Effects of postmortem muscle temperature and time on the water-holding capacity of turkey muscle

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Effects of postmortem muscle temperature and time on the water-holding capacity of turkey muscle

Lesiak, Michael Thomas, Ph.D.
Iowa State University, 1987
Effects of postmortem muscle temperature and time on the water-holding capacity of turkey muscle

by

Michael Thomas Lesiak

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY

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INTRODUCTION

To produce boneless poultry products with desirable quality characteristics conventional processing uses cold boning methods. Hot boning which is a significant change from the conventional methods, has gained interest due to the potential savings in labor, space and energy requirements (Lyon and Hamm, 1986). Hot boning is the postmortem process where muscle is removed from the carcass while it is close to body temperature.

Hot boning has a significant effect on muscle toughness due to the resulting muscle shortening. Research emphasis has been placed on this characteristic and various methods have been investigated to overcome toughness associated with hot boning (Hamm, 1983; Lyon and Hamm, 1986). Postmortem temperature and storage time are other factors that have been investigated in combination with hot boning, and which also have a significant influence on muscle texture characteristics (Smith et al., 1969; Kim et al., 1986; Dutson and Carter, 1985). While the effect of these factors has been investigated in relation to texture, less attention has been given to their effect on muscle water-holding capacity (WHC).

WHC of uncooked poultry is important because it influences raw muscle yield and sensory characteristics of
the cooked product. Drip loss that occurs in fresh poultry could be water from the muscle cell or water which was picked up during water chilling. If postmortem muscle drip loss is extensive, it may influence sensory characteristics like drip loss from frozen and thawed muscle influences sensory characteristics. The amount of drip loss that occurs in beef has been related to the extent of muscle shortening at various postmortem temperatures (Honikel et al., 1986). The relationship in poultry is not as clear due to the use of water chilling methods.

WHC is also a critical factor when water addition and cooking are employed in further processing steps. Processing yield, and the influence WHC has on sensory characteristics of further processed products are important considerations. Because further processing may occur several days after slaughter, the influence of storage time must be considered. With the growth in consumption of further processed poultry products (processing beyond cut-up parts), there is a need to understand the effect that postmortem muscle temperature and storage time have on WHC when a hot boning process is utilized.

The purpose of this study was to investigate the effect of postmortem temperature and storage time on the water-holding capacity of hot boned turkey muscle.
LITERATURE REVIEW

Muscle pH

After an animal has been bled, muscle oxygen is depleted through aerobic glycolysis metabolism. After oxygen is depleted, the muscle continues to generate adenosine triphosphate (ATP) through anaerobic glycolysis metabolism. ATP is the muscle's energy source and is used continually by the muscle to maintain cellular functions. Muscle glycogen and creatine phosphate are compounds that are utilized in anaerobic glycolysis to produce ATP. After a short time postmortem, these compounds are depleted and ATP production is less than consumption resulting in falling muscle ATP levels. With low muscle ATP levels rigor mortis develops. Rigor mortis is the muscle stiffening that results from permanent interaction between thick and thin filaments of muscle myofibrils, when ATP is depleted. Lactic acid is an end product of glycogen breakdown under conditions of anaerobic glycolysis. As anaerobic glycolysis continues, lactic acid accumulates and lowers muscle pH until glycogen is depleted or until the enzymes related to glycogen breakdown are inactivated (Lawrie, 1985). Muscle pH is a critical factor because it affects important quality characteristics such as color, shrink, texture, cooking loss, tenderness, processing parameters and meat binding.
The extent of pH fall is influenced by factors such as species, muscle type, drug injection, antemortem stress and slaughter struggling (Lawrie, 1985). Compared to dark muscles, the extent of pH fall has been shown to be greater in poultry breast muscle where white fibers predominate (Froning and Norman, 1966; Hay et al., 1973b). Certain muscle differences in ultimate pH can be attributed to the level of glycogen normally associated with fiber type and the capacity for glycolytic or oxidative metabolism.

Khan (1971) reported that initial postmortem pH in chicken breast muscle varied between commercial (pH 6.1-6.3) and laboratory (pH 6.8-7.0) slaughter operations though ultimate pH was the same (pH 5.7-5.8). Stewart et al. (1984b) also observed differences in the initial muscle pH between groups of birds used in different experiments. The higher initial pH observed in birds slaughtered in the laboratory by Khan (1971) was related to a longer time for rigor mortis to develop. Rigor mortis occurred in 5-7 hours for birds slaughtered in a laboratory versus 3-4 hours for birds slaughtered commercially. Honikel et al. (1983) indicated that ATP, temperature and pH each played a role in the time for rigor mortis to develop. They noted that in beef a postmortem muscle temperature of 0°C compared with 10-38°C resulted in rigor mortis development at a higher pH,
though ATP levels were equivalent. In another study, Honikel et al. (1986) indicated when muscle temperature was 10°C, the muscle pH for rigor development was higher in pork (pH 6.15) than beef (pH 6.0). Temperature and pH have an influence on the time of rigor development, however, actual rigor development is solely dependent on ATP concentration. Other researchers have related pH to rigor development and have used an early postmortem pH of 5.9 or higher as an indicator of prerigor muscle conditions (Froning and Neelakantan, 1971).

Postmortem pH at 15 min has also been used as an indicator of dark, firm and dry (DFD), pale, soft and exudative (PSE), and normal broiler breast meat (Niewiarowicz and Pikul, 1979). DFD is muscle that has a higher than normal ultimate pH while PSE is usually characterized by a rapid postmortem pH decline. Others have noted that poultry does exhibit both DFD and PSE characteristics and that breast muscle may exhibit a postmortem pH pattern similar to PSE pork (Ma and Addis, 1973; Kijowski and Niewiarowicz, 1978; van Hoof, 1979; van Hoof and Dezeure-Wallays, 1980). The rate of postmortem pH decline in turkey breast muscle has been observed to be comparable to or to exceed that of PSE pork. With extensive slaughter struggling, a muscle pH of 5.5 can be reached within 5 minutes postmortem. Kijowski and Niewiarowicz
(1980) measured broiler muscle pH at 15 minutes postmortem to classify muscle conditions as follows: pH 6.5 for DFD, pH 6.2 for normal and pH 5.7 for PSE. In laboratory slaughter (Kahn, 1971), where initial pH of muscle is in the high pH range (6.8-7.0), separation of DFD and normal muscle would not be possible at 15 minutes. Due to the extended time for the laboratory muscle to reach ultimate pH compared to commercial slaughter conditions, pH differences might only be detected later than 15 minutes postmortem as glycolysis progresses. The occurrence of PSE and DFD conditions effects the quality of both sensory and functional characteristic of the muscle.

Muscles which contain more white fibers have the potential for a faster rate of pH decline due to the glycolytic nature of white fibers. Rate of pH decline also may be influenced by other antemortem factors such as shipping and handling that would alter muscle glycogen levels or the stress condition of the animal. Thomson et al. (1986) indicated that electrical stunning prior to death, which is widely used in poultry slaughtering, slowed the rate of pH decline in the early postmortem period but it did not affect ultimate pH.

Temperature is an extrinsic factor that affects the rate of pH decline. In general, the higher the temperature the faster pH declines. The influence of muscle temperature
variation on the rate of pH decline, depends on the time postmortem and the level of muscle ATP. During the 0-4 hours postmortem time period in beef when ATP levels are high, muscle temperatures near 0°C accelerate the rate of pH decline. This accelerated rate is associated with the occurrence of "cold-shortening". Cold-shortening occurs when cold temperatures initiate a release of calcium from the mitochondria and sarcoplasmic reticulum into the myofibril structure. The increased calcium concentration stimulates an increased rate and extent of contraction. The increased rate of contraction causes an increased rate of lactic acid accumulation and pH decline. From 0 to 4 hours postmortem the rate of pH decline is the fastest at 0°C and the slowest at 14°C. After 4 hours postmortem, the rate of pH decline is the fastest at 30°C and the slowest at 0°C (Honikel et al., 1981b). Temperatures above 30°C have been used to generate PSE-like conditions in pork due to the faster rate of pH decline at those temperatures compared to lower temperatures (Bodwell et al., 1966). While beef held at temperatures of 37°C postmortem had an increased rate of pH decline, the rate was lower than that observed in pork (Tarrant and Mothersill, 1977). This observation could be associated with the content of red versus white fibers in beef compared to pork.

Dutson and Carter (1985) cite work associating
temperature with the rate of pH decline and rigor
development in poultry. Higher temperatures promote a more
rapid decline in postmortem pH (Stewart et al., 1984a).
Work reporting a cold-shortening effect in poultry breast
muscle (Smith et al., 1969) did not show a high rate of pH
decline during the early postmortem period at 0°C as was
shown in beef. It is important to note that rigor
development is generally shorter in poultry, from 1 to 4
hours (Kijowski et al., 1982; Smith et al., 1969) compared
to beef, about 10 hours (Honikel et al., 1981b). It is
possible that any increase in the rate of pH decline due to
cold temperature is not as dramatic in poultry compared to
beef since poultry has a normally rapid rate of pH decline.
Though temperature effects the rate of pH decline, it
generally does not influence the ultimate muscle pH (Honikel
et al., 1981b; Smith et al., 1969).

Hot boning involves the removal of prerigor muscle from
bones and this process has been shown to effect the rate of
pH decline. The glycolytic rate measured in an excised
muscle from beef according to Marsh (1983) is not the same
as muscle which remains attached to the carcass and is
undisturbed. Similar results have been shown in broiler
breast muscle by Stewart et al. (1984b). They found that
muscle excision and the severing of muscle attachments
produced a more gradual pH decline which was attributed to a
decline in the rate of anaerobic glycolysis. It was noted this slower rate of decline could not be attributed to a difference in muscle temperature. They postulated that severed muscle which is allowed to contract unimpeded has a reduced need for ATP and therefore a reduced rate of anaerobic glycolysis results. Though hot boning muscle has been shown to effect the rate of pH decline, it does not alter the ultimate pH (Stewart et al., 1984a; Lyon et al., 1985).

After the muscle has reached an ultimate pH due to postmortem glycolysis, further changes in the muscle are possible with aging. A slight rise in pH has been observed when muscle is held at temperatures above freezing (Forrest et al., 1975; Lawrie, 1985). These changes were considered to be associated with proteolysis of protein molecules into smaller units. Hay et al. (1973b) however described a slightly different finding regarding pH changes during storage time. They presented information showing that from Day 2 to Day 7 of storage at 2°C, chicken leg meat pH remained constant (pH 5.9) while breast muscle fell from pH 5.6 to 5.4. No indication was given as to the statistical differences between these values. If pH changes during aging are linked to proteolysis, factors that influence proteolysis might also explain variation in pH changes observed during aging.
Sarcomere Length And Muscle Shortening

Muscle fibers are composed of smaller units called myofibrils. Under phase contrast microscopy, myofibrils appear with cross-striations of light (I-band) and dark (A-band) regions. A central dark line in the I-band is called the Z-line. The region from one Z-line to the next in a myofibril is called a sarcomere. Sarcomere length (the distance between Z-lines) is dependent upon the degree of muscle contraction. Muscle contraction is generally a function of ATP level and the concentration of calcium released from the sarcoplasmic reticulum (SR) and mitochondria (Lawrie, 1985). As ATP levels fall postmortem, the calcium regulating ability of the SR is lost and calcium concentration increases in the myofibril. Due to ATP still being present, the increased calcium concentration stimulates contraction. When ATP is depleted due to contraction and a loss in the ability to regenerate ATP, the muscle remains in a contracted state. The initial contraction indicates the development of rigor and after depletion of ATP, the muscle is considered to be in full rigor. The time needed to reach this contracted or shortened state depends on the species of animal. Rigor onset occurs at approximately 10 hours in beef and rigor shortening is generally complete after 3 hours in chickens and 5 hours in turkeys (Honikel et al., 1981b; Smith et al.,
1969). Sarcomere lengths during the prerigor period vary considerably because the muscle has the potential to both contract and relax, however after rigor development, sarcomere lengths are much more uniform (Sayre, 1970). Some work in poultry has shown a sarcomere length increase during the early postmortem period as the muscle developed rigor mortis. Later work suggested that this observation was due to homogenization of prerigor muscle and that the stimulus caused a greater contraction during the early prerigor period when ATP level was highest (Ma et al., 1971; Ma and Addis, 1973; Sayre, 1970). Other types of muscle stimulation such as high temperatures during scalding, scalding time and physical beating during feather picking also cause sarcomere shortening and increased muscle toughness. The greatest toughness occurs when the stimulation takes place immediately after slaughter, when the ATP level is high (Pool et al., 1959; Klose et al., 1959). Additional factors that influence the extent of rigor contraction and sarcomere length are muscle restraint, boning, fiber type, temperature and those factors that influence the characteristics of postmortem anaerobic glycolysis and ATP levels (Hay et al., 1973b).

Temperature has a significant effect on sarcomere shortening and has been studied as it relates to palatability. Generally, the least sarcomere shortening
occurs over a range of intermediate muscle temperatures (10-16°C) that may vary due to animal species and muscle fiber type. At these temperatures (10-16°C) the sarcomere shortening that occurs is due to "rigor shortening" which is associated with the depletion of ATP (Honikel et al., 1981b; Honikel et al., 1983).

In beef at muscle temperatures just above freezing, sarcomere shortening increases, however, this decrease in sarcomere length occurs early postmortem under prerigor conditions and does not increase significantly with rigor shortening. This prerigor shortening is associated with cold temperatures affecting the ability of the mitochondria and sarcoplasmic reticulum (SR) to retain or accumulate calcium from the myofibril (Honikel et al., 1981b). Whiting (1980) indicated that as muscle temperature and pH declined, both mitochondria and the SR lost calcium-uptake activities and stability, with the mitochondria losing that activity more rapidly than the SR. This may indicate that initial shortening is stimulated by calcium being released from the mitochondria but that both the SR and mitochondria play a role in cold-shortening.

Smith et al. (1969) found that broiler muscle also exhibits a cold-shortening effect. They indicated that over the range of temperatures investigated that shortening was greater at 0°C than 12-18°C. Similar results have been
observed in turkey (Welbourn et al. 1968). Papa and Fletcher (1986) investigating the effect of temperature on rigor development in excised broiler muscle found that rigor shortening at 2 hours postmortem was accelerated at 4°C compared to 16°C. Sarcomere lengths were shorter at 4°C (1.62μ) than at 16°C (1.73μ) which is an indication of cold-shortening in poultry.

As muscle temperature in beef increases from 16°C to 37°C, sarcomere shortening increases. Honikel et al. (1981b) attributed this shortening to rigor shortening only and not to any prerigor shortening. Similar to the effect at cold temperatures, Whiting (1980) showed that higher temperatures and muscle pH effect the ability of the mitochondria and SR to accumulate and retain calcium. Calcium accumulation and retention abilities declined with decreasing pH and increasing temperature, especially above 25°C for the mitochondria and above 40°C for the SR. A reduction in calcium accumulation and retention abilities may not be observed in beef where the pH decline is relatively slow. In animal species with a faster pH decline, a reduction in mitochondria and SR calcium regulating abilities could be a factor in sarcomere shortening.

High temperatures also have been demonstrated to affect poultry muscle shortening. Papa and Fletcher (1986) noted
that broiler muscle sarcomere lengths were shortest at 0°C and 40°C compared to 16°C. Smith et al. (1969) also has observed that muscle shortening was greater at higher temperatures compared to those between 12-18°C. At 24 hours postmortem, muscles held at 0°C had the shortest sarcomeres while muscles held in the 12-18°C range had sarcomeres with the least shortening. These relative sarcomere lengths in broiler muscle at 24 hours postmortem are similar to those found in beef (Honikel et al., 1986) which show the greatest sarcomere shortening at the coldest temperatures, intermediate sarcomere shortening at the highest temperatures and minimum sarcomere shortening around 10°C.

During storage of rigor muscle, changes in sarcomere length have been reported while other studies have found no change once rigor has developed. Sayre (1970), investigating myofibril fragmentation in chicken breast muscle up to 24 hours postmortem found that sarcomere length did not change after rigor development. In another study using chicken, Kijowski et al. (1982) reported similar results for breast over the same time period as reported by Sayre (1970). However, in leg muscle, a significant sarcomere lengthening was observed from 8 to 24 hours postmortem (Kijowski et al., 1982). While muscle sarcomere length variation and lengthening occurring during the early postmortem period can be associated to stimulation and the
utilization of ATP, changes in sarcomere length of rigor muscle can not be associated with ATP utilization.

Hay et al. (1973b) observed changes in sarcomere length for both breast and thigh muscles during 7 days postmortem. In breast, sarcomere length at 3 hours (1.76µ) and 48 hours (1.73µ) postmortem were longer than at 168 hours postmortem (1.56µ), shortening occurred from 48 to 168 hours postmortem. In leg, sarcomere length at 48 hours (2.96µ) and 168 hours (2.78µ) were longer than that at 3 hours (1.88µ); leg sarcomere lengthening occurred after 3 hours postmortem. Other observations they made in the sarcomere related to the appearance of the Z-line. During aging, the Z-lines in breast myofibrils were degraded, but Z-lines in leg myofibrils were unaffected by aging. They speculated that the lengthening that occurred in leg muscle, though not related to ATP, may be related to proteolysis and muscle stretching. Proteolysis differences observed in Z-line degradation may cause the difference between breast and thigh sarcomere length changes. Some changes in sarcomere lengths observed were attributed to myofibril preparation methods. Many factors could influence sarcomere lengths such as preparation methods, muscle type, temperature, muscle excision and proteolysis. Due to these factors, the mechanisms and specific changes in sarcomere length that occur over time are not clearly understood.
Muscle fiber type can influence sarcomere length and shortening. Sarcomere lengths are shorter in breast which has predominantly white fibers than leg which has predominantly red fibers (Hay et al., 1973b). Red fibers with longer sarcomere lengths generally have slower and more prolonged contraction. Welbourn et al. (1968) listed the following sarcomere lengths for turkey muscles (nonexcised) for specific muscle temperatures postmortem; breast $1.71 \mu$ at 0°C and $1.99 \mu$ at 16°C, thigh $2.21 \mu$ at 0°C and $2.38 \mu$ at 16°C. Fischer et al. (1980) indicated that the temperature where minimum shortening occurs in pork muscle was influenced by fiber type with the minimum shortening occurring 6°C lower in white fibers than red fibers. Cold-shortening effects are found also to be greater in red muscles than white muscles (Hamm, 1982). Compared to white fibers, red fibers have a higher content of mitochondria which are thought to react to cold temperatures and initiate cold-shortening. While red fiber sarcomere lengths are longer than white fiber sarcomere length, Kijowski et al. (1982) noted that postmortem percentage shortening was greater in chicken leg myofibrils compared to breast.

Muscle excision prerigor increases sarcomere shortening (Kim et al., 1986) because muscle shortening is not restrained by opposing muscles or bone. Papa and Fletcher (1985a) reported that conventionally processed breast muscle
had a sarcomere length of 1.86\(\mu\) while hot boned breast sarcomere length averaged 1.60\(\mu\); a difference of 0.26\(\mu\). The time elapsed postmortem before the muscle is removed is also an influence in muscle contraction. Early removal of the breast postmortem resulted in a 8.8 percent shortening while removal after 4 hours resulted in only a 0.4 percent decrease in length (Lyon and Dickens, 1986). This indicates that rigor was well developed by the time the muscle was removed at 4 hours postmortem.

Drip Loss

Drip loss is the fluid lost from muscle during postmortem storage or upon thawing of frozen muscle. To understand changes in drip loss, it is desirable to understand how water is associated with muscle components. Acton and Dick (1985) summarized the types of water in muscle and the factors that influence the ability of muscle to retain water. They indicated that most of the water in muscle is associated with the myofibril contractile proteins. Water in muscle exists as either bound, immobilized or as free water.

Bound water is bound very tightly to protein structure and accounts for five percent or less of the total water in muscle. The amount of bound water in muscle does not change.
Immobilized water is the next layer of water associated with the protein structures. The quantity of water immobilized is dependent on: the level of protein ionization or the charge density of hydrophilic amino acid groups; physical forces exerted on the protein; and the distance the water is located from the protein structure.

Free water is the next layer of water which is held by capillary action of myofibril filaments. Free water has no attraction or restriction placed on its movement. Offer and Trinick (1983) indicated that in addition to the myofibril filaments, water retention by capillary action is also located in extracellular space and space between myofibrils. The influence of this type of capillarity in fresh meats is demonstrated by the difference in drip loss due to fiber diameter. A smaller fiber diameter produces a muscle with greater capillarity. When a fine grained muscle containing small diameter fibers is cut across the fibers, less drip loss will form compared to a course grain muscle containing large diameter fibers. Fiber diameter which can vary between muscles and can even vary within a muscle (Smith and Fletcher, 1986) partially explains the difference in drip loss between muscles.

Postmortem pH exerts an influence on the water in muscle by altering the net charge of protein molecules. At a pH of about 5.2 water retention is at a minimum due to
minimum net protein charge. An increase or decrease in pH from 5.2, increases net protein charge and increases the amount of water immobilized in the protein structure (Hamm and Deatherage, 1960). Dark, firm and dry (DFD) beef with a pH significantly above normal postmortem pH retains more water than normal beef causing it to appear dry. Pale, soft and exudative (PSE) pork has a near normal pH but due to a rapid decline in pH at high muscle temperature it does not retain as much water and therefore has extensive drip loss compared to normal muscle.

Additional factors are thought to effect water retention in PSE muscle. Honikel et al. (1986) suggested possible disruption of cell membranes that enables very early postmortem leakage of water from the muscle. Disruption may not influence the overall loss of water significantly but it would effect how soon postmortem the loss occurred. Another factor in addition to pH, is the loss of protein charge due to protein denaturation during development of PSE (Bendall and Wismer-Pedersen, 1962). Penny (1977) found that the highest drip loss occurred at postmortem temperatures above 30°C and suggested that denaturation was a contributory factor to the drip loss observed in pork. A similar condition is observed in turkey, (van Hoof, 1979) where increased muscle water loss also is attributed partially to protein denaturation. Inner
regions of beef muscles at about 30°C, when the muscle pH dropped to 5.7, were considered to have encountered protein denaturation. These same regions also were found to have a greater drip loss (Tarrant and Mothersill 1977).

Penny (1977) described the events leading to drip formation due to rigor shortening. After the initial postmortem shrinkage of fibers, movement of water from between the myofibril filaments occurs. With a reduction in sarcoplasm osmotic pressure, water moves across the cell membrane into extracellular spaces and appears as drip on the surface of the muscle. Reducing particle size by grinding, increases surface area and shortens the time for drip loss to be expressed.

Rigor development and the extent of muscle shortening in beef were directly related to the extent of muscle drip loss postmortem (Hamm, 1960). Honikel et al. (1986) studied the effect of muscle shortening on drip loss and showed that the amount of shortening found after rigor development was linearly related to the amount of drip observed in unrestrained red muscles of both beef and pork. Drip loss increased over time for all temperatures and the rate of increase was considered to be a function of the slow rate of movement of water along extracellular spaces. The greatest total drip loss and shortening was observed at temperatures below 6°C. Minimum total drip and shortening was seen
between 6°C and 18°C. Intermediate levels of drip and shortening were reported for temperatures above 18°C. It was considered that three events influenced the process of drip loss formation. The first was prerigor shortening due to muscle temperature. Second was the drop in postmortem pH and the third was irreversible association of thick and thin filaments due to the onset of rigor mortis. Thaw rigor which occurs when muscle is frozen in the prerigor state then thawed, experiences rigor development very quickly and extreme shortening of muscle fibers occurs. Under these conditions extreme amounts of drip loss are observed.

The relationship between increased sarcomere shortening and increased drip loss also is observed in hot boned beef (Hamm, 1982). Treat and Goodwin (1973) indicated that chicken muscle chilled, then cut up, lost more weight during storage than hot-cut birds. However, the chill cut birds were water chilled and the hot-cut birds were not water chilled, so the water lost from the chill cut birds may have been chill water rather than muscle water. For this reason the importance of postmortem muscle drip loss in poultry processing is difficult to ascertain because water pickup occurs when water chilling methods are used.
Protein Solubility

There are three protein fractions in muscle: the sarcoplasmic proteins are metabolic proteins that make up about 32 percent of the total protein; the myofibrillar proteins are contractile proteins which make up about 52 percent of total protein; and stromal proteins, the connective tissue proteins are about 12 percent of total protein. The sarcoplasmic proteins are water soluble, the myofibrillar proteins are salt soluble while the stromal proteins are insoluble in water or salt solutions. The myofibrillar proteins are considered the most important fraction in muscle because they influence the ability of the muscle tissue to retain inherent or added water (Acton and Dick, 1985).

Myofibrillar protein solubility is a muscle tissue functional property that is altered by denaturation. Denaturation is a process where protein structure, charge and bonding change; going from the native to the denatured protein state (Ziegler and Acton, 1984). Protein solubility also has been related to the muscle tissues ability to retain water upon cooking. For this reason, protein solubility or extractability are often used to evaluate treatment effects on muscle protein denaturation and water binding.

The susceptibility of a muscle to postmortem
denaturation of proteins is dependent on muscle type. The proteins of white muscle are considered to denature more readily than red muscles. This difference can be related to observations of PSE conditions in different muscle types (Hamm, 1982; van Hoof and Dezeure-Wallys, 1980). Bendall and Wismer-Pedersen (1962) suggested that in PSE muscle, sarcoplasmic proteins were denaturing and precipitating on the myofibrillar proteins and in this way decreased the solubility of these fractions. Clarke et al. (1983) described how sarcoplasmic proteins bind to actin and other associated structural proteins, as a means to regulate metabolic activity and to provide organization to the glycolytic enzymes of the sarcoplasm. Any denaturation of these proteins while they were associated with the structural proteins would significantly affect the protein charge of the system and influence protein solubility.

Reduced protein solubility due to protein denaturation has been observed in poultry (Kijowski and Niewiarowicz, 1980; Landes et al., 1971). Ma and Addis (1973) attributed protein denaturation in poultry to a rapid postmortem decline in pH while the muscle was close to body temperature. Penny (1969) attribute the loss of extractability under high temperature and low pH conditions specifically to myofibrillar protein denaturation. Tarrant and Mothersill (1977) also considered the decrease in
solubility of beef muscle, in areas where the temperature was high during pH decline, as an indication of myofibrillar protein denaturation. They indicated that with muscle temperatures of 30°C and a pH of 5.7 that significant denaturation of both sarcoplasmic and myofibrillar proteins occurred.

Changes in postmortem protein solubility have been related to normal pH decline, the development of rigor and aging. In beef, 33 percent of the total decrease in postmortem solubility was considered to be due to pH decline and 67 percent due to rigor development in salted homogenates (Honikel et al., 1981a). In chicken, Kijowski (1984) found that soluble myofibrillar protein decreased with rigor onset and that it increased with postmortem aging. Increased extraction with postmortem aging also was noted by van den Berg et al. (1963). They attributed the increase to proteolysis and also indicated that extractability was greater in breast than thigh. While myofibrillar protein solubility increases with aging, a decrease in solubility of sarcoplasmic proteins with aging has been suggested based on gel electrophoresis results (Hay et al., 1973a).

Rigor development has an influence on extractability of muscle proteins so there may be some influence based on the extent of rigor contraction. Galluzzo and Regenstein (1978)
observed that uncontracted muscle is more readily extracted than contracted muscle due to the greater number of crosslinkages between thick and thin filaments. While uncontracted muscle was more readily extracted, the differences in the total amount of extracted protein was not noted. Smith et al. (1969) indicated that extractability was not related to postmortem shortening, however, they questioned the results due to the extraction solution used. They suggested that the solution used could have extracted protein that would have been classified as insoluble protein in other extraction solutions. Differences in protein extraction may be attributed to the conditions used to extract the protein fraction. Variation in homogenization methods, extraction times, and solution ionic strength, buffers and composition can influence the protein being extracted.

In an experiment where isolated myofibrils with various sarcomere lengths were exposed to the same extraction solution simultaneously, Offer and Trinick (1983) found that sarcomere length had no major effect on protein extraction. Based on their work, it might be considered that in muscle where commercial levels of salt and phosphate are used, that with adequate distribution and time, sarcomere length may have little effect on protein extraction or solubility.
Water-Holding Capacity

Postmortem muscle characteristics which affect muscle drip loss and protein solubility can also influence muscle water-holding capacity (WHC). With a shift of muscle pH away from the pH where the net charge is zero, drip loss decreases, protein solubility increases, and the muscles' WHC also increases (Hamm, 1960; Miller et al., 1968; Ristic and Schon, 1977). Part of the decrease in WHC of PSE muscle is due to protein denaturation. Protein denaturation due to high postmortem temperature and pH decline that increases drip loss and decreases protein solubility also decreases muscle WHC (van Hoof and Dezeure-Wallays, 1980).

Differences in WHC are apparent between muscles. When salt and phosphates are added to poultry meat, light muscles such as breast, have a higher WHC than dark muscles such as thigh. This was true even though the pH of dark meat remained higher after salt and phosphate addition (Lyon, 1983; Ristic and Schon, 1977). Goodwin and Maness (1984) when using marinades containing salt and phosphates also found that breast was higher yielding than thighs. Vadehra et al. (1973) noted that breast had a lower WHC than thigh or drum but indicated that this finding differed from earlier results (Vadehra et al. 1970). The difference was attributed to a higher ionic strength of the solution used in the second study. It appears that while WHC of different
muscles may vary depending on the ionic strength of the solution used, in the range of salt and phosphate normally used in poultry muscle processing that breast has the highest WHC.

Early information on how salt increased WHC indicated that salt shifted the isoelectric point to a lower pH which resulted in an increase in WHC for muscle in the normal pH range (Hamm, 1960). While salt increases the ionic strength of the system, phosphates exert an influence on WHC by increasing ionic strength and pH (Trout and Schmidt, 1983). The increase in WHC is due to an increase in the electrostatic forces on the protein filament network. These forces causes the filaments to repel and hold more water through capillary action. Through the action of salt and phosphate, poultry muscle cooking losses are reduced significantly (Young and Lyon, 1986; Froning and Sackett, 1985).

Offer and Trinick (1983) investigating sodium chloride and pyrophosphate effects on muscle myofibrils proposed additional mechanisms involved in determining WHC. They showed that with addition of solutions containing salt and phosphate that myofibrils swell and change appearance under the light microscope. Noted were changes due to protein extraction in the length of the A-band and density of the Z-lines and in the extent of swelling in the various regions
of the sarcomere. Maximum swelling or WHC of the myofibril was related to the levels of salt and phosphate used and the extent of sarcomere A-band extraction. The change in the A-band, induced by salt and phosphate, was considered to be due to a displacement of the equilibrium between myosin filaments and myosin molecules in favor of the molecules, and a direct effect on the binding between myosin heads and actin. Though phosphate lowered the salt concentration required to obtain swelling it was not thought to change maximum swelling. Sarcomere length had no effect on swelling when adequate levels of salt and phosphates were used. Similar findings that indicated sarcomere length had no influence on WHC were reported by Honikel et al. (1981b).

Another aspect considered to be involved in the myofibril WHC was the element of transverse restraints such as the Z-line and M-line (Offer and Trinick, 1983; Honikel et al., 1981b). Offer and Trinick (1983) found the M-line retarded the swelling and WHC of the A-band while the Z-line limited I-band swelling. When I-band swelling was retarded this also limited A-band swelling in the region where thin and thick filaments overlap. M-lines and Z-lines rigidity was found to vary and was related to how the structures reacted to the salt and phosphate solutions used. Proteolytic breakdown of the Z- and M-lines also was thought to play a part in expanding and permitting maximum swelling
of the myofibril. They concluded that WHC was partly due to
the disruption of transverse structural restraints such as
actomyosin crossbridges, M-lines and Z-lines.

An increase in WHC with aging was noted by Hamm (1960).
He indicated that increased WHC was related to proteolysis,
which caused a loosening of the protein structure in muscle.
Kijowski (1984) determined changes that occur in protein
structure and extractability of chicken muscle during aging.
After rigor development extraction of myofibrillar protein
increased with aging. Extractability of alpha-actinin also
increased with aging and was associated with degradation of
the Z-line. The appearance of the 30,000 dalton component,
which is an indicator of proteolytic activity, also was
observed 96 hours postmortem. Others have noted alpha-
actinin breakdown occurring during aging of chicken muscle
for 7 days (Hay et al., 1973a). These changes could impart
differences in WHC over time.

Differences in proteolytic activity could explain some
of the difference in WHC between muscles during aging.
Observations have been made that chicken thigh requires a
longer aging time than breast (Wyche and Goodwin, 1974), and
that in leg muscle, Z-lines and M-lines were only slightly
affected by aging. In addition, the 30,000 dalton component
in leg develops slower and to a lesser extent during aging
than in breast muscle (Hay et al., 1973b; Hay et al.,
1973a). This is an indication that there is less proteolytic activity in leg than in breast. The more extensive and earlier protein degradation that occurs in breast could partly explain why the WHC of breast is greater than leg.

Solubilized or extracted muscle protein, by salt and phosphate, is capable of forming a protein matrix. The protein matrix, which is often referred to as a protein gel, is largely responsible for water retention (WHC) in many processed meats and for the binding between meat pieces in sectioned and formed products (Ziegler and Acton, 1984). Extraction and gel matrix formation is enhanced by processing methods such as tumbling, grinding or comminution. The effect of extraction and structure formation is demonstrated by the increase in WHC that is observed as muscle particle size is reduced (Vadehra et al., 1970). The importance of structure in WHC also was emphasized by Trout and Schmidt (1983) who indicated that on a molecular level that WHC was determined by the production of a three-dimensional protein structure. The thick filament protein myosin was considered to play a key role in this gel matrix formation. Other research also has noted the importance of myosin to protein network formation and the harboring of water (Schmidt et al., 1981; Siegel and Schmidt, 1979; Ziegler and Acton, 1984). Both pH and ionic
strength effects of salt and phosphates were considered to be important factors that acted on myosin to develop a desirable structure for water retention (Trout and Schmidt, 1983).

Due to the relationship between gel strength and WHC, gel strength has been used as a means to evaluate WHC. Breast salt soluble proteins were shown to form stronger gels than thigh protein (Foegeding, 1986). Acton and Dick (1986) also found that it took less thermal energy to aggregate actomyosin gels from thigh than breast. They related this to the greater WHC and lower cooking losses of breast compared to thigh that was observed by a number of other researchers evaluating actual processed poultry products. This agrees with recent work by Wang and Chen (1986) who found that cooking losses were greater for dark muscles than breast.

It is known that as temperature increases during cooking, WHC decreases. Hamm and Deatherage (1960) detailed protein changes in muscle over the temperature range of 20 to 80°C. They indicated that no significant change occurs between 20 to 30°C. Mild denaturation or the unfolding of proteins and the formation of new bonds occurs between 30 to 40°C. Between 40 to 50°C strong denaturation occurs with the formation of new stable crosslinks and a decrease in negative charges as temperature increases. The process of
denaturation and crosslinking continues between 50 to 55°C and then above 55°C negative charges decrease again. The formation of a tighter network of protein structure continues until at 65°C denaturation is almost complete. A stepwise decrease in WHC and pH was associated with the loss of acidic protein groups. Based on these changes physical and electrostatic forces that exist as temperature increases will determine the amount of water that is lost from the protein structure during cooking.

Muscle Texture

Toughness has been and still is a concern in poultry muscle processing. Early work by de Fremery and Pool (1960) indicated that treatments that cause a more rapid pH decline, loss of glycogen and ATP, induce greater muscle toughness. Examples of treatments of this type are mechanical stimulation (feather picking) and freezing then thawing of prerigor muscle. Prevention of toughening by injection of a buffer solution to control pH decline, was found to lower shear values (Peterson and Lilyblade, 1979). This effect was probably due to the buffers effect on rigor development and muscle WHC, both of which are processes associated with pH decline.

Others have also associated tenderness to ultimate pH and pH decline. Observations were that increased ultimate
pH increased tenderness and that a pH of 6.2 or higher just after slaughter and a ultimate pH of 5.7 also were desirable to the quality of muscle tenderness (Khan and Nakamura, 1970). Initial muscle pH below pH 6.2 was associated with slaughter struggling and greater toughness. While ultimate pH has a direct effect on tenderness, pH decline and tenderness have been noted to be parallel functions of the rigor process rather than to have a cause and effect relationship (Stewart et al., 1984a).

Cutting poultry and removal of muscle from the bone soon after slaughter (hot boning) have been found to increase toughness (Pool et al., 1959; Dodge and Stadelman, 1960). The increased toughness of prerigor muscle removed from the bone also has been shown to increase muscle shear values (Klose et al., 1972). Total removal of the muscle from the bone is not necessary to have a significant effect on tenderness. Severing muscle attachments or altering the muscle tension profile while it is attached to the bone, will increase muscle toughness and shear values (Treat and Goodwin, 1973; Papa and Fletcher, 1985c; Papa and Fletcher, 1985b; Klose et al., 1971). The basic effect is that restraints that keep the muscle from contracting are removed resulting in greater shortening during rigor development.

Wyche and Goodwin (1974) did not observe differences in shear values between muscles that were hot cut and muscles
chilled then cut. They attributed this to muscle stimulation caused by the picking system used. As a result, the hot cut muscle had progressed further into rigor mortis development before boning and the amount of shortening that occurred did not produce a significant difference in shear values. This indicates that the time period for rigor development influences toughening effects observed in hot boned muscle. Generally, the sooner after slaughter that muscle excision occurs the greater the muscle shear values and toughness will be (Stewart et al., 1984a; Sams and Janky, 1986). After a 4 hour postmortem holding period, no difference in tenderness and shear values were observed between hot boned and bone-in muscle (Lyon and Hamm, 1985; Lyon et al., 1985). Thomson et al. (1986) cite a number of authors that recommend postmortem holding time to avoid adverse postmortem toughening. The times range from 3 hours to 6 hours, 6 hours was recommended for muscle that would be frozen soon after slaughter. Postmortem holding time requirements can vary with factors that effect the rate of postmortem glycolysis. Stewart et al. (1984a) found that shear values did not increase with muscle boning at 4 hours when the muscle was held at 25°C prior to boning. When muscle was chilled prior to boning at 4 hours, a significant increase in shears values was found. This was due to lower temperatures slowing the rate of postmortem glycolysis and
the prerigor muscle conditions existing at 4 hours postmortem.

Postmortem muscle temperature has been shown to effect muscle shortening in boneless poultry. Kahn (1971) investigated the effect of temperature on postmortem glycolysis and tenderness. Findings indicated that with a post-slaughter pH of 6.1 to 7.0, temperatures between 30 and 37°C increased toughness of excised breast muscle. Temperatures between 10 and 25°C during rigor development produced more tender muscle. The temperature effect was seen only as the muscle pH dropped from 6.3 to 5.9. These pH values would be associated with the rigor state of the muscle. The pH of 5.9 has been used as an indication of prerigor muscle conditions (Froning and Neelakantan, 1971). Smith et al. (1969) found that boneless poultry muscle held at 0°C produced a cold-shortening effect which has been shown to increase muscle toughness.

Increased shear values have not always been observed for bone-in muscle exposed to cold postmortem temperatures. Welbourn et al. (1968) found sarcomere lengths decreased in both bone-in breast and thigh. However, they indicated that compared to 16°C, a postmortem muscle temperature of 0°C resulted in increased shear press values for thigh but not for breast. This observation in breast also was reported by Stewart et al. (1984a). They showed shear values of bone-in
breast muscle, that was held for 4 hours postmortem at 25°C, were not significantly different than bone-in muscle chilled at 0°C immediately after slaughter. While shortening occurs in bone-in and boneless muscles a significant increase in shear values did not always occur for bone-in breast muscle. Welbourn et al. (1968) reported no significant correlations between sarcomere length and shear values. The lack of correlation between sarcomere length and shear values indicates that factors in addition to muscle shortening influence tenderness.

Results show that early postmortem temperature was a major determinant on beef tenderness in addition to shortening effects. Increased tenderness was related to increased proteolytic activity at higher muscle temperatures during the early postmortem period and to a higher pH where enzymes such as Calcium Activated Factor (CAF) have greater activity (Marsh, 1983; Lochner et al., 1980). Elevated postmortem temperatures beyond the early postmortem period would increase the rate of tenderization through out the aging period (Dutson, 1983b). The term cold toughening incorporates the effects of reduced sarcomere length (cold-shortening) and reduced autolysis due to cold postmortem muscle temperatures (Dutson and Carter, 1985).

The extent of proteolytic activity and tenderness also is influenced by the muscle type and species. In chickens,
proteolysis was not considered to be a factor in tenderness during aging of the leg since aging effects are relatively slower in thigh compared to breast (Hay et al., 1973a; Wyche and Goodwin, 1974). Kijowski (1984) compared species for rate of aging and indicated that the species ranked from slowest to fastest was beef, pork and poultry.

The amount of water retained in muscle with or without salt influences texture. Decreased breast tenderness has been attributed to increased cooking losses (van den Berg et al., 1963; van den Berg et al., 1964). Babji et al. (1982) was able to increase WHC and lower shear values by injecting a salt solution into bone-in turkey breast muscle. Reduced shear values by the addition of salt and phosphate or by marinating meat in salt solutions have been reported by other researchers (Lyon, 1983; Goodwin and Maness, 1984). Based on shear values, Froning and Sackett (1985) did not find increased tenderness with salt and phosphate addition even though cooking loss was reduced. In their study, little water was used to incorporate salt and phosphate which may have influenced the results. Earlier, Hamm (1960) noted that tenderness is not only due to WHC, so a correlation between tenderness and WHC may not be found in all cases. Muscle shortening and proteolysis are other factors involved in tenderness, although increases in WHC or the reduction of cooking loss would generally be expected to
increase tenderness.

Salt and phosphate have been used to overcome the toughening that occurs with prerigor removal of poultry muscle in the hot boning process. Chilling the hot boned muscle in a salt brine was found to improve tenderness and increase WHC. Salt brine chilling also reduced shear force differences between hot boned and conventionally chilled and boned muscle (Mathusa and Janky, 1984; Sams and Janky 1986). Reduction of drip loss by salt brine chilling (Carpenter et al., 1979) also may contribute to the improvement in tenderness observed by the process.

Mechanical tenderizing methods and use of salt and phosphate (alone or in combination) have been found to reduce shear values of hot boned muscle (Lyon and Hamm, 1986). Hamm (1983) found that hot boned chicken breast meat, chilled for 30 min and then tumbled for 45 min, had shear values at 24 hr similar to muscle that was chilled on the carcass and aged for 24 hr. While hot boned poultry muscle has a greater tenderness problem, it can be overcome by the addition of salt and phosphates.

Explanation of dissertation format

The dissertation is divided into three parts, each part being a complete paper to be submitted to a scientific journal. Part I examines the effect of postmortem muscle
temperature and time on the water-holding capacity of turkey breast muscle. Part II examines the effect of postmortem muscle temperature and time on the water-holding capacity of turkey thigh muscle. Part III examines the effects of postmortem time before chilling and chilling temperatures on water-holding capacity and texture of turkey breast muscle.
PART I. EFFECTS OF POSTMORTEM MUSCLE TEMPERATURE AND TIME ON THE WATER-HOLDING CAPACITY OF TURKEY BREAST
EFFECTS OF POSTMORTEM MUSCLE TEMPERATURE AND TIME
ON THE WATER-HOLDING CAPACITY OF TURKEY BREAST

by

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Running Title: Turkey breast water-holding capacity
ABSTRACT

Turkey breast muscle excised immediately after slaughter was held at 0, 12 or 30°C from 0.25 to 4 hr postmortem and then stored at 2°C. Muscle pH, drip loss, sarcomere length, homogenate supernatant weight, salt-soluble protein and cooking yields were determined at various times postmortem. Ultimate pH was not influenced by postmortem temperatures and did not change during storage. The higher temperature and longer storage times interacted to produce the greatest drip losses. Sarcomere lengths were shortest at 0°C but no difference in lengths was found between 12 and 30°C. Supernatant weight was greatest at 30°C and increased with storage time. Supernatant salt-soluble protein increased with higher temperatures and longer storage time. No differences were found in cooking yield of water homogenates. Homogenate cooking yields were lower for 30°C and increased during storage when homogenates contained water, salt and phosphate. Lower postmortem temperatures and shorter storage time produced the highest water-holding capacity in turkey breast muscle.
INTRODUCTION

To produce boneless products with desirable quality characteristics conventional poultry processing uses cold boning methods. Hot boning, which is a significant change from the conventional methods, has gained interest due to the potential savings in labor, space and energy requirements (Lyon and Hamm, 1986). Hot boning is the postmortem process where muscle is removed from the carcass while it is close to body temperature.

Hot boning has a significant effect on muscle toughness due to the resulting muscle shortening. Research emphasis has been placed on this characteristic and various methods have been investigated to overcome toughness associated with hot boning (Hamm, 1983; Lyon and Hamm, 1986). Postmortem temperature and storage time are other factors that have been investigated in combination with hot boning, and which also have a significant influence on muscle texture characteristics (Smith et al., 1969; Kim et al., 1986; Dutson and Carter, 1985). While the effect of these factors has been investigated in relation to texture, less attention has been given to their effect on muscle water-holding capacity (WHC).

WHC of uncooked poultry is important because it influences raw muscle yield and sensory characteristics of
the cooked product. Drip loss that occurs in fresh poultry could be water from the muscle cell or water which was picked up during water chilling. If postmortem muscle drip loss is extensive, it may adversely influence sensory characteristics in the same manner that drip loss from frozen and thawed muscle adversely influences sensory characteristics. The amount of drip loss that occurs in beef has been related to the extent of muscle shortening at various postmortem temperatures (Honikel et al., 1986). The relationship in poultry is not as clear due to the use of water chilling methods.

WHC is also a critical factor when water addition and cooking are employed in further processing steps. Processing yield and the influence WHC has on sensory characteristics of further processed products are important considerations. Because further processing may occur several days after slaughter, the influence of storage time must be considered. With the growth in consumption of further processed poultry products (processing beyond cut-up parts), there is a need to understand the effect that postmortem muscle temperature and storage time have on WHC when a hot boning process is utilized.

The purpose of this study was to investigate the effect of postmortem temperature and storage time on the water-holding capacity of hot boned turkey breast muscle.
MATERIALS AND METHODS

The effect of 0, 12 and 30°C postmortem muscle temperatures and the effect of 24, 96 and 168 hr postmortem storage times were evaluated in turkey breast muscle.

Live tom turkeys weighing 12.3 to 13.6 kg were obtained from a local producer, transported to the Iowa State University Meat Laboratory and held overnight. At the time of slaughter, the birds were placed in a restraining cone and stunned using an electric knife. Postmortem time started after a 3 minute bleeding period. Immediately after bleeding, the birds were skinned and the P. major breast muscles were removed.

Sample Preparation

The P. major breast muscle from one side of each bird was sampled for drip loss. Muscle strips approximately 100 mm long, 17 mm wide and 10 mm thick were removed from the skin side of the muscle. Muscle strips were randomly placed into labeled Nasco Whirl-Pak bags. Duplicate bags were placed in 0, 12 and 30°C water baths at 15 minutes postmortem. After 4 hr of incubation, the samples were transferred to a 2°C cooler.

After muscle strips were removed for drip loss determination, the remaining breast muscle was cut into
approximately 10 mm thick slices starting at the anterior (neck) end of the muscle and progressing to the posterior (tail) end. The slices were randomly placed into 3 labeled bags and then a bag was placed in 0, 12 or 30°C water baths at 15 minutes postmortem. After 4 hr of incubation, bagged slices were transferred to a 2°C cooler. Six to eight hours postmortem, the slices in each bag were trimmed of fat and ground twice through a 3 mm plate. Fluid exudate inside the bags from the muscle slices was mixed back into the ground samples, which were then held in a 2°C cooler.

Drip Loss

An initial muscle strip weight was determined. At 24, 96 and 168 hr postmortem the muscle strip was blotted dry with a paper towel and then weighed to determine muscle strip weight at that time postmortem. Percent drip loss was calculated by subtracting the muscle strip weight from the initial weight, multiplying by 100 and then dividing by the initial weight.

Muscle pH

Triplicate pH readings were taken on each sample at 0.25, 0.50, 1, 3, 8, 24, 96 and 168 hr postmortem. Readings were made using a Corning (Medfield, Massachusetts) model 125 pH meter and a pencil tip style combination pH probe
electrode (Lab Research Products, Lincoln, Nebraska) which was inserted directly into the muscle. Mean values were calculated for each postmortem temperature and time. Statistical differences were not calculated for pH values because no method of stopping the change in muscle pH were used.

Water-Holding Capacity

Two types of homogenate cooking loss were used to measure water-holding capacity (WHC) at 24, 96 and 168 hr postmortem. The first homogenate (HW) contained 24g of ground muscle and 12g of water (2°C). The second homogenate (HWSP) contained 24g of ground muscle and 12g of a solution (2°C) of water, salt (sodium chloride) and sodium tripolyphosphate (STPP). HWSP salt and STPP concentrations were 1.5% and 0.5% of the homogenate weight respectively. Homogenates were made by placing the meat and water or water, salt and STPP solution into a 180 ml Nasco Whirl-Pak bag and then agitating the contents using a Stomacher (Seward Laboratory, London, England) type action for forty cycles. Approximately 6g of each homogenate, in duplicate, was placed into pre-weighed 10 ml Kimax test tubes and reweighed. The tubes were capped using marbles and at one hr after homogenization the tubes were placed in a boiling water bath. After 20 min, the samples were removed and
allowed to cool to room temperature. Free juice was drained and the cooked meat piece was blotted using a paper towel. The meat piece was placed back in the tube and reweighed. Percent cooking yield was determined by dividing the cooked meat weight by the raw homogenate weight and multiplying by 100. This procedure is similar to methods used by Honikel et al. (1981a).

Supernatant Weight And Salt-Soluble Protein

HWSP homogenates were made at 24, 96 and 168 hr postmortem and were used to evaluate WHC. One hour after homogenization, 14g of a solution (water, salt 1.5% and STPP 0.5% at 2°C) was added to 6g of homogenate HWSP in a 50 ml Nalgene centrifuge tube, in duplicate. The salt and STPP levels in the diluted homogenate were 1.5% and 0.5% respectively. The tube was capped and shaken vigorously by hand for 10 sec. The tubes were centrifuged at 20,000xg for 15 min at 5°C, after which the supernatant was decanted and weighed. A solution (water, salt 1.5% and STPP 0.5% at 2°C) equal to the weight of the pellet was added to the supernatant to adjust the supernatant protein concentration to a diluted homogenate basis. To determine the amount of salt-soluble protein (SSP) in the adjusted supernatant, a sample was diluted with water to cause the SSP to precipitate. Five grams of adjusted supernatant was added
to 25 ml of water (2°C) in a 50 ml Nalgene centrifuge tube and then centrifuged at 20,000xg for 15 min at 5°C. The supernatant was decanted and the precipitated salt-soluble proteins contained in the pellet were resolubilized with 2.5g of a water, salt (2%) and STPP (1%) solution (2°C). One half gram of the resolubilized protein solution was added to 0.5 ml of 1N NaOH and then vortexed. Protein concentration was determined using the biuret method (Layne, 1957), and reported as milligrams of supernatant salt-soluble protein per gram of diluted homogenate.

Sarcomere Length

Muscle strips used for drip loss determinations were sampled for sarcomere length at 192 hr postmortem. Approximately 0.2g of muscle from random locations in the muscle strip were homogenized with 10 ml of 0.05M phosphate buffer (pH 7.1). Homogenization was performed in a 50 ml Nalgene tube using a Brinkmann homogenizer (model PT10/35, Brinkmann Instruments, Westbury, New York) with a setting of 8 for 5 sec. Sarcomere length was measured using a phase contrast microscope equipped with a eyepiece micrometer at a magnification of 500x. A total of 16 measurements were made on each sample and means were calculated for each postmortem temperature. Statistical differences were not calculated for sarcomere length values because of the relatively few
measures that were made.

Statistical Analysis

Five birds were utilized in each of three replications. Drip losses, percent yield for HW and HWSP homogenates, supernatant weights and supernatant protein concentrations were analyzed using a randomized split-plot design. Least significant differences (LSD) were calculated when significant F-values (P<.05) were found. Breast portions from each bird which were exposed to one of the three postmortem temperatures were considered main plots and samples from these portions which were used at 24, 96 and 168 hr postmortem were considered subplots. Analysis of variance and LSD were completed using SAS (SAS Institute Inc., 1985) procedures. For pH and sarcomere length no mean separation technique was used.
RESULTS AND DISCUSSION

Changes in postmortem pH were monitored in breast muscle excised immediately after slaughter and held at selected temperatures during the early postmortem period (0.25-4 hr) and then at 2°C during storage. Based on DFD, normal and PSE classification methods, the initial postmortem pH of 6.27 (Table 1) indicates the muscles would have a normal rate of pH decline (Kijowski and Niewiarowicz, 1980; van Hoof and Dezeure-Wallays, 1980). The most rapid drop in pH was found within the first hour postmortem for all muscle temperatures. During the first hour postmortem, the 0°C muscle temperature caused the greatest drop in pH. Observations of an increased rate of pH decline have been reported for beef muscles which experience cold shortening at temperatures near 0°C (Honikel et al., 1981b). Cold shortening has been shown to occur in poultry muscle which was stored at 0°C (Smith et al., 1969), so the rate of pH decline observed in this study with turkey may be associated with cold shortening. While temperature influenced the rate of pH decline, it did not influence the ultimate pH of the breast muscle which was essentially the same at 8 hr. In addition, from 8 to 168 hr postmortem there was essentially no change in the pH readings (Table 1).

Sarcomere length determinations were made on the same
samples that were used for drip loss evaluations. Sampling for sarcomere lengths was at 192 hr postmortem. Average sarcomere lengths were the same for the breast strips at 12 and 30°C temperatures but shorter at 0°C (Table 2). The difference between 0 and 12°C sarcomere lengths is consistent with other reports, at comparable temperatures, which showed increased shortening in poultry at 0°C (Smith et al., 1969; Welbourn et al., 1968). Papa and Fletcher (1986), working with excised broiler breast muscle, found sarcomere lengths of 1.62μ at 4°C and 1.73μ at 16°C, which are similar to the lengths reported here. They also indicated that the shortest sarcomere lengths were found at 0 and 40°C, with little difference observed between 4, 16 and 24°C. The results shown here indicate that the shortening that occurs at 30°C is similar to that at intermediate temperatures.

Some indication of the influence of muscle excision may be gained by comparing these results to those reported by Welbourn et al. (1968) for bone-in turkey. They reported average breast sarcomere lengths of 1.71μ at 0°C and 1.99μ at 16°C chill temperatures. This compares to an average sarcomere length of 1.95μ for breast muscle sarcomeres obtained from commercial turkey operations in a preliminary study. The information reported here suggests that compared to sarcomeres of bone-in breast and intermediate
temperatures, that boning or 0°C results in a reduction in sarcomere length of about 0.25μ, while 0°C in addition to boning reduces the length another 0.1μ (0.35μ total).

Drip loss determinations were made 24, 96 and 168 hr postmortem on muscle strips which were held at 0, 12 or 30°C for the first 4 hr postmortem and then at 2°C during storage. The greatest losses were observed for the 30°C postmortem temperature and losses increased with time for all postmortem temperatures (Table 3). There was a significant (P<.05) interaction found between postmortem temperature and storage time. The interaction can be seen as the increased rate of drip formation at 30°C (slope .023) compared to 0 and 12°C (slopes .016). In beef, minimum drip loss has been shown to correspond with minimum sarcomere shortening (Honikel et al., 1986). This was not observed in this experiment with turkey where sarcomere shortening was greatest at 0°C but no difference in sarcomere length was found between 12 and 30°C. Minimum drip loss was found at 0 and 12°C, while the greatest drip losses occurred at 30°C. The observed increase in breast muscle drip loss may be related to protein denaturation occurring at postmortem muscle temperatures of ≥30°C (Bendall and Wismer-Pedersen, 1962; Penny, 1977; Tarrant and Mothersill, 1977).

Muscle homogenates were made at 24, 96 and 168 hr postmortem using breast muscle which was held at 0, 12 or
30°C for the first 4 hr postmortem and then at 2°C during storage. Differences were found in supernatant weight and salt-soluble protein (SSP) due to postmortem temperature and storage time (Table 4). There was no difference in supernatant weight between the 0 and 12°C homogenates but more supernatant was lost from the 30°C homogenate indicating lower WHC. Increases in supernatant weight occurred during storage from 24 to 96 hr and from 96 to 168 hr. Though no interaction was detected, the results were similar to those observed for drip loss, where increased drip loss occurred at 30°C and during storage. This may be an indication that these raw homogenates have similar water retention abilities as the raw muscle strips used for drip loss determinations.

The amount of SSP was observed to increase with both postmortem temperature and during storage (Table 4). Proteolytic activity is likely the determining factor related to these results. Elevated early postmortem temperature should increase proteolytic activity, which causes greater disruption of myofibrillar proteins (Dutson, 1983). Due to this disruption, greater amounts of salt-soluble protein are extracted and are found in the supernatant fraction of the homogenate. Protein degradation and increases in protein solubility during postmortem storage have been reported by Kijowski (1984) in chicken.
Reduced solubility of a particular protein or group of proteins due to denaturation at the 30°C postmortem temperature appears to be masked by an overall increase in total salt-soluble protein.

Percent cooking yield for a homogenate with water (HW) and a homogenate with water, salt and STPP (HWSP) were used as measures of water-holding capacity. No differences were detected due to either postmortem temperature or storage time in HW percent cooking yield (Table 5). Similar findings have been reported by Honikel et al. (1981b) for the effect of postmortem temperature on cooking yield of beef and water homogenates. These results indicate that the ability of the proteins to retain inherent water or added water when cooked was not influenced by postmortem protein changes.

Different results are observed when water, salt and STPP are added to the homogenate. Differences are observed for HWSP percent cooking yield due to postmortem temperature and storage time (Table 5). The 30°C postmortem temperature reduced homogenate cooking yield compared to the 0 and 12°C temperatures. Reduced water retention capabilities for the breast slices in 30°C postmortem temperature were noted previously for drip loss and supernatant weight. Changes in protein charge and extraction of protein by salt and phosphate alter the arrangement of proteins thereby
increasing the water retained upon cooking (Offer and Trinick, 1983; Trout and Schmidt, 1983). Early postmortem temperature in turkey breast influences how the proteins respond to salt and phosphate action which ultimately determines cooking yield. Compared to the homogenate with water (HW) the results show that salt and STPP increase homogenate cooking yield approximately 12.4%.

At 168 hr postmortem an increase in WHC was observed (Table 5). Increases in WHC with storage have been noted previously and was considered to be related to postmortem proteolytic processes (Hamm, 1960). Disruption of transverse structures such as Z-lines and M-lines, which occurs in poultry may be the mechanism influencing the results seen here (Offer and Trinick, 1983; Kijowski, 1984).

Comparing results for SSP and cooking yield indicates that increases in SSP do not correspond directly to greater cooking yield. The greatest SSP was observed at 30°C while the lowest cooking yield was found for this temperature. This observation would be expected if the proteins, which influence the cooking yield the most, were altered by protein denaturation and/or were not influenced by proteolytic activity. While SSP increases significantly during storage, a significant increase in cooking yield might only be observed after Z-line and M-line structures are adequately degraded. The level of salt and STPP that is
used also may influence the time required to obtain protein extraction and an increase in cooking yield (Offer and Trinick, 1983).

It is concluded that in uncooked breast muscle, WHC is reduced by a postmortem temperature of 30°C. Cooked muscle WHC was influenced by this temperature when salt and STPP was used in the WHC test. In addition, increased drip loss is observed in uncooked breast muscle during storage, but when water, salt and STPP were used, cooked muscle yields increased during storage.
REFERENCES


ACKNOWLEDGEMENTS

The authors thank Oscar Mayer Foods Corporation, Madison, Wisconsin, for partial support of the study. We also thank the Ellsworth, Iowa group of Louis Rich, Inc. for their cooperation and assistance in obtaining birds for the study.
Table 1. Mean pH values of breast muscle at various postmortem temperatures and times

<table>
<thead>
<tr>
<th>Water Bath Temperature (°C)</th>
<th>0.25</th>
<th>0.5</th>
<th>1</th>
<th>3</th>
<th>8</th>
<th>24</th>
<th>96</th>
<th>168</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.27</td>
<td>6.09</td>
<td>5.84</td>
<td>5.77</td>
<td>5.59</td>
<td>5.52</td>
<td>5.55</td>
<td>5.53</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.16</td>
<td>0.16</td>
<td>0.14</td>
<td>0.12</td>
<td>0.08</td>
<td>0.06</td>
<td>0.06</td>
<td>0.09</td>
</tr>
<tr>
<td>12</td>
<td>6.27</td>
<td>6.13</td>
<td>5.98</td>
<td>5.78</td>
<td>5.58</td>
<td>5.53</td>
<td>5.56</td>
<td>5.54</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.16</td>
<td>0.16</td>
<td>0.18</td>
<td>0.11</td>
<td>0.09</td>
<td>0.07</td>
<td>0.07</td>
<td>0.09</td>
</tr>
<tr>
<td>30</td>
<td>6.27</td>
<td>6.20</td>
<td>6.03</td>
<td>5.76</td>
<td>5.55</td>
<td>5.51</td>
<td>5.53</td>
<td>5.50</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.16</td>
<td>0.15</td>
<td>0.15</td>
<td>0.11</td>
<td>0.10</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
</tr>
</tbody>
</table>

^n=15.  
^b Samples were held in a 2°C cooler after 4 hr postmortem.
Table 2. Mean sarcomere lengths of breast muscle myofibrils at various postmortem temperatures

<table>
<thead>
<tr>
<th>Water Bath Temperature (°C)</th>
<th>0</th>
<th>12</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarcomere length (μ)</td>
<td>1.63</td>
<td>1.76</td>
<td>1.76</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.12</td>
<td>0.15</td>
<td>0.21</td>
</tr>
</tbody>
</table>

^ Samples were measured at 192 hr postmortem; n=15.

^b Samples were held in a 2°C cooler after 4 hr postmortem.
Table 3. Mean drip loss percentages of breast muscle at various postmortem temperatures and storage times

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>0</th>
<th>12</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>0.95%</td>
<td>1.11%</td>
<td>3.26%</td>
</tr>
<tr>
<td>96</td>
<td>2.15%</td>
<td>2.36%</td>
<td>5.18%</td>
</tr>
<tr>
<td>168</td>
<td>3.33%</td>
<td>3.45%</td>
<td>6.62%</td>
</tr>
</tbody>
</table>

^ Significant time by temperature interaction, P<0.05; S.E. = 0.19; n=15.

^ Samples were held in a 2°C cooler after 4 hr postmortem.
Table 4. Mean homogenate<sup>a</sup> supernatant weight and salt soluble protein (SSP) of breast muscle at various postmortem temperatures and storage times

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weight (g)</th>
<th>SSP (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Bath</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°C)&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>15.11&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.63&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>12</td>
<td>15.15&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.75&lt;sup&gt;cd&lt;/sup&gt;</td>
</tr>
<tr>
<td>30</td>
<td>15.42&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.90&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.06</td>
<td>0.09</td>
</tr>
<tr>
<td>Time (hours)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>14.97&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.46&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>96</td>
<td>15.28&lt;sup&gt;d&lt;/sup&gt;</td>
<td>2.78&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>168</td>
<td>15.42&lt;sup&gt;e&lt;/sup&gt;</td>
<td>3.03&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.06</td>
<td>0.07</td>
</tr>
</tbody>
</table>

<sup>a</sup> Homogenate HWSP contained water, salt and STPP.

<sup>b</sup> Samples were held in a 2°C cooler after 4 hr postmortem.

<sup>c,d,e</sup> Means in each column with different superscripts are significantly different, P<.05; n=45.
Table 5. Mean homogenate\(^{a}\) cooking yield percentages of breast muscle at various postmortem temperatures and storage times

<table>
<thead>
<tr>
<th>Treatment</th>
<th>HW</th>
<th>HWSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Bath</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°C) (^{b})</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>63.69%</td>
<td>76.42%(^{c})</td>
</tr>
<tr>
<td>12</td>
<td>63.06%</td>
<td>76.66%(^{c})</td>
</tr>
<tr>
<td>30</td>
<td>62.88%</td>
<td>73.99%(^{d})</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.65</td>
<td>0.35</td>
</tr>
<tr>
<td>Time (hours)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>63.72%</td>
<td>75.43%(^{c})</td>
</tr>
<tr>
<td>96</td>
<td>62.44%</td>
<td>75.34%(^{c})</td>
</tr>
<tr>
<td>168</td>
<td>62.88%</td>
<td>76.30%(^{d})</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.61</td>
<td>0.29</td>
</tr>
</tbody>
</table>

\(^{a}\) Homogenate HW contained water and HWSP contained water, salt and STPP.

\(^{b}\) Samples were held in a 2°C cooler after 4 hr postmortem.

\(^{c,d}\) Means in each column with different superscripts are significantly different, P<.05; n=45.
PART II. EFFECTS OF POSTMORTEM MUSCLE TEMPERATURE AND
TIME ON THE WATER-HOLDING CAPACITY OF TURKEY THIGH
EFFECTS OF POSTMORTEM MUSCLE TEMPERATURE AND TIME
ON THE WATER-HOLDING CAPACITY OF TURKEY THIGH

by

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Running Title: Turkey thigh water-holding capacity
ABSTRACT

Turkey thigh muscle excised immediately after slaughter was held at 0, 12 and 30°C from 0.25 to 4 hr postmortem and then stored at 2°C. At selected times postmortem, muscle pH, drip loss, sarcomere length, homogenate supernatant weight, salt soluble protein and cooking yields were determined. Temperature influenced the rate of pH decline but not ultimate pH and the ultimate pH did not change during storage. Minimum sarcomere shortening occurred at 12°C and the greatest shortening occurred at 0°C. An interaction between temperature and postmortem time produced the lowest rate and extent of drip loss at 12°C and the greatest amount of drip loss at 30°C. Increasing temperature and storage time increased supernatant salt soluble protein levels. Longer storage times resulted in higher supernatant weights, while storage time had no effect on cooking yields. The 0°C temperature increased supernatant weight and decreased homogenate cooking yields. These findings indicate that high and low postmortem temperatures and longer storage produce the lowest water-holding capacity in raw turkey thigh muscle, while low postmortem temperatures produced the lowest cooked muscle water-holding capacity.
INTRODUCTION

Hot boning is the postmortem process where muscle is removed from the carcass while it is at close to body temperature. Hot boning, which is a significant change from conventional cold boning methods, has gained interest due to the potential savings in labor, space and energy requirements (Lyon and Hamm, 1986).

Hot boning has a significant effect on muscle toughness compared to conventional processing due to the resulting muscle shortening. The toughness aspect has received research emphasis to determine the influencing factors and various methods have been investigated to overcome toughness associated with hot boning (Hamm, 1983; Lyon and Hamm, 1986). Postmortem temperature and storage time are factors that have been investigated in combination with hot boning, and which have a significant influence on muscle texture characteristics (Smith et al., 1969; Kim et al., 1986; Dutson and Carter, 1985). While the effect of these factors has been investigated in relation to texture, less attention has been given to their effect on muscle water-holding capacity (WHC).

Drip loss that occurs in fresh poultry could be either muscle cell drip loss or water picked up during water chilling. For this reason muscle drip loss considerations
in poultry are not clear when water chilling is used. The amount of muscle drip loss that occurs, can adversely influence the yield of raw muscle, and sensory characteristics similar to how extensive drip loss from thawing frozen muscle does. Postmortem temperature influences muscle shortening and, in beef, the amount of shortening has been directly related to the amount of drip loss that is observed (Honikel et al., 1986). Hot boning could potentially alter the pattern of muscle temperature changes postmortem compared to conventional processing and therefore influence muscle shortening and drip loss. A study using turkey breast muscle has shown that postmortem temperature influences drip loss, but that the effect may not be related directly to sarcomere shortening as it was in beef (Lesiak, 1987).

WHC is also a critical factor when addition of water, salt and phosphate are used along with cooking during further processing steps. Yield and WHC influences on sensory characteristics are important considerations. Because further processing may occur several days after slaughter, the influence of storage time has increased importance and must be considered. Research with turkey breast muscle has shown that postmortem temperature and storage time effect cooking yield when water, salt and phosphate were added to muscle homogenates (Lesiak, 1987).
With increase production of further processed poultry products (processing beyond cut-up parts), there is a need to understand the role that postmortem muscle temperature and storage time play on thigh WHC, when the muscles are boned immediately after slaughter.

The purpose of this study was to investigate the effect of postmortem temperature and storage time on the water-holding capacity of hot boned turkey thigh muscle.
MATERIALS AND METHODS

The effect of 0, 12 and 30°C postmortem muscle temperatures and the effect of 24, 96 and 168 hr postmortem storage times were evaluated in turkey thigh muscle.

Live tom turkeys weighing 12.3 to 13.6 kg were obtained from a local producer, transported to the Iowa State University Meat Laboratory and held overnight. At the time of slaughter, the birds were placed in a restraining cone and stunned using an electric knife. Postmortem time started after a 3 minute bleeding period. Immediately after bleeding, the birds were skinned, the thighs were removed and boned.

Sample Preparation

The tensor fasciae muscles from each thigh were removed and sampled for drip loss. Muscle strips approximately 100 mm long, 17 mm wide and the thickness of the muscle (approximately 15mm) were taken from each muscle. Muscle strips were randomly loaded into labeled Nasco Whirl-Pak bags. Duplicate bags were placed in 0, 12 and 30°C water baths at 15 minutes postmortem. After 4 hr of incubation, the samples were transferred to a 2°C cooler.

After muscle strips were removed for drip loss determination, the remaining thigh was cut across the
muscles into approximately 10 mm thick pieces starting at the dorsal (pelvic) end of the thigh and progressing to the ventral (drum) end. The pieces were randomly placed into 3 labeled bags and then a bag was placed in 0, 12 or 30°C water baths at 15 minutes postmortem. After 4 hr of incubation, bagged pieces were transferred to a 2°C cooler. Six to eight hours postmortem, the pieces in each bag were trimmed of fat and ground twice through a 3 mm plate. Fluid exudate inside the bags from the muscle pieces was mixed back into the ground samples, which were then held in a 2°C cooler.

Drip Loss
An initial muscle strip weight was determined. At 24, 96 and 168 hr postmortem the muscle strip was blotted dry with a paper towel and then weighed to determine muscle strip weight at that time postmortem. Percent drip loss was calculated by subtracting the muscle strip weight from the initial weight, multiplying by 100 and then dividing by the initial weight.

Muscle pH
Triplicate pH readings were taken on each sample at 0.25, 0.50, 1, 3, 8, 24, 96 and 168 hr postmortem. Readings were made using a Corning (Medfield, Massachusetts) model
125 pH meter and a pencil tip style combination pH probe electrode (Lab Research Products, Lincoln, Nebraska) which was inserted directly into the muscle. Mean values were calculated for each postmortem temperature and time. Statistical differences were not calculated for pH values because no method of stopping the change in muscle pH were used.

Water-Holding Capacity

Two types of homogenate cooking loss were used to measure water-holding capacity (WHC) at 24, 96 and 168 hr postmortem. The first homogenate (HW) contained 24g of ground muscle and 12g of water (2°C). The second homogenate (HWSP) contained 24g of ground muscle and 12g of a solution (2°C) of water (sodium chloride), salt and sodium tripolyphosphate (STPP). HWSP salt and STPP concentrations were 1.5% and 0.5% of the homogenate weight respectively. Homogenates were made by placing the meat and water or water, salt and STPP solution into a 180 ml Nasco Whirl-Pak bag and then agitating the contents using a Stomacher (Seward Laboratory, London, England) type action for forty cycles. Approximately 6g of each homogenate, in duplicate, was placed into pre-weighed 10 ml Kimax test tubes and reweighed. The tubes were capped using marbles and at 1 hr after homogenization the tubes were placed in a boiling
water bath. After 20 min, the samples were removed and allowed to cool to room temperature. Free juice was drained and the cooked meat piece was blotted using a paper towel. The meat piece was placed back in the tube and reweighed. Percent cooking yield was determined by dividing the cooked meat weight by the weight of the raw homogenate and multiplying by 100. This procedure is similar to methods used by Honikel et al. (1981a).

Supernatant Weight And Salt Soluble Protein

HWSP homogenates were made at 24, 96 and 168 hr postmortem and were used to evaluate WHC. One hour after homogenization, 14g of a solution (water, salt 1.5% and STPP 0.5% at 2°C) was added to 6g of homogenate HWSP in a 50 ml Nalgene centrifuge tube, in duplicate. The salt and STPP levels in the diluted homogenate were 1.5% and 0.5% respectively. The tube was capped and vigorously shaken by hand for 10 sec. The tubes were centrifuged at 20,000xg for 15 min at 5°C, after which the supernatant was decanted and weighed. A solution (water, salt 1.5% and STPP 0.5% at 2°C) equal to the weight of the pellet was added to the supernatant to adjust the supernatant protein concentration to a diluted homogenate basis. To determine the amount of salt-soluble protein (SSP) in the adjusted supernatant, a sample was diluted with water to cause the SSP to
precipitate. Five grams of adjusted supernatant was added to 25 ml of water (2°C) in a 50 ml Nalgene centrifuge tube and then centrifuged at 20,000xg for 15 min at 5°C. The supernatant was decanted and the precipitated SSP contained in the pellet were resolubilized in 2.5g of a solution (water, salt 2% and STPP 1% at 2°C). One half gram of the resolubilized protein solution was added to 0.5 ml of 1N NaOH and then vortexed. Protein concentration was determined using the biuret method (Layne, 1957), and reported as milligrams of supernatant salt soluble protein per gram of diluted homogenate.

Sarcomere Length

Muscle strips used for drip loss determinations were sampled for sarcomere length at 216 hr postmortem. Approximately 0.2g of muscle from random locations in the muscle strip were homogenized with 10 ml of 0.05M phosphate buffer (pH 7.1). Homogenization was performed in a 50 ml Nalgene tube using a Brinkmann homogenizer (model PT10/35, Brinkmann Instruments, Westbury, New York) with a setting of 8 for 10 seconds. Sarcomere length was measured using a phase contrast microscope equipped with a eyepiece micrometer at a magnification of 500x. A total of 16 measurements were made on each sample and means were calculated for each postmortem temperature. Statistical
differences were not calculated for sarcomere length values because of the relatively few measures that were made.

Statistical Analysis

Five birds were utilized in each of three replications. Drip losses, percent yield for HW and HWSP homogenates, supernatant weights and supernatant protein concentrations were analyzed using a randomized split-plot design. Least significant differences (LSD) were calculated when significant F-values (P<.05) were found. Thigh portions from each bird which were exposed to one of the three temperatures postmortem were considered main plots and samples from these portions which were used at 24, 96 and 168 hr postmortem were considered subplots. Analysis of variance and LSD were completed using SAS (SAS Institute Inc., 1985) procedures. For pH and sarcomere length no mean separation technique was used.
RESULTS AND DISCUSSION

Thigh muscle excised immediately after slaughter was held at selected temperatures during the early postmortem period (0.25-4 hr) and then stored at 2°C during storage. Muscle pH was monitored for each postmortem temperature and during storage. Initial and ultimate pH values (Table 1) were about 0.2 units higher for thigh compared to breast values observed in a previous study (Lesiak, 1987). The greatest decline occurred in the first hr postmortem for all temperatures. The rate of decline was high during this early postmortem period for all temperatures with the colder temperatures showing a slightly greater pH decline through 1 hr postmortem. An increased rate of pH decline has been associated with cold shortening in beef (Honikel et al., 1981b). A greater pH decline has also been observed in turkey breast muscle at 0°C which was found to have greater sarcomere shortening (Lesiak, 1987). After 3 hr postmortem, muscle pH among the postmortem temperatures was essentially the same (Table 1). There was a slight decline in pH from 3 to 24 hr, but pH remained constant from 8 to 168 hr postmortem.

Sarcomere length and drip loss were determined using strips of thigh tensor fasciae muscle which were held at 0, 12 or 30°C up to 4 hr postmortem and then stored at 2°C
during storage. Overall sarcomere lengths were longer for thigh (Table 2) compared to sarcomere lengths reported for breast in a previous study (Lesiak, 1987). Welbourn et al. (1968) also found that thigh sarcomere lengths were longer than breast in nonexcised turkey muscle. In evaluating postmortem temperature effects, they reported bone-in thigh sarcomere lengths of 2.21\(\mu\) for 0°C and 2.38\(\mu\) for 16°C. A sarcomere length of 2.31\(\mu\) was found for thigh muscle obtained from commercial turkey operations in a preliminary study. Comparing these sarcomere lengths for bone-in thigh to those in Table 2 gives an indication of the effect of temperature and hot boning on sarcomere length. In relation to bone-in and intermediate temperatures, about 0.15\(\mu\) greater shortening occurs in thigh which is hot boned or held at 0°C, while 0°C in addition to hot boning results in about 0.35\(\mu\) additional shortening (0.5\(\mu\) total). Cold shortening is evident for both bone-in and excised thigh muscle. The results reported here also show that sarcomere shortening at 0°C is greater than that at 12°C or 30°C. The relative shortening observed is similar to what has been reported for beef muscle, were intermediate shortening was found at 30°C compared to 0 and 12°C (Honikel et al., 1981b).

Prior to sampling for sarcomere length determination the thigh muscle strips were used for drip loss evaluation.
Drip loss (Table 3) for all temperatures and storage times was lower for thigh compared to breast muscle in a similar study (Lesiak, 1987). A significant interaction (P<.05) was found between postmortem temperature and storage time. The interaction can be seen as a lower rate of drip loss formation at 12°C (slope .009) compared to 0°C (slope .015) and 30°C (slope .016). While the amount of drip loss was the same at 24 hr between 0 and 12°C, the thigh strips at 0°C lost more weight over time than strips at 12°C. The drip loss at 30°C was greater and increased at about the same rate as occurred at 0°C. Increased drip loss has been related to greater sarcomere shortening (Honikel et al., 1986). This could explain the differences observed between 0 and 12°C, but it may only be part of the reason for the amount of loss observed at 30°C. Based on sarcomere length alone, 0°C would be expected to cause the greatest drip loss, however, at 30°C less shortening and more drip loss occurred compared to 0°C. Protein denaturation at 30°C may be an additional factor related to the drip loss observed. Other studies have suggested protein denaturation at muscle temperatures of ≥30°C to be a contributory factor in the amount of drip loss observed (Penny, 1977; Tarrant and Mothersill, 1977).

Higher supernatant weights indicate lower water-holding capacity at 0°C compared to 30°C and as storage time
increases (Table 4). Supernatant SSP was found to increase with increased temperature and storage time which has also been observed in turkey breast muscle by Lesiak (1987). Other comparisons to the breast study show that the mean concentration of SSP was lower in thigh (1.88mg/g) compared to breast (2.76mg/g) and that the increase in SSP between 0 and 30°C temperatures was nearly the same for breast (0.27mg/g) and thigh (0.31mg/g). During storage from 24 to 168 hr, the increase in SSP was lower for thigh (0.16mg/g) compared to breast (0.57mg/g). This indicates that the 2°C storage temperature, less proteolytic activity occurred in thigh than in breast. A slower aging process and less proteolysis has been reported for poultry thigh compared to breast (Hay et al., 1973; Wyche and Goodwin, 1974).

Homogenate cooking yield was used as a measure of water-holding capacity of thigh muscle held at 0, 12 and 30°C until 4 hr postmortem and then at 2°C during storage. Two types of homogenates were evaluated, one contained added water (HW) and the other contained water, salt and STPP (HWSP). A lower yield was found for HW at 0°C while no difference was observed due to storage time (Table 5). This finding differs from breast where no difference was found between temperatures (Lesiak, 1987) and in beef, where temperature did not influence water homogenate cooking yield (Honikel et al., 1981b). Thigh muscle pH could influence
yield, however pH was not considered to be different at 0°C compared to 12 and 30°C. It is unclear if the extent of shortening that occurred at 0°C could be an influencing factor.

Similar to HW cooking yield results, HWSP cooking yield for 0°C also was found to be lower than at 12 or 30°C, while there was no difference between 12 and 30°C postmortem temperatures (Table 5). Breast muscle results (Lesiak, 1987) have shown that 30°C produced lower yields. In addition, breast and thigh strips at 30°C had the greatest drip loss. A lower HWSP cooking yield may be expected for thigh but was not observed. The greater drip loss in breast and thigh at 30°C, and the lower cooking yields in breast at 30°C were thought to be related to protein denaturation. These results would indicate that protein denaturation did not influence HWSP cooking yields for thigh.

Shorter sarcomere lengths were observed at 0°C for breast and for thigh, however, the amount of shortening at 0°C compared to 12°C was greater in thigh (0.33μ) than breast (0.13μ). Investigations into postmortem temperature and myofibril swelling characteristics using beef, indicated that sarcomere length did not have an influence on WHC (Honikel et al., 1981b; Offer and Trinick, 1983). However salt and phosphate levels, and extraction time were influencing factors on the extraction of the A-band and
swelling of the myofibril. Based on the difference in sarcomere lengths in thigh and the salt and STPP levels used, the time required to obtain extraction and swelling may have been an influencing factor on HWSP cooking yields observed for 0°C in this study.

No difference in HWSP cooking yields for thigh were observed during storage (Table 5). WHC increases have been reported during storage and were considered to be related to proteolysis (Lesiak, 1987; Hamm, 1960). A proteolytic effect may not be observed in thigh due to the slower aging and proteolysis activity in thigh relative to breast (Hay et al., 1973; Wyche and Goodwin, 1974). Additional comparisons of thigh and breast cooking yield results shows that breast yields are approximately 7.4% higher than thigh and that salt and STPP addition increases homogenate cooking yield approximately 12.3%.

Thigh muscle water-holding capacity characteristics were influenced by postmortem temperature and storage time. The extent that a particular temperature had on water-holding capacity depended on the method used to determine water-holding capacity. The temperature effects for thigh differed from what was observed in a previous study for breast. Storage time did not have as great an effect in thigh water-holding capacity compared to breast.
REFERENCES


ACKNOWLEDGEMENTS

The authors thank Oscar Mayer Foods Corporation, Madison, Wisconsin, for partial support of the study. We also thank the Ellsworth, Iowa group of Louis Rich, Inc. for their cooperation and assistance in obtaining birds for the study.
Table 1. Mean pH values of thigh muscle at various postmortem temperatures and times

<table>
<thead>
<tr>
<th>Water Bath Temperature (°C)</th>
<th>0.25</th>
<th>0.5</th>
<th>1</th>
<th>3</th>
<th>8</th>
<th>24</th>
<th>96</th>
<th>168</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.44</td>
<td>6.10</td>
<td>5.89</td>
<td>5.85</td>
<td>5.70</td>
<td>5.66</td>
<td>5.70</td>
<td>5.69</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.26</td>
<td>0.14</td>
<td>0.18</td>
<td>0.14</td>
<td>0.14</td>
<td>0.13</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>12</td>
<td>6.44</td>
<td>6.14</td>
<td>6.07</td>
<td>5.90</td>
<td>5.75</td>
<td>5.71</td>
<td>5.75</td>
<td>5.73</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.26</td>
<td>0.23</td>
<td>0.24</td>
<td>0.15</td>
<td>0.13</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
</tr>
<tr>
<td>30</td>
<td>6.44</td>
<td>6.26</td>
<td>6.17</td>
<td>5.89</td>
<td>5.75</td>
<td>5.72</td>
<td>5.75</td>
<td>5.71</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.26</td>
<td>0.22</td>
<td>0.25</td>
<td>0.18</td>
<td>0.15</td>
<td>0.12</td>
<td>0.13</td>
<td>0.12</td>
</tr>
</tbody>
</table>

\( \text{a} \) \( n=15 \).

\( \text{b} \) Samples were held in a 2°C cooler after 4 hr postmortem.
Table 2. Mean sarcomere lengths of thigh muscle myofibrils at various postmortem temperatures

<table>
<thead>
<tr>
<th>Water Bath Temperature (°C)</th>
<th>0</th>
<th>12</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarcomere length (μ)</td>
<td>1.89</td>
<td>2.22</td>
<td>2.16</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.27</td>
<td>0.28</td>
<td>0.29</td>
</tr>
</tbody>
</table>

a Samples were measured at 216 hr postmortem; n=15.

b Samples were held in a 2°C cooler after 4 hr postmortem.
Table 3. Mean drip loss percentages of thigh muscle at various postmortem temperatures and storage times\textsuperscript{a}

<table>
<thead>
<tr>
<th>Time (hours)</th>
<th>Water Bath Temperature (°C) \textsuperscript{b}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>24</td>
<td>0.63%</td>
</tr>
<tr>
<td>96</td>
<td>1.76%</td>
</tr>
<tr>
<td>168</td>
<td>2.81%</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Significant time by temperature interaction, P<.05; S.E. = 0.22; n=15.

\textsuperscript{b} Samples were held in a 2°C cooler after 4 hr postmortem.
Table 4. Mean homogenate\textsuperscript{a} supernatant weight and salt soluble protein (SSP) of thigh muscle at various postmortem temperatures and storage times

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weight (g)</th>
<th>SSP (mg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Bath</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°C) \textsuperscript{b}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>15.97\textsuperscript{c}</td>
<td>1.75\textsuperscript{c}</td>
</tr>
<tr>
<td>12</td>
<td>15.91\textsuperscript{cd}</td>
<td>1.83\textsuperscript{c}</td>
</tr>
<tr>
<td>30</td>
<td>15.81\textsuperscript{d}</td>
<td>2.06\textsuperscript{d}</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>Time (hours)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>15.68\textsuperscript{c}</td>
<td>1.78\textsuperscript{c}</td>
</tr>
<tr>
<td>96</td>
<td>15.92\textsuperscript{d}</td>
<td>1.92\textsuperscript{d}</td>
</tr>
<tr>
<td>168</td>
<td>16.08\textsuperscript{e}</td>
<td>1.94\textsuperscript{d}</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.04</td>
<td>0.05</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Homogenate HWSP contained water, salt and STPP.

\textsuperscript{b} Samples were held in a 2°C cooler after 4 hr postmortem.

\textsuperscript{c,d,e} Means in each column with different superscripts are significantly different, \textit{P}<.05; \textit{n}=45.
Table 5. Mean homogenate\textsuperscript{a} cooking yield percentages of thigh muscle at various postmortem temperatures and storage times

<table>
<thead>
<tr>
<th>Treatment</th>
<th>HW</th>
<th>HWSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Bath</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature (°C) \textsuperscript{b}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>55.07%\textsuperscript{c}</td>
<td>66.84%\textsuperscript{c}</td>
</tr>
<tr>
<td>12</td>
<td>56.49%\textsuperscript{d}</td>
<td>68.69%\textsuperscript{d}</td>
</tr>
<tr>
<td>30</td>
<td>56.38%\textsuperscript{d}</td>
<td>68.74%\textsuperscript{d}</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.60</td>
<td>0.52</td>
</tr>
<tr>
<td>Time (hours)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>56.20%</td>
<td>68.45%</td>
</tr>
<tr>
<td>96</td>
<td>55.57%</td>
<td>67.62%</td>
</tr>
<tr>
<td>168</td>
<td>56.18%</td>
<td>68.45%</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.49</td>
<td>0.42</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Homogenate HW contained water and HWSP contained water, salt and STPP.

\textsuperscript{b} Samples were held in a 2°C cooler after 4 hr postmortem.

\textsuperscript{c,d} Means in each column with different superscripts are significant different, $P<.05$; $n=45$. 
PART III. EFFECTS OF POSTMORTEM TIME BEFORE CHILLING AND CHILLING TEMPERATURES ON WATER-HOLDING CAPACITY AND TEXTURE OF TURKEY BREAST MUSCLE
EFFECTS OF POSTMORTEM TIME BEFORE CHILLING AND CHILLING TEMPERATURES ON WATER-HOLDING CAPACITY AND TEXTURE OF TURKEY BREAST MUSCLE

by

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Running Title: Turkey breast water-holding capacity and texture
ABSTRACT

In Part I of the study turkey breast muscle excised immediately after slaughter was chilled at 0°C and then at 3 hr postmortem stored at 2°C. The postmortem time before chilling was varied and the effect on muscle pH, drip loss and homogenate cooking yield was determined. In Part I, pH on day 1 postmortem and cooking yield of water homogenates were not influenced by the postmortem time before chilling. Drip losses increased as the postmortem time before chilling was increased. Water, salt and phosphate homogenate cooking yield decreased when breast muscle was chilled after 60 min postmortem. In Part II prerigor breast slices were held at either 0 or 12°C and then at 3 hr postmortem stored at 2°C. Sarcomere length and drip loss were determined on uncooked breast muscle. After the addition of water, salt and phosphate and cooking, breast slice cooking yield and shear force were determined. In Part II sarcomere length was shorter and drip loss was lower in breast at 0°C compared to breast at 12°C. No differences were observed for further processed muscle cooking yield and shear force due to postmortem chilling temperature.
INTRODUCTION

Changing from conventional cold boning poultry processing to hot boning methods has gained interest due to the potential savings in labor, space and energy requirements (Lyon and Hamm, 1986). The process of hot boning involves removing muscle from the bone while it is at or near body temperature. Due to increased toughness associated with hot boning, methods to minimize toughening have been investigated (Hamm, 1983; Lyon and Hamm, 1986). In addition to hot boning, postmortem temperature has been shown to influence texture characteristics (Smith et al., 1969; Kim et al., 1986; Dutson and Carter, 1985). While texture effects related to postmortem temperature and hot boning have been investigated in poultry, the effects on water-holding capacity (WHC) are not as well understood. WHC is important because of the influence it can have on processing yields and sensory characteristics.

Postmortem temperature effects on excised beef muscle WHC have been observed. When beef muscle was exposed to above 25°C and below 4°C postmortem temperatures, greater muscle shortening occurred and was found to be directly related to greater amounts of muscle drip loss (Honikel et al., 1981b). Temperatures near 0°C, where the greatest shortening was found, produced the most drip loss. In
turkey thigh muscle, 0°C chilling resulted in greater drip loss than at 12°C, but the greatest drip losses were observed at 30°C (Lesiak, 1987). Thigh muscle homogenate cooking yields were reduced by a 0°C postmortem temperature. Greater drip loss and lower homogenate cooking yields were observed for turkey breast muscle at 30°C, while 0 and 12°C minimized water losses (Lesiak, 1987). These results, which show significant effects on WHC, were for muscle that was excised immediately after slaughter and then exposed to various temperatures.

In changing to a hot boning process, the postmortem time before chilling would change from the conventional cold boning system. Because postmortem temperature has an influence on WHC, it is important to understand what effect postmortem time before chilling has on WHC to help in designing a hot boning system. Another factor in addition to time is chilling temperature, since boning could influence how fast the muscle is chilled. While better WHC was observed at 0 and 12°C for excised turkey breast compared to 30°C (Lesiak, 1987), it is likely that texture would be altered by chilling temperature based on previous hot boning and postmortem temperature studies. However, it is unclear whether toughness would be a concern at colder temperatures using hot boned muscle, if the muscle were to be further processed (processing beyond cut-up parts, i.e.,
brine addition and cooking). With increased production of further processed poultry products, it is essential to understand the influence of postmortem temperature of hot boned muscle on toughness, when the muscle is further processed.

The purposes of this study were to determine the effect of postmortem time before chilling on hot boned breast muscle WHC, and postmortem temperature effect on shear force of hot boned turkey breast muscle which is further processed.
MATERIALS AND METHODS

Live tom turkeys weighing 11.4 to 13.6 kg were obtained from a local producer, transported to the Iowa State University muscle Laboratory and held overnight. At the time of slaughter the birds were placed in a restraining cone and stunned using an electric knife. Postmortem time started after a 3 min bleeding period. Immediately after bleeding, the birds were skinned and the P. major breast muscles were removed.

EXPERIMENT I: POSTMORTEM TIME BEFORE CHILLING

Treatments And Sample Preparation

Postmortem times before chilling were 15, 30, 45, 60, 90 and 120 min. The P. major breast muscle from one side of each bird was sampled for drip loss. Muscle strips approximately 50 mm long, 33 mm wide and 10 mm thick were removed from the skin side of the muscle. Muscle strips were randomly placed into labeled Nasco Whirl-Pak bags and then placed in a 30°C water bath at 14 min postmortem to maintain a constant muscle temperature. At 15, 30, 45, 60, 90 and 120 min postmortem, duplicate bags were transferred to a 0°C water bath. At 3 hr postmortem the samples were
transferred to a 2°C cooler.

After drip loss muscle strips were removed, the breast muscle was cut into approximately 10 mm thick slices starting at the anterior (neck) end of the muscle and progressing to the posterior (tail) end. The slices were randomly loaded into labeled bags and then placed in a 30°C water bath at 14 min postmortem. At 15, 30, 45, 60, 90 and 120 min one sample bag was transferred to a 0°C water bath. At 3 hr postmortem the samples were transferred to a 2°C cooler. Six to eight hours postmortem, the slices in each bag were trimmed of fat and ground twice through a 3 mm plate. Fluid exudate inside the bags from the muscle slices was mixed back into the ground samples, which were then held in a 2°C cooler.

Drip Loss

An initial muscle strip weight was determined and on day 1 postmortem the muscle strip was blotted dry with a paper towel and reweighed. Percent drip loss was calculated by subtracting the muscle strip weight from the initial weight, multiplying by 100 and then dividing by the initial weight.
Muscle pH

Triplicate pH readings were taken on the muscle slices in each sample bag just prior to being transferred to the 0°C water bath and again on day 1 postmortem. Readings were made using a Corning (Medfield, Massachusetts) model 125 pH meter and a pencil tip style combination pH probe electrode (Lab Research Products, Lincoln, Nebraska) which was inserted directly into the muscle. Mean values were calculated for each postmortem time before chilling. Statistical differences were not calculated for pH values because no method of stopping the change in muscle pH were used.

Water-Holding Capacity

Two types of homogenate cooking loss were used to measure water-holding capacity (WHC) on day 1 postmortem. The first homogenate (HW) contained 24g of ground muscle and 12g of water (2°C). The second homogenate (HWSF) contained 24g of ground muscle and 12g of a solution of water, salt (sodium chloride) and sodium tripolyphosphate (STPP). HWSF salt and STPP concentrations were 1.5% and 0.5% of the homogenate weight respectively. Homogenates were made by placing the muscle and water or water, salt and phosphate solution into a 180 ml Nasco Whirl-Pak bag and then agitating the contents using a Stomacher (Seward Laboratory,
London, England) type action for forty cycles. Approximately 6g of each homogenate, in duplicate, was placed into pre-weighed 10 ml Kimax test tubes and weighed. The tubes were capped using marbles and at one hr after homogenization the tubes were placed in a boiling water bath. After 20 min, the samples were removed and allowed to cool to room temperature. Free juice was drained and the cooked muscle piece was blotted using a paper towel. The muscle piece was placed back in the tube and reweighed. Percent cooking yield was determined by dividing cooked muscle weight by the raw homogenate weight and multiplying by 100. This procedure is similar to methods used by Honikel et al. (1981a).

Data Analysis

Five birds were used in each of three replications. Percent drip loss and percent yield for HW and HWSP homogenates were analyzed using a randomized design. A least significant difference (LSD) was calculated, to determine differences between the various postmortem times before chilling, when a significant F-value (P<.05) was found. Analysis of variance and LSD were completed using SAS (SAS Institute Inc., 1985) procedures. No mean separation technique was used on muscle pH values.
EXPERIMENT II: CHILLING TEMPERATURES

Treatments And Sample Preparation

Postmortem chilling temperatures of 0 and 12°C were evaluated for their effect on further processed breast shear force. From the remaining P. major breast muscle of each bird used in Part I, 4 slices (2.6 cm thick) were taken parallel to and starting at the ventral (keel) edge of the muscle. The slices were loaded into labeled 11x25 cm Cryovac bags (W. R. Grace & Co., type B540) and placed in either a 0 or 12°C water bath at 15 min postmortem. Placement of the first slice alternated between the two temperatures and adjacent slices were placed in different temperature water baths. At 3 hr postmortem the samples were transferred to a 2°C cooler.

Drip Loss

An initial slice weight was determined and on day 1 postmortem the muscle slice was removed from the bag, blotted with a paper towel and weighed. Percent drip loss was calculated by subtracting the slice weight from the initial weight, multiplying by 100 and then divided by the initial slice weight.
Sarcomere Length

After drip loss was determined on day 1 postmortem the slices were sampled for sarcomere length. Approximately 0.2g of muscle from random locations on the slice surface were homogenized with 10 ml of 0.05M phosphate buffer (pH 7.1). Homogenization was performed in a 50 ml Nalgene tube using a Brinkmann homogenizer (model PT10/35, Brinkmann Instruments, Westbury, New York) with a setting of 8 for 5 seconds. Sarcomere length was measured using a phase contrast microscope equipped with a eyepiece micrometer at a magnification of 500x. A total of 16 measurements were made on each sample and means were calculated for each postmortem temperature. Statistical differences were not calculated for sarcomere length values because of the relatively few measures that were made.

Cooking Loss

On day 1 postmortem after sampling for sarcomere length, a solution (2°C) of water, salt and STPP was added to the bagged breast slice based on the slice weight. Solution was added at a ratio of 0.25 parts to 1 part muscle. The bag was sealed and the bag contents was massaged by hand for 30 sec. The final mixture containing 1.5% salt and 0.5% STPP. Samples were held in a 2°C cooler for 20 hr after which the bag contents was massaged again
for 30 seconds. Bagged slices were loaded into racks which had a spacing of 2.6 cm and placed into a 78°C water bath. Samples were removed when the slice internal temperature reached 72°C. After cooling to room temperature, the bags were opened and the free juice was drained. The cooked muscle slice was blotted with a paper towel and weighed. The percent cook yield was determined by multiplying the cooked slice weight by 100 and then dividing by the raw slice plus the added solution weight.

Warner-Bratzler Shear

Cooked slices were sampled at room temperature using a 13.7 mm diameter circular bore. The Warner-Bratzler shear apparatus had a blade thickness of 1.1 mm, a blade gap of 2.4 mm and a blade speed of 2.8 mm per second. Eight sample cores from each slice were sheared across the length of the core and peak kilograms of force per 13.7 mm core diameter was recorded. The high and low values from each slice were eliminated to reduce any outlier effect.

Statistical Analysis

Five birds were used in each of three replications. Percent drip loss, percent cook yield and Warner-Bratzler shear force were analyzed using a randomized design. When a
significant F-value (P<.05) was found, a least significant difference (LSD) was calculated to determine differences between the two temperatures. Analysis of variance and LSD were completed using SAS (SAS Institute Inc., 1985) procedures. No mean separation technique was used on sarcomere length values.
RESULTS AND DISCUSSION

EXPERIMENT I: POSTMORTEM TIME BEFORE CHILLING

Turkey breast muscle excised prerigor was chilled at 0°C and then at 3 hr postmortem stored at 2°C. The postmortem time before chilling was varied to determine the effects on water-holding capacity. Muscle pH was measured on samples just prior to being placed in the 0°C chilling water and again on day 1 postmortem; the results are listed in Table 1. Muscle pH declined from a value of 6.22 at 15 min postmortem to a value of 5.80 at 120 min postmortem. Although pH varied at the time of chilling initiation, pH on day 1 postmortem did not vary. Other work has shown that temperature affected the rate of pH decline but it did not influence the ultimate muscle pH (Honikel et al., 1981b; Lesiak, 1987).

Drip loss was determined on breast muscle strips loaded in bags which were placed in 0°C chilling water at various postmortem times. As postmortem time before chilling increased, drip loss increased (Table 2). Previous work with breast muscle indicated that a postmortem temperature of 30°C increased drip loss compared to 0 and 12°C postmortem temperatures (Lesiak, 1987). This would indicate that the sooner postmortem muscle temperatures are lowered, less drip loss will occur.
Homogenates were made using breast muscle that was placed in 0°C chilling water at various times postmortem. One homogenate contained water (HW) and another contained water, salt and STPP (HWSP). On day 1 postmortem, HW and HWSP homogenates were made and cooking yield was determined. No differences in HW cooking yields were due to postmortem time before chilling (Table 2). These results are similar to previous work which indicates that postmortem temperature does not have an influence on muscle and water homogenate cooking yields (Lesiak, 1987; Honikel et al., 1981b).

Postmortem time before chilling influenced HWSP cooking yields (Table 2). No difference was detected for chilling initiation times from 15 to 60 min or between 90 and 120 min. A reduction in yield was found between these two periods with the largest reduction occurring between 60 (pH 5.94) and 90 min (pH 5.90). It is important to note that when the homogenates were made on day 1 postmortem, no differences in pH existed between the samples. In poultry, a postmortem pH of 5.9 or higher has been used as an indicator of prerigor muscle conditions (Froning and Neelakantan, 1971) and the damaging effects of high temperature on tenderness have been related to pH values of 5.9 or higher (Kahn, 1971). Previous work with turkey breast has shown that a postmortem temperature of 30°C caused a reduction in cooking yields of homogenates.
containing water, salt and STPP (Lesiak, 1987). These observations would indicate that muscle temperature at the onset of rigor is the main factor altering cooking yields of homogenates containing water, salt and STPP. Changes in HWSP cooking yields occur during a particular postmortem time period, while changes in drip loss occurred throughout the postmortem period. This indicates that the mechanisms influencing drip loss and cooking yields are different.

EXPERIMENT II: CHILLING TEMPERATURES

Postmortem temperature effects on texture of turkey breast muscle excised prerigor were evaluated using the remaining breast half from the birds used in Part I. Breast slices were held at 0 or 12°C from 0.25 to 3 hr postmortem and then stored at 2°C. On day 1 postmortem, a longer sarcomere length was found at 12°C than 0°C (Table 3). In an earlier study, a greater difference was observed in breast sarcomere length between these temperatures (Lesiak, 1987). Drip loss (Table 4) was found to be lower at 0°C than at 12°C. In a previous study (Lesiak, 1987), the drip loss at 0°C was not significantly (P<.05) different from 12°C. The sample weight and surface area were different between the two studies.

After drip loss and sarcomere length determinations were made, water, salt and STPP were added to the slices and
then held for 20 hr at 2°C. The slices were then cooked and
cooking yield determined. No differences were found between
the two chilling temperatures (Table 4) or in a previous
study evaluating cooking yields of breast muscle chilled at
0 and 12°C (Lesiak, 1987).

Cooked slices were sampled for shear force evaluation.
No differences in shear force between the two temperatures
were found (Table 4). Greater shear forces that were
expected for the 0°C temperature may have been minimized by
the addition of water, salt and STPP. Other researchers
have found that salt and phosphate improved tenderness
(Goodwin and Maness, 1984; Mathusa and Janky, 1984; Lyon and
Hamm, 1986).

Results from Part I and II indicate that the postmortem
time before chilling has an influence on uncooked and cooked
muscle water-holding capacity. In addition, the differences
found in uncooked muscle drip loss due to postmortem
temperatures of 0 and 12°C, was not reflected in WHC or
shear force of cooked muscle containing added water, salt
and STPP.
REFERENCES


ACKNOWLEDGEMENTS

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Table 1. Mean breast muscle pH at various postmortem times before chilling and on day 1 postmortem

<table>
<thead>
<tr>
<th>Postmortem Time Before Chilling (min.)</th>
<th>pH</th>
<th>S.D.</th>
<th>pH on day 1</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>6.22</td>
<td>0.15</td>
<td>5.57</td>
<td>0.09</td>
</tr>
<tr>
<td>30</td>
<td>6.02</td>
<td>0.15</td>
<td>5.55</td>
<td>0.08</td>
</tr>
<tr>
<td>45</td>
<td>6.02</td>
<td>0.14</td>
<td>5.55</td>
<td>0.06</td>
</tr>
<tr>
<td>60</td>
<td>5.94</td>
<td>0.10</td>
<td>5.56</td>
<td>0.07</td>
</tr>
<tr>
<td>90</td>
<td>5.90</td>
<td>0.16</td>
<td>5.56</td>
<td>0.06</td>
</tr>
<tr>
<td>120</td>
<td>5.80</td>
<td>0.09</td>
<td>5.56</td>
<td>0.06</td>
</tr>
</tbody>
</table>

a n=15.
Table 2. Mean drip loss and homogenate<sup>a</sup> cooking yield percentages<sup>b</sup> for various postmortem times before chilling

<table>
<thead>
<tr>
<th>Postmortem time before chilling (min)</th>
<th>Drip Loss %</th>
<th>Cooking Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>HW %</td>
</tr>
<tr>
<td>15</td>
<td>0.50&lt;sup&gt;c&lt;/sup&gt;</td>
<td>64.95</td>
</tr>
<tr>
<td>30</td>
<td>0.88&lt;sup&gt;d&lt;/sup&gt;</td>
<td>64.19</td>
</tr>
<tr>
<td>45</td>
<td>0.93&lt;sup&gt;d&lt;/sup&gt;</td>
<td>64.38</td>
</tr>
<tr>
<td>60</td>
<td>1.17&lt;sup&gt;de&lt;/sup&gt;</td>
<td>64.00</td>
</tr>
<tr>
<td>90</td>
<td>1.37&lt;sup&gt;ef&lt;/sup&gt;</td>
<td>64.16</td>
</tr>
<tr>
<td>120</td>
<td>1.60&lt;sup&gt;f&lt;/sup&gt;</td>
<td>63.55</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.11</td>
<td>0.31</td>
</tr>
</tbody>
</table>

<sup>a</sup> Homogenate HW contained water and HWSP contained water, salt and STPP.

<sup>b</sup> Drip loss and cooking yields were determined on day 1 postmortem.

<sup>c, d, e, f</sup> Means in each column with different superscripts are significantly different, P<.05; n=15.
Table 3. Mean sarcomere lengths of breast muscle myofibrils at various postmortem muscle temperatures

<table>
<thead>
<tr>
<th>Water Bath Temperature (°C)</th>
<th>Sarcomere length (µ)</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1.73</td>
<td>0.09</td>
</tr>
<tr>
<td>12</td>
<td>1.77</td>
<td>0.06</td>
</tr>
</tbody>
</table>

\(a\) n=15.

\(b\) Samples were held in a 2°C cooler after 4 hr postmortem.
Table 4. Mean drip loss percentages, cooking yield percentages and shear force of breast muscle at various postmortem temperatures

<table>
<thead>
<tr>
<th>Water bath Temperature (°C)</th>
<th>Drip Loss %</th>
<th>Cooking Yield %</th>
<th>Shear Force (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.53&lt;sup&gt;b&lt;/sup&gt;</td>
<td>82.19</td>
<td>2.58</td>
</tr>
<tr>
<td>12</td>
<td>0.76&lt;sup&gt;c&lt;/sup&gt;</td>
<td>82.72</td>
<td>2.42</td>
</tr>
<tr>
<td>S.E.</td>
<td>0.05</td>
<td>0.41</td>
<td>0.08</td>
</tr>
</tbody>
</table>

<sup>a</sup> Samples were held in a 2°C cooler after 3 hr postmortem.

<sup>b, c</sup> Means in each column with different superscripts are significantly different, p<.05; n=15.
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SUMMARY

Hot boning of poultry has gained interest due to potential savings that can be obtained with the adoption of the hot boning method. Hot boning, postmortem temperature and storage time effects on texture have been studied. The effects of postmortem temperature and storage time on water-holding capacity needed to be evaluated when the hot boning method was utilized.

The purpose of this study was to determine the effect of early postmortem muscle temperature and storage time on the water-holding capacity of hot boned turkey muscle.

At 15 min postmortem, bagged muscle strips and bagged muscle slices were placed in 0, 12 or 30°C water baths and stored at 2°C after 4 hr postmortem. Muscle slice pH was measured at various times postmortem. Postmortem evaluations were conducted at 24, 96 and 168 hr postmortem. Drip loss and sarcomere length were determined using the muscle strips. Muscle slices were ground and homogenates containing water or water, salt and phosphate were made. Cooking yields were determined on both homogenates, while supernatant weight and salt-soluble protein were determined using the homogenate containing water, salt and phosphate. Testing was conducted using turkey breast and thigh muscle.

The results of the study show that early postmortem
temperature and storage time has an influence on the water-holding capacity of turkey muscle. Breast and thigh muscle differ for some of the parameters evaluated. The ultimate muscle pH was not altered by temperature and it did not change during storage of the muscles. The rate of muscle pH decline was greatest at 0°C. The greatest sarcomere shortening occurred at 0°C and the least at 12°C in both muscles. Differences in sarcomere shortening were observed between breast and thigh at the 30°C temperature. Overall breast muscle had shorter sarcomere lengths and greater drip losses than thigh. The greatest drip losses occurred at 30°C for both muscles, though increased sarcomere shortening occurred only in thigh at this temperature. The greatest shortening was found at 0°C in breast and thigh, but at 0°C, an increase in drip loss was observed only in thigh. This indicates that muscle temperature and sarcomere shortening are factors which influence the drip loss of turkey muscle. Supernatant weight results show that greater amounts (lower WHC) occurred at 30°C in breast and at 0°C in thigh. Similar results were seen for homogenate cooking yields where lower cooking yields were also observed at 30°C in breast muscle and at 0°C in thigh muscle. Supernatant salt soluble protein levels were not related to cooking yield. For both muscles, supernatant salt soluble protein increased with
temperature and storage time, as expected; probably due to proteolytic activity. In addition, cooking yields and salt soluble protein levels were greater in breast than thigh. With increased storage time, drip losses and supernatant weights increased. Storage time had no effect on thigh cooking yields, but an increase in cooking yield was observed in breast when salt and phosphate were used in the homogenate. An increase of this type may be related to proteolytic activity and the increase in breast, and not thigh, could be due to greater proteolytic activity in breast compared to thigh.

With higher yields being observed at lower temperatures in breast, the postmortem time before chilling was investigated to determine the effect on water-holding capacity. Bagged breast muscle was placed in a 0°C water bath at various postmortem times and stored at 2°C after 3 hr postmortem. On day 1 postmortem drip loss and cooking yield of ground muscle homogenates containing water or water, salt and phosphate were determined. As part of the study, breast muscle slices were placed in 0 or 12°C water baths at 15 min postmortem and after 3 hr postmortem stored at 2°C. On day 1 postmortem drip loss and sarcomere length were determined. Water, salt and phosphate were added to the breast slices and on day 2 postmortem cooking yield and shear force were determined.
Breast drip loss was reduced when the postmortem time before chilling is minimized. Cooking yields of breast homogenates containing water, salt and phosphate declined when chilling occurred after 60 minutes postmortem, which was about the time the muscle pH dropped to 5.9. The effect of chilling temperature on the texture (shear force) of cooked breast slices containing water, salt and phosphate was also evaluated. No difference in breast slice shear force was found between 0 and 12°C postmortem temperatures.

Based on these observations chilling excised breast muscle to lower temperatures rapidly postmortem would produce greater water-holding capacity and texture would not be influenced if the muscle was further processed. Postmortem muscle temperatures near 0°C are detrimental to the water-holding capacity of thigh muscle. Though drip losses increase with storage time for breast and thigh, storage time was not detrimental to cooking yield.
CONCLUSIONS

1. In hot boned turkey breast muscle, water-holding capacity is highest at 0°C and 12°C, and lowest at 30°C.

2. In hot boned turkey thigh muscle, water-holding capacity is highest at 12°C and lowest at 0°C and 30°C.

3. Longer storage times (168 hr compared to 24 hr) caused water-holding capacity to decrease in hot boned turkey breast and thigh.

4. Increasing the postmortem time to 60 min before chilling causes the water-holding capacity of hot boned turkey breast muscle to decline.

5. Postmortem temperature does not influence the tenderness (shear values) of hot boned further processed turkey breast.

6. Ultimate pH of turkey breast and thigh was not affected by postmortem temperature or storage time.


condition in the breast muscles of chicken broiler. Fleischwirtschaft 59:405. (Abstr.)


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