EFFECTS OF HOT CARCASS WEIGHT AND ANATOMICAL CARCASS LOCATION ON POSTMORTEM TEMPERATURE AND MEAT QUALITY

BY

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THESIS

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ABSTRACT

The U.S. pork industry has experienced a steady increase in pork hot carcass weights over the past 26 years causing concerns about compromised chilling and its impact on meat quality. The objective was to determine the effect of hot carcass weight and anatomical carcass location on postmortem muscle temperature and its relationship to meat quality. Carcasses (N=71) were divided into three categories based on hot carcass weight (HCW): Average (99-101 kg), Heavy (116-126 kg), and Very Heavy (134-144 kg). Temperature data were collected for the ham (semimembranosus), loin (longissimus dorsi), and shoulder (latissimus dorsi) for all carcasses from 1h to 22h postmortem. The next day, pH, visual color, and instrumental color of longissimus dorsi (LD), serratus ventralis (SV), triceps brachii (TB), semitendinosus (ST), and semimembranosus (SM) were determined. Additionally, boneless loin chops were used to determine drip loss, proximate composition, and Warner-Bratzler shear force (cooked to 63°C and 71°C). The effect of HCW, location, and their interaction was analyzed using the MIXED procedure of SAS. Relationships between quality traits and postmortem muscle temperature were determined using the CORR procedure of SAS. Very Heavy carcasses were warmer than Heavy carcasses ($P<0.04$) and Average ($P<0.02$) carcasses from 10h to 22h. From 16h to 22h, Heavy carcasses were warmer ($P\leq0.04$) than Average carcasses. Hams were warmer ($P<0.001$) than shoulders from 1h to 22h postmortem and warmer ($P<0.001$) than loins from 2h to 22h postmortem. Shoulders were warmer ($P<0.003$) than loins from 4h to 22h postmortem. Carcass weight categories did not affect pH or color of loins, SM, TB, or SV ($P\geq0.08$) and did not alter Warner-Bratzler shear force for the boneless loins at either degree of doneness ($P\geq0.33$). Loin temperature was weakly correlated with loin pH from 19h to 22h postmortem (r=0.23 to 0.31, $P\leq0.05$) and with drip loss from 18h to 21h postmortem (r=-0.26 to -0.29, $P\leq0.04$). Warner-Bratzler shear force at both degree of doneness was not correlated ($P\geq0.05$) with temperature

from 1h to 22h postmortem. Overall, these results suggest that increasing HCW decreases chilling rate but did not result in negative effects on the quality of the loin, shoulder, or ham.

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CHAPTER 1: REVIEW OF LITERATURE

INTRODUCTION

Due to the increase in economy of scale, the U.S. pork industry has experienced a steady increase in pork hot carcass weights. Over the past 26 years there has been an increase of 0.6 kg/year while the average pork carcass weight has increased from 82 kg to 97 kg. (*USDA/NASS QuickStats Ad-Hoc Query Tool*, n.d.). Furthermore, Harsh et al. (2017) projected that by the year 2030 pork carcasses are to reach an average weight of 104 kg with increases to 118 kg by 2050. While increasing carcass weights are beneficial due to increasing the size of primals, therefore increasing saleable product and allowing the ability to create novel cuts from larger primals (Cisneros et al., 1996a). There are concerns about the impact of increased carcass weights on chilling and pork quality. Many of U.S. pork abattoirs were built more than 20 years ago when carcass weights were much less than they are today. While processors have adjusted chilling protocols to account for today's carcass weights. These pork abattoirs may not have the chilling capacity to chill heavier carcasses at the same rate as lighter carcasses now and in the future. Previous research established that heavier carcasses chill more slowly than lighter carcasses (Price et al., 2022),which can be due to heavier carcasses having a smaller surface area to volume ratio which decreases chilling rate in comparison to smaller carcasses (Overholt et al., 2019). Additionally, hams chill more slowly than loins (Arkfeld et al., 2016; Melody et al., 2004). Given that heavier carcasses produce larger primals (Cisneros et al., 1996a), there is concern that increasing ham size will require even more time to chill.

Chilling is a fundamental step in establishing and maintaining the safety and quality of meat. Proper chilling is important to reduce the occurrence of negative quality effects, such as pale, soft, and exudative (PSE) pork and cold-shortening. Slowed temperature decline can lead to

an extension of postmortem protein degradation due to elevated muscle temperatures, negatively affecting meat quality (Chauhan & England, 2018; Scheffler & Gerrard, 2007a). However, recent research demonstrated that slower chilling rates due to increased carcass weight had little to no negative effects on loin quality, with more tender loins (Shackelford et al., 2012), and redder loins (Rosenvold et al., 2010) occurring in slower chilled carcasses. Therefore, the goal of this literature review is to provide background information on increased carcass weight and its connection to postmortem metabolism, carcass chilling, and pork quality.

MUSCLE TO MEAT CONVERSION

Energy Metabolism

A critical time period for pork quality is the initial postmortem period where the rate and extent of postmortem metabolism in the muscle is determined. Following exsanguination, tissues continue to make ATP to maintain homeostasis despite the loss of the circulatory system that deprives tissues of oxygen. Therefore, ATP production postmortem is the result of anaerobic energy pathways (Aberle et al., 2001; Matarneh et al., 2017) Phosphocreatine, PCr, is the first pathway that is utilized for creating energy in a time of anoxia and high ATP turnover (Bendall, 1960; Scheffler & Gerrard, 2007b). The use of these high energy phosphates is not sustainable though, and stores of PCr are quickly depleted. Once 70% of PCr has been used, ATP will decline rapidly in muscle tissues leading to a build-up of ADP. This triggers tissues to use glycogen stores in the muscle to maintain energy levels (Bendall, 1960; Scheffler & Gerrard, 2007b). Glycogen is stored in the sarcoplasm of the muscle fiber and the amount of glycogen in the muscle at the time of exsanguination directly impacts the extent of metabolism postmortem (Briskey, 1964).

There are two pathways used to convert muscle glycogen stores into energy: glycogenolysis and glycolysis. Glycogenolysis is the catabolism of glycogen which results in the production of Glucose-6-Phosphate and a small amount of free glucose, which both can be converted to energy through glycolysis. During glycolysis, the metabolism of glucose results in the net production of 2 ATP and the production of 2 pyruvate. Energy is produced by the muscle postmortem to try to maintain homeostasis but also to prevent the formation of actomyosin crossbridges (Briskey, 1964; England et al., 2017; Scheffler et al., 2011). Under anaerobic conditions, pyruvate will be reduced into lactate which will remain in the muscle because it cannot be transported elsewhere in the body to be metabolized (Aberle et al., 2001; Matarneh et al., 2017). The reaction of pyruvate to lactate will hydrolyze ATP and produce hydrogen ions (H^+) and heat which causes a decrease in muscle pH and an increase in muscle temperature (Scheffler & Gerrard, 2007b). Eventually, ATP breakdown will exceed the production of ATP through glycolysis at which point actomyosin bonds will form and rigor is complete.

Temperature Decline and Meat Quality

Temperature coupled with pH decline can lead to meat quality issues, which is why this postmortem relationship is crucial. As previously stated, an increase in temperature results in an increase in the rate and extent of metabolism in muscle, which can result in an increase of denaturation of proteins (Briskey, 1964; Briskey & Wismer-Pedersen, 1961). Specifically, maintaining high temperatures during initial pH decline can lead to the development of pale, soft, and exudative (PSE) meat. PSE meat is characterized by its pale color, soft texture, and its low water holding capacity. The high temperature and low pH results in an increased postmortem glycolytic rate, which can lead to protein denaturation of sarcoplasmic and myofibrillar proteins and decreased protein functionality (Barbut et al., 2008; Briskey, 1964; Scheffler & Gerrard,

2007b). The denaturation of both myofibrillar and sarcoplasmic proteins have been linked to water-holding capacity, specifically increased denaturation leads to decreased water-holding capacity (Scheffler & Gerrard, 2007b). Furthermore, the increased precipitation of sarcoplasmic proteins due to conditions that cause PSE leads to paler color (Joo et al., 1999).

While maintaining high temperatures postmortem leads to quality issues, decreasing carcass temperatures too quickly postmortem can lead to other quality issues. Low temperatures before the onset of rigor will result in thaw rigor or cold shortening depending on the intensity of the temperature decline. Thaw rigor occurs when the muscle is frozen before the onset of rigor can occur. When the muscle is thawed, there will be an influx of calcium which will result in major sarcomere shortening. Cold shortening also results from low temperatures, 15°C or below, before the onset of rigor, however this temperature decline is not as extreme as in thaw rigor. During cold shortening Ca^{+2} will leak from the sarcoplasmic reticulum into the sarcoplasm due to the sarcoplasmic reticulum calcium pump no longer properly functioning. This influx of calcium in the sarcoplasm will result in the contraction and shortening of the sarcomere (Bendall, 1960; Davey & Gilbert, 1974). Sarcomere shortening results from the overlapping of thin and thick filaments and the I-band decreasing in size. This will cause a decrease in tenderness and decrease the water holding capacity of the muscle (Aberle et al., 2001; Matarneh et al., 2017; Savell et al., 2005).

Pork Quality

Ultimate pH is defined as the concentration of hydrogen ions in the muscle at approximately 24 hours postmortem. The scale for pH ranges from 0 (acidic) to 14 (basic), with 0 having a greater concentration of hydrogen ions, 14 having a lower concentration of hydrogen

ions, and 7 representing a neutral solution. Living muscle has a pH of 7.2 which will decline to a pH range of 5.3-6.5 but can vary based on the species. Differences in ultimate pH can be attributed to the amount of glycogen present in the muscle at slaughter and its conversion to pyruvate during the conversion of muscle to meat (Lonergan et al., 2008).

Water-holding capacity is the ability of the meat to retain water when external force is applied (Pearce et al., 2011). Meat contains approximately 75% water which is important in maintaining the profitability of the product through increasing processing yields and meat quality, such as juiciness, tenderness, and flavor (Aberle et al., 2001; Warner, 2017). Water exists in meat in three different types, bound, immobilized, and free. Bound water is attracted to charged molecules like proteins and will stay bound to proteins even when external mechanical and physical forces are applied (Huff-Lonergan & Lonergan, 2005). Immobilized water is found in the spaces between the thick and thin filaments where it is held in place by steric effects and its attraction to bound water. Therefore, immobilized water is released as purge during the rigor process and postmortem pH decline (Huff-Lonergan & Lonergan, 2005; Pearce et al., 2011). Free water is held in the sarcoplasmic area through capillary action and can easily be mobilized from the muscle. Shrinking of the myofibrils and external forces can result in the movement of free water (Huff-Lonergan & Lonergan, 2005; Pearce et al., 2011).

Furthermore, during the process of rigor, meat undergoes pH decline which impacts water-holding capacity. As the pH reaches the isoelectric point of major proteins, myosin=5.4 and actin=5.2, the muscle will lose the ability to bind charged molecules such as water (Huff-Lonergan & Lonergan, 2005). The postmortem decline of pH results in the denaturation of proteins especially when carcasses experience low pH and high temperatures. This denaturation of proteins results in changes in the myofibrillar lattice and shrinking of sarcomeres resulting in

less space for water and decreased water-holding capacity (Offer, 1991; Pearce et al., 2011). This shrinking of sarcomeres impacts immobilized water the most because it is attracted to bound water and not a protein which increases the loss through drip channels (Matarneh et al., 2017).

Color is one of the most influential traits impacting meat purchasing decisions for consumers (Mancini & Hunt, 2005). Myoglobin is the water-soluble protein that serves as the major meat color pigment. Myoglobin is made up of an eight α-helices globular protein that surrounds a heme group where the iron atom is located. The sixth binding site of the heme group is where ligands such as; oxygen, carbon monoxide, water, and nitric oxide bind to form different myoglobin structures. The ligand bound at the sixth coordinate and the state of the iron determines the state of myoglobin. There are four states of myoglobin in muscle: Metmyoglobin, Deoxymyoglobin, Oxymyoglobin, and Carboxymyoglobin, which differ in the ligand bound to the sixth site and the valence of the iron atom. Oxymyoglobin is the relatively stable form of myoglobin that has an oxygen bound at the sixth coordinate which results in a bright red color and a ferrous iron. Deoxymyoglobin is myoglobin that is not bound to an oxygen molecule and appears purple-red in color. Metmyoglobin appears as a brown color due to the low concentration of oxygen, water bound at the sixth coordinate, and ferric iron. Carboxymyoglobin occurs when deoxymyoglobin has a carbon monoxide bond to the sixth coordinate and produces a stable red color. (Aberle et al., 2001; King et al., 2023; Matarneh et al., 2017; Suman & Joseph, 2013).

Depending on the amount and state of myoglobin, meat color can vary. Color can be determined through visual appearance (subjective) or colorimeters and spectrophotometers (objective). Subjective evaluation of visual appearance is completed by trained personnel who uses a standard scale of color measurements. The most common scale used in the United States

is the color standards set by NPPC. The scale ranges from 1 to 6 with 1 being the palest (L* 61) color and 6 being the darkest, red color (L* 31). A score of 1 represents a pale pinkish gray to white color while a score of 6 represent a dark purplish red (National Pork Producers Council (NPPC), 1999). Color can be measured objectively through the use of colorimeters. Colorimeters use the CIE L*a*b* system to determine lightness (L*), redness (a*), and yellowness (b*). Lightness is an indicator of the brightness and darkness of a color, and determined on a scale from 0 (black) to 100 (white). Redness is measured on a scale from –60 (green) to +60 (red). Yellowness is measured on a scale from -60 (blue) to +60 (yellow). The combination of a* and b* values can determine the hue of meat. These values can also be used to determine the chroma, saturation index, of a sample. The farther that a* and b* are from the origin determine how vivid the color is (AMSA, 2012).

Tenderness is one of the main palatability traits consumers need to have a satisfactory eating experience (Dransfield, 1994; Miller et al., 1995; Savell et al., 1987). The factors that influence tenderness are sarcomere length, connective tissue, and the proteolysis of the myofibrillar proteins (Koohmaraie et al., 2002a). Sarcomeres are the contractile unit of the muscle and sarcomere length is determined during the onset of rigor. The contractile state of the muscle at this time can also alter tenderness because shorter sarcomeres results in an increase in force to break through the filaments. Collagen is a connective tissue that can impact the tenderness of the muscle. Collagen increases as an animal ages and is greater in muscles used in locomotion compared with muscles used for support.

Tenderness can be measured through objective and subjective methods. Objective measures of tenderness are determined by the force required to shear through a standardized piece of meat. Two of the common methods of determining tenderness values are Warner-

Bratzler shear force (WBSF) and slice shear force (SSF). WBSF uses cold uniform cores of cooked meat where muscle fibers are sheared parallel to a v-shaped blade, while slice shear force uses a single hot one centimeter slice taken parallel to the muscle fibers and are sheared with a blunt-end blade perpendicular to the muscle fiber orientation (American Meat Science Association (AMSA), 2016; Shackelford et al., 1999). Lower shear values are considered to be more tender and desirable, whereas certified tender values, specifically in beef, are 4.4 kg for WBSF and 20 kg for SSF (ASTM, 2011). A subjective measure of tenderness is completed through the use of trained or untrained sensory panels and their perceptions of tenderness. Training of panelists establishes uniform scales for sensory attributes. This allows researchers to determine the magnitude of differences in tenderness between samples. Untrained or consumer panelists can also evaluate tenderness but these scores are based on their own preferences. Additionally, researchers can employ consumer panelists to determine the acceptability or desirability of meat based on tenderness.

CARCASS CHILLING

Types and Methods of Chilling

There are multiple methods of chilling but typically blast, spray, and conventional chilling methods are used within the pork industry. Blast-chilling typically chills pork carcasses at -20 to -40°C for 1 to 3 hour immediately after harvest, and after this carcasses are placed into a conventional or spray chiller (Huff-Lonergan & Page, 2001). Spray chilling sprays cold water on carcasses periodically and combines this with the movement of air to chill carcasses. Conventional chilling hangs carcasses in a cooler that is approximately 1°C with air moving over the carcasses at a constant velocity for 24 hours. Systems use various chilling mediums to

transfer heat out of carcasses and chill carcasses to optimal temperatures before fabrication (Huff-Lonergan & Page, 2001). The best chilling system is one that decreases temperature and slows pH decline while maintaining meat quality.

Each chilling system uses various chilling mechanisms to transfer heat out of carcasses and decrease the temperature of the carcasses as quickly as possible. There are two main mechanisms of chilling; convection and conduction. Many types of convection exist, however processing facilities typically use forced convection. Forced convection uses the movement of a cooling medium, water or air, over the surface of a carcass to transfer heat. Another chilling mechanism used is conduction which is the movement of heat from high to low temperatures. Typically, this is seen through the movement of heat from the inner parts of the carcass to the surface and then transferred into the environment. These chilling mechanisms combined allow carcasses to chill efficiently while trying to maintain the quality of the meat (Huff-Lonergan & Page, 2001).

Factors Affecting Chilling

Carcass chilling is impacted by different properties of the carcass, which can impact the transfer of heat. The various properties that impact the chilling rate are shape, size, fat cover, temperature difference, and cooling medium flow (Savell et al., 2005). Overholt et al. (2019) reported that heavier carcasses had a smaller surface area to volume ratio, which would impact their chilling rate. Heat can only leave the carcass through the surface, so this decrease in ratio will result in a decrease in the rate of heat dissipation. This decrease in the rate of heat removal and change in ratio leads to concerns about compromised chilling of heavy weight carcasses. Furthermore, subcutaneous fat is an insulator, which affects the removal of heat and slows down

the rate of temperature decline (Koohmaraie et al., 1988; Marsh, 1977). Therefore, carcasses that have a higher amount of subcutaneous fat cover will chill more slowly. Temperature difference between carcasses and chilling systems will affect the speed of heat removal. Carcasses that enter a chilling system that uses lower temperatures, such as blast-chill, will chill more quickly than carcasses placed in a system that uses higher temperatures, such as conventional chilling. Lastly, cooling mediums can impact the chilling of carcasses. The use of spray-chilling systems allows for additional evaporative chilling to occur on carcasses to reduce temperature (Gigiel et al., 1989). Air velocity within chilling systems can also impact chilling, increasing air velocity in a chilling system can help chill carcasses faster especially in conventional chilling systems (Brown & James, 1992).

Hot Carcass Weight and Chilling

Brown & James (1992) observed that heavier carcasses chilled more slowly than lighter carcasses when comparing 40 to 150 kg carcasses in a conventional chilling system. After 10 hours of chilling at 0°C a 40 kg carcass reached the required temperature, 7°C, whereas a 100 kg carcass took 16 hours to reach a similar temperature in the same chilling system. Similarly, many studies reported that increased carcass weights results in slower chilling when carcasses weigh, 50 to 83 kg, 85 to 105 kg, and 104 to 130 kg, (Coulter et al., 1995; Overholt et al., 2019; Price et al., 2022). Price et al. (2022) reported that in the first 5 hours postmortem, hot carcass weight explained 25.4% of the variability in chilling rate, which increased to 32.1% from 5 hours to 13 hours postmortem. Moreover, (Daudin & Kuitche, 1996) observed that decreasing carcass weight from 100 to 50 kg resulted in a 35% increase in temperature decline.

Primals and Chilling

Differences in temperature decline also occurs between primals in the pork carcass. In general, hams chilled more slowly than loins in blast, step-wise, and conventional chilling systems (Arkfeld et al., 2016; Jones et al., 1993; Melody et al., 2004; Overholt et al., 2019; Rosenvold et al., 2010; Springer et al., 2003). For example, in pigs weighing between 53 kg and 130 kg in a blast chilling system, (Arkfeld et al., 2016) longissimus dorsi muscles within the loin primal reached ambient temperature (approximately 1°C) at 14 hours postmortem, while semimembranosus muscles within the ham primal declined to only 2°C at 22 hours postmortem. In contrast, temperature decline of the pork shoulder primal is less understood. Limited studies report shoulder temperature decline similar to the ham primal but slower than the loin in different chilling systems (James et al., 1983; Rosenvold et al., 2010).

The differences in chilling between primals can be attributed to differences in shape, size, fat insulation, and predominant fiber type (Aberle et al., 2001). Primals vary in their ratio of surface area to volume ratio which impacts the rate of heat dissipation. There is a lower surface area to volume ratio for hams compared to loins indicating that loins will chill quicker (Ohene-Adjei et al., 2002). In addition, primals with a lower surface area to volume ratio, such as the shoulder and ham, form temperature gradients throughout chilling because heat releases through the surface. Therefore slowing down the rate of heat dissipation in larger primals resulting in slower chilling for the center portions. Furthermore, amount of subcutaneous fat can affect primal chilling. As stated previously, subcutaneous fat is an insulator that decreases heat removal and temperature decline. A report by (Mitchell et al., 1998) estimated 23.9% fat in hams, 33.94% fat in loins, and 27.02% fat in shoulders through chemical analysis, indicating that loins typically have more subcutaneous fat cover compared to the ham and shoulder. Therefore, we would

expect loins to chill more slowly compared to hams and shoulders of the same dimensions due to the fat content. However loins have other characteristics mentioned previously that factor together for the loin to chill more quickly than the shoulder and ham. Predominate fiber type (red vs white) varies between primals, and can result in differences during postmortem metabolism (Karlsson et al., 1999). Muscles that are more glycolytic contain more type IIB fibers and undergo more postmortem glycolysis, which produces more heat initially postmortem (Ohene-Adjei et al., 2002). Therefore, in the context of primals we would expect the loin and ham to undergo more postmortem glycolysis and produce more heat due to the higher ratio of glycolytic fibers. However the shoulder primal has a higher ratio of oxidative fibers which will decrease the amount of postmortem glycolysis and heat production. All of these factors combined can result in differences in heat production postmortem and chilling postmortem.

PROTEIN DEGRADATION

During storage postmortem, meat held at temperatures ranging from 2°C to 4°C can undergo metabolism that results in the degradation of muscle proteins, specifically during carcass chilling and the post-fabrication aging period. These proteins have different roles in muscle structure; some degraded proteins can disrupt the myofibril structure and improve tenderness.

Muscle Proteins

Myofibrillar proteins make up the myofibril in the muscle and aid in contraction or structure of the myofibril. These proteins make up the majority of skeletal muscle, accounting for 55-60% of the total muscle proteins (Asghar et al., 1985). Myosin and actin are the two main proteins in the myofibril and are the proteins responsible for muscle contraction. Additionally, myofibrillar proteins are also responsible for binding water, gelation, and encapsulation of fats for emulsification (Xiong, 2014).

Troponin and tropomyosin are two regulatory proteins involved in muscle contraction. Troponin acts as the calcium regulator for muscle contraction. Troponin binds to calcium and sends information to actin resulting in structural changes that activate the myosin ATPase activity and contraction (Zot & Potter, 1987). Troponin complex consists of three parts: Troponin C, Troponin I, and Troponin T. Troponin C (TnC) is known as a calcium receptor protein which has four calcium binding sites. These four sites of calcium binding fall into two categories, high and low affinity for the binding of calcium. Sites I and II have low affinity while sites III and IV have high affinity for binding calcium. Furthermore, sites I and II are the calcium regulation sites for contraction, sites III and IV bind calcium and magnesium (Ohtsuki & Morimoto, 2013; Zot & Potter, 1987). The binding of calcium in TnC allows for the regulation of activation of thin filament in contraction. Troponin I (TnI) is responsible for inhibiting the actomyosin ATPase, and therefore inhibiting contraction. TnI can inhibit contraction regardless of the amount of calcium present. Troponin T (TnT) binds the troponin complex to tropomyosin. Tropomyosin is an actin-associated protein that helps regulate muscle contraction and relaxation. Specifically, tropomyosin moves from a myosin-blocking position to a nonblocking position. This allows for the contraction and relaxation of the muscle. Troponin and tropomyosin work together during muscle contraction. Every time that the troponin complex interacts with calcium the tropomyosin protein moves and allows for the interaction between actin and myosin. Absence of calcium results in another movement of tropomyosin to block myosin form interacting with actin.

Desmin is an intermediate filament protein that is typically found in the Z-line region. As animals age, desmin becomes more concentrated around the Z-discs. This is due to desmin linking individual myofibrils to the Z-discs (Clark et al., 2002; Dara et al., 2021). Furthermore,

desmin is important in the maintenance of structural and mechanical integrity of the contractile structure of the muscle (Paulin & Li, 2004). While desmin does not contribute to muscle contraction, it plays a large role in overall muscle integrity.

Proteolytic Systems in Muscle and Meat

There are several proteolytic systems including lysosomal cathepsins, calpains, and proteinases within muscle. Lysosomal cathepsins are located within the lysosomes of muscle cells, however during the postmortem period when temperatures and pH are dropping these lysosomes can rupture (Koohmaraie, 1994). Cathepsins B, D, H, and L are present in the muscle fibers and degrade some proteins during the postmortem aging period (Bowker et al., 2010). These cathepsins do not play a key role in postmortem tenderization; however, these cathepsins do degrade small amounts of myofibrillar proteins.

The primary role of the calpain system in postmortem protein degradation is tenderization. Calpains are calcium dependent proteases found in muscle fibers and made up of isoforms μ-calpain and m-calpain (Huff-Lonergan & Lonergan, 1999). The m-calpain is located in the cytosol while μ-calpain is mostly bound to myofibrils. Each isoform requires a different amount of calcium to activate, m-calpain requiring more calcium to activate (Bhat et al., 2018). Since m-calpain requires so much more calcium, μ-calpain has a more significant role in postmortem proteolysis and tenderization. Calpains in muscle are involved in the degradation of titin, nebulin, desmin, troponin-T, troponin-I, and tropomyosin. However, calpains do not degrade major myofibrillar proteins such as myosin and actin (Huff Lonergan et al., 2010; Huff-Lonergan & Lonergan, 1999). Degradation of myofibrillar proteins occurs through calpains becoming active through binding calcium, and then calpains will cleave proteins into large

polypeptides (Bhat et al., 2018). Furthermore, calpastatin is the protein inhibitor and a regulating factor for calpains. Calpastatin binds to the active site of calpain creating the calpastatin-calpain complex and inhibits the proteolytic activity of calpain (Ertbjerg, 2022).

Another proteolysis system within muscle is proteasomes. Within the muscle, proteasomes are responsible for the degradation of misfolded, damaged, and unneeded proteins within the cell (Koohmaraie & Geesink, 2006). The ubiquitin-proteasome system is important in the muscle for processes such as cell cycle progression, apoptosis, and transcriptional regulation (Ertbjerg, 2022). Through this system, proteins that need to be degraded are targeted by the 26S proteasome due to the multi-ubiquitin chain attached to the protein. E1 ubiquitin-activating enzyme, E2 ubiquitin-conjugating enzyme, and E3 ubiquitin-protein ligases are responsible for the ubiquitination of proteins that need to be degraded. This allows the protein to be recognized by the 26S proteasome and be degraded (Kitajima et al., 2020). While there is an important role for these proteasomes in living muscle, there is not a significant degradation of myofibrils by these proteasomes in the postmortem muscle (Huff Lonergan et al., 2010). Even though proteasomes cannot degrade myofibrils, proteasomes do degrade the protein substrates that the calpains produce in the cell and sarcoplasmic proteins (Goll et al., 2008).

Temperature Effects on Muscle Proteolytic Systems

Decreasing the temperature of meat is important to regulate enzyme activity and protein breakdown throughout the carcass. Enzymes will continue to be active until conditions, such as lower pH and temperatures, are no longer favorable for enzyme function. Enzymes that are specific to protein degradation in meat products are calpain, cathepsin and proteasome. Myofibrillar proteins, troponin-T and desmin, along with others are degraded by calpains (Huff-Lonergan et al., 1996).

Proteolytic systems, like all enzymes, have a range of temperatures where they can be active. Calpains are active at temperatures below 40℃ and cathepsin below 50℃ (Gibson & Newsham, 2018; Pomponio & Ertbjerg, 2012). These temperatures are rarely exceeded during the postmortem period but do establish an upper-limit for enzyme activity. Furthermore, if temperatures are below freezing, -2 to -3℃, calpain and cathepsins are inactive (Bhat et al., 2018). Additionally, enzyme activity increases with higher temperatures to increase protein degradation, therefore in the initial postmortem period when carcass temperatures are high there is an increase in enzyme activity (Huff Lonergan et al., 2010; Pomponio & Ertbjerg, 2012).

O'Halloran et al. (1997) reported that cathepsins, which are located in the lysosomes, can be impacted by increased carcass temperature due to the disruption of the lysosomal membrane. This can lead to an increase in cathepsin released resulting in increased protein degradation in carcasses that maintain a higher temperature for longer periods of time thus increasing cathepsin activity (Moeller et al., 1976, 1977) . Additionally, (Pomponio & Ertbjerg, 2012) demonstrated that both μ-calpain and m-calpain are activated by higher temperature incubation, indicating that higher carcass temperatures can lead to more enzyme activity and therefore the potential to have more proteolytic degradation. However, maintaining higher temperatures for extended periods of time postmortem, results in decreased formation of new autolysis products and instability of enzymes, which will result in a loss of activity (Pomponio & Ertbjerg, 2012).

Chilling at different temperatures or using different chilling methods that have increased chilling temperatures, result in increased protein proteolysis, such as cathepsin activity and myofibrillar fragmentation index (Rees et al., 2002; Rosenvold et al., 2010). Specifically (Rees et al., 2003) reported that chilling pork carcasses at 14℃ promoted proteolytic activity relative to chilling at 2℃ due to the increased temperature early postmortem and lower pH. However,

(Shackelford et al., 2012) found that chilling rate did not significantly affect postmortem protein proteolysis for samples taken from fast and slow chilling carcasses.

Protein Degradation and Pork Quality

The amount of degradation of specific proteins is responsible for many pork quality factors, including tenderness and water-holding capacity. Differences in degradation of myofibrillar proteins, which are the largest group of muscle proteins, are responsible for the variation in tenderness between chops (Koohmaraie et al., 2002b). Pork that undergoes a larger amount of titin, troponin-T, nebulin, filament, and desmin degradation exhibit lower shear and star probe values, indicating the weakening of myofibrils resulting in a more tender product (Carlson et al., 2017; Huff-Lonergan et al., 1996; Ramos et al., 2021). Specifically troponin degradation has a key relationship with pork tenderness and overall postmortem proteolysis (Carlson et al., 2017; Huff Lonergan et al., 2010). Carlson et al. (2017) study demonstrated that chops with low star probe values experienced a greater amount of degraded desmin and troponin-T products.

Furthermore, water-holding capacity is directly affected by protein degradation, specifically proteolysis of intermediate filament proteins, such as desmin (Huff-Lonergan & Lonergan, 2005). Increased degradation of desmin leads to reduced shrinkage of muscle cells, and therefore more area for water to accumulate inside cells reducing water escaping into drip channels (Kristensen & Purslow, 2001). There was a positive correlation between intact desmin and drip or purge loss throughout postmortem storage for pork sirloins stored up to seven days postmortem (Zhang et al., 2006). Similarly, enhanced loins that experienced less desmin degradation had increased purge loss (Davis et al., 2004).

HOT CARCASS WEIGHT AND PORK QUALITY

There are several factors that contribute to pork quality including ultimate pH, water holding capacity, color, and tenderness. Ultimate pH impacts many other fresh pork quality factors such as: water holding capacity, color, and tenderness (Huff-Lonergan et al., 2002; Melody et al., 2004). Changes in pH decline that occur too rapidly or too slowly can alter water-holding capacity and color due to changes in the degradation of sarcoplasmic and myofibrillar proteins as demonstrated by PSE and DFD meat (Bendall & Swatland, 1988; Offer, 1991).

Ultimate pH and Water-Holding Capacity

There are varying results on hot carcass weight and its impact on ultimate pH. A review of literature by (Wu et al., 2017), stated that an increase in hot carcass weight resulted in a decline in the ultimate pH of meat. When comparing pigs from 100 to 160 kg, (Cisneros et al., 1996b) reported a 0.2 unit decrease in ultimate pH with every 10 kg increase in slaughter weight. Furthermore, carcass weight is only responsible for 1.23% of the variability in ultimate loin pH in pork carcasses (Harsh et al., 2017). In contrast, (Beattie et al., 1999; Park & Lee, 2011; Price et al., 2022; Rice et al., 2019) all observed no significant changes in ultimate pH with increasing carcass weights ranging from 70 to 113 kg, 110 to 125 kg, 104 to 130 kg, and 111 to 124 kg, respectively.

Previous work has also demonstrated that slower chilling results in no differences in the ultimate pH of the loin (Dransfield et al., 1991; Price et al., 2022; Shackelford et al., 2012). (Rosenvold et al., 2010) observed smaller pH values at 24 hours postmortem for stepwise chilled, slower chilled, carcasses compared to conventionally chilled. We can speculate that heavier carcasses from 100 to 130 kg will experience slower chilling rates which will result in a decrease or no change in ultimate pH.

Increased carcass weights and decreased chilling rates can lead to concerns with water-holding capacity. Rice et al. (2019) reported no significant differences in longissimus muscle drip loss or purge loss with increased carcass weight. In contrast, (Virgili et al., 2003) reported a 0.34 percentage unit increase in longissimus drip loss for every 10 kg increase in hot carcass weight and (Cisneros et al., 1996a) observed a 0.30 percentage unit increase of drip loss in the longissimus for every 10 kg increase in slaughter weight. Another factor directly related to water holding capacity is cook loss. Price et al. (2019) observed a reduction of 0.51 percentage units in loin chop cook loss for every 10-kg increase in carcass weights where carcass weight only explained 15% of the variation. Similarly, other studies observed a decrease in cook loss percentage with increased carcass weights for loin chops cooked to 73°C, 71°C, and 68°C, respectively (Đurkin et al., 2012; Harsh et al., 2017; Virgili et al., 2003). Price et al. (2022) reported no differences in cook loss for loin chops cooked to 63°C from fast and slow chilling carcasses, however when chops were cooked to 71°C, faster chilling carcass had increased cook loss percentage. Rosenvold et al. (2010) reported no differences in cook loss for bicep femoris chops cooked to 70°C, from conventional and step-wise chilling systems. In contrast, (Tomović et al., 2008) reported lower cook loss percentage in semimembranosus chops, cooked to 75°C, from rapid chilling compared to slower chilling methods.

Color and Marbling

Hot carcass weights and chilling rates can influence objective color measurements. Increased hot carcass weight decreased L* and increased a* resulting in darker, redder loins. (Harsh et al., 2017). However, (Park & Lee, 2011) reported a numerical increase in a*, redness, but not a significant difference between hot carcass weight categories, ranging weights from 110 kg to 140 kg. While (Rice et al., 2019) had no differences between hot carcass categories and

instrumental color values. Lighter carcasses resulted in increased L* values (Beattie et al., 1999). No differences in L* values for boneless pork chops were reported between fast, medium, and slow chilling groups by (Price et al., 2022). Semimembranosus muscles were not different when carcasses were chilled slowly through conventional chilling or through rapid chilling (Tomović et al., 2008). In a study by (Rosenvold et al., 2010), there is also increased L* values but also increased a* values indicating loins were lighter and more red in color when undergoing stepwise chilling, a slower method of carcass chilling.

Huff-Lonergan et al. (2002) reported that carcass weight is weakly correlated with marbling scores (r =0.09). However studies have reported inconsistent results when evaluating the increased carcass weights and marbling scores. Harsh et al. (2017) reported that increased carcass weights did not have differences in subjective marbling score at 1 d postmortem, however subjective marbling score did increase with carcass weight at 20 d of aging. However, (Park & Lee, 2011) reported that increasing slaughter weight, from 110 kg to 125 kg, increases marbling score. Most studies reported no differences in subjective marbling with increased carcass weight (Cisneros et al., 1996a; Correa et al., 2006; Piao et al., 2004; Price et al., 2019). Furthermore, increased carcass weight did not impact chop lipid percentage (Correa et al., 2006; Price et al., 2019).

Sensory Attributes

Conflicting results are reported between increased carcass weights and shear force values. (Harsh et al., 2017) observed a 1.26 kg decrease in slice shear force for every 10 kg increase in carcass weight for carcasses weighing 53 to 129 kg. Similarly, (Price et al., 2019) reported for every 1 kg increase in carcass weight there was a 0.07 kg decrease in slice shear force value for carcasses weighing 78 to 145 kg. On the contrary (Rice et al., 2019), (Cisneros et al., 1996a),

(Beattie et al., 1999), and (Latorre et al., 2004) all reported no significant differences in shear force with increased carcass weights for carcasses weighing 111 to 124 kg, 100 to 160 kg, 70 to 100 kg, and 116 to 133 kg, respectively. Furthermore, (Rice et al., 2019) reported that consumer panelist found chops from increased carcass weight groups to be tenderer than lighter carcasses.

Many chilling studies that report carcasses undergoing fast-chilling result in increased shear force values when compared to slower chilling (Feldhusen & Kühne, 1992; James et al., 1983; Price et al., 2022; Rees et al., 2002; Rosenvold et al., 2010; Shackelford et al., 2012). Specifically (Shackelford et al., 2012) observed that faster chilling resulted in increased shear values for longissimus muscle and that faster chilling resulted in a 13-fold increase in the frequency of slice shear values over 25 kg or samples labeled excessively tough. In contrast, (Dransfield et al., 1991) observed that chilling rate had no impact on toughness when compared to conventional chilling, but found that the differences in toughness could be attributed to other factors such as stunning and suspension methods.

Another sensory attribute that can be impacted by carcass weight is juiciness. (Rice et al., 2019) reported a tendency for juiciness to increase with increased carcass weights from consumer panel scores. Furthermore, (Cisneros et al., 1996a) and (Park & Lee, 2011) reported no differences in juiciness scores from a trained panel when carcass weights increased. When chops were cooked to 71℃ trained panelist found chops from heavier carcasses to be more juicy, however there were no differences in juiciness scores from trained panelist when chops were cooked to 63℃ (Price et al., 2022).

CONCLUSION

As reviewed, increased carcass weights can lead to slower chilling rates resulting in differences in pork quality. This may be due to the differences that occur in protein degradation

or the relationship of pH and temperature postmortem due to the slower temperature decline. Previous research has contradicting results on the impact of slower chilling on pork quality, which could be due to differences in the chilling systems or stunning methods. Therefore, the objective was to determine the effects of hot carcass weight and carcass location on postmortem muscle temperature and its relationship with loin, shoulder, and ham quality traits.

LITERATURE CITED

Aberle, E. D., Forrest, J. C., Gerrard, D. E., & Mills, E. W. (2001). *Principles of meat science*. Kendall Hunt.

American Meat Science Association (AMSA). (2016). Research Guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. *AMSA*.

Arkfeld, E. K., Wilson, K. B., Overholt, M. F., Harsh, B. N., Lowell, J. E., Hogan, E. K., Klehm, B. J., Bohrer, B. M., Mohrhauser, D. A., King, D. A., Wheeler, T. L., Dilger, A. C., Shackelford, S. D., & Boler, D. D. (2016). Pork loin quality is not indicative of fresh belly or fresh and cured ham quality. *Journal of Animal Science*, *94*(12), 5155–5167. https://doi.org/10.2527/jas.2016-0886

Asghar, A., Samejima, K., Yasui, T., & Henrickson, R. L. (1985). Functionality of muscle proteins in gelation mechanisms of structured meat products. *Critical Reviews in Food Science & Nutrition*, *22*(1), 27–106.

ASTM. (2011). *Standard specification for tenderness marketing claims associated with meat cuts derived from beef*. ASTM International West Conshohocken (PA).

Barbut, S., Sosnicki, A. A., Lonergan, S. M., Knapp, T., Ciobanu, D. C., Gatcliffe, L. J., Huff-Lonergan, E., & Wilson, E. W. (2008). Progress in reducing the pale, soft and exudative (PSE) problem in pork and poultry meat. *Meat Science*, *79*(1), 46–63. https://doi.org/https://doi.org/10.1016/j.meatsci.2007.07.031

Beattie, V. E., Weatherup, R. N., Moss, B. W., & Walker, N. (1999). The effect of increasing carcass weight of finishing boars and gilts on joint composition and meat quality. *Meat Science*, *52*(2), 205–211.

Bendall, J. R. (1960). Postmortem changes in muscle. *The Structure and Function of Muscle*, *2*(Part 1), 243–309.

Bendall, J. R., & Swatland, H. J. (1988). A review of the relationships of pH with physical aspects of pork quality. *Meat Science*, *24*(2), 85–126. https://doi.org/https://doi.org/10.1016/0309-1740(88)90052-6

Bhat, Z. F., Morton, J. D., Mason, S. L., & Bekhit, A. E.-D. A. (2018). Role of calpain system in meat tenderness: A review. *Food Science and Human Wellness*, *7*(3), 196–204. https://doi.org/https://doi.org/10.1016/j.fshw.2018.08.002

Bowker, B. C., Eastridge, J. S., Paroczay, E. W., Callahan, J. A., & Solomon, M. B. (2010). Aging/tenderization mechanisms. *Handbook of Meat Processing. Ed. F. Toldrá. Blackwell Publishing, Ames, Iowa*, 87–104.

Briskey, E. J. (1964). Etiological Status and Associated Studies of Pale, Soft, Exudative Porcine Musculature*. In C. O. Chichester, E. M. Mrak, & G. F. Stewart (Eds.), *Advances in Food Research* (Vol. 13, pp. 89–178). Academic Press. https://doi.org/https://doi.org/10.1016/S0065-2628(08)60100-7

Briskey, E. J., & Wismer-Pedersen, J. (1961). Biochemistry of Pork Muscle Structure. 1. Rate of Anaerobic Glycolysis and Temperature Change versus the Apparent Structure of Muscle Tissue a. *Journal of Food Science*, *26*(3), 297–305.

Brown, T., & James, S. J. (1992). Process design data for pork chilling. *International Journal of Refrigeration*, *15*(5), 281–289. https://doi.org/https://doi.org/10.1016/0140-7007(92)90043-T

Carlson, K. B., Prusa, K. J., Fedler, C. A., Steadham, E. M., Outhouse, A. C., King, D. A., Huff-Lonergan, E., & Lonergan, S. M. (2017). Postmortem protein degradation is a key contributor to fresh pork loin tenderness. *Journal of Animal Science*, *95*(4), 1574–1586. https://doi.org/10.2527/jas.2016.1032

Chauhan, S. S., & England, E. M. (2018). Postmortem glycolysis and glycogenolysis: insights from species comparisons. *Meat Science*, *144*, 118–126. https://doi.org/10.1016/J.MEATSCI.2018.06.021

Cisneros, F., Ellis, M., McKeith, F. K., McCaw, J., & Fernando, R. L. (1996a). Influence of slaughter weight on growth and carcass characteristics, commercial cutting and curing yields, and meat quality of barrows and gilts from two genotypes. *Journal of Animal Science*, *74*(5), 925–933. https://doi.org/10.2527/1996.745925x

Clark, K. A., McElhinny, A. S., Beckerle, M. C., & Gregorio, C. C. (2002). Striated muscle cytoarchitecture: an intricate web of form and function. *Annual Review of Cell and Developmental Biology*, *18*(1), 637–706.

Color, A. M. (2012). Measurement Guidelines. *American Meat Science Association: Savoy, IL, USA*.

Correa, J. A., Faucitano, L., Laforest, J. P., Rivest, J., Marcoux, M., & Gariépy, C. (2006). Effects of slaughter weight on carcass composition and meat quality in pigs of two different growth rates. *Meat Science*, *72*(1), 91–99. https://doi.org/https://doi.org/10.1016/j.meatsci.2005.06.006

Coulter, S., Pham, Q. T., McNeil, I., & McPhail, N. G. (1995). Geometry, cooling rates and weight losses during pig chilling. *International Journal of Refrigeration*, *18*(7), 456–464. https://doi.org/https://doi.org/10.1016/0140-7007(95)00039-E

Dara, P. K., Geetha, A., Mohanty, U., Raghavankutty, M., Mathew, S., Chandragiri Nagarajarao, R., & Rangasamy, A. (2021). Extraction and Characterization of Myofibrillar Proteins from Different Meat Sources: A Comparative Study. *Journal of Bioresources and Bioproducts*, *6*(4), 367–378. https://doi.org/https://doi.org/10.1016/j.jobab.2021.04.004

Daudin, J. D., & Kuitche, A. (1996). Modelling of temperature and weight loss kinetics during meat chilling for time variable conditions using an analytical based method — III. Calculations versus measurements on pork carcass hindquarters. *Journal of Food Engineering*, *29*(1), 39–62. https://doi.org/https://doi.org/10.1016/0260-8774(95)00063-1

Davey, C. L., & Gilbert, K. V. (1974). The mechanism of cold-induced shortening in beef muscle. *International Journal of Food Science & Technology*, *9*(1), 51–58.

Davis, K. J., Sebranek, J. G., Huff-Lonergan, E., & Lonergan, S. M. (2004). The effects of aging on moisture-enhanced pork loins. *Meat Science*, *66*(3), 519–524. https://doi.org/https://doi.org/10.1016/S0309-1740(03)00154-2

Dransfield, E. (1994). Tenderness of meat, poultry and fish. *Quality Attributes and Their Measurement in Meat, Poultry and Fish Products*, 289–315.

Dransfield, E., Ledwith, M. J., & Taylor, A. A. (1991). Effect of electrical stimulation, hip suspension and ageing on quality of chilled pig meat. *Meat Science*, *29*(2), 129–139. https://doi.org/https://doi.org/10.1016/0309-1740(91)90060-4

Đurkin, I., Dadić, M., Brkić, D., Lukić, B., Kušec, G., Mikolin, M., & Jerković, I. (2012). Influence of gender and slaughter weight on meat quality traits of heavy pigs. *Acta Agric Slov*, 211–214.

England, E. M., Matarneh, S. K., Scheffler, T. L., & Gerrard, D. E. (2017). Chapter 4 - Perimortal Muscle Metabolism and its Effects on Meat Quality. In P. P. Purslow (Ed.), *New Aspects of Meat Quality* (pp. 63–89). Woodhead Publishing. https://doi.org/https://doi.org/10.1016/B978-0-08-100593-4.00004-7

Ertbjerg, P. (2022). Chapter 5 - Current understanding on the role of proteolysis on meat quality. In P. Purslow (Ed.), *New Aspects of Meat Quality (Second Edition)* (pp. 95–114). Woodhead Publishing. https://doi.org/https://doi.org/10.1016/B978-0-323-85879-3.00022-2

Feldhusen, F., & Kühne, M. (1992). Effects of ultrarapid chilling and ageing on length of sarcomeres, and tenderness of pork. *Meat Science*, *32*(2), 161–171. https://doi.org/https://doi.org/10.1016/0309-1740(92)90103-B

Gibson, M., & Newsham, P. (2018). Chapter 12 - Meat: Food and Science of the Animal Kingdom. In M. Gibson & P. Newsham (Eds.), *Food Science and the Culinary Arts* (pp. 169–223). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-811816-0.00012-9

Gigiel, A., Butler, F., & Hudson, B. (1989). Alternative methods of pig chilling. *Meat Science*, *26*(1), 67–83. https://doi.org/https://doi.org/10.1016/0309-1740(89)90057-0

Goll, D. E., Neti, G., Mares, S. W., & Thompson, V. F. (2008). Myofibrillar protein turnover: The proteasome and the calpains. *Journal of Animal Science*, *86*(suppl_14), E19–E35. https://doi.org/10.2527/jas.2007-0395

Harsh, B. N., Arkfeld, E. K., Mohrhauser, D. A., King, D. A., Wheeler, T. L., Dilger, A. C., Shackelford, S. D., & Boler, D. D. (2017). Effect of hot carcass weight on loin, ham, and belly quality from pigs sourced from a commercial processing facility. *Journal of Animal Science*, *95*(11), 4958–4970.

Huff-Lonergan, E., Baas, T. J., Malek, M., Dekkers, J. C. M., Prusa, K., & Rothschild, M. F. (2002). Correlations among selected pork quality traits. *Journal of Animal Science*, *80*(3), 617–627. https://doi.org/10.2527/2002.803617x

Huff-Lonergan, E., & Lonergan, S. M. (1999). Postmortem mechanisms of meat tenderization: The roles of the structural proteins and the calpain system. *Quality Attributes of Muscle Foods*, 229–251.

Huff-Lonergan, E., & Lonergan, S. M. (2005). Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. *Meat Science*, *71*(1), 194–204.

Huff-Lonergan, E., Mitsuhashi, T., Beekman, D. D., Parrish Jr., F. C., Olson, D. G., & Robson, R. M. (1996). Proteolysis of specific muscle structural proteins by μ-calpain at low pH and temperature is similar to degradation in postmortem bovine muscle. *Journal of Animal Science*, *74*(5), 993–1008. https://doi.org/10.2527/1996.745993x

Huff-Lonergan, E., & Page, J. (2001). The role of carcass chilling in the development of pork quality. *National Pork Producers Council*, 1–8.

Huff Lonergan, E., Zhang, W., & Lonergan, S. M. (2010). Biochemistry of postmortem muscle — Lessons on mechanisms of meat tenderization. *Meat Science*, *86*(1), 184–195. https://doi.org/https://doi.org/10.1016/j.meatsci.2010.05.004

James, S. J., Gigiel, A. J., & Hudson, W. R. (1983). The ultra rapid chilling of pork. *Meat Science*, *9*(1), 63–78. https://doi.org/https://doi.org/10.1016/0309-1740(83)90054-2

Jones, S. D. M., Jeremiah, L. E., & Robertson, W. M. (1993). The effects of spray and blast-chilling on carcass shrinkage and pork muscle quality. *Meat Science*, *34*(3), 351–362. https://doi.org/https://doi.org/10.1016/0309-1740(93)90083-T

Joo, S. T., Kauffman, R. G., Kim, B. C., & Park, G. B. (1999). The relationship of sarcoplasmic and myofibrillar protein solubility to colour and water-holding capacity in porcine longissimus muscle. *Meat Science*, *52*(3), 291–297. https://doi.org/https://doi.org/10.1016/S0309-1740(99)00005-4

Karlsson, A. H., Klont, R. E., & Fernandez, X. (1999). Skeletal muscle fibres as factors for pork quality. *Livestock Production Science*, *60*(2–3), 255–269.

King, D. A., Hunt, M. C., Barbut, S., Claus, J. R., Cornforth, D. P., Joseph, P., Kim, Y. H. B., Lindahl, G., Mancini, R. A., & Nair, M. N. (2023). American meat science association guidelines for meat color measurement. *Meat and Muscle Biology*, *6*(4).

Kitajima, Y., Yoshioka, K., & Suzuki, N. (2020). The ubiquitin–proteasome system in regulation of the skeletal muscle homeostasis and atrophy: from basic science to disorders. *The Journal of Physiological Sciences*, *70*(1), 40.

Koohmaraie, M. (1994). Muscle proteinases and meat aging. *Meat Science*, *36*(1), 93–104. https://doi.org/https://doi.org/10.1016/0309-1740(94)90036-1

Koohmaraie, M., & Geesink, G. H. (2006). Contribution of postmortem muscle biochemistry to the delivery of consistent meat quality with particular focus on the calpain system. *Meat Science*, *74*(1), 34–43. https://doi.org/https://doi.org/10.1016/j.meatsci.2006.04.025

Koohmaraie, M., Kent, M. P., Shackelford, S. D., Veiseth, E., & Wheeler, T. L. (2002). Meat tenderness and muscle growth: is there any relationship? *Meat Science*, *62*(3), 345–352. https://doi.org/https://doi.org/10.1016/S0309-1740(02)00127-4

Koohmaraie, M., Seideman, S. C., & Crouse, J. D. (1988). Effect of subcutaneous fat and high temperature conditioning on bovine meat tenderness. *Meat Science*, *23*(2), 99–109. https://doi.org/https://doi.org/10.1016/0309-1740(88)90018-6

Kristensen, L., & Purslow, P. P. (2001). The effect of ageing on the water-holding capacity of pork: role of cytoskeletal proteins. *Meat Science*, *58*(1), 17–23. https://doi.org/https://doi.org/10.1016/S0309-1740(00)00125-X

Latorre, M. A., Lázaro, R., Valencia, D. G., Medel, P., & Mateos, G. G. (2004). The effects of gender and slaughter weight on the growth performance, carcass traits, and meat quality characteristics of heavy pigs1. *Journal of Animal Science*, *82*(2), 526–533. https://doi.org/10.2527/2004.822526x

Lonergan, S., Boler, D., & Moeller, S. (2008). Pork quality: pH decline and pork quality. *Pork Information Gateway*, 1–3.

Mancini, R. A., & Hunt, Mc. (2005). Current research in meat color. *Meat Science*, *71*(1), 100–121.

Marsh, B. B. (1977). Temperature and postmortem change: energy use and meat quality. *Proceedings-Meat Industry Research Conference (USA)*.

Matarneh, S. K., England, E. M., Scheffler, T. L., & Gerrard, D. E. (2017). Chapter 5 - The Conversion of Muscle to Meat. In F. Toldra´ (Ed.), *Lawrie´s Meat Science (Eighth Edition)* (pp. 159–185). Woodhead Publishing. https://doi.org/https://doi.org/10.1016/B978-0-08-100694-8.00005-4

Melody, J. L., Lonergan, S. M., Rowe, L. J., Huiatt, T. W., Mayes, M. S., & Huff-Lonergan, E. (2004). Early postmortem biochemical factors influence tenderness and water-holding capacity of three porcine muscles1. *Journal of Animal Science*, *82*(4), 1195–1205. https://doi.org/10.2527/2004.8241195x

Miller, M. F., Hoover, L. C., Cook, K. D., Guerra, A. L., Huffman, K. L., Tinney, K. S., Ramsey, C. B., Brittin, H. C., & Huffman, L. M. (1995). Consumer acceptability of beef steak tenderness in the home and restaurant. *Journal of Food Science*, *60*(5), 963–965.

Mitchell, A. D., Scholz, A. M., Pursel, V. G., & Evock-Clover, C. M. (1998). Composition analysis of pork carcasses by dual-energy x-ray absorptiometry. *Journal of Animal Science*, *76*(8), 2104–2114. https://doi.org/10.2527/1998.7682104x

Moeller, P. W., Fields, P. A., Dutson, T. R., Landmann, W. A., & Carpenter, Z. L. (1976). Effect of high temperature conditioning on subcellular distribution and levels of lysosomal enzymes. *Journal of Food Science*, *41*(1), 216–217.

Moeller, P. W., Fields, P. A., Dutson, T. R., Landmann, W. A., & Carpenter, Z. L. (1977). High temperature effects on lysosomal enzyme distribution and fragmentation of bovine muscle. *Journal of Food Science*, *42*(2), 510–512.

National Pork Producers Council (NPPC). (1999). Official color and marbling standards. In *NPPC*.

Novakofski, J., Park, S., Bechtel, P. J., & McKeith, F. K. (1989). Composition of cooked pork chops: Effect of removing subcutaneous fat before cooking. *Journal of Food Science*, *54*(1), 15–17.

Offer, G. (1991). Modelling of the formation of pale, soft and exudative meat: Effects of chilling regime and rate and extent of glycolysis. *Meat Science*, *30*(2), 157–184. https://doi.org/https://doi.org/10.1016/0309-1740(91)90005-B

O'Halloran, G. R., Troy, D. J., Buckley, D. J., & Reville, W. J. (1997). The role of endogenous proteases in the tenderisation of fast glycolysing muscle. *Meat Science*, *47*(3), 187–210. https://doi.org/https://doi.org/10.1016/S0309-1740(97)00046-6

Ohene-Adjei, S., Ellis, M., McKeith, F. K., & Brewer, M. S. (2002). Relationship of chilling rate and location within muscle on the quality of ham and loin muscles. *Journal of Muscle Foods*, *13*(3), 239–251.

Ohtsuki, I., & Morimoto, S. (2013). Troponin. In W. J. Lennarz & M. D. Lane (Eds.), *Encyclopedia of Biological Chemistry (Second Edition)* (pp. 445–449). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-378630-2.00195-X

Overholt, M. F., Arkfeld, E. K., Bryan, E. E., King, D. A., Wheeler, T. L., Dilger, A. C., Shackelford, S. D., & Boler, D. D. (2019). Effect of hot carcass weight on the rate of temperature decline of pork hams and loins in a blast-chilled commercial abattoir123. *Journal of Animal Science*, *97*(6), 2441–2449. https://doi.org/10.1093/jas/skz131

Park, B.-C., & Lee, C. (2011). Feasibility of increasing the slaughter weight of finishing pigs. *Journal of Animal Science and Technology*, *53*(3), 211–222.

Paulin, D., & Li, Z. (2004). Desmin: a major intermediate filament protein essential for the structural integrity and function of muscle. *Experimental Cell Research*, *301*(1), 1–7. https://doi.org/https://doi.org/10.1016/j.yexcr.2004.08.004

Pearce, K. L., Rosenvold, K., Andersen, H. J., & Hopkins, D. L. (2011). Water distribution and mobility in meat during the conversion of muscle to meat and ageing and the impacts on fresh meat quality attributes — A review. *Meat Science*, *89*(2), 111–124. https://doi.org/https://doi.org/10.1016/j.meatsci.2011.04.007

Piao, J. R., Tian, J. Z., Kim, B. G., Choi, Y. I., Kim, Y. Y., & Han, I. K. (2004). Effects of sex and market weight on performance, carcass characteristics and pork quality of market hogs. *Asian-Australasian Journal of Animal Sciences*, *17*(10), 1452–1458.

Pomponio, L., & Ertbjerg, P. (2012). The effect of temperature on the activity of μ- and m-calpain and calpastatin during post-mortem storage of porcine longissimus muscle. *Meat Science*, *91*(1), 50–55. https://doi.org/https://doi.org/10.1016/j.meatsci.2011.12.005

Price, H. E., Barkley, K. E., Lerner, A. B., Harsh, B. N., Woodworth, J. C., Tokach, M. D., Dritz, S. S., Goodband, R. D., DeRouchey, J. M., O'Quinn, T. G., Allerson, M. W., Fields, B., King, D. A., Wheeler, T. L., Shackelford, S. D., Boler, D. D., & Dilger, A. C. (2022). Differences in carcass chilling rate underlie differences in sensory traits of pork chops from pigs with heavier carcass weights. *Journal of Animal Science*, skac206. https://doi.org/10.1093/jas/skac206

Price, H. E., Lerner, A. B., Rice, E. A., Lowell, J. E., Harsh, B. N., Barkley, K. E., Honegger, L. T., Richardson, E., Woodworth, J. C., & Tokach, M. D. (2019). Characterizing ham and loin quality as hot carcass weight increases to an average of 119 kilograms. *Meat and Muscle Biology*, *3*(1).

Ramos, P. M., Pedrão, M. R., Bell, L. C., Scheffler, T. L., & Ramos, P. M. (2021). Early Postmortem Metabolism and Protease Activation in Fast Glycolytic and Slow Oxidative Bovine Muscles. *Meat and Muscle Biology*, *5*(1).

Rees, M. P., Trout, G. R., & Warner, R. D. (2002). Tenderness of pork m. longissimus thoracis et lumborum after accelerated boning. Part I. Effect of temperature conditioning. *Meat Science*, *61*(2), 205–214.

Rees, M. P., Trout, G. R., & Warner, R. D. (2003). The influence of the rate of pH decline on the rate of ageing for pork. II: Interaction with chilling temperature. *Meat Science*, *65*(2), 805–818. https://doi.org/https://doi.org/10.1016/S0309-1740(02)00285-1

Rice, E. A., Lerner, A. B., Olson, B. A., Prill, L. L., Drey, L. N., Price, H. E., Lowell, J. E., Harsh, B. N., Barkley, K. E., & Honegger, L. T. (2019). Effects of increased pork hot carcass weights. II: Loin quality characteristics and palatability ratings. *Meat and Muscle Biology*, *3*(1).

Rosenvold, K., Borup, U., & Therkildsen, M. (2010). Stepwise chilling: Tender pork without compromising water-holding capacity. *Journal of Animal Science*, *88*(5), 1830–1841. https://doi.org/10.2527/jas.2009-2468

Savell, J. W., Branson, R. E., Cross, H. R., Stiffler, D. M., Wise, J. W., Griffin, D. B., & Smith, G. C. (1987). National consumer retail beef study: palatability evaluations of beef loin steaks that differed in marbling. *Journal of Food Science*, *52*(3), 517–519.

Savell, J. W., Mueller, S. L., & Baird, B. E. (2005). The chilling of carcasses. *Meat Science*, *70*(3), 449–459. https://doi.org/https://doi.org/10.1016/j.meatsci.2004.06.027

Scheffler, T. L., & Gerrard, D. E. (2007a). Mechanisms controlling pork quality development: The biochemistry controlling postmortem energy metabolism. *Meat Science*, *77*(1), 7–16. https://doi.org/https://doi.org/10.1016/j.meatsci.2007.04.024

Scheffler, T. L., & Gerrard, D. E. (2007b). Mechanisms controlling pork quality development: The biochemistry controlling postmortem energy metabolism. *Meat Science*, *77*(1), 7–16. https://doi.org/10.1016/J.MEATSCI.2007.04.024

Scheffler, T. L., Park, S., & Gerrard, D. E. (2011). Lessons to learn about postmortem metabolism using the AMPKγ3R200Q mutation in the pig. *Meat Science*, *89*(3), 244–250. https://doi.org/https://doi.org/10.1016/j.meatsci.2011.04.030

Shackelford, S. D., King, D. A., & Wheeler, T. L. (2012). Chilling rate effects on pork loin tenderness in commercial processing plants. *Journal of Animal Science*, *90*(8), 2842–2849. https://doi.org/10.2527/jas.2011-4855

Shackelford, S. D., Wheeler, T. L., & Koohmaraie, M. (1999). Tenderness classification of beef: II. Design and analysis of a system to measure beef longissimus shear force under commercial processing conditions. *Journal of Animal Science*, *77*(6), 1474–1481.

Springer, M. P., Carr, M. A., Ramsey, C. B., & Miller, M. F. (2003). Accelerated chilling of carcasses to improve pork quality. *Journal of Animal Science*, *81*(6), 1464–1472. https://doi.org/10.2527/2003.8161464x

Suman, S. P., & Joseph, P. (2013). Myoglobin chemistry and meat color. *Annual Review of Food Science and Technology*, *4*(1), 79–99.

Taylor, R. (1990). Interpretation of the correlation coefficient: a basic review. *Journal of Diagnostic Medical Sonography*, *6*(1), 35–39.

Tomović, V. M., Petrović, L. S., & Džinić, N. R. (2008). Effects of rapid chilling of carcasses and time of deboning on weight loss and technological quality of pork semimembranosus muscle. *Meat Science*, *80*(4), 1188–1193. https://doi.org/https://doi.org/10.1016/j.meatsci.2008.05.013

USDA/NASS QuickStats Ad-hoc Query Tool. (2023). Retrieved January 10, 2023, from https://quickstats.nass.usda.gov/results/95D8617D-2715-3F7D-A67F-C36D8C081D02

Virgili, R., Degni, M., Schivazappa, C., Faeti, V., Poletti, E., Marchetto, G., Pacchioli, M. T., & Mordenti, A. (2003). Effect of age at slaughter on carcass traits and meat quality of Italian heavy pigs. *Journal of Animal Science*, *81*(10), 2448–2456.

Warner, R. D. (2017). Chapter 14 - The Eating Quality of Meat—IV Water-Holding Capacity and Juiciness. In F. Toldra´ (Ed.), *Lawrie´s Meat Science (Eighth Edition)* (pp. 419–459). Woodhead Publishing. https://doi.org/https://doi.org/10.1016/B978-0-08-100694-8.00014-5

Wu, F., Vierck, K. R., DeRouchey, J. M., O'Quinn, T. G., Tokach, M. D., Goodband, R. D., Dritz, S. S., & Woodworth, J. C. (2017). A review of heavy weight market pigs: status of knowledge and future needs assessment. *Translational Animal Science*, *1*(1), 1.

Xiong, Y. L. (2014). Chemical and Physical Characteristics of Meat | Protein Functionality. In M. Dikeman & C. Devine (Eds.), *Encyclopedia of Meat Sciences (Second Edition)* (pp. 267–273). Academic Press. https://doi.org/https://doi.org/10.1016/B978-0-12-384731-7.00088-X

Zhang, W. G., Lonergan, S. M., Gardner, M. A., & Huff-Lonergan, E. (2006). Contribution of postmortem changes of integrin, desmin and μ-calpain to variation in water holding capacity of pork. *Meat Science*, *74*(3), 578–585. https://doi.org/https://doi.org/10.1016/j.meatsci.2006.05.008

Zot, A. S., & Potter, J. D. (1987). Structural aspects of troponin-tropomyosin regulation of skeletal muscle contraction. *Annual Review of Biophysics and Biophysical Chemistry*, *16*(1), 535–559.

CHAPTER 2: EFFECT OF HOT CARCASS WEIGHT AND CARCASS LOCATION ON POSTMORTEM TEMPERATURE AND MEAT QUALITY

ABSTRACT

The objective was to determine the effects of hot carcass weight and carcass location on postmortem muscle temperature and its relationship with meat quality traits. Carcasses (n=71) were categorized based on carcass weight: Average (99-101 kg), Heavy (116-126 kg), and Very Heavy (134-144 kg). Temperature loggers were placed in the carcasses at the ham (semimembranosus), loin (longissimus dorsi), and shoulder (lattisimus dorsi) at approximately 45 minutes postmortem and removed at 22 hours postmortem. At 1 d postmortem, pH, visual color, instrumental color, of boneless loins, serratus ventralis (SV), triceps brachii (TB), semitendinosus (ST) and semimembranosus (SM) were determined. Additionally, drip loss, proximate composition, and Warner-Bratzler shear force (WBSF), cooked to 63°C and 71°C was determined for boneless loins. Data were analyzed using the MIXED procedure of SAS to determine the effect of carcass weight, location, and their interaction. Relationships between postmortem muscle temperature and quality traits were determined with the CORR procedure of SAS. From 10h to 22h, temperatures of Very Heavy carcasses were warmer than Heavy ($P<0.04$) and Average ($P<0.02$) carcasses. Heavy carcasses were warmer than average ($P\leq0.04$) carcasses from 16h to 22h. Hams were warmer than shoulders ($P<0.001$) from 1h to 22h and warmer than loins ($P<0.001$) from 2h to 22h. From 4h to 22h, shoulders were warmer than loins ($P<0.001$). Carcass weight category did not affect pH or color of loins, SM, TB, or SV ($P\geq0.08$) and did not alter the WBSF of loins at either degree of doneness ($P\geq0.33$). Loin pH was correlated with temperature from 19h to 22h postmortem (r=0.23 to 0.31, $P\leq0.05$), furthermore drip loss was correlated with temperature from 18h to 21h postmortem (r=-0.26 to -0.33, $P\leq0.04$). Visual color and instrumental color of the loin were not correlated with temperature at

any time point 1h to 22h ($P \geq 0.09$). These results suggest that increasing HCW slows carcass chilling but did not result in negative effects on loin, shoulder, or ham quality.

INTRODUCTION

Over the past 26 years there has been an increase of 0.6 kg/year in pork hot carcass weights, with a current industry average of 97 kg (*USDA/NASS QuickStats Ad-Hoc Query Tool*, 2023). Carcass weights continuing to increase at this rate projects that carcasses will average 104 kg by 2030 and 118 kg by 2050 (Harsh et al., 2017). While there are several benefits to increasing carcass weights, these increases raise concerns about compromised chilling and impacts on meat quality.

Proper chilling is important in maintaining food safety and meat quality, while reducing the occurrence of negative quality effects such as cold-shortening and pale, soft, and exudative (PSE) pork. Cold shortening can occur when meat is chilled to 10°C in 3 hours or less and results in increased toughness due to the shortening of sarcomeres (Bendall, 1973; Dransfield & Lockyer, 1985). PSE pork results from accelerated glycolysis and fast pH decline paired with higher muscle temperatures (Briskey & Wismer-Pedersen, 1961). While these quality defects represent the extremes, more subtle differences in chilling rate can alter meat quality. (Shackelford et al., 2012) reported that changes in tenderness of loin chops can be attributed to changes in chilling rate due to the duration of blast-chilling during the first several hours postmortem.

Furthermore, the rate of temperature decline differs between heavy and light carcasses. For example, Price et al. (2022) reported that heavier carcasses (130 kg) chilled more slowly than light (104 kg) and medium (116 kg and 122 kg) carcasses. There are reports that hams chill more slowly than loins for carcasses weighing 85-100 kg (Arkfeld et al., 2016; Overholt et al., 2019). However, all these studies were completed within commercial plants that implemented

blast-chilling, therefore it was anticipated that the temperature decline of these carcasses would be slower due to carcass weight and the chilling capacity of the university chilling system. Reducing temperature decline rate can lead to an extension in postmortem metabolism, due to the elevated temperature and increase in enzymatic activity (Moeller et al., 1976, 1977).

MATERIALS AND METHODS

Temperature Decline

Pigs from three different commercial sire lines were transported to the University of Illinois Meat Science Laboratory (Urbana, IL) over eight weeks. Pigs were held in lairage for a minimum of 16 hours with free access to water but no access to feed. All pigs were immobilized with electrical stunning and terminated through exsanguination under the supervision of the United States Food and Safety Inspection. Carcasses (N=71) were categorized based on hot carcass weight (HCW): average (99-101 kg), heavy (116-126 kg), and very heavy (134-144 kg). Data loggers (Thermochron iButton Device, model DS1921G, range: -40°C to 85°C, Maxim Integrated, San Jose, CA, USA) were placed in right sides of carcasses at approximately 45 minutes postmortem. For the shoulder, data loggers were placed in the latissimus dorsi muscle on the lateral side of the carcass near the fourth rib. The loin data loggers were placed in the longissimus dorsi muscle on the lateral side of the carcass near the 10^{th} rib. Ham data loggers were placed in the semimembranosus muscle on the medial side of the carcass posterior to the symphysis pubis bone. Ambient data loggers were placed with shroud pins in the spinous process of the thoracic vertebrae at approximately the fifth rib. Temperature was recorded for every minute from 1 h to 22 h postmortem. Carcasses were placed into a cooler set to 3°C with fans and were held here until 22 h postmortem. At 1 h postmortem, ambient temperature averaged from 2.50°C to 6.59°C and declined to an average temperature between -2.25°C and 2.50°C at 11

h postmortem. At 22 h postmortem, average ambient temperature ranged between -0.40°C to 2.00°C. After 22 h, data loggers were removed from carcasses.

Carcass Characteristics

Carcass composition was determined on the left side of each carcass. Left sides were separated between the 10th and 11th rib with a hand saw to expose the longissimus thoracis (LTL). Back fat thickness was measured at the 10th rib, approximately ¾ the distance of the LTL from the dorsal process of the vertebral column. The surface of the LTL was traced on acetate paper to determine the loin muscle area (LMA). These LTL tracings were measured twice at a later time with the digitizer tablet (Wacom, Vancouver, WA) and Adobe Photoshop C26 (Adobe Systems Inc., San Jose, CA, USA). Both measurements were averaged to determine the LMA. Following this, the left side of the carcass was weighed and fabricated into primal and subprimal cuts following (Boler et al., 2011) protocol. Right sides were also fabricated into primal and subprimal cuts with a shoulder-loin separation between the fourth and fifth rib.

Early Loin Quality Evaluation

Loin quality measurements for drip loss, pH, instrumental color, visual color, visual marbling, and subjective firmness were conducted by trained University of Illinois personnel at 1 d postmortem. The ventral surface of the longissimus dorsi at approximately the 10th rib was used for quality measurements. Loins were allowed to oxygenate for 20 minutes prior to quality measurements. Loin ultimate pH was measured with a Hanna Foodcare Portable pH meter calibrated to pH 4 and 7 buffers at 4°C with a Hanna electrode (Hanna 4198163 pH 80 meter, -2.0-20.0 pH/±2000.0 mV; Hanna FC2323 meat specific electrode, Hanna Instruments Woonsocket, RI, USA). Instrumental L*(lightness), a*(redness), and b*(yellowness) were determined with a Minolta CR-400 Chroma meter colorimeter (Minolta CR-400 Chroma meter

colorimeter, 2º observer, 8mm closed aperture, and D65 illuminant calibrated, Minolta Camera Company, Osaka, Japan). A single trained technician recorded visual color, visual marbling (NPPC, 1999), and subjective firmness (NPPC, 1991) for all weeks.

A drip chop, approximately 50 g, was collected before loins were sliced into chops. Each drip chop was weighed (initial weight), attached to a hook, and suspended in a WhirlPak bag (Nasco Sampling, Madison, WI, USA) at 4°C. Chops were reweighed (final weight) after 24 hours. Drip loss was expressed as weight lost as a percentage of initial weight.

Loins were sliced into 2.54 cm chops with a PUMA push-style slicer (TREIF, Shelton, CT, USA). Chops were removed from the 10^{th} rib cut surface moving posteriorly. Chop 1 was used for Proximate Analysis and were vacuum packaged, frozen, and stored at -20°C until use. Chops 2 and 3 were used for Warner-Bratzler Shear Force (WBSF). WBSF chops were vacuum packaged and aged for 14 days at 4°C. After 14 days, the chops were stored in -20°C until use for determination of cook loss percentage and WBSF.

Ham Quality Evaluation

Trained University of Illinois technicians at 1 d postmortem measured ham quality. The blonde spot on the medial side of the semimembranosus was used for quality measurements. The light side located on the medial side of the semitendinosus and the dark portion located on the most distal side of the semitendinosus from the femur were used for quality measurements. Ultimate pH was measured with a Hanna Foodcare Portable pH meter calibrated to pH 4 and 7 buffers at 4°C with a Hanna electrode. Semimembranosus and semitendinosus were allowed to oxygenate for 20 minutes prior to quality measurements. Instrumental L*(lightness), a*(redness), and b*(yellowness) were determined with a Minolta CR-400 Chroma meter colorimeter.

Shoulder Quality Evaluation

The serratus ventralis and the triceps brachii were sliced into 2.54 cm chops. Shoulder quality was measured at 1 d postmortem on the chop surface of the serratus ventralis and the triceps brachii. Instrumental L*(lightness), a*(redness), and b*(yellowness) were determined with a Minolta CR-400 Chroma meter colorimeter and ultimate pH was measured with a Hanna Foodcare Portable pH meter calibrated to pH 4 and 7 buffers at 4°C with a Hanna electrode.

Proximate Analysis

Chops were allowed to partially thaw and then subcutaneous fat was trimmed before chops were homogenized in a food processor (Hamilton Beach, model 70720, Glen Allen, VA, USA). Samples, 10 g, were taken in duplicate from each chop and placed into aluminum tins and covered with two sheets of filter paper. Samples were placed in 110°C oven for a minimum of 24 hours to determine moisture content. Following the method described by (Novakofski et al., 1989), extraction was completed using a chloroform methanol solution for a minimum of 8 hours to determine samples lipid content. Proximate analysis results are recorded as a percentage of the original wet weight.

Cook Loss and Warner-Bratzler Shear Force

Loin chops for Warner-Bratzler shear force were removed from the freezer and allowed to thaw for approximately 24 hours at 4°C. Each chop was weighed individually (initial weight) and cooked on Faberware Open Hearth grill (model 455N, Walter Kidde, Bronx, NY, USA). Internal temperatures were monitored during cooking using thermocouples (type K, range: -200°C to 1250°C, standard error: ±2.2°C, Omega Engineering, Stamford, CT, USA).

Thermocouples were placed at approximately the geometric center of the chops and attached to an Omega HH378 Data Logger Thermometer (Omega Engineering, Norwalk, CT, USA). Chop 2 was cooked to an internal temperature of 31°C, flipped, and cooked to an internal temperature of 63°C. Chop 3 was cooked to an internal temperature of 36°C, flipped, and cooked to an internal temperature of 71°C. Chops were removed from the grill and allowed to rest until reaching maximum internal temperature. Chops were cooled until reaching an internal temperature of approximately 25°C then final chops weights were recorded (final weight). Cook loss was expressed as weight lost as a percentage of initial (uncooked) weight.

Four 1.25 cm cores were removed parallel to muscle fiber direction. Cores were sheared perpendicular to muscle fiber orientation using the Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, 134 NY/Stable Microsystems, Goldalming, UK) with a load cell capacity of 100 kg and a blade speed of 3.33 mm/s. The average of the four cores was recorded as the WBSF for the sample.

Statistical Analysis

Carcass characteristic and meat quality data were analyzed as a one-way ANOVA using the MIXED procedure of SAS with the fixed effect HCW category. The effect of HCW category was considered significant at $P < 0.05$. Temperature data were compared between carcass locations and HCW category within each hour postmortem as a two-way ANOVA using the MIXED procedure of SAS (SAS Inst. In., Cary, NC, USA). Fixed effects of HCW category and carcass location were included with ambient temperature as a covariate. The effect of HCW category, carcass location, and the interactions of HCW category and carcass location were considered significant at $P<0.05$. Least square means were separated using the probability of

difference (PDIFF) option. The UNIVARIATE procedure of SAS was used to determine the normality of residuals. Homogeneity of variances were tested using the Levene's hovtest option in the GLM procedure of SAS. Pearson correlation coefficients between loin quality traits and loin temperature, ham quality traits and ham temperature, and shoulder quality traits and shoulder temperature were determined through the CORR procedure of SAS. Correlations were considered significant at $P<0.05$. Correlations were considered weak at $r \leq |0.35|$, moderate at $|0.36| \geq r \leq |0.67|$, and strong at $r \geq |0.68|$ (Taylor, 1990).

RESULTS

Carcass Characteristics

By design, HCW were different (P>0.001) between Average (104.5 kg), Heavy (122.0 kg) and Very Heavy (138.4 kg) carcasses. Very Heavy carcasses had a larger carcass yield percent when compared to Average (P<0.001) and Heavy (P=0.003) carcasses, but Average and Heavy carcasses were not different (P=0.16) from each other. Very Heavy carcasses had increased longissimus muscle area compared to Heavy (P<0.001) and Average (P<0.001) carcasses, while longissimus muscle area was greater (P<0.001) in Heavy carcasses compared with Average carcasses. Average carcasses had less back fat than Heavy (P=0.005) and Very Heavy (P<0.001) carcasses, while Heavy carcasses had less back fat depth than Very Heavy carcasses (P=0.03).

Temperature Decline

Carcass weight category and location affected postmortem temperature ($P<0.05$). There were no interactions between carcass weight category and location ($P\geq0.08$) at any postmortem time. Thus, the effects of carcass location and carcass weight category were additive. However,

for full information, the interaction means were presented on Table 2. Ambient temperature was also reported on Table 2 and used as a covariate in the analysis of carcass temperatures to account for environmental variability.

There were no average temperature differences between carcass weight categories from 1 h to 8 h postmortem ($P \geq 0.09$). However at 9 h postmortem, Very Heavy carcasses were at least 1°C warmer (P=0.01) than Average carcasses, but not different (P=0.06) than Heavy carcasses. From 10 h to 22 h postmortem, Very Heavy carcasses were warmer than Average (P<0.02) and heavy (P<0.04) carcasses. At 10 h postmortem, Very Heavy carcasses were at least 0.95°C warmer (P=0.02) than Average carcasses and 0.63°C warmer (P=0.04) than Heavy carcasses when averaged between all carcass locations. At 22 h postmortem, Very Heavy carcasses were at least 1.84°C warmer (P<0.001) than Average carcasses and at least 0.76°C warmer (P<0.001) than Heavy carcasses. Average and Heavy carcasses were not different from 1 h to 15 h postmortem (P≥0.09), however from 16 h to 22 h postmortem Average carcasses were colder (P≤0.04) than Heavy carcasses. At 16 h postmortem, Average carcasses were 0.69°C colder (P=0.04) than Heavy carcasses. At 22 h postmortem, Average carcasses were 1.08°C colder (P<0.001) than Heavy carcasses. Therefore, in general, heavier carcasses chilled more slowly than lighter carcasses, especially after 10 h postmortem.

Postmortem temperature was different between locations at 1 h postmortem where hams and loins were warmer (P<0.001) than shoulders. At 1 h postmortem, hams were 1.46°C warmer (P<0.001) and loins were 1.28°C warmer (P<0.001) than shoulders. Hams and loin temperatures were not different (P=0.48) at 1 h postmortem. Hams continued to have a greater postmortem temperature (P<0.001) at each hour when compared to shoulders until 22 h postmortem when data collection ceased. At 22h postmortem, hams were 2.27°C warmer than shoulders and

3.67°C warmer than loins. Furthermore, hams had greater postmortem temperatures (P<0.001) than loins from 2 h to 22 h. At 22 h postmortem, hams are 2.27°C warmer (P<0.001) than shoulders and 3.67°C warmer (P<0.001) than loins. From 4 h to 22 h postmortem, shoulders had greater temperatures (P<0.003) than loins. At 4 h postmortem, shoulders are 1.64°C warmer (P<0.003) than loins and at 22 h postmortem shoulders are 1.40°C warmer (P<0.001) than loins. Overall, hams chilled the slowest and loins chilled the fastest with shoulders falling intermediate to both.

Carcass weight was correlated with loin temperature from 2 h to 22 h postmortem (P≤0.03). The relationship between loin temperature and carcass weight increased from (r = 0.26) at 2 h to a peak at 18 h postmortem (r = 0.54). The strength of relationship declined slightly after 18 h postmortem, but the relationship was still moderately strong (r=0.49) at the end of chilling. Carcass weight was also correlated with both shoulder and ham temperature from 13 h to 22 h postmortem (P≤0.04). The relationship between shoulder temperature and carcass weight increased from (r=0.25) at 13 h to its peak at 22 h postmortem (r=0.51). Ham temperature and carcass weight relationship was similar with an increase from (r=0.26) at 13 h to a peak relationship (r=0.63) at 22 h postmortem.

Loin Quality

Ultimate pH tended (P=0.08) to be higher in the Very Heavy carcasses (5.57) compared to Average (5.52) and Heavy (5.52) carcasses. Color, marbling, and firmness scores and drip loss were not different (P≥0.35) between carcass weight categories. Similarly, there were no differences (P≥0.91) between carcass weight categories for lightness, redness, and yellowness. Extractable lipid percentage did not differ between carcass weight categories (P=0.19), but Average carcasses (73.90%) had greater (P=0.01) moisture content compared with Very Heavy

carcasses (73.19%). Cook loss and WBSF did not differ between carcass weight categories in loin chops cooked to 63℃ ($P \geq 0.33$) or 71℃ ($P \geq 0.40$).

From 1 h to 18 h, there was no correlation between ultimate pH and temperature ($P \geq 0.11$). At 19 h through 22h postmortem, temperature and ultimate pH were weakly correlated (r = 0.23 to 0.31, $P \leq 0.05$). Visual color and subjective firmness were not correlated with temperature at any time point from 1 h to 22 h postmortem ($P \geq 0.19$). Subjective marbling score was not correlated with temperature from 1 h to 6 h ($P \geq 0.06$) and 19 h to 22 h ($P \geq 0.07$), however it was weakly correlated with temperature from 7 h through 18 h postmortem (r = 0.24 to 0.30, $P \leq 0.04$). Loin lightness, redness, and yellowness were not correlated with temperature at any time point from 1 h to 22 h postmortem ($P \geq 0.09$). Drip loss was not correlated with temperature from 1 h to 17 h postmortem ($P \geq 0.06$), however it was weakly correlated with temperature from 18 h to 21 h postmortem (r = -0.26 to -0.29, $P \leq 0.04$). At 22 h postmortem, drip loss was not correlated with temperature ($P = 0.12$). Moisture content percent was not correlated with temperature from 1 h to 13 h postmortem ($P \geq 0.08$) or at 22 h postmortem ($P = 0.24$). However, temperature and moisture content percent were weakly correlated from 14 h through 21 h postmortem (r = -0.24 to -0.33, $P \leq 0.04$). Extractable lipid percentage was weakly correlated with temperature from 11 h to 15 h postmortem (r = 0.24 to 0.33, $P \leq 0.04$) and moderately correlated from 16 h to 21 h postmortem (r = 0.36 to 0.38, $P \leq 0.002$). Extractable lipid percentage was not correlated with temperature from 1 h to 10 h ($P \geq 0.07$) or at 22 h postmortem ($P \geq 0.74$). There were no correlations between WBSF and temperature at any time point for either chops cooked to 63℃ ($P \geq 0.43$) or 71℃ ($P \geq 0.42$). Cook loss percentage from chops cooked to 63℃ was not correlated with temperature from 2 h to 22 h postmortem ($P \geq 0.08$), however it was weakly correlated with temperature at 1 h postmortem (r =0.27, $P = 0.02$). Cook loss percentage from

chops cooked to 71°C was weakly correlated to temperature from 5 h to 12 h postmortem (r = -0.23 to -0.35, $P \leq 0.04$) and 16 h to 20 h postmortem (r = -0.33 to -0.23, $P \leq 0.05$). Cook loss percentage from chops cooked to 71°C was moderately correlated from 13 h to 15 h postmortem (r = -0.36, $P \leq 0.002$), but not correlated to temperature from 1 h to 4 h postmortem ($P \leq 0.07$) and 21 h to 22 h postmortem ($P \geq 0.10$).

Ham Quality

Ultimate pH as not different ($P \geq 0.11$) between carcass weight categories for the light ST, dark ST, or the SM. There was no difference ($P=0.15$) between carcass weight categories and lightness of the light ST. The light ST of Average carcasses (11.32), were redder ($P=0.01$) than Heavy (9.68) and redder ($P=0.03$) than Very Heavy (9.92) carcasses. There were no differences ($P= 0.68$) between Heavy and Very Heavy carcasses for light ST redness values. The light ST of Average carcasses (7.34) were more yellow ($P=0.004$) than Heavy carcasses (5.19). There were no differences ($P= 0.08$) between Average and Very Heavy carcasses and no differences ($P=0.21$) between Heavy and Very Heavy carcasses for yellowness.

Heavy carcasses (44.99) had a lighter ($P=0.04$) dark ST when compared to both Average (42.78) and Very Heavy carcasses (43.29). There were no differences in dark ST lightness between Average and Very Heavy carcasses ($P = 0.58$). Redness did not differ ($P \geq 0.14$) between carcass weight categories for the dark ST. Average carcasses had a dark ST that was more yellow ($P=0.01$) compared to both Heavy and Very Heavy carcasses. Heavy and Very Heavy carcasses were not different in yellowness ($P=0.72$). There were no differences between carcass weight categories and lightness or redness of the SM ($P \geq 0.39$). The SM tended ($P = 0.09$) to be less yellow in the Heavy carcasses (3.63) compared to the Average (4.86) and Very Heavy (4.87) carcasses.

Ham temperature did not correlate (P=0.06) with SM lightness, redness, yellowness, or pH at any time point from 1 h to 22 h. There was no correlation between ham temperature and light ST L* (P≥ 0.09) or pH (P≥ 0.15) from 1 h to 22 h postmortem. Dark ST lightness, yellowness, and pH were not correlated (P≥0.07) with ham temperature at any time point postmortem. Ham temperature was weakly correlated with light ST redness from 4 h to 5 h postmortem (r = 0.25 to 0.28, P≥ 0.03) and dark ST redness from 4 h to 8 h postmortem (r = 0.24 to 0.29, P≥ 0.05). Light ST redness was not correlated with temperature from 1 h to 3 h (P≥ 0.07) and from 6 h to 22 h postmortem (P≥ 0.07). Furthermore, dark ST redness was not correlated with redness from 1 h to 3 h (P≥ 0.19) and from 9 h to 22 h postmortem (P≥ 0.06). Light ST yellowness was not correlated with temperature from 1 h to 3 h (r = -0.12 to 0.19, P≥0.12) and from 9 h to 22 h postmortem (r = 0.09 to 0.20, P≥0.09). Light ST yellowness was moderately correlated with temperature at 4 h (r = 0.37, P≥0.002) and weakly correlated from 5 h to 8 h (r = 0.24 to 0.33, P≥0.05).

Shoulder Quality

There were no differences (P≥0.11) in ultimate pH or color traits between carcass weight categories for either the SV or the TB. From 1 h to 11 h postmortem TB yellowness was not correlated with shoulder temperature (P≥0.06). However, TB yellowness was weakly correlated (r=0.24, P≥0.04) with shoulder temperature at 12 h postmortem and from 14 h to 19 h postmortem (r = 0.23 to 0.27, P≥0.03). Lightness and redness of the TB were not correlated with any shoulder temperature from 1 h to 22 h postmortem (P≥0.11). TB pH was weakly correlated (r=0.23, P=0.05) with temperature at 22 h postmortem, however it was not correlated with shoulder temperature from 1 h to 21 h postmortem (P≥0.12). Shoulder temperature did not correlate (P≥0.13) with any SV quality measurement from 1 h to 22 h postmortem.

DISCUSSION AND CONCLUSION

In this study, we examined the effect of hot carcass weight and carcass location on postmortem muscle temperature and quality traits of the loin, shoulder, and ham. Previous research studies have focused on the differences of chilling rate due to increases in carcass weight and their effect on loin quality. These studies determined that increased carcass weight results in slower chilling (Coulter et al., 1995; Daudin & Kuitche, 1996; Overholt et al., 2019; Price et al., 2022) and decreased shear force values (Harsh et al., 2017; Price et al., 2019; Shackelford et al., 2012). In addition, while it has been established that hams chill more slowly than loins (Arkfeld et al., 2016; Jones et al., 1993; Melody et al., 2004; Overholt et al., 2019; Rosenvold et al., 2010), postmortem temperature decline in the pork shoulder has not been extensively studied. The hypothesis of this study was that increasing carcass weights would result in slower temperature decline, which could potentially result in improvement of loin tenderness and meat quality.

In agreement with our hypothesis, (Price et al., 2022) reported that increasing carcass weight by 10 kg results in a decrease in chilling rate of 0.255°C/h during the first 5 h postmortem, where 25.4% of the variation in chilling rate was due to hot carcass weight. In comparison, in the current study, Average carcasses were 1.84°C and Heavy carcasses were 0.76°C colder than Very Heavy carcasses at the end of chilling, indicating that heavier carcasses chill more slowly. This decrease in temperature decline can be attributed to the decrease in surface area to volume ratio when carcasses increase in weight, which in turn will decrease the release of heat from the surface of the carcass (Overholt et al., 2019).

Similar to previous research, hams chilled more slowly than loins in all carcass weight categories. Arkfeld et al. (2016) and Overholt et al. (2019) both reported that hams chilled more

slowly than loins no matter the carcass weight, where loins reached ambient temperature sometime during chilling and hams did not reach ambient temperature during the time temperature was recorded. Melody et al. (2004) also reported that semimembranosus muscles had the highest temperatures throughout chilling with the longissimus dorsi having lower temperatures. In pigs with lighter carcass weights than today's industry standard (James et al., 1983; Rosenvold et al., 2010), postmortem temperature decline in shoulders chill more similar to hams and slower than loins in both rapid and stepwise chilling systems. In the current study, shoulders follow a temperature decline curve more similar to loins. At 4 h postmortem, shoulders are 1.64°C warmer than loins and then at 22h postmortem shoulders are 1.40°C warmer than loins. However, at 4 h postmortem, shoulders are 7.88°C colder than hams and at 22 h postmortem shoulders are 2.28°C colder than hams. Overall, the effect of carcass weight category and location were additive in nature. At 22 h postmortem, Very Heavy carcasses are 1.8°C warmer than Average carcasses, and hams are 3.7°C warmer than loins so Very Heavy hams are 5.5°C warmer than Average loins.

Multiple studies have reported decreases in slice shear force values with increased carcass weight. For examples, (Harsh et al., 2017) reported a 1.26 kg decrease per 10 kg increase in carcass weight and (Price et al., 2022) reported a 1.01 kg decrease per 10 kg increase in carcass weight, both for chops cooked to 71°C. In contrast, others have reported no differences in shear force values when carcass weights are increased (Beattie et al., 1999; Cisneros et al., 1996c; Latorre et al., 2004; Rice et al., 2019). Similarly, the results of the current study showed no differences between Warner-Bratzler shear force values at 63°C or 71°C. In conclusion, loin quality traits were not different between carcass weight groups, which can be influenced by the

slow chilling of the carcasses. The current study chilled carcasses under university conditions, which is not as comparable to the blast chilling typically found in industry.

In the current study, pH and postmortem temperature have a weak correlation at the end of chilling, 19 h to 22 h postmortem. This weak correlation is surprising due to the established relationship between pH and temperature during postmortem metabolism (Briskey, 1964; Briskey & Wismer-Pedersen, 1961). Therefore, a relationship between temperature and pH would be expected throughout the postmortem chilling. In addition, the lack of relationship between temperature and WBSF values is surprising. Temperature during early postmortem has been reported to play a significant role in the rate of postmortem tenderization in meat (Huff Lonergan et al., 2010; Marsh, 1977).

The current study reported that increasing carcass weight results in no differences in instrumental color for the two shoulder muscles, SV and TB. No differences indicates that increasing carcass weights will not negatively affect the color of the shoulder which can allow for the development of new novel cuts from the shoulder of heavier carcasses. Similarly, the current study reports no differences in instrumental color for the SM with increasing carcass weights. In contrast previous research indicates that heavier carcasses produce SM that are redder (Harsh et al., 2017). Đurkin et al. (2012) reported that with every 10 kg increase in live weight there was a 0.34 unit increase in a* scores for the SM. Furthermore, in the current study, yellowness (b*) differs for the dark ST among hot carcass weights. Lighter carcasses produced more yellow, as indicated by higher b* values, dark ST compared to heavier carcasses. However, the importance and impact of yellowness, b*, on pork quality and consumer perception is not well documented.

Overall, increasing carcass weight results in decreased temperature decline, but no impact on loin, shoulder, or ham quality traits. Moreover, primals chill differently with hams chilling the slowest, loins the fastest, and shoulders falling intermediate to both. Nevertheless, this study results indicate that commercial processors should focus on reaching correct internal temperatures in hams compared to loins and shoulders.

TABLES AND FIGURES

Table 1. Effect of carcass weight on carcass characteristics

	Carcass Weight Category[1]				
Item	Average	Heavy	Very Heavy	SEM	*P*-value
Carcass Count, n	20	26	25		
Ending Live Weight, kg	132.2[a]	153.4[b]	172.0[c]	0.52	<0.01
Hot Carcass Weight[2], kg	104.5[a]	122.0[b]	138.4[c]	0.51	<0.01
Carcass Yield[3], %	79.04[a]	79.52[a]	80.49[b]	0.25	<0.01
Longissimus Muscle Area, cm^2	49.70[a]	55.46[b]	60.65[c]	1.19	<0.01
10^{th} rib back fat depth, cm	2.21[a]	2.63[b]	2.93[c]	0.11	<0.01

[1] Carcasses were placed into weight categories based on HCW; Average (99-101 kg), Heavy (116-126 kg), Very Heavy (134-144 kg)

[2] Hot carcass weight includes leaf fat

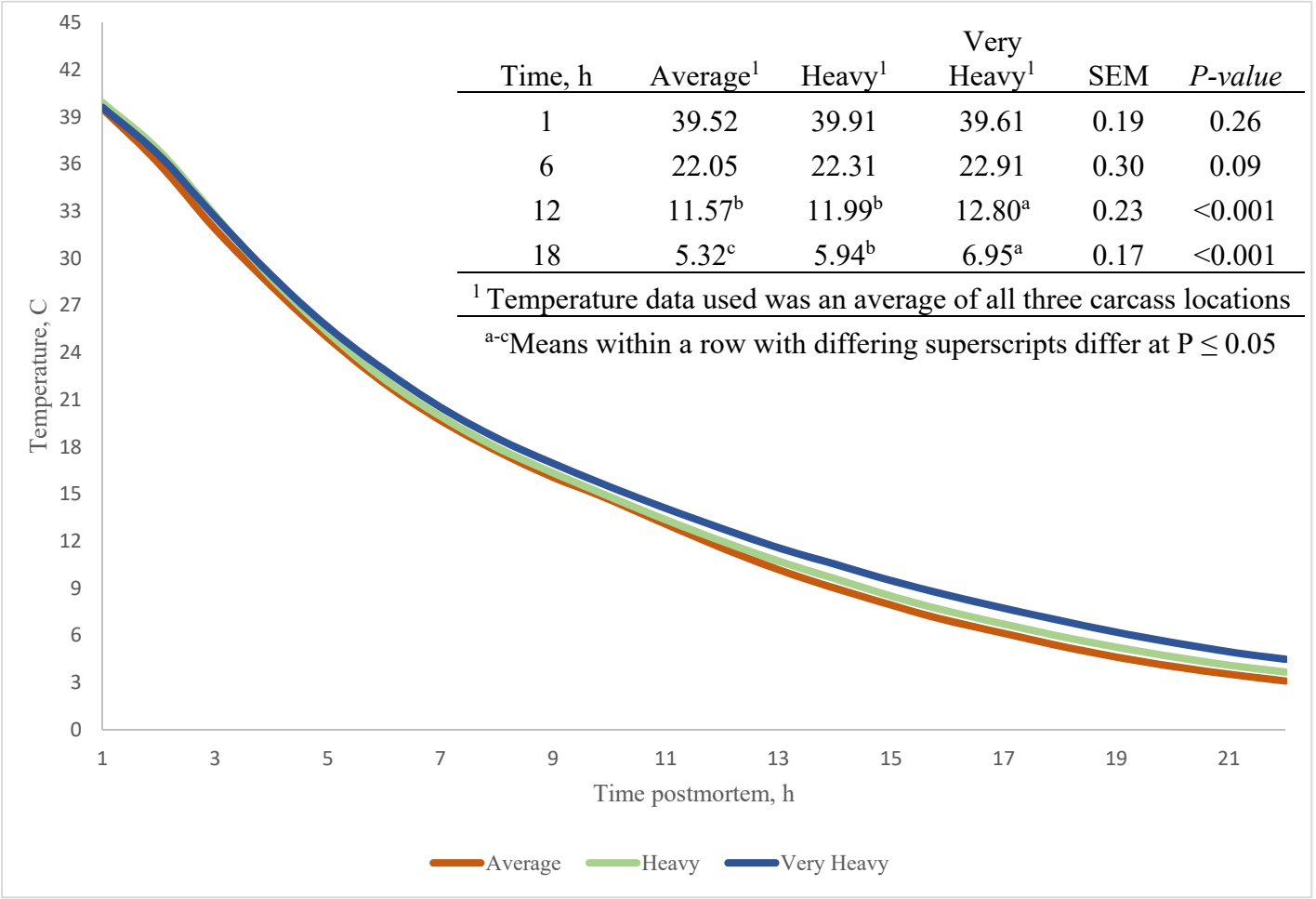
[3] Carcass yield, % = (hot carcass weight/ending live weight)x100

[a-c] Least squared means within a row having differing superscripts are considered significant ($P \leq 0.05$)

Table 2. Effect of carcass weight category[1] and location on temperature decline from 60 to 1320 minutes postmortem

		Average			Heavy			Very Heavy				*P*-values		
Item	Ambient	Shoulder	Loin	Ham	Shoulder	Loin	Ham	Shoulder	Loin	Ham	SEM	HCW	Location	HCW × Location
Count, n	70	20	20	20	26	26	26	25	25	24				
60	5.89	38.70	39.80	39.90	39.08	40.39	40.33	38.50	39.94	40.43	0.36	0.27	<0.01	0.74
120	4.15	34.06	34.39	39.51	34.88	36.25	39.52	34.29	35.95	39.51	0.59	0.25	<0.01	0.41
180	3.59	29.82	28.42	37.39	30.65	30.36	37.17	30.15	30.53	37.16	0.66	0.33	<0.01	0.24
240	3.81	26.16	23.51	34.84	26.84	25.22	34.18	26.60	25.94	34.23	0.64	0.41	<0.01	0.08
300	3.96	23.14	20.06	31.41	23.51	21.30	31.12	23.54	22.16	31.23	0.61	0.33	<0.01	0.28
360	4.33	20.52	17.32	28.22	20.69	18.19	28.09	20.89	19.31	28.55	0.57	0.12	<0.01	0.45
420	3.69	18.35	15.22	25.32	18.51	15.97	25.43	18.70	17.00	25.91	0.52	0.09	<0.01	0.58
480	3.19	16.60	13.65	22.80	16.70	14.27	22.95	16.94	15.28	23.50	0.48	0.06	<0.01	0.64
540	2.36	15.21	12.21	20.49	15.39	12.89	20.87	15.61	13.87	21.43	0.46	0.03	<0.01	0.64
600	1.03	14.00	11.10	18.55	14.12	11.55	18.95	14.43	12.55	19.52	0.45	0.02	<0.01	0.76
660	0.73	12.67	9.57	16.80	12.93	10.04	17.16	13.32	11.26	17.73	0.44	0.01	<0.01	0.69
720	1.29	11.35	8.05	15.07	11.90	8.65	15.52	12.38	9.90	16.17	0.44	<0.01	<0.01	0.77
780	1.31	10.20	6.73	13.45	10.87	7.37	14.00	11.40	8.66	14.70	0.43	<0.01	<0.01	0.80
840	1.27	9.08	5.71	12.11	9.81	6.29	12.79	10.55	7.55	13.54	0.42	<0.01	<0.01	0.93
900	1.35	8.00	4.70	11.02	8.67	5.30	11.59	9.55	6.55	12.36	0.39	<0.01	<0.01	0.94
960	1.44	6.81	3.99	9.81	7.55	4.55	10.59	8.66	5.68	11.42	0.36	<0.01	<0.01	0.98
1020	1.27	5.92	3.37	8.79	6.65	3.93	9.74	7.71	5.01	10.54	0.34	<0.01	<0.01	0.97
1080	1.09	5.02	2.79	7.67	5.82	3.44	8.76	6.83	4.47	9.70	0.31	<0.01	<0.01	0.94
1140	1.44	4.24	2.26	6.79	5.07	2.97	7.95	5.98	3.84	8.94	0.28	<0.01	<0.01	0.81
1200	1.28	3.53	1.91	5.88	4.48	2.61	7.15	5.32	3.40	8.17	0.25	<0.01	<0.01	0.49
1260	1.20	3.01	1.56	5.14	3.94	2.29	6.46	4.69	2.93	7.50	0.23	<0.01	<0.01	0.17
1320	1.32	2.53	1.28	4.43	3.54	2.08	5.85	4.21	2.73	6.83	0.21	<0.01	<0.01	0.13

[1] Carcasses were placed into weight categories based on HCW; Average (99-101 kg), Heavy (116-126 kg), Very Heavy (134-144 kg)

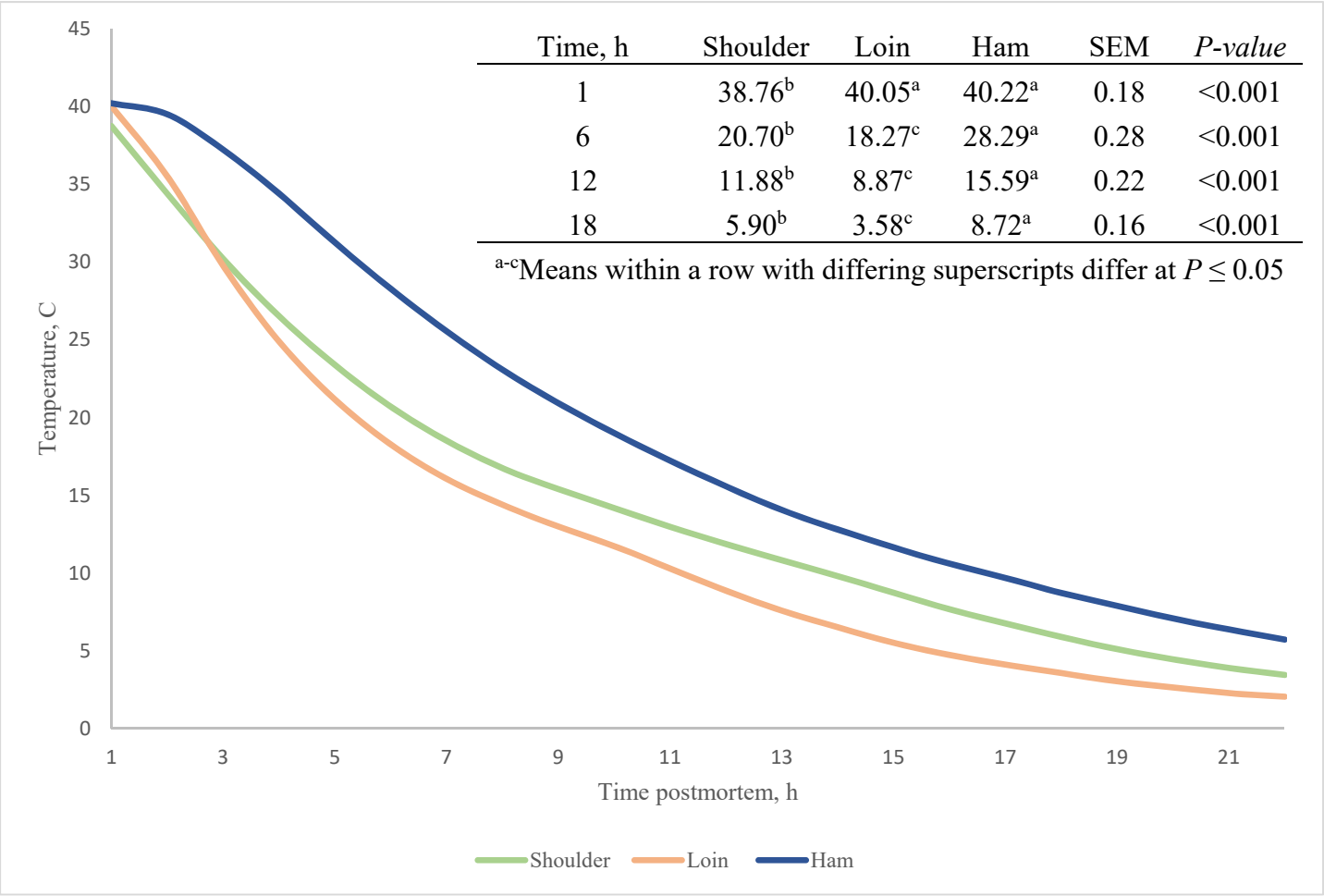


Time, h	Average[1]	Heavy[1]	Very Heavy[1]	SEM	*P-value*
1	39.52	39.91	39.61	0.19	0.26
6	22.05	22.31	22.91	0.30	0.09
12	11.57[b]	11.99[b]	12.80[a]	0.23	<0.001
18	5.32[c]	5.94[b]	6.95[a]	0.17	<0.001

[1] Temperature data used was an average of all three carcass locations

[a-c]Means within a row with differing superscripts differ at P ≤ 0.05

Figure 1: Temperature decline curves of the carcass during from 1 h to 22 h postmortem of carcasses categorized as Average (99-109kg), Heavy (116-126kg), and Very Heavy (134-144kg).

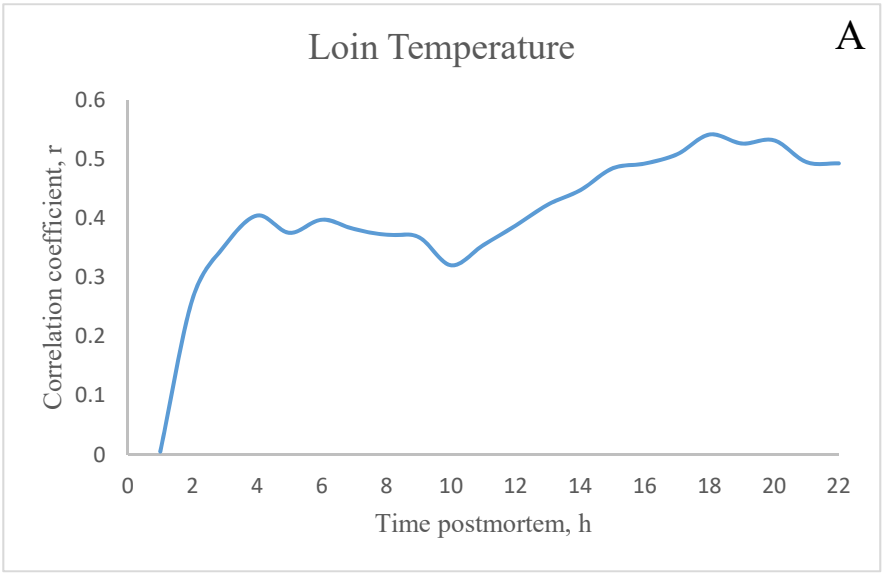


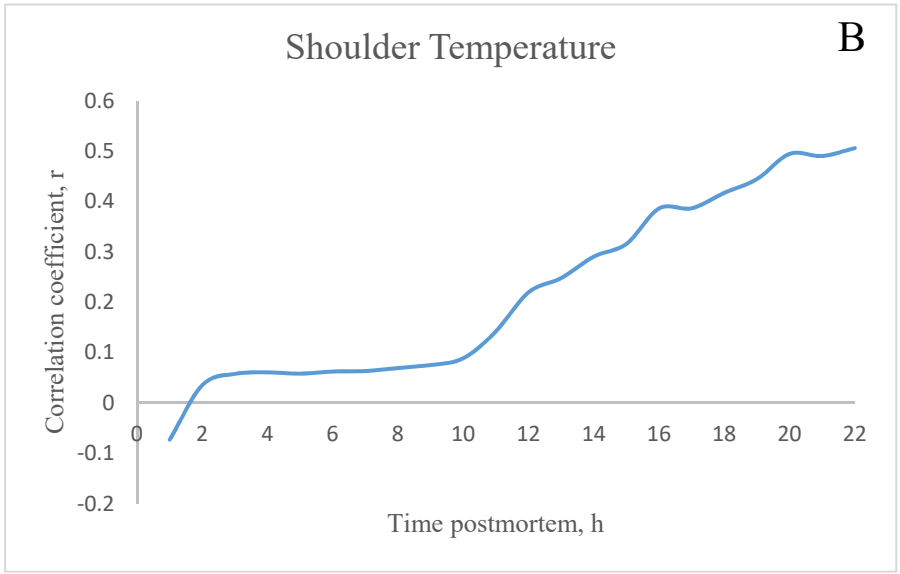
Time, h	Shoulder	Loin	Ham	SEM	*P-value*
1	38.76[b]	40.05[a]	40.22[a]	0.18	<0.001
6	20.70[b]	18.27[c]	28.29[a]	0.28	<0.001
12	11.88[b]	8.87[c]	15.59[a]	0.22	<0.001
18	5.90[b]	3.58[c]	8.72[a]	0.16	<0.001

[a-c]Means within a row with differing superscripts differ at $P \leq 0.05$

Figure 2: Temperature decline curves of the loin, shoulder, and ham from 1 h to 22 h postmortem.

Figure 3: (A) Pearson correlation coefficients (r) between hot carcass weight and loin temperature during chilling from 1 h to 22 h postmortem. (B) Pearson correlation coefficients (r) between hot carcass weight and shoulder temperature during chilling from 1 h to 22 h postmortem. (C) Pearson correlation coefficients (r) between hot carcass weight and ham temperature during chilling from 1 h to 22 h postmortem.





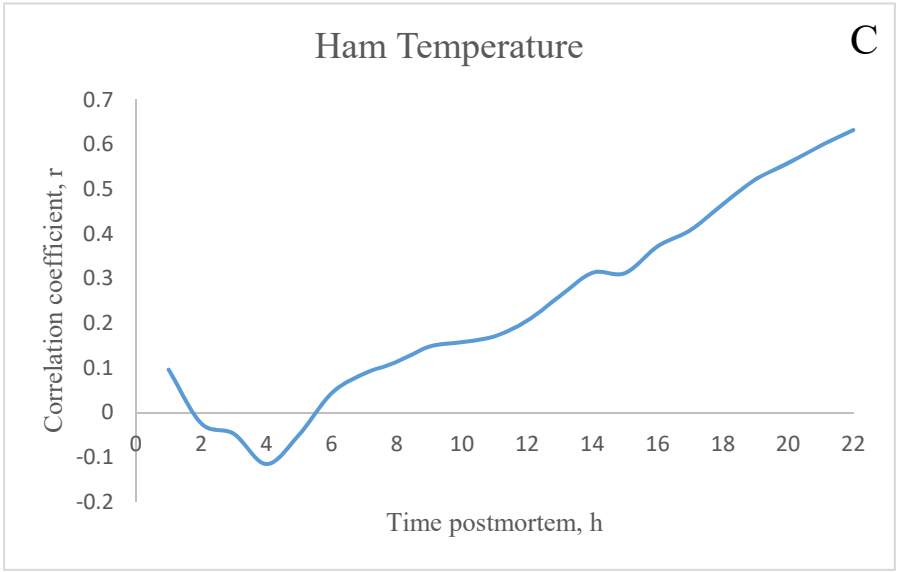


Table 3. Effect of carcass weight category on loin and chop quality

Item	Carcass Weight Category[1]			SEM	*P*-value
	Average	Heavy	Very Heavy		
Carcass Count, n	20	26	25		
Ventral Loin Surface[2]					
pH	5.52	5.52	5.57	0.02	0.08
NPPC color score[3]	3.33	3.29	3.28	0.12	0.96
NPPC marbling score[4]	1.63	1.46	1.66	0.12	0.35
NPPC firmness score[5]	3.15	3.19	3.16	0.10	0.94
Lightness[6], L*	49.07	48.81	48.60	0.81	0.91
Redness[6], a*	5.63	5.59	5.79	0.40	0.92
Yellowness[6], b*	10.63	10.43	10.50	0.39	0.93
Drip Loss[7], %	5.04	5.71	4.70	0.48	0.25
Moisture, %	73.90[a]	73.45[ab]	73.19[b]	0.19	0.02
Extractable Lipid, %	2.97	3.14	3.48	0.21	0.19
Aged Loin Chops[8]					
WBSF (63°C), kg	3.02	3.14	3.27	0.12	0.33
Cook Loss[9], % (63°C)	17.44	18.80	19.00	0.59	0.11
WBSF (71°C), kg	3.47	3.70	3.66	0.14	0.40
Cook Loss, % (71°C)	29.08	27.46	26.57	0.92	0.13

[1] Carcasses were placed into weight categories based on HCW; Average (99-101 kg), Heavy (116-126 kg), Very Heavy (134-144 kg)

[2] Early postmortem traits were evaluated 1 d postmortem

[3] NPPC color based on the 1999 standards measured in half point increments where 1 = palest, 6 = darkest.

[4] NPPC marbling based on the 1999 standards measured in half point increments where 1 = least amount of marbling, 6 = most amount of marbling

[5] NPPC firmness based on the 1991 scale measured in whole point increments where 1 = softest, 5 = firmest.

[6] L* measures darkness (0) to lightness (100; greater L* indicates a lighter color), a* measures redness (greater a* indicates a redder color), b* measures yellowness (greater b* indicates a more yellow color).

[7] Drip loss, % = ((Initial wt, g.) / (Final wt., g)) ×100

[8] Loin chops were aged for 14 days

[9] Cook loss, % = [(initial weight, kg – cooked weight, kg) ÷ initial weight, kg] × 100

[a-b] Least squared means within a row having differing superscripts are considered significant ($P \leq 0.05$)

Table 4. Correlation between postmortem temperature and loin quality traits from 1 h to 22 h postmortem[1]

	Variable			
Item	pH	Drip Loss[2], %	Moisture, %	Extractable Fat, %
Temp at 1 h	-0.06688	0.19063	-0.19124	-0.1208
	(0.5794)	(0.1282)	(0.1101)	(0.3156)
Temp at 2 h	0.01748	0.10162	-0.19416	0.02545
	(0.8849)	(0.4205)	(0.1047)	(0.8331)
Temp at 3 h	0.03263	0.06376	-0.17753	0.09252
	(0.7870)	(0.6138)	(0.1386)	(0.4428)
Temp at 4 h	0.06882	0.01004	-0.11913	0.10871
	(0.5685)	(0.9367)	(0.3224)	(0.3668)
Temp at 5 h	0.06811	-0.06211	-0.13532	0.13919
	(0.5725)	(0.6231)	(0.2605)	(0.2470)
Temp at 6 h	0.07080	-0.07794	-0.14237	0.15709
	(0.5574)	(0.5372)	(0.2363)	(0.1908)
Temp at 7 h	0.06888	-0.10202	-0.14403	0.16979
	(0.5682)	(0.4187)	(0.2308)	(0.1569)
Temp at 8 h	0.08181	-0.12903	-0.15781	0.17874
	(0.4976)	(0.3057)	(0.1887)	(0.1359)
Temp at 9 h	0.07438	-0.13735	-0.15240	0.19777
	(0.5376)	(0.2753)	(0.2045)	(0.0983)
Temp at 10 h	0.06988	-0.14716	-0.13558	0.21277
	(0.5625)	(0.2421)	(0.2596)	(0.0748)
Temp at 11 h	0.08259	-0.15262	-0.16398	**0.24032**
	(0.4935)	(0.2249)	(0.1718)	**(0.0435)**
Temp at 12 h	0.08637	-0.17905	-0.19856	**0.27757**
	(0.4739)	(0.1535)	(0.0969)	**(0.0191)**
Temp at 13 h	0.08213	-0.17641	-20745	**0.27208**
	(0.4959)	(0.1598)	(0.0826)	**(0.0217)**
Temp at 14 h	0.09186	-0.18352	**-0.23902**	**0.30814**
	(0.4461)	(0.1434)	**(0.0447)**	**(0.0089)**
Temp at 15 h	0.09384	-0.21006	**-0.24633**	**0.32994**
	(0.4364)	(0.0931)	**(0.0384)**	**(0.0050)**
Temp at 16 h	0.12975	-0.23579	**-0.27441**	**0.36558**
	(0.2808)	(0.0586)	**(0.0206)**	**(0.0017)**
Temp at 17 h	0.13867	-0.23415	**-0.26926**	**0.35544**
	(0.2488)	(0.0605)	**(0.0232)**	**(0.0024)**
Temp at 18 h	0.19066	**-0.25828**	**-0.30846**	**0.37881**
	(0.1112)	**(0.0378)**	**(0.0089)**	**(0.0011)**
Temp at 19 h	**0.23321**	**-0.25524**	**-0.31673**	**0.37460**
	(0.0503)	**(0.0402)**	**(0.0071)**	**(0.0013)**
Temp at 20 h	**0.27567**	**-0.28709**	**-0.33168**	**0.36963**
	(0.0200)	**(0.0204)**	**(0.0047)**	**(0.0015)**
Temp at 21 h	**0.31114**	**-0.27020**	**-0.32546**	**0.35967**
	(0.0083)	**(0.0295)**	**(0.0056)**	**(0.0021)**
Temp at 22 h	**0.30469**	-0.19666	-0.14030	0.04018
	(0.0098)	(0.1164)	(0.2432)	(0.7394)

[1] Upper row is the correlation coefficient between traits. *P*-value for difference from zero provided in parenthesis.

[2] Drip loss, % = ((Initial wt, g.) / (Final wt., g)) ×100

Table 5. Correlation between postmortem temperature and subjective color measurements from 1 h to 22 h postmortem[1]

	Variable		
Item	NPPC Color Score[2]	NPPC Marbling Score[3]	NPPC Subjective Firmness[4]
Temp at 1 h	-0.19396	-0.1178	0.03775
	(0.1051)	(-0.3279)	(0.7546)
Temp at 2 h	-0.11622	-0.01742	0.01624
	(0.3344)	(-0.8853)	(0.8931)
Temp at 3 h	-0.0402	0.05303	0.00166
	(0.7392)	(0.6605)	(0.9891)
Temp at 4 h	0.02593	0.13762	-0.01046
	(0.8301)	(0.2524)	(0.9310)
Temp at 5 h	0.05275	0.20036	-0.04538
	(0.6622)	(0.0939)	(0.7071)
Temp at 6 h	0.08037	0.22072	-0.03933
	(0.5052)	(0.0644)	(0.7447)
Temp at 7 h	0.09547	**0.24089**	-0.03015
	(0.4284)	**(0.0430)**	(0.8029)
Temp at 8 h	0.11505	**0.25039**	-0.03681
	(0.3394)	**(0.0352)**	(0.7605)
Temp at 9 h	0.13419	**0.26731**	-0.01701
	(0.2646)	**(0.0242)**	(0.8880)
Temp at 10 h	0.15856	**0.27053**	-0.01507
	(0.1866)	**(0.0225)**	(0.9007)
Temp at 11 h	0.14803	**0.28236**	-0.02351
	(0.2180)	**(0.0170)**	(0.8457)
Temp at 12 h	0.14718	**0.29131**	-0.01849
	(0.2206)	**(0.0137)**	(0.8784)
Temp at 13 h	0.13845	**0.28302**	-0.00817
	(0.2496)	**(0.0168)**	(0.9461)
Temp at 14 h	0.13660	**0.29999**	-0.02404
	(0.2560)	**(0.0110)**	(0.8423)
Temp at 15 h	0.14102	**0.29064**	-0.04161
	(0.2408)	**(0.0139)**	(0.7305)
Temp at 16 h	0.14540	**0.29816**	-0.05035
	(0.2263)	**(0.0116)**	(0.6767)
Temp at 17 h	0.14078	**0.26777**	-0.5336
	(0.2416)	**(0.0240)**	(0.6585)
Temp at 18 h	0.12864	**0.25942**	-0.02903
	(0.2850)	**(0.0289)**	(0.8101)
Temp at 19 h	0.09537	0.21718	-0.02550
	(0.4289)	(0.0689)	(0.8328)
Temp at 20 h	0.05168	0.18399	-0.03995
	(0.6687)	(0.1246)	(0.7408)
Temp at 21 h	0.04026	0.13720	-0.00352
	(0.7389)	(0.2539)	(0.9767)
Temp at 22 h	-0.01890	-0.00731	-0.09744
	(0.8757)	(0.9517)	(0.4188)

[1] Upper row is the correlation coefficient between traits. *P*-value for difference from zero provided in parenthesis.

[2] NPPC color based on the 1999 standards measured in half point increments where 1 = palest, 6 = darkest.

[3] NPPC marbling based on the 1999 standards measured in half point increments where 1 = least amount of marbling, 6 = most amount of marbling
greatest amount of marbling.

[4] NPPC firmness based on the 1991 scale measured in whole point increments where 1 = softest, 5 = firmest.

Table 6. Correlation between postmortem temperature and loin instrumental color measurements from 1 h to 22 h postmortem[1]

	Variable		
Item	Lightness[2], L*	Redness[3], a*	Yellowness[4], b*
Temp at 1 h	0.1083	-0.03139	-0.04134
	(0.3686)	(0.7950)	(0.7321)
Temp at 2 h	0.04232	-0.14159	-0.07794
	(0.7260)	(0.2389)	(0.5183)
Temp at 3 h	-0.02694	-0.1489	-0.05919
	(0.8236)	(0.2152)	(0.6239)
Temp at 4 h	-0.09596	-0.14604	-0.00159
	(0.4260)	(0.2243)	(0.9895)
Temp at 5 h	-0.12403	-0.05337	0.07064
	(0.3028)	(0.6584)	(0.5583)
Temp at 6 h	-0.15422	-0.03060	0.08071
	(0.1991)	(0.8000)	(0.5034)
Temp at 7 h	-0.17263	0.00702	0.11752
	(0.1500)	(0.9536)	(0.3290)
Temp at 8 h	-0.16543	0.04126	0.13878
	(0.1680)	(0.7326)	(0.2484)
Temp at 9 h	-0.17931	0.06367	0.13826
	(0.1346)	(0.5978)	(0.2502)
Temp at 10 h	-0.20041	0.07554	0.15141
	(0.0938)	(0.5312)	(0.2075)
Temp at 11 h	-0.19416	0.09928	0.14931
	(0.1047)	(0.4101)	(0.2139)
Temp at 12 h	-0.19286	0.10857	0.15121
	(0.1071)	(0.3675)	(0.2081)
Temp at 13 h	-0.19042	0.12107	0.14819
	(0.1117)	(0.3145)	(0.2174)
Temp at 14 h	-0.18853	0.13096	0.14460
	(0.1154)	(0.2763)	(0.2289)
Temp at 15 h	-0.19045	0.14947	0.15131
	(0.1116)	(0.2135)	(0.2078)
Temp at 16 h	-0.19386	0.16074	0.15870
	(0.1052)	(0.1805)	(0.1862)
Temp at 17 h	-0.18749	0.16157	0.14872
	(0.1174)	(0.1783)	(0.2158)
Temp at 18 h	-0.16855	0.13032	0.12576
	(0.1600)	(0.2787)	(0.2960)
Temp at 19 h	-0.12715	0.12809	0.13056
	(0.2907)	(0.2871)	(0.2778)
Temp at 20 h	-0.09756	0.11115	0.12519
	(0.4183)	(0.3561)	(0.2982)
Temp at 21 h	-0.05739	0.08440	0.11522
	(0.6345)	(0.4841)	(0.3386)
Temp at 22 h	0.03913	0.02430	-0.02521
	(0.7459)	(0.8406)	(0.8347)

[1] Upper row is the correlation coefficient between traits. *P*-value for difference from zero provided in parenthesis.

[2] L* measures darkness (0) to lightness (100; greater L* indicates a lighter color).

[3] a* measures redness (greater a* indicates a redder color).

[4] b* measures yellowness (greater b* indicates a more yellow color).

Table 7. Correlation between postmortem temperature and Warner-Bratzler shear force and cook loss from 1 h to 22 h postmortem[1]

	Variable			
Item	WBSF (63°C)	Cook Loss[2] (63°C)	WBSF (71°C)	Cook Loss[2] (71°C)
Temp at 1 h	0.09223	**0.26776**	0.04183	-0.05035
	(0.4443)	**(0.0240)**	(0.7291)	(-0.6767)
Temp at 2 h	0.03447	0.11638	0.01041	-0.1599
	(0.7754)	(0.3338)	(0.9314)	(-0.1829)
Temp at 3 h	-0.00205	0.04569	-0.00583	-0.17074
	(0.9865)	(0.7051)	(0.9615)	(0.1545)
Temp at 4 h	-0.03481	-0.03081	-0.04538	-0.21296
	(0.7732)	(0.7987)	(0.7071)	(0.0746)
Temp at 5 h	-0.05538	-0.04633	-0.05594	**-0.24063**
	(0.6464)	(0.7012)	(0.6431)	**(0.0432)**
Temp at 6 h	-0.04998	-0.03424	-0.6156	**-0.25988**
	(0.6790)	(0.7768)	(0.61)	**(0.0286)**
Temp at 7 h	-0.04775	-0.03693	-0.06268	**-0.26864**
	(0.6925)	(0.7598)	(0.6035)	**(0.0235)**
Temp at 8 h	-0.05615	-0.05374	-0.05397	**-0.28935**
	(0.6419)	(0.6563)	(0.6549)	**(0.0144)**
Temp at 9 h	-0.04885	-0.04501	-0.06661	**-0.29385**
	(0.6858)	(0.7094)	(0.5810)	**(0.0129)**
Temp at 10 h	-0.06670	-0.06370	-0.06405	**-0.31934**
	(0.5850)	(0.5977)	(0.5957)	**(0.0066)**
Temp at 11 h	-0.07109	-0.05360	-0.05391	**-0.32365**
	(0.5558)	(0.6571)	(0.6552)	**(0.0059)**
Temp at 12 h	-0.07125	-0.02954	-0.06389	**-0.3541**
	(0.5549)	(0.8068)	(0.5966)	**(0.0024)**
Temp at 13 h	-0.06336	-0.01413	-0.06308	**-0.35670**
	(0.5996)	(0.9069)	(0.6013)	**(0.0023)**
Temp at 14 h	-0.06110	-0.00952	-0.06611	**-0.36382**
	(0.6127)	(0.9372)	(0.5838)	**(0.0018)**
Temp at 15 h	-0.08885	0.01429	-0.06044	**-0.35635**
	(0.4612)	(0.9058)	(0.6166)	**(0.0023)**
Temp at 16 h	-0.08602	0.02851	-0.06532	**-0.33353**
	(0.4757)	(0.8134)	(0.5884)	**(0.0045)**
Temp at 17 h	-0.09610	0.06714	-0.04131	**-0.29132**
	(0.4253)	(0.5780)	(0.7323)	**(0.0137)**
Temp at 18 h	-0.08000	0.11053	-0.01256	**-0.29183**
	(0.5072)	(0.3588)	(0.9172)	**(0.0135)**
Temp at 19 h	-0.04974	0.16558	0.02787	**-0.25308**
	(0.6804)	(0.1676)	(0.8175)	**(0.0332)**
Temp at 20 h	-0.06243	0.18830	0.04755	**-0.23061**
	(0.6050)	(0.1158)	(0.6937)	**(0.0530)**
Temp at 21 h	-0.01935	0.20862	0.09795	-0.19643
	(0.8727)	(0.0808)	(0.4164)	(0.1006)
Temp at 22 h	-0.07276	-0.08073	0.08623	0.02326
	(0.5615)	(0.5033)	(0.4912)	(0.8473)

[1] Upper row is the correlation coefficient between traits. *P*-value for difference from zero provided in parenthesis.

[2] Cook loss, % = [(initial weight, kg – cooked weight, kg) ÷ initial weight, kg] × 100

Table 8. Effect of carcass weight category on ham quality at 1 d postmortem

	Carcass Weight Category[1]				
Item	Average	Heavy	Very Heavy	SEM	*P*-value
Carcass Count, n	20	26	25		
Semitendinosus, Light[2]					
pH	5.70	5.76	5.83	0.05	0.11
Lightness[3], L*	55.71	52.86	54.88	1.14	0.15
Redness[4], a*	11.32[a]	9.68[b]	9.92[b]	0.48	0.03
Yellowness[5], b*	7.34[a]	5.19[b]	6.05[ab]	0.55	0.02
Semitendinosus, Dark[6]					
pH	5.85	5.90	5.89	0.05	0.76
Lightness[3], L*	42.78[b]	44.99[a]	43.29[b]	0.68	0.04
Redness[4], a*	16.31	14.88	15.63	0.54	0.14
Yellowness[5], b*	6.07[a]	4.58[b]	4.76[b]	0.39	0.01
Semimembranosus[7]					
pH	5.62	5.63	5.65	0.02	0.49
Lightness[3], L*	52.86	51.71	53.39	1.00	0.39
Redness[4], a*	10.27	10.27	10.66	0.45	0.74
Yellowness[5], b*	4.86	3.63	4.87	0.50	0.09

[1] Carcasses were placed into weight categories based on HCW; Average (99-101 kg), Heavy (116-126 kg), Very Heavy (134-144 kg)

[2] Measurement taken on the medial side of the semitendinosus

[3] L* measures darkness (0) to lightness (100; greater L* indicates a lighter color).

[4] a* measures redness (greater a* indicates a redder color).

[5] b* measures yellowness (greater b* indicates a more yellow color).

[6] Measurement taken on the distal side of the semitendinosus from the femur.

[7] Measurement taken on the medial side at the blonde spot.

[a-b] Least squared means within a row having differing superscripts are considered significant ($P \leq 0.05$)

Table 9. Correlation between postmortem ham temperature from 1 h to 22 h postmortem and light semitendinosus quality traits at 1 d postmortem[1]

	Variable			
	Semitendinosus, Light			
Item	Lightness,[2] L*	Redness,[3] a*	Yellowness,[4] b*	pH
Temp at 1 h	0.03189	-0.21565	-0.1248	0.00516
	(0.7933)	(0.073)	(0.3033)	(0.9662)
Temp at 2 h	0.14142	-0.04088	0.09237	-0.02038
	(0.2429)	(0.7369)	(0.4469)	(0.867)
Temp at 3 h	0.14945	0.0829	0.19003	-0.0465
	(0.2169)	(0.4951)	(0.1151)	(0.7023)
Temp at 4 h	0.20356	**0.27972**	**0.36849**	-0.03693
	(0.091)	**(0.019)**	**(0.0017)**	(0.7615)
Temp at 5 h	0.18683	**0.25281**	**0.33068**	-0.01694
	(0.1215)	**(0.0347)**	**(0.0052)**	(0.8893)
Temp at 6 h	0.18093	0.21877	**0.30346**	0.01652
	(0.1339)	(0.0688)	**(0.0107)**	(0.892)
Temp at 7 h	0.16318	0.17689	**0.25657**	0.03352
	(0.1771)	(0.1429)	**(0.032)**	(0.783)
Temp at 8 h	0.13885	0.17124	**0.23895**	0.04484
	(0.2516)	(0.1564)	**(0.0464)**	(0.7124)
Temp at 9 h	0.12946	0.14137	0.2025	0.06586
	(0.2855)	(0.2431)	(0.0927)	(0.5881)
Temp at 10 h	0.11046	0.14551	0.1869	0.08629
	(0.3626)	(0.2294)	(0.1213)	(0.4776)
Temp at 11 h	0.11548	0.15798	0.20485	0.07159
	(0.3411)	(0.1915)	(0.0889)	(0.5559)
Temp at 12 h	0.10425	0.15103	0.1943	0.08067
	(0.3904)	(0.212)	(0.107)	(0.5068)
Temp at 13 h	0.11521	0.14335	0.19638	0.08693
	(0.3422)	(0.2365)	(0.1032)	(0.4743)
Temp at 14 h	0.10506	0.11986	0.18487	0.1032
	(0.3867)	(0.323)	(0.1255)	(0.3952)
Temp at 15 h	0.10451	0.12861	0.17505	0.09593
	(0.3892)	(0.2886)	(0.1472)	(0.4295)
Temp at 16 h	0.10764	0.0999	0.16187	0.12043
	(0.3751)	(0.4106)	(0.1806)	(0.3207)
Temp at 17 h	0.0978	0.06494	0.12945	0.14984
	(0.4206)	(0.5933)	(0.2855)	(0.2157)
Temp at 18 h	0.14008	0.05848	0.1505	0.15591
	(0.2474)	(0.6306)	(0.2136)	(0.1974)
Temp at 19 h	0.13024	0.06474	0.14786	0.1241
	(0.2825)	(0.5944)	(0.2219)	(0.306)
Temp at 20 h	0.13848	0.03014	0.13747	0.15126
	(0.2529)	(0.8044)	(0.2565)	(0.2113)
Temp at 21 h	0.15599	0.01613	0.13392	0.15285
	(0.1972)	(0.8945)	(0.269)	(0.2065)
Temp at 22 h	0.12952	-0.00492	0.0927	0.17252
	(0.2852)	(0.9677)	(0.4453)	(0.1532)

[1] Upper row is the correlation coefficient between traits. *P*-value for difference from zero provided in parenthesis

[2] L* measures darkness (0) to lightness (100;greater L* indicates a lighter color).

[3] a* measures redness (greater a* indicates redder color)

[4] b* measures yellowness (greater b* indicates a more yellow color).

Table 10. Correlation between postmortem ham temperature from 1 h to 22 h postmortem and dark semitendinosus quality traits at 1 d postmortem[1]

	Variable			
	Semitendinosus, Dark			
Item	Lightness,[2] L*	Redness,[3] a*	Yellowness,[4] b*	pH
Temp at 1 h	0.03902	-0.08188	-0.14751	0.07597
	(0.7484)	(0.5004)	(0.223)	(0.5319)
Temp at 2 h	0.05336	0.07677	-0.0009	0.10129
	(0.6609)	(0.5276)	(0.9941)	(0.4041)
Temp at 3 h	0.0626	0.16011	0.06933	0.07601
	(0.6067)	(0.1855)	(0.5685)	(0.5317)
Temp at 4 h	0.03575	**0.29247**	0.21475	0.02767
	(0.7689)	**(0.014)**	(0.0742)	(0.8201)
Temp at 5 h	0.0416	**0.2918**	0.1708	0.0394
	(0.7324)	**(0.0142)**	(0.1574)	(0.746)
Temp at 6 h	0.05258	**0.26915**	0.13037	0.05198
	(0.6655)	**(0.0243)**	(0.282)	(0.6691)
Temp at 7 h	0.05761	**0.24337**	0.07886	0.06271
	(0.6357)	**(0.0423)**	(0.5164)	(0.606)
Temp at 8 h	0.06158	**0.23708**	0.07053	0.05734
	(0.6125)	**(0.0481)**	(0.5618)	(0.6373)
Temp at 9 h	0.06359	0.22603	0.03908	0.05069
	(0.601)	(0.0599)	(0.7481)	(0.6769)
Temp at 10 h	0.0682	0.20573	0.02825	0.06029
	(0.5748)	(0.0875)	(0.8165)	(0.62)
Temp at 11 h	0.08716	0.18603	0.03303	0.05892
	(0.4731)	(0.1231)	(0.7861)	(0.628)
Temp at 12 h	0.09081	0.17184	0.01653	0.04505
	(0.4547)	(0.1549)	(0.892)	(0.7111)
Temp at 13 h	0.10088	0.15033	-0.00738	0.04513
	(0.406)	(0.2142)	(0.9517)	(0.7106)
Temp at 14 h	0.12087	0.12694	-0.01506	0.05677
	(0.3189)	(0.295)	(0.9015)	(0.6406)
Temp at 15 h	0.09868	0.12389	-0.02171	0.04347
	(0.4164)	(0.3069)	(0.8584)	(0.7209)
Temp at 16 h	0.11	0.10864	-0.04216	0.0743
	(0.3647)	(0.3707)	(0.7289)	(0.541)
Temp at 17 h	0.10689	0.09564	-0.05737	0.09612
	(0.3785)	(0.4309)	(0.6371)	(0.4286)
Temp at 18 h	0.12338	0.09515	-0.04293	0.09251
	(0.3089)	(0.4333)	(0.7242)	(0.4463)
Temp at 19 h	0.11807	0.11488	-0.03352	0.06386
	(0.3303)	(0.3437)	(0.7829)	(0.5995)
Temp at 20 h	0.13586	0.06706	-0.0588	0.0927
	(0.2621)	(0.5812)	(0.6287)	(0.4453)
Temp at 21 h	0.13643	0.09066	-0.04282	0.0669
	(0.2601)	(0.4554)	(0.7249)	(0.5821)
Temp at 22 h	0.12793	0.06108	-0.06846	0.12239
	(0.2912)	(0.6154)	(0.5733)	(0.3128)

[1] Upper row is the correlation coefficient between traits. *P*-value for difference from zero provided in parenthesis

[2] L* measures darkness (0) to lightness (100;greater L* indicates a lighter color).

[3] a* measures redness (greater a* indicates redder color)

[4] b* measures yellowness (greater b* indicates a more yellow color).

Table 11. Correlation between postmortem ham temperature from 1 h to 22 h postmortem and semimembranosus quality traits at 1 d postmortem[1]

	Variable			
	Semimembranosus			
Item	Lightness,[2] L*	Redness,[3] a*	Yellowness,[4] b*	pH
Temp at 1 h	-0.02339	0.07498	0.07374	-0.00992
	(-0.8476)	(0.5373)	(0.5441)	(0.935)
Temp at 2 h	-0.02679	0.05511	0.08753	0.05462
	(0.8258)	(0.6505)	(0.4712)	(0.6534)
Temp at 3 h	-0.04227	0.0895	0.08373	0.04927
	(0.7283)	(0.4612)	(0.4908)	(0.6855)
Temp at 4 h	-0.02962	0.10239	0.09425	0.07773
	(0.8077)	(0.399)	(0.4377)	(0.5225)
Temp at 5 h	-0.04151	0.12655	0.09191	0.07676
	(0.733)	(0.2965)	(0.4492)	(0.5277)
Temp at 6 h	-0.05726	0.15457	0.09081	0.08678
	(0.6377)	(0.2014)	(0.4547)	(0.475)
Temp at 7 h	-0.07428	0.16344	0.09269	0.08663
	(0.5411)	(0.1764)	(0.4454)	(0.4758)
Temp at 8 h	-0.08401	0.14953	0.05588	0.07672
	(0.4893)	(0.2167)	(0.6459)	(0.5279)
Temp at 9 h	-0.07644	0.15668	0.06147	0.0552
	(0.5294)	(0.1952)	(0.6132)	(0.6499)
Temp at 10 h	-0.08529	0.15195	0.04875	0.06754
	(0.4827)	(0.2092)	(0.6886)	(0.5785)
Temp at 11 h	-0.07765	0.18285	0.6504	0.04989
	(0.5229)	(0.1297)	(0.5927)	(0.6817)
Temp at 12 h	-0.07323	0.17675	0.05374	0.03399
	(0.5469)	(0.1433)	(0.6586)	(0.78)
Temp at 13 h	-0.04322	0.16556	0.05377	0.04309
	(0.7224)	(0.1708)	(0.6584)	(0.7232)
Temp at 14 h	-0.03811	0.19211	0.06629	0.04314
	(0.7541)	(0.1111)	(0.5856)	(0.7229)
Temp at 15 h	-0.01695	0.18223	0.07176	0.02863
	(0.8892)	(0.1311)	(0.5549)	(0.814)
Temp at 16 h	-0.01228	0.17284	0.05528	0.05325
	(0.9196)	(0.1525)	(0.6494)	(0.6615)
Temp at 17 h	-0.00579	0.17238	0.07961	0.06422
	(0.9621)	(0.1536)	(0.5124)	(0.5974)
Temp at 18 h	0.01108	0.18935	0.10306	0.05044
	(0.9274)	(0.1164)	(0.3959)	(0.6784)
Temp at 19 h	0.03903	0.2034	0.13243	0.03334
	(0.7483)	(0.0913)	(0.2744)	(0.7841)
Temp at 20 h	0.05264	0.1962	0.15285	0.05233
	(0.6652)	(0.1036)	(0.2065)	(0.667)
Temp at 21 h	0.07294	0.2199	0.1953	0.05392
	(0.5485)	(0.0673)	(0.1052)	(0.6575)
Temp at 22 h	0.08644	0.22476	0.18339	0.08683
	(0.4767)	(0.0614)	(0.1286)	(0.4748)

[1] Upper row is the correlation coefficient between traits. *P*-value for difference from zero provided in parenthesis

[2] L* measures darkness (0) to lightness (100;greater L* indicates a lighter color).

[3] a* measures redness (greater a* indicates redder color)

[4] b* measures yellowness (greater b* indicates a more yellow color).

Table 12. Effect of carcass weight category on shoulder quality

	Carcass Weight Category[1]				
Item	Average	Heavy	Very Heavy	SEM	*P*-value
Carcass Count, n	20	26	25		
Serratus ventralis[2]					
pH	5.82	5.88	5.87	0.06	0.71
Lightness[3], L*	42.69	42.62	42.35	0.75	0.94
Redness[4], a*	15.76	16.33	16.27	0.44	0.58
Yellowness[5], b*	5.88	6.88	6.50	0.42	0.21
Triceps brachii[2]					
pH	5.90	5.83	5.92	0.06	0.56
Lightness[3], L*	41.12	39.57	40.06	0.55	0.11
Redness[4], a*	15.40	15.45	15.13	0.66	0.92
Yellowness[5], b*	4.52	5.24	5.07	0.31	0.21

[1] Carcasses were placed into weight categories based on HCW; Average (99-101 kg), Heavy (116-126 kg), Very Heavy (134-144 kg)

[2] Measurement was taken on the chop surface.

[3] L* measures darkness (0) to lightness (100; greater L* indicates a lighter color).

[4] a* measures redness (greater a* indicates a redder color).

[5] b* measures yellowness (greater b* indicates a more yellow color).

Table 13. Correlation between postmortem shoulder temperature from 1 h to 22 h postmortem and triceps brachii quality traits at 1 d postmortem[1]

	Variable			
	Triceps brachii			
Item	Lightness,[2] L*	Redness,[3] a*	Yellowness,[4] b*	pH
Temp at 1 h	0.03894	-0.11108	-0.08828	-0.01595
	(0.7472)	(0.3564)	(0.4641)	(0.8957)
Temp at 2 h	0.06854	-0.12049	-0.01508	-0.07406
	(0.5701)	(0.3169)	(0.9007)	(0.5423)
Temp at 3 h	0.01004	-0.04887	0.06268	-0.07586
	(0.9337)	(0.6857)	(0.6035)	(0.5325)
Temp at 4 h	-0.00326	-0.02766	0.07991	-0.0487
	(0.9785)	(0.8189)	(0.5077)	(0.6889)
Temp at 5 h	-0.00326	-0.02766	0.10992	-0.0337
	(0.9785)	(0.8189)	(0.3615)	(0.7818)
Temp at 6 h	-0.00698	0.0262	0.13122	-0.02327
	(0.9539)	(0.8283)	(0.2754)	(0.8484)
Temp at 7 h	-0.02895	0.05188	0.13732	-0.00377
	(0.8106)	(0.6674)	(0.2535)	(0.9753)
Temp at 8 h	-0.01053	0.06541	0.16986	0.002233
	(0.9306)	(0.5878)	(0.1567)	(0.9854)
Temp at 9 h	-0.00853	0.07699	0.18552	0.0186
	(0.9437)	(0.5234)	(0.1214)	(0.8785)
Temp at 10 h	-0.00877	0.08135	0.19592	0.01522
	(0.9421)	(0.5)	(0.1015)	(0.9005)
Temp at 11 h	0.01757	0.08413	0.22422	-0.01762
	(0.8844)	(0.4855)	(0.0601)	(0.8849)
Temp at 12 h	0.03375	0.06911	**0.24005**	-0.02811
	(0.7799)	(0.5669)	**(0.0438)**	(0.8173)
Temp at 13 h	0.02649	0.03963	0.21991	-0.05342
	(0.8264)	(0.7428)	(0.0654)	(0.6605)
Temp at 14 h	0.02895	0.0493	**0.24036**	-0.05658
	(0.8106)	(0.6831)	**(0.0435)**	(0.6418)
Temp at 15 h	0.02914	0.03763	**0.24997**	-0.06784
	(0.8094)	(0.7554)	**(0.0355)**	(0.5768)
Temp at 16 h	0.01376	0.06501	**0.26515**	-0.04263
	(0.9094)	(0.5901)	**(0.0254)**	(0.726)
Temp at 17 h	-0.01675	0.07172	**0.2389**	-0.01687
	(0.8897)	(0.5522)	**(0.0448)**	(0.8898)
Temp at 18 h	-0.0506	0.1149	**0.24346**	0.04557
	(0.6752)	(0.34)	**(0.0408)**	(0.708)
Temp at 19 h	-0.0996	0.14346	**0.22983**	0.08197
	(0.4086)	(0.2327)	**(0.0538)**	(0.4999)
Temp at 20 h	-0.13427	0.13511	0.18256	0.13383
	(0.2643)	(0.2613)	(0.1276)	(0.2694)
Temp at 21 h	-0.16529	0.15756	0.14714	0.18847
	(0.1684)	(0.1894)	(0.2208)	(0.1182)
Temp at 22 h	-0.19358	0.15971	0.09962	**0.23047**
	(0.1058)	(0.1834)	(0.4085)	**(0.0549)**

[1] Upper row is the correlation coefficient between traits. *P*-value for difference from zero provided in parenthesis

[2] L* measures darkness (0) to lightness (100;greater L* indicates a lighter color).

[3] a* measures redness (greater a* indicates redder color)

[4] b* measures yellowness (greater b* indicates a more yellow color).

Table 14. Correlation between postmortem shoulder temperature from 1 h to 22 h postmortem and serratus ventralis quality traits at 1 d postmortem[1]

	Variable			
	Serratus ventralis			
Item	Lightness,[2] L*	Redness,[3] a*	Yellowness,[4] b*	pH
Temp at 1 h	-0.02548	-0.06858	-0.01892	-0.02777
	(0.833)	(0.5698)	(0.8755)	(0.8182)
Temp at 2 h	0.05737	-0.02229	0.06035	-0.08174
	(0.6346)	(0.8536)	(0.6171)	(0.498)
Temp at 3 h	0.06304	-0.00109	0.08013	-0.07097
	(0.6015)	(0.9928)	(0.5065)	(0.5564)
Temp at 4 h	0.04803	0.00133	0.06045	-0.03223
	(0.6908)	(0.9912)	(0.6165)	(0.7896)
Temp at 5 h	0.03562	0.03587	0.07183	-0.01699
	(0.768)	(0.7665)	(0.5517)	(0.8882)
Temp at 6 h	0.01854	0.04643	0.06652	0.00536
	(0.878)	(0.7006)	(0.5815)	(0.9646)
Temp at 7 h	-0.00812	0.06491	0.05663	0.03161
	(0.9464)	(0.5907)	(0.639)	(0.7935)
Temp at 8 h	-0.00194	0.07997	0.07101	0.03864
	(0.9872)	(0.5074)	(0.5562)	(0.749)
Temp at 9 h	-0.01255	0.10434	0.07347	0.06033
	(0.9173)	(0.3865)	(0.5426)	(0.6172)
Temp at 10 h	0.00835	0.10833	0.08363	0.03715
	(0.9449)	(0.3685)	(0.4881)	(0.7584)
Temp at 11 h	0.04108	0.13696	0.13159	0.01527
	(0.7338)	(0.2547)	(0.274)	(0.8994)
Temp at 12 h	0.05084	0.16621	0.16309	0.02115
	(0.6737)	(0.1659)	(0.1742)	(0.861)
Temp at 13 h	0.05035	0.17262	0.16284	0.01725
	(0.6767)	(0.15)	(0.1748)	(0.8865)
Temp at 14 h	0.05331	0.17818	0.16129	0.02164
	(0.6589)	(0.1371)	(0.179)	(0.8578)
Temp at 15 h	0.04692	0.1688	0.15399	0.0094
	(0.6976)	(0.1594)	(0.1998)	(0.938)
Temp at 16 h	0.0551	0.16603	0.14777	0.01126
	(0.6481)	(0.1664)	(0.2188)	(0.9257)
Temp at 17 h	0.05102	0.13967	0.12381	0.0206
	(0.6726)	(0.2454)	(0.3036)	(0.8646)
Temp at 18 h	0.0229	0.14624	0.10469	0.05371
	(0.8496)	(0.2236)	(0.3849)	(0.6564)
Temp at 19 h	-0.00892	0.09766	0.04647	0.08425
	(0.9411)	(0.4178)	(0.7004)	(0.4848)
Temp at 20 h	-0.05179	0.10881	0.02339	0.11795
	(0.668)	(0.3664)	(0.8465)	(0.3273)
Temp at 21 h	-0.07909	0.09266	-0.01965	0.15728
	(0.5121)	(0.4422)	(0.8708)	(0.1902)
Temp at 22 h	-0.10318	0.09393	-0.04048	0.18272
	(0.39109)	(0.4359)	(0.7375)	(0.1272)

[1] Upper row is the correlation coefficient between traits. *P*-value for difference from zero provided in parenthesis

[2] L* measures darkness (0) to lightness (100;greater L* indicates a lighter color).

[3] a* measures redness (greater a* indicates redder color)

[4] b* measures yellowness (greater b* indicates a more yellow color).

LITERATURE CITED

Arkfeld, E. K., Wilson, K. B., Overholt, M. F., Harsh, B. N., Lowell, J. E., Hogan, E. K., Klehm, B. J., Bohrer, B. M., Mohrhauser, D. A., King, D. A., Wheeler, T. L., Dilger, A. C., Shackelford, S. D., & Boler, D. D. (2016). Pork loin quality is not indicative of fresh belly or fresh and cured ham quality1,2,3. *Journal of Animal Science*, *94*(12), 5155–5167. https://doi.org/10.2527/jas.2016-0886

Beattie, V. E., Weatherup, R. N., Moss, B. W., & Walker, N. (1999). The effect of increasing carcass weight of finishing boars and gilts on joint composition and meat quality. *Meat Science*, *52*(2), 205–211.

Briskey, E. J. (1964). Etiological Status and Associated Studies of Pale, Soft, Exudative Porcine Musculature*. In C. O. Chichester, E. M. Mrak, & G. F. Stewart (Eds.), *Advances in Food Research* (Vol. 13, pp. 89–178). Academic Press. https://doi.org/https://doi.org/10.1016/S0065-2628(08)60100-7

Briskey, E. J., & Wismer-Pedersen, J. (1961). Biochemistry of Pork Muscle Structure. 1. Rate of Anaerobic Glycolysis and Temperature Change versus the Apparent Structure of Muscle Tissue a. *Journal of Food Science*, *26*(3), 297–305.

Brown, T., & James, S. J. (1992). Process design data for prok chilling. *International Journal of Refrigeration*, *15*(5), 281–289. https://doi.org/https://doi.org/10.1016/0140-7007(92)90043-T

Cisneros, F., Ellis, M., McKeith, F. K., McCaw, J., & Fernando, R. L. (1996). Influence of slaughter weight on growth and carcass characteristics, commercial cutting and curing yields, and meat quality of barrows and gilts from two genotypes. *Journal of Animal Science*, *74*(5), 925–933. https://doi.org/10.2527/1996.745925x

Coulter, S., Pham, Q. T., McNeil, I., & McPhail, N. G. (1995). Geometry, cooling rates and weight losses during pig chilling. *International Journal of Refrigeration*, *18*(7), 456–464. https://doi.org/https://doi.org/10.1016/0140-7007(95)00039-E

Daudin, J. D., & Kuitche, A. (1996). Modelling of temperature and weight loss kinetics during meat chilling for time variable conditions using an analytical based method — III. Calculations versus measurements on pork carcass hindquarters. *Journal of Food Engineering*, *29*(1), 39–62. https://doi.org/https://doi.org/10.1016/0260-8774(95)00063-1

Đurkin, I., Dadić, M., Brkić, D., Lukić, B., Kušec, G., Mikolin, M., & Jerković, I. (2012). Influence of gender and slaughter weight on meat quality traits of heavy pigs. *Acta Agric Slov*, 211–214.

Harsh, B. N., Arkfeld, E. K., Mohrhauser, D. A., King, D. A., Wheeler, T. L., Dilger, A. C., Shackelford, S. D., & Boler, D. D. (2017). Effect of hot carcass weight on loin, ham, and belly quality from pigs sourced from a commercial processing facility. *Journal of Animal Science*, *95*(11), 4958–4970.

Huff Lonergan, E., Zhang, W., & Lonergan, S. M. (2010). Biochemistry of postmortem muscle — Lessons on mechanisms of meat tenderization. *Meat Science*, *86*(1), 184–195. https://doi.org/https://doi.org/10.1016/j.meatsci.2010.05.004

James, S. J., Gigiel, A. J., & Hudson, W. R. (1983). The ultra rapid chilling of pork. *Meat Science*, *9*(1), 63–78. https://doi.org/https://doi.org/10.1016/0309-1740(83)90054-2

Jones, S. D. M., Jeremiah, L. E., & Robertson, W. M. (1993). The effects of spray and blast-chilling on carcass shrinkage and pork muscle quality. *Meat Science*, *34*(3), 351–362. https://doi.org/https://doi.org/10.1016/0309-1740(93)90083-T

Latorre, M. A., Lázaro, R., Valencia, D. G., Medel, P., & Mateos, G. G. (2004). The effects of gender and slaughter weight on the growth performance, carcass traits, and meat quality characteristics of heavy pigs1. *Journal of Animal Science*, *82*(2), 526–533. https://doi.org/10.2527/2004.822526x

Marsh, B. B. (1977). Temperature and postmortem change: energy use and meat quality. *Proceedings-Meat Industry Research Conference (USA)*.

Melody, J. L., Lonergan, S. M., Rowe, L. J., Huiatt, T. W., Mayes, M. S., & Huff-Lonergan, E. (2004). Early postmortem biochemical factors influence tenderness and water-holding capacity of three porcine muscles1. *Journal of Animal Science*, *82*(4), 1195–1205. https://doi.org/10.2527/2004.8241195x

Novakofski, J., Park, S., Bechtel, P. J., & McKeith, F. K. (1989). Composition of cooked pork chops: Effect of removing subcutaneous fat before cooking. *Journal of Food Science*, *54*(1), 15–17.

Overholt, M. F., Arkfeld, E. K., Bryan, E. E., King, D. A., Wheeler, T. L., Dilger, A. C., Shackelford, S. D., & Boler, D. D. (2019). Effect of hot carcass weight on the rate of temperature decline of pork hams and loins in a blast-chilled commercial abattoir123. *Journal of Animal Science*, *97*(6), 2441–2449. https://doi.org/10.1093/jas/skz131

Price, H. E., Barkley, K. E., Lerner, A. B., Harsh, B. N., Woodworth, J. C., Tokach, M. D., Dritz, S. S., Goodband, R. D., DeRouchey, J. M., O'Quinn, T. G., Allerson, M. W., Fields, B., King, D. A., Wheeler, T. L., Shackelford, S. D., Boler, D. D., & Dilger, A. C. (2022). Differences in carcass chilling rate underlie differences in sensory traits of pork chops from pigs with heavier carcass weights. *Journal of Animal Science*, skac206. https://doi.org/10.1093/jas/skac206

Price, H. E., Lerner, A. B., Rice, E. A., Lowell, J. E., Harsh, B. N., Barkley, K. E., Honegger, L. T., Richardson, E., Woodworth, J. C., & Tokach, M. D. (2019). Characterizing ham and loin quality as hot carcass weight increases to an average of 119 kilograms. *Meat and Muscle Biology*, *3*(1).

Rice, E. A., Lerner, A. B., Olson, B. A., Prill, L. L., Drey, L. N., Price, H. E., Lowell, J. E., Harsh, B. N., Barkley, K. E., & Honegger, L. T. (2019). Effects of increased pork hot carcass weights. II: Loin quality characteristics and palatability ratings. *Meat and Muscle Biology*, *3*(1).

Rosenvold, K., Borup, U., & Therkildsen, M. (2010). Stepwise chilling: Tender pork without compromising water-holding capacity1. *Journal of Animal Science*, *88*(5), 1830–1841. https://doi.org/10.2527/jas.2009-2468

Shackelford, S. D., King, D. A., & Wheeler, T. L. (2012). Chilling rate effects on pork loin tenderness in commercial processing plants1,2. *Journal of Animal Science*, *90*(8), 2842–2849. https://doi.org/10.2527/jas.2011-4855

Taylor, R. (1990). Interpretation of the correlation coefficient: a basic review. *Journal of Diagnostic Medical Sonography*, *6*(1), 35–39.