corresponding to higher water holding capacities, were associated with the lower shear values for replications as well as for treatment groups.

Although no direct conclusion or specific recommendations can be made, the results of this experiment indicate that an electrical stimulation system used at a point just prior to chilling the dressed chicken carcasses may be a feasible method of reducing toughening in the birds. The lower shear values and higher EMI's of these treatments, both of which indicate improved tenderness (reduced toughening) support this assumption. Further studies to clarify the effects of ES on chicken muscle are needed before specific conclusions can be made about the effectiveness of ES in improving the tenderness of chill-packed chicken.

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