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Differences in carcass chilling rate underlie differences in sensory traits of pork chops from pigs with heavier carcass weights

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Abstract

Pork hot carcass weights (HCW) have been increasing 0.6 kg per year, and if they continue to increase at this rate, they are projected to reach an average weight of 118 kg by the year 2050. This projection in weight is a concern for pork packers and processors given the challenges in product quality from heavier carcasses of broiler chickens. However, previous work demonstrated that pork chops from heavier carcasses were more tender than those from lighter carcasses. Therefore, the objective was to determine the effects of pork hot carcass weights, ranging from 90 to 145 kg with an average of 119 kg, on slice shear force and sensory traits of Longissimus dorsi chops when cooked to 63 or 71 °C, and to assess if differences in chilling rate can explain differences in sensory traits. Carcasses were categorized retrospectively into fast, medium, or slow chilling-rates based on their chilling rate during the first 17 h postmortem. Loin chops cut from 95 boneless loins were cooked to either 63 or 71 °C and evaluated for slice shear force and trained sensory panel traits (tenderness, juiciness, and flavor) using two different research laboratories. Slopes of regression lines and coefficients of determination between HCW and sensory traits were calculated using the REG procedure in SAS and considered different from 0 at $P \leq 0.05$. As hot carcass weight increased, chops became more tender as evidenced by a decrease in SSF (63 °C $\beta = -0.0412$, $P = 0.01$; 71 °C $\beta = -0.1005$, $P < 0.001$). Furthermore, HCW explained 25% ($R^2 = 0.2536$) of the variation in chilling rate during the first 5 h of chilling and 32% ($R^2 = 0.3205$) of the variation in chilling rate from 5 to 13 h postmortem. Slow- and medium-rate chilling carcasses were approximately 12 kg heavier ($P < 0.05$) than fast chilling carcasses. Slice shear force of chops cooked to 63 and 71 °C was reduced in slow and medium chilling compared with fast chilling carcasses. Carcass temperature at 5 h postmortem explained the greatest portion of variation ($R^2 = 0.071$) in slice shear force of chops cooked to 63 °C. These results suggest that carcasses tend to chill slower as weight increases, which resulted in slight improvements in sensory traits of boneless pork chops regardless of final degree of doneness cooking temperature.

Lay Summary

Pork carcass weights have increased year over year for at least the past 25 yr. The poultry industry has experienced similar increases in carcass weights in the recent past. The increases in broiler carcass weights have resulted in detrimental impacts on quality. Contrary to the poultry industry, increases in pork carcass weights have resulted in a general improvement in pork quality, including tenderness. The underlying cause of these improvements has not been explained. In the present study, chilling rate was associated with carcass weights, particularly during the first 5 h postmortem. In fact, carcass temperature measured in the Longissimus dorsi muscle at 5 h postmortem was the most predictive of instrumental tenderness values when boneless pork chops were cooked according to UDSA guidelines for whole-muscle pork products. The metabolic conversion of muscle to meat is most active during this initial chilling period. Therefore, chilling rate, which is associated with carcass weight, may be influencing the conversion of muscle to meat and provide some explanation as to why heavy carcasses result in more tender pork chops.

Key words: chilling rate, degree of doneness, heavy pigs, sensory traits, tenderness, water-holding capacity

Abbreviations: DFITTS, difference of fit statistic; HCW, hot carcass weight; kg, kilogram; SSF, slice shear force; VIF, variance inflation factor

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Introduction

Pork carcass weights in the United States and Canada have been steadily increasing over time (USDA ERS, 2018; Barducci et al., 2019). Specifically, hot carcass weights have increased 17% in the United States since 1995 from an average of 82 kilograms (kg) to an average of 96 kg (USDA ERS, 2018). If this increase of 0.6 kg of carcass weight per year persists, pork carcasses will weigh more than 105 kg by 2030 and 118 kg by 2050. Increases in carcass weights of other meat-animal sources, particularly broilers, have coincided with increases in muscle myopathies detrimental to eating experience, and increased weights and growth rates are often attributed as the cause of these issues (Kuttappan et al., 2016). These potential parallels raise concerns about the impact of heavier pork carcass weights on sensory traits, particularly tenderness and juiciness, as these are among the most influential pork quality traits that determine consumers' overall eating experience (Enfält et al., 1997).

There have been publications pointing out that increased carcass weights would result in reduced pork tenderness due to increases in muscle fiber diameter with increasing weights (Čandek-Potokar et al., 1998). Increased muscle fiber diameter has been associated with reductions in tenderness in beef (Crouse et al., 1991; Chriki, et al., 2013) and pork (Lee, et al., 2012). As Park (2010) reported, the diameter of all muscle fiber types of the loin increased as live weights increased from 110 to 140 kg, the potential of increasing carcass weights to increase muscle fiber diameter and reduce tenderness seemed plausible. However, a recent meta-analysis reported that, as carcass weight increased from 53 to 129 kg, measures of pork chop tenderness were improved (Harsh et al., 2017). In an additional study, increased pork carcass weight was associated with increased tenderness of the longissimus muscle as measured by slice shear force (SSF). For every 1-kg increase in carcass weight, slice shear force was reduced by 0.07 kg (Price et al. 2019). Interestingly, Price et al. 2019 measured fiber diameter in a portion of this population of pigs but did not detect an increase in muscle fiber diameter with increasing carcass weights. Therefore, not only does the increased tenderness of pork from heavier carcass defy expectations, but also the mechanisms underlying this improved tenderness in heavier pigs are unclear.

Previous results suggest that heavier carcasses chill more slowly than lighter carcasses. For example, loins from carcasses weighing 105 kg chilled slower than those from carcasses weighing 85 kg (Overholt et al., 2019). Under commercial conditions, slower chilled loins were more tender than more rapidly chilled loins despite being paler in color with less perceived marbling (Shackelford et al. 2012). Additionally, faster chilling rates resulted in less tender pork at 4 d post-mortem even though the rate of pH decline was reduced (Rees et al., 2002). Furthermore, chilling carcasses too quickly can potentially result in reduced tenderness due to cold shortening (Savell et al., 2005). Therefore, differences in carcass chilling could be related to improved tenderness in heavier pigs.

Therefore, the objective was to determine the effects of hot carcass weight on chilling rate of pork carcasses that ranged in hot carcass weight from 90 to 145 kg, and to assess the effects of chilling rates on sensory traits of loin chops. The hypothesis was that carcasses that chilled more slowly would be heavier and would have improved sensory traits.

Materials and Methods

Protocols used in the live phase portion of the experiment were approved by the Kansas State University Institutional Animal Care and Use Committee. Pigs were slaughtered in a federally inspected facility under the supervision of the United States Department of Agriculture (USDA) Food Safety and Inspection Service. Meat was purchased from the production facility and then transported to the U.S. Meat Animal Research Center (Clay Center, NE) for slice shear force and trained sensory panel evaluation and to the University of Illinois Meat Science Laboratory (Urbana, IL) for trained sensory panel evaluation.

Pigs and experimental design

This experiment used a subset of 95 loins from experiments published previously (Lerner et al., 2020; Price et al., 2019). A total of 976 pigs (resulting from the mating of PIC 327 boars with PIC Camborough females, PIC, Hendersonville, TN) were used in a 160-d growth study to evaluate differences in space allowance and marketing strategy on pigs with an average market weight of approximately 165 kg. Details of the live phase portion of the experiment were explained in Lerner et al. (2020). Fresh loin and ham quality was evaluated on approximately two-thirds of those pigs. Details of methodology and findings were reported by Price et al. (2019). For the present study, postmortem loin temperature was captured and trained sensory panel analyses were performed on a subset of these pigs selected at random within hot carcass weight categories resulting in the 95 carcasses represented herein. Carcasses were categorized into HCW categories similar to Rice et al. (2019). Light carcasses weighed less than 111.8 kg. Medium-light carcasses weighed 111.8 to 119.1 kg and medium-heavy carcass weighed 119.1 to 124.4 kg. Heavy weight carcasses weighed more than 124.4 kg (Table 1).

Abattoir data collection

Pigs were loaded on trucks and transported approximately 565 km upon the completion of the live phase portion of the experiment (Lerner et al., 2020). Pigs were provided ad libitum access to water but no access to feed during lairage. Pigs were slaughtered on 2 separate days using CO_2 immobilization and terminated via exsanguination. Immediately after evisceration, a sequential identification number was written on the shoulder of each carcass and the respective pen number (indicative of live animal space treatment) tattoo was recorded for subsequent tracking of primal pieces. Hot carcass weight was measured at approximately 39 min postmortem, and temperature data loggers (Thermochron-iButton-40C-thru-85C,

Table 1. Classification of carcasses into chilling categories

	Temperature at 3 h postmortem	Time to reach 8 °C	Time to reach 5 °C
Fast	10–17 °C	3.5–6 h	4–12 h
Medium	14.5–19.5 °C	7–8 h	13–15 h
Slow	20–25 °C	9–14 h	16–17 h

To be categorized as fast, carcasses must have qualified as fast for at least 2 criteria and could not have qualified as slow for any criteria. To be categorized as slow, carcasses must have qualified as slow for at least 2 criteria and could not have qualified as fast for any criteria. All other carcasses were categorized as medium.

Embedded Data Systems, Lawrenceburg, KY) were inserted approximately 2–3 cm deep into the loin in the area of the tenth rib of approximately every third carcass. Data loggers recorded time and temperature at 1-min intervals. Temperature decline was recorded from before entering the blast-chiller for approximately 95 min and then held in equilibration bays until removal at approximately 17 h postmortem. Because of the proprietary nature of the blast chilling conditions, the exact chilling specifications are not available. However, the ambient temperature around carcasses averaged below 0 °C beginning at 55 min postmortem and lasting until between 2.5 and 3 h postmortem. The average minimum ambient temperature reached was below −13 °C. After 3.5 h postmortem, average ambient temperature was between 4.25 and 5.58 °C. Temperature decline data were collected on a total of 221 carcasses, split approximately evenly between the two slaughter days. Carcasses were fabricated into bone-in loins and then into boneless loins as described in the Institutional Meat Purchase Specifications (IMPS number 414; USDA, 2014) for evaluation.

Classifying temperature decline rate

Carcasses were retrospectively categorized into fast, medium, and slow chilling–based actual carcass temperature at 3 h postmortem, time required for a carcass to reach 8 °C, and time required to reach 5 °C. Fast chilling carcasses had temperatures between 10 and 17 °C at 3 h postmortem, medium chilling carcasses had temperatures between 17.5 and 19.5 °C at 3 h postmortem, and slow chilling carcasses had temperatures between 20 and 25 °C at 3 h postmortem. Fast chilling carcasses reached 8 °C between 3.5 and 6 h, medium chilling carcasses reached 8 °C between 7 and 8 h, and slow chilling carcasses reached 8 °C between 9 and 14 h. Fast chilling carcasses reached 5 °C between 4 and 12 h, medium chilling carcasses reached 5 °C between 13 and 15 h, and slow chilling carcasses reached 5 °C between 16 and 17 h. To be classified as a "fast-chilling" carcass, carcasses had to meet at least two of the three criteria of fast and be no worse than medium for any single criteria. To be classified as a "slow-chilling" carcass, carcasses had to meet the criteria of slow for at least two of three criteria and be no better than medium for any single criteria. All other carcasses with available chilling rate data were classified as medium chilling (Table 1). There were 31 carcasses meeting the criteria for fast chilling, 38 carcasses meeting the criteria for medium chilling, and 26 carcasses meeting the criteria for slow chilling (Table 2). Additionally, chilling rate was calculated for discrete times postmortem by dividing the absolute change in temperature by elapsed time. For example, for the chilling rate from 5 to 13 h postmortem was calculated for each carcass by dividing the absolute change in loin temperature by 8 and expressed as the change in degrees Celsius per h (Δ°C/h).

Loins

During loin fabrication, an identifier button corresponding to the shoulder sequence number was placed in the ventral surface of each boneless loin. Then loins were vacuum-packaged, boxed, and transported on ice in coolers to the U.S. Meat Animal Research Center (USMARC). Upon arrival, loins were unboxed, weighed, and then stored on carts ventral side up in a single-layer at 4 °C until 14 d postmortem. After aging, loins were removed from the packaging and weighed. Purge loss was calculated using the equation: [(initial weight, g − aged weight, g)/initial weight, g] × 100. At 14 d postmortem, loins were prepared for slicing using a Grasselli NSL 400 portion meat slicer (Grasselli SPA, Albinea, Italy) and cut 2.54 cm thick following the procedures as described in detail by Price et al. (2019). Chops were numbered from the anterior end with chop 1, proceeding to the posterior end with chop 13 and designated to either slice shear force or trained sensory evaluations. A detailed schematic of chop allocation was provided in Price et al. (2019). Chops 3, 4, 5, and 6 were used for slice shear force determination, and chops 2, 8, and 11 were vacuum-packaged, frozen, and shipped to the University of Illinois Meat Science Laboratory for trained sensory analysis of chops cooked to 63 °C. Chops 7 and 9 were also vacuum-packaged and frozen but remained at USDA MARC and were used for trained sensory analysis of chops cooked to 71 °C.

Slice shear force

Slice shear force was measured on 2 chops cooked to 63 °C and 2 chops cooked to 71 °C following the procedures outlined by Shackelford et al. (2004). Immediately after cutting, fresh (never frozen) chops were weighed to record initial weight. The following day (15 d postmortem), chops were cooked using a belt grill (Magigrill, model TBG60; MagiKitch'n Inc., Quakertown, PA). To achieve a targeted internal temperature of 63 °C, belt grill settings of the top grill heat = 163 °C, bottom grill heat = 163 °C, preheat = 149 °C, height = 2.16 cm, and cook dwell time of 4.00 min. To achieve a targeted internal temperature of 71 °C, the same belt grill settings were used except cook dwell time was extended to 5.25 min. Immediately after the chops exited the belt grill, a needle thermocouple probe (Omega Hypodermic Needle Probes; Stamford, CT) was inserted into the geometric center of each chop and endpoint temperature was determined using a digital thermometer (Oakton Temp 10k Thermocouple Thermometer; Edison, NJ). After each chop reached maximal internal temperature, which occurred approximately 2 min after the chops exited the belt grill, the endpoint temperature was recorded for each chop and the chops were weighed and cooking loss was calculated: [(Initial weight, g − cooked weight, g)/ initial weight, g] × 100. After cooking and weighing, a 1-cm-thick, 5-cm-long slice was removed from each chop parallel to the muscle fibers. Each sample was sheared once with a flat, blunt-end blade using an electronic testing machine (TMS-PRO Texture Measurement System; Food Technology Corporation; Sterling, VA). The SSF values from the 2 chops assigned to each temperature end point were then averaged, giving one SSF value for chops cooked to 63 °C and one SSF value for chops cooked to 71 °C used for all analyses.

Trained sensory panels

Chops were cooked to 63 °C (recent USDA recommended cooking temperature for whole-muscle pork) and 71 °C (historical suggested cooking temperature) to address changes in USDA final temperature cooking temperature recommendations for whole-muscle pork cuts (USDA, 2020). The objectives were not to compare end point cooking temperatures. Differences in tenderness estimates of pork chops cooked to differing endpoint temperatures have been well established (Rincker et al., 2008; Moeller et al., 2010; Cassens et. al. 2021) and recently substantiated using consumer evaluations

Table 2. The effect of temperature decline category on pork quality and sensory traits of boneless pork chops from carcasses with an average carcass weight of 119 kg

Trait	Chilling rate category[1]			SEM	*P*
	Fast	Medium	Slow		
Carcasses, *n*	31	38	26		
Hot carcass weight, kg	111.27[a]	121.89[b]	124.97[b]	1.68	< 0.0001
Estimated lean, %	54.67[b]	52.69[a]	52.69[a]	0.30	< 0.0001
Loin depth, mm	64.81[a]	67.21[ab]	69.76[b]	1.51	0.05
Fat depth, mm	13.20[a]	16.94[b]	17.15[b]	0.54	< 0.0001
Ultimate pH	5.50	5.51	5.52	0.03	0.86
Extractable lipid, %	1.84[a]	2.37[b]	2.20[ab]	0.15	0.02
Instrumental lightness, L*	53.78	54.42	54.26	0.52	0.58
Slice shear force (63 °C), kg	10.80[b]	9.71[a]	9.98[a]	0.42	0.02
Cooking loss (63 °C), %	12.80	12.33	12.39	0.22	0.19
Slice shear force (71 °C), kg	11.71[b]	9.82[a]	9.67[a]	0.42	< 0.001
Cooking loss (71 °C), %	18.71[b]	17.82[a]	17.57[a]	0.38	0.01
[2]Trained sensory (63 °C)					
Tenderness	9.32[a]	9.77[b]	9.87[b]	0.15	0.01
Juiciness	9.02	9.03	9.26	0.14	0.39
Flavor	1.80	1.84	1.88	0.04	0.31
[3]Trained sensory (71 °C)					
Thaw/purge loss, %	5.10[b]	4.86[b]	4.46[a]	0.12	< 0.001
Tenderness	5.91[a]	6.57[b]	6.63[b]	0.14	< 0.001
Juiciness	5.66[a]	6.14[b]	6.27[b]	0.12	< 0.001

[1]Carcasses were retrospectively categorized into fast, medium, or slow chilling rates based on three criteria. Fast chilling carcasses were categorized as those with a loin temperature between 10 and 17 °C at 3 h postmortem, reached 8 °C between 3.5 and 6 h postmortem, and 5 °C between 4 and 12 h postmortem. To be classified as "fast chilling," carcasses had to meet the criteria for fast in 2 of 3 categories and not be slower than medium chilling rate in any single category. Slow chilling carcasses were categorized as those with a loin temperature between 20 and 25 °C at 3 h postmortem, reached 8 °C between 9 and 14 h postmortem, and 5 °C between 16 and 17 h postmortem. To be classified as "slow chilling," carcasses had to meet the criteria for slow in 2 of 3 categories and not be faster than medium chilling rate in any single category. All other carcasses were categorized as medium chilling.
[2]Chops were evaluated at the University of Illinois. Values represent evaluations on a 15-cm anchored scale (0 = extremely tough, extremely dry, or no pork flavor and 15 = extremely tender, extremely juicy, or very intense pork flavor).
[3]Chops were evaluated at the U.S. Meat Animal Research Center. Values represent evaluations on an 8-point scale (1 = extremely tough/extremely dry, 2 = very tough/very dry, 3 = moderately tough/moderately dry, 4 = slightly tough/slightly dry, 5 = slightly tender/slightly juicy, 6 = moderately tender/moderately juicy, 7 = very tender/very juicy, 8 = extremely tender/extremely juicy).
[a–c]Means within a row with differing superscripts differ at $P \leq 0.05$.

(Honegger et al., 2019, 2022). Comparisons between cooking temperatures were outside the scope of this experiment and should be avoided. Rather the objective was to use multiple methodologies (i.e., using multiple research laboratories with optimized protocols) to validate the overall findings of the experiment.

Chops cooked to 63 °C

Chops were assigned to sensory sessions using an incomplete randomized block approach based on carcass weight categories for each sensory panel generated using the OPTEX procedure in SAS (SAS Inst. Inc., Cary, NC) with 8 chops per panel. Sensory evaluation was conducted by a 6-member panel of students and staff selected from a pool of experienced and trained panelist at the University of Illinois. Panelists were trained for tenderness, juiciness, and pork flavor. Tenderness and juiciness training was completed by cooking a pork tenderloin to 71 °C and several different pork chops (enhanced and not enhanced) to different degrees of doneness (63 °C—medium-rare, 71 °C—medium, and 80 °C—well-done). Flavor training was completed by cooking a pork blade steak to an internal temperature of 71 °C. As a group, panelists determined an anchor for tenderness, juiciness, and flavor.

Procedures used for sensory evaluation of chops cooked to 63 °C followed the same protocol described by Wilson et al. (2017). Chops for sensory evaluation were allowed to thaw for approximately 24 h prior to each panel evaluation by placing the vacuum-packaged chops in a refrigerator at 4 °C. Chops were cooked using a Farberware Open Hearth grill (model 455N; Walter Kidde, Bronx, NY). Internal temperature was monitored during cooking using copper-constantan thermocouples (Type T; OMEGA Engineering, Stamford, CT) placed in the geometrical center of each chop and connected to a digital scanning thermometer (model 92000-00; Barnant Co., Barrington, IL). Chops were cooked on one side to an internal temperature of 31 °C, flipped, and then cooked until they reached an internal temperature of 63 °C. Immediately after reaching 63 °C internal temperature, chops were removed from the grill. At the conclusion of the 3-min rest period, subcutaneous fat and edges were removed from each chop and the remaining portion was cut using a sample sizer into approximately 1-cm cubes that did not contain visible connective tissue. Panelists were placed in individual, breadbox-style booths with red lights to mask color differences among samples. Tenderness, juiciness, and flavor were measured on a 15-cm anchored scale (0 = extremely tough, extremely dry, or no pork flavor and 15 = extremely tender, extremely juicy, or very intense pork flavor). Each panelist received unsalted saltine crackers and apple juice for palate cleansing between samples. Each panelist was provided 2 cubes per sample on a paper plate. The entire study consisted of 18 sampling days and 278 samples, which encompassed all 95 carcasses selected for postmortem temperature recording. Sessions were held at least 1 h apart to reduce sensory fatigue. Results from all 6 panelists from each chop were averaged for use in data analyses.

Chops cooked to 71 °C

Chops were randomly assigned to sensory sessions based on carcass weight categories for each sensory panel. Two chops from a loin for each weight category were thawed for 24 h at 5 °C and cooked to 71 °C using the same technique as described for SSF. Cooking loss was calculated from each chop after a final cooking temperature was recorded, following the procedures and equations used for SSF measurement. Chops were trimmed of subcutaneous fat and edges were squared, then placed in a Plexiglas guide to be cut into 1 cm × 1 cm × chop thickness cubes. All cubes from both chops were mixed and three cubes were randomly selected and placed in a white paper cup with a 3-digit random code and served to each panelist. Sensory testing was conducted by a 10-member trained panel at the U.S. Meat Animal Research Center seated in individual booths with red lights to prevent bias due to sample color. This panel was recruited and trained in accordance with the guidelines of Cross et al. (1978) and the American Meat Science Association (2016). Panelists rated overall tenderness and juiciness on an 8-point scale (1 = extremely tough or dry; 8 = extremely tender or juicy). On each of 35 panel evaluation days, panelists evaluated 8 test samples consisting of 2 samples from each of the 4 HCW classes. Only one panel session was conducted on each evaluation day. Sample order was randomized within each panel session. Because there was no delay between cooking and serving, all panelists evaluated samples in the same order.

Panelists were served a "warm-up" sample, which was from an additional chop from the same loin as one of the test samples for that day. Panelists were provided distilled water and unsalted crackers to cleanse the palate between samples. Tenderness and juiciness were measured on an 8-point scale (1 = extremely tough/extremely dry, 2 = very tough/very dry, 3 = moderately tough/moderately dry, 4 = slightly tough/slightly dry, 5 = slightly tender/slightly juicy, 6 = moderately tender/moderately juicy, 7 = very tender/very juicy, 8 = extremely tender/extremely juicy).

Statistical analysis

Carcass weight categories and carcass chilling rate categories were compared with a one-way ANOVA in SAS with weight or chilling rate included as fixed variables. Predictive ability of HCW, carcass temperature, and chilling rate was calculated for each dependent variable using the regression procedure of SAS (SAS Inst. Inc., Cary, NC). Coefficients of determination (R^2) and the slope of each regression line were calculated to predict trends in slice shear force and sensory attributes and were considered significantly different from 0 at $P \le 0.05$. Multicollinearity among variables was tested using a variance inflation factor (VIF) test and it was determined no variables exceeded a VIF > 10. Excessive influence of individual observations was tested by calculating a Difference of Fit Statistic (DFITTS). No observations were determined to have excessive influence on the overall regression lines.

Pearson correlation coefficients between HCW and carcass temperature during the chilling period were calculated using the CORR procedure of SAS (SAS Inst. In., Cary, NC) for every hour postmortem. Multiple regression analyses were conducted using the regression procedure of SAS (SAS Inst. Inc., Cary, NC) to determine which independent variables were most predictive of instrumental tenderness and sensory traits. Independent variables included HCW, carcass temperature at 45 min postmortem, 5 h postmortem, 13 h postmortem, 17 h postmortem, chilling rate during the first 5 h of chilling, chilling rate from 5 h through 13 h postmortem, and chilling rate from 13 h through 17 h postmortem. Independent variables were allowed to be included and excluded from the final regression model using a stepwise selection of independent variables approach using a SLENTRY and SLTAY level = 0.25. A more conservative SLENTRY and SLSTAY threshold was used than often employed in meat science research as an attempt to determine maximum predictive ability of the final regression model.

Results

Hot carcass weight and sensory traits

The mean HCW of the 95 carcasses used for this experiment was 119.27 kg, and therefore, were representative of the projected average carcass weight of pork carcasses in 2050. Ultimate pH, extractable lipid, and instrumental lightness (L*) did not differ ($P \ge 0.51$) among carcass weight categories (Table 3). However, trained sensory tenderness was different among categories. Slice shear force of chops cooked to 71 °C was reduced ($P \le 0.05$) in heavy and medium heavy carcasses compared with light and medium light carcasses. Sensory tenderness from chops cooked to 63 °C was improved ($P \le 0.05$) in medium light, medium heavy, and heavy carcasses compared with light carcasses. Similarly, Sensory tenderness from chops cooked to 71 °C was improved ($P \le 0.05$) in medium light, medium heavy, and heavy carcasses compared with light carcasses. Differences in HCW explained 5.6% ($R^2 = 0.056$) of the variation in SSF of chops cooked 63 °C (Figure 1A) and 19% ($R^2 = 0.190$) of the variation in SSF of chops cooked to 71 °C (Figure 1B). Slice shear force decreased 0.41 kg in chops cooked to 63 °C and 1.01 kg in chops cooked to 70 °C for every 10-kg increase in HCW.

Hot carcass weight and chilling rate

Longissimus dorsi muscle temperatures were not different ($P = 0.65$) among HCW categories at 45 min postmortem (Figure 2). However, by 5 h postmortem, light carcasses were at least 1.2 °C colder ($P \le 0.03$) than light medium and light heavy carcasses and were 3.5 °C colder ($P < 0.0001$) than heavy carcasses. Likewise, light medium and light heavy carcasses were 1.5 °C colder ($P \le 0.01$) than heavy carcasses. By 13 h postmortem, light carcasses were 0.87 °C colder ($P \le 0.01$) than medium heavy and heavy carcasses and were 1.2 °C colder ($P < 0.0001$) than heavy carcasses. By 17 h postmortem, light carcasses were still 0.73 °C colder ($P \le 0.01$) than medium heavy and heavy carcasses (Figure 2).

Carcass temperature correlated ($P < 0.05$) with carcass weight, and that relationship became progressively stronger through the first 6 h of chilling (Figure 3A). The relationship between HCW and carcass temperature increased from

Table 3. The effect of hot carcass weight category on pork quality and sensory traits of boneless pork chops from carcasses with an average carcass weight of 119 kg

Trait	Hot carcass weight category[1]				SEM	*P*
	Light	Medium-Light	Medium-Heavy	Heavy		
Carcasses, *n*	20	23	21	31		
Hot carcass weight, kg	104.24[a]	116.12[b]	121.65[c]	129.68[d]	0.94	<0.001
Estimated lean, %	54.66[b]	53.42[a]	53.00[a]	52.79[a]	0.37	<0.01
Loin depth, mm	64.00[a]	65.00[a]	66.47[a]	71.20[b]	1.64	<0.01
Fat depth, mm	13.58[a]	15.35[ab]	16.22[b]	16.96[b]	0.69	<0.01
Ultimate pH	5.52	5.49	5.53	5.51	0.03	0.73
Extractable lipid, %	2.28	2.06	2.09	2.18	0.18	0.83
Instrumental lightness, L*	53.92	54.30	53.57	54.64	0.59	0.51
Slice shear force (63 °C), kg	10.87	9.94	9.61	10.18	0.36	0.09
Cooking loss (63 °C), %	13.05[b]	12.49[ab]	11.99[a]	12.49[ab]	0.24	0.03
Slice shear force (71 °C), kg	11.90[b]	10.40[a]	9.67[a]	9.90[a]	0.49	0.01
Cooking loss (71 °C), %	18.76[b]	18.28[a]	17.50[a]	17.77[a]	0.32	0.02
[2]Trained sensory (63 °C)						
Tenderness	9.24[a]	9.71[b]	9.90[b]	9.71[b]	0.17	0.05
Juiciness	9.12	8.89	9.28	9.08	0.16	0.37
Flavor	1.83	1.82	1.85	1.85	0.05	0.96
[3]Trained sensory (71 °C)						
Thaw/purge loss, %	5.16[c]	5.05[bc]	4.71[ab]	4.54[a]	0.14	< 0.01
Tenderness	5.77[a]	6.55[b]	6.40[b]	6.61[b]	0.16	< 0.001
Juiciness	5.60[a]	6.07[b]	6.05[b]	6.22[b]	0.14	0.01

[1]Carcasses were categorized into light, medium-light, medium-heavy, or heavy based on hot carcass weight categories described by Rice et al. (2019) (doi: 10.22175/mmb2019.07.0027). Light carcasses had carcass weights > 111.8 kg, medium-light were 111.8 kg to 119.1 kg, medium-heavy were 119.1 kg to 124.4 kg, and heavy were > 124.4 kg.
[2]Chops were evaluated at the University of Illinois. Values represent evaluations on a 15-cm anchored scale (0 = extremely tough, extremely dry, or no pork flavor and 15 = extremely tender, extremely juicy, or very intense pork flavor).
[3]Chops were evaluated at the U.S. Meat Animal Research Center. Values represent evaluations on an 8-point scale (1 = extremely tough/extremely dry, 2 = very tough/very dry, 3 = moderately tough/moderately dry, 4 = slightly tough/slightly dry, 5 = slightly tender/slightly juicy, 6 = moderately tender/moderately juicy, 7 = very tender/very juicy, 8 = extremely tender/extremely juicy).
[a–d]Means within a row with differing superscripts differ at $P \leq 0.05$.

45 min postmortem ($r = 0.14$) to a maximum at 6 h postmortem ($r = 0.63$; Figure 3A). The strength of the relationship between carcass weight and carcass temperature declined after 6 h postmortem but remained moderately strong ($r = 0.37$) even through 17 h postmortem. Hot carcass weight explained 25.4% ($R^2 = 0.25$) of the variation in carcass chilling rate through the first 5 h of chilling (Figure 3B). During this period of chilling, every 10-kg increase in HCW resulted in a decrease of 0.255 °C/h chilling rate. In other words, heavier carcasses chilled slower than lighter carcasses during this initial period of chilling.

After 5 h of chilling, heavier carcasses chilled more quickly than lighter carcasses. Hot carcass weight explained 32.1% ($R^2 = 0.32$) of the variation in carcass chilling rate from 5 h through 13 h of chilling (Figure 3C). During this period of chilling, every 10-kg increase in HCW resulted in an increase of 0.116 °C/h chilling rate. Hot carcass weight explained 15.1% ($R^2 = 0.15$) of the variation in carcass chilling rate from 13 through 17 h of chilling (Figure 3D). During this period of chilling, every 10-kg increase in HCW resulted in an increase of 0.037 °C/h chilling rate. Therefore, after having an initially slower rate in chilling, heavier carcasses chilled more quickly from 5 to 17 h postmortem.

The differences in chilling rates associated with HCW should be understood in the context of actual differences in postmortem temperature. Carcasses were categorized into different chilling rate categories irrespective of HCW. There were no differences ($P = 0.40$) in longissimus dorsi muscle temperature between fast and medium chilling carcasses at 45 min postmortem, but both were 0.62 °C colder ($P \leq 0.04$) than slow chilling carcasses. At 5 h postmortem, fast chilling carcasses were 2.72 °C colder ($P < 0.0001$) than medium chilling carcasses which were 2.13 °C colder ($P < 0.0001$) than slow chilling carcasses. At 13 h postmortem, fast chilling carcasses were 0.94 °C colder ($P < 0.0001$) than medium chilling carcasses which were 1.05 °C colder ($P < 0.0001$) than slow chilling carcasses. At 17 h postmortem, fast chilling carcasses were 0.63 °C colder ($P < 0.0001$) than medium chilling carcasses which were 0.86 °C colder ($P < 0.0001$) than slow chilling carcasses (Figure 4A).

Among carcasses categorized as fast chilling, the majority (45%) were from the "light" category with 35% from the medium light, 16% from the medium heavy category, and 3% from the heavy category. In contrast, slow-chilling carcasses had the greatest (54%) representation of heavy carcasses followed by medium heavy (27%), medium light (12%), and only 8% in the light category (Figure 4B). In the medium chilling category, heavy carcasses were the largest constituent (42%) with equal representation of medium heavy and medium light (24%) categories, and 11% light carcasses (Figure 4B).

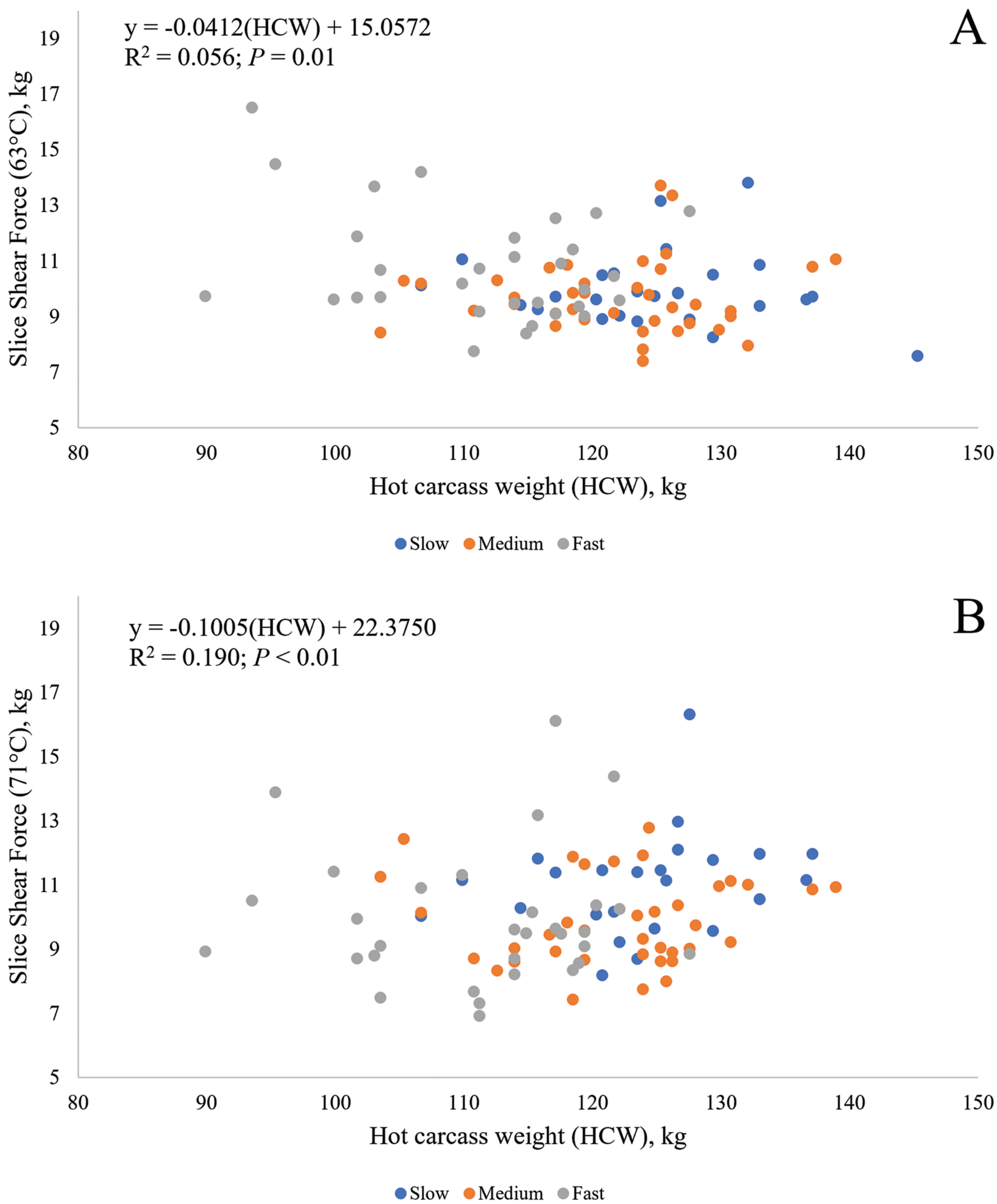


Figure 1. Effect of hot carcass weight on slice shear force of boneless pork chops aged 14 d and cooked to either (A) 63 °C or (B) 71 °C. Data are depicted as the pooled linear regression of the trait using the hot carcass weight as the independent variable. Depictions of chilling rates (slow, medium, and fast) were provided to illustrate the segregation of carcasses based on chilling rate category.

Chilling rate category and sensory traits

Even though carcass chilling categories were assigned independent of HCW, fast chilling carcasses were 10.62 kg lighter than medium chilling carcasses ($P < 0.0001$) carcasses and 13.70 kg lighter than slow chilling carcasses ($P < 0.0001$; Table 2). There were no differences ($P = 0.16$) in HCW between medium and slow chilling carcasses. There were no differences in ultimate pH or instrumental lightness of loins among chilling rate categories ($P \geq 0.58$), but carcasses rated as medium chilling rate had 0.52 percentage units more ($P < 0.01$) marbling than carcasses rated as fast chilling (Table 2). Fast chilling carcasses yielded less tender loins compared with medium and slow chilled carcasses. Slice shear force in chops cooked to 63 °C was increased ($P \leq 0.05$) in fast chilling carcasses compared with medium and slow chilling, though cook loss was not different ($P = 0.19$) among categories. In chops cooked to 71 °C, SSF was also reduced ($P < 0.001$) in fast chilling carcasses compared with medium and slow chilling carcasses, and cook loss was increased ($P \leq 0.01$) in fast chilling carcasses. Differences in instrumental tenderness were confirmed using trained sensory panelist where tenderness estimates of chops from medium and slow carcasses were greater ($P \leq 0.02$) than chops from fast chilling carcasses in both loins cooked to 63 °C and those cooked to 71 °C

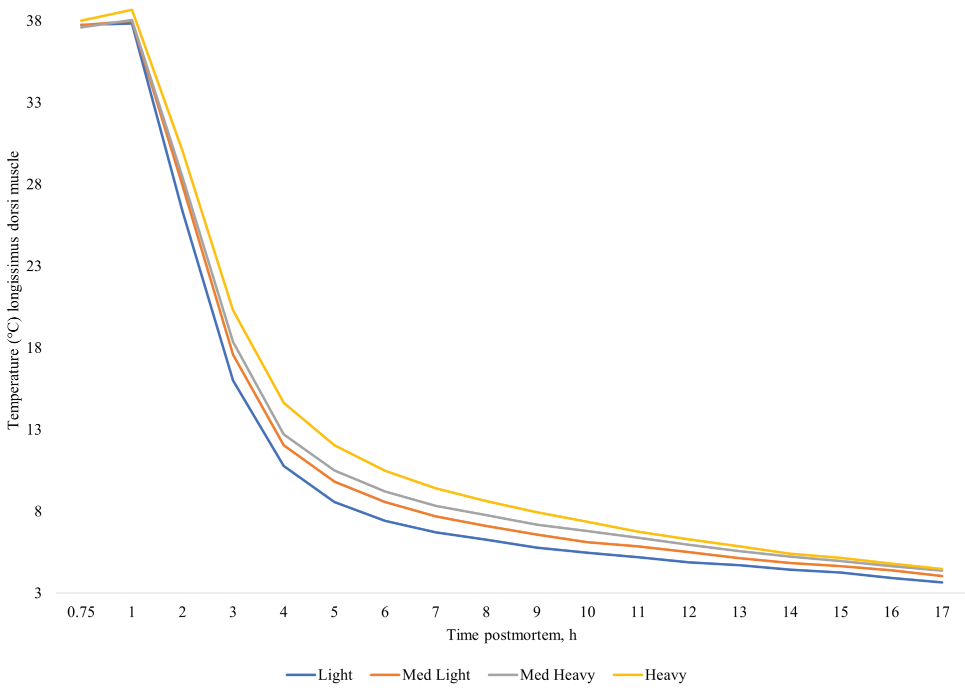


Figure 2. Temperature decline curves of the longissimus dorsi muscle during the first 17 h postmortem of carcasses categorized as light (<111.8 kg), medium-light (111.8 to 119.1 kg), medium-heavy (119.1 to 124.4), or heavy (> 124.4 kg). Hot carcass weight categories were the same as those described by Rice et al. (2019) (doi: 10.22175/mmb2019.07.0027).

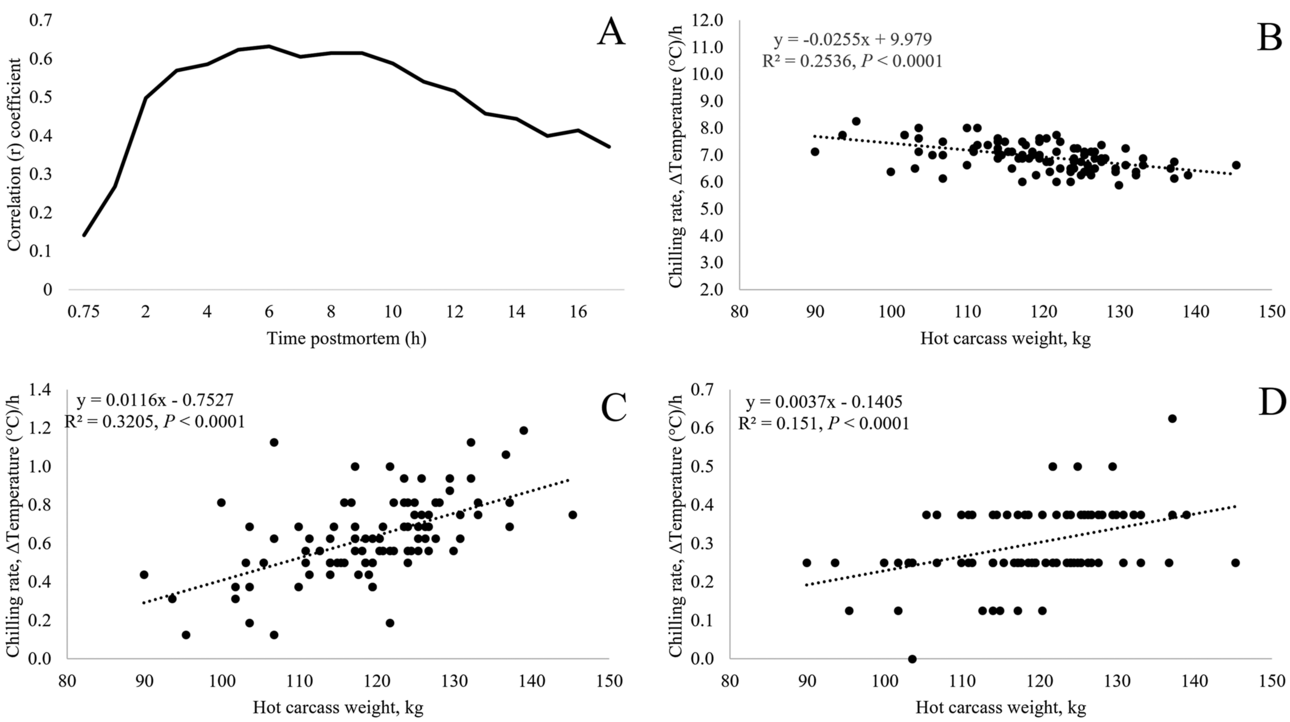
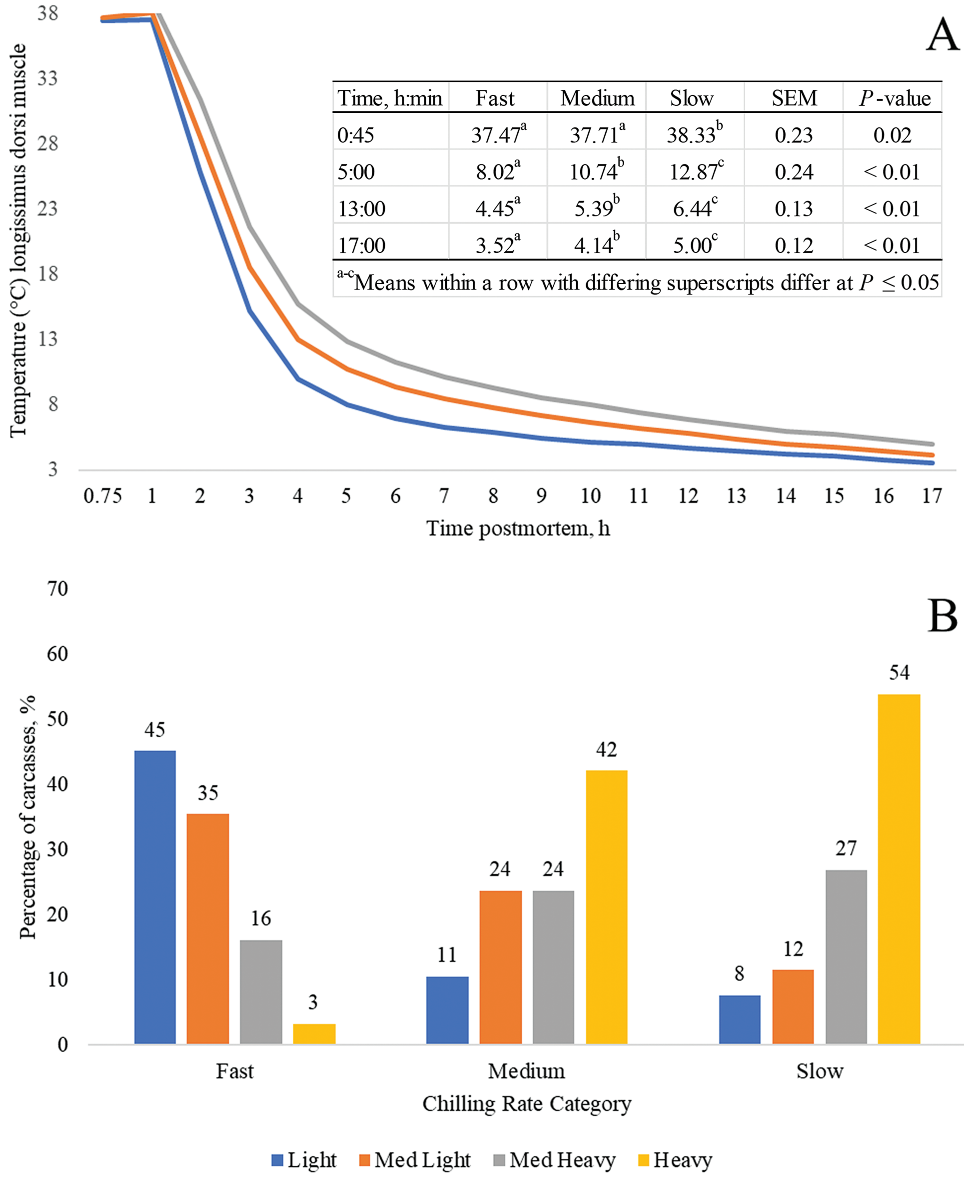


Figure 3. (A) Pearson correlation coefficients (r) between hot carcass weight, and actual carcass temperature during chilling from 45 min to 17 h postmortem. (B) Effect of hot carcass weight on chilling rate (Δ temperature °C/h) of pork carcasses from 45 min to 5 h postmortem. (C) Effect of hot carcass weight on chilling rate (Δ temperature °C/h) of pork carcasses from 5 to 13 h postmortem. (D) Effect of hot carcass weight on chilling rate (Δ temperature °C/h) of pork carcasses from 13 to 17 h postmortem.

(Table 2). There were no differences ($P \geq 0.50$) in instrumental tenderness or sensory tenderness between medium and slow chilling carcasses regardless of final chop cooking temperature (Table 2). There were no differences ($P \geq 0.31$) in juiciness or flavor among chilling categories in chops cooked to 63 °C. However, in chops cooked to 71 °C, chops from fast chilling carcasses were rated as less juicy ($P \leq 0.01$) than those from medium and slow chilling carcasses (Table 2).



Time, h:min	Fast	Medium	Slow	SEM	P-value
0:45	37.47[a]	37.71[a]	38.33[b]	0.23	0.02
5:00	8.02[a]	10.74[b]	12.87[c]	0.24	< 0.01
13:00	4.45[a]	5.39[b]	6.44[c]	0.13	< 0.01
17:00	3.52[a]	4.14[b]	5.00[c]	0.12	< 0.01

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

Figure 4. (A) Temperature decline curves of the longissimus dorsi muscle during the first 17 h postmortem of carcasses categorized as fast, medium, or slow chilling. Carcasses were retrospectively categorized into fast, medium, or slow chilling rates based on three criteria. Fast chilling carcasses were categorized as those with a loin temperature between 10 and 17 °C at 3 h postmortem, reached 8 °C between 3.5 and 6 h postmortem, and 5 °C between 4 and 12 h postmortem. To be classified as "fast chilling," carcasses had to meet the criteria for fast in 2 of 3 categories and not be slower than medium chilling rate in any single category. Slow chilling carcasses were categorized as those with a loin temperature between 20 and 25 °C at 3 h postmortem, reached 8 °C between 9 and 14 h postmortem, and 5 °C between 16 and 17 h postmortem. To be classified as "slow chilling," carcasses had to meet the criteria for slow in 2 of 3 categories and not be faster than medium chilling rate in any single category. All other carcasses were categorized as medium chilling. (B) Histogram of the percentage of carcasses within each chilling rate category categorized within each hot carcass weight category. Carcasses categorized into hot carcass weight categories according to Rice et al. (2019) (doi: 10.22175/mmb2019.07.0027) as light (<111.8 kg), medium-light (111.8 to 119.1 kg), medium-heavy (119.1 to 124.4), or heavy (>124.4 kg).

Carcass temperature and instrumental tenderness

Longissimus dorsi muscle temperature at 45 min postmortem was not predictive of SSF of chops cooked to 63 °C (R^2 = 0.01, P = 0.15) or 71 °C (R^2 = 0.00, P = 0.44; Figure 5A and B). Longissimus dorsi muscle temperature at 5 h postmortem explained 6% (R^2 = 0.06) of the variation in SSF of chops cooked to 63 °C (Figure 5C) and 16% (R^2 = 0.16) of the variation in SSF of chops cooked to 71 °C (Figure 5D). Every 5 °C increase in muscle temperature at 5 h postmortem resulted in a 0.75-kg decrease in SSF of chops when cooked to 63 °C and a 2.1-kg decrease in SSF of chops when cooked to 71 °C. Longissimus dorsi muscle temperature at 13 h postmortem explained 3% (R^2 = 0.03) of the variation in SSF of chops cooked to 63 °C (Figure 6A) and 15% (R^2 = 0.15) of the variation in SSF of chops cooked to 71 °C (Figure 6B). Every 5 °C increase in muscle temperature at 13 h postmortem resulted in a 1.70-kg decrease in SSF of chops when cooked to 63 °C and a 4.54-kg decrease in SSF of chops when cooked to 71 °C. Longissimus dorsi muscle temperature at 17 h postmortem explained 2% (R^2 = 0.02) of the variation in SSF of chops cooked to 63 °C (Figure 6C) and 11% (R^2 = 0.11) of the variation in SSF of chops cooked to 71 °C (Figure 6D). Every 5 °C

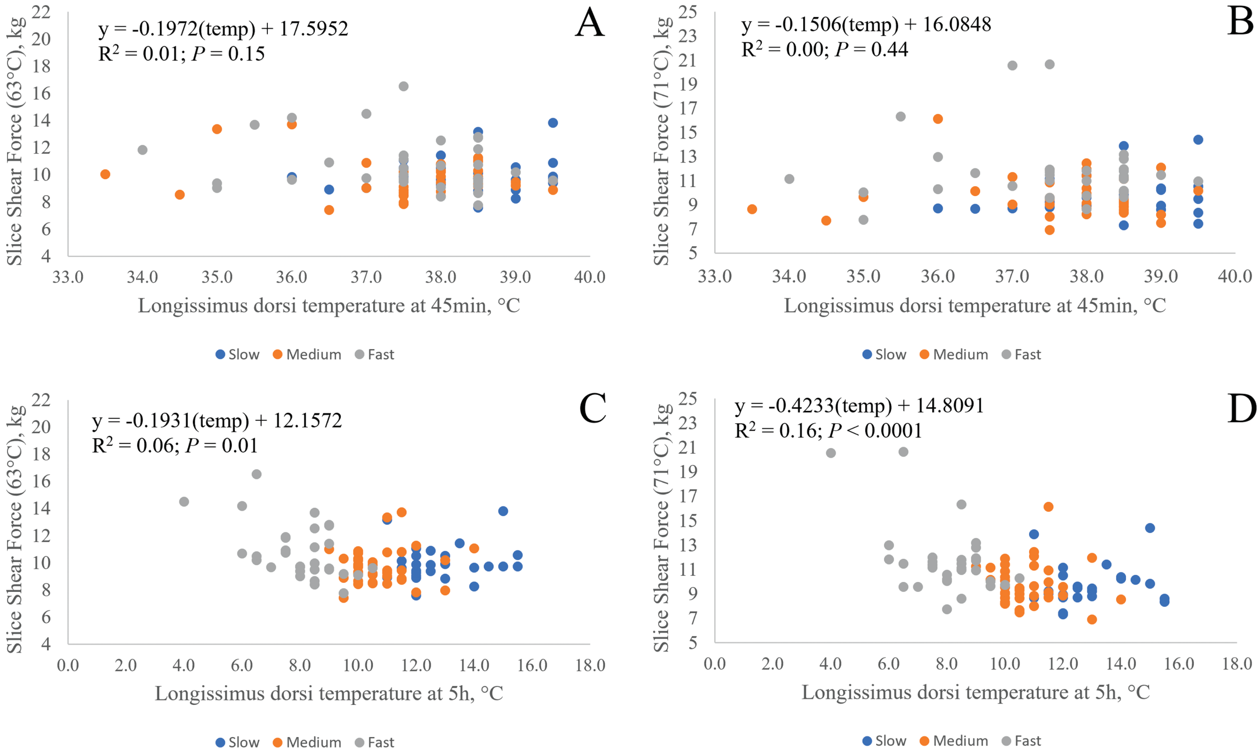


Figure 5. Effect of longissimus dorsi muscle temperature (°C) at 45 min postmortem on slice shear force of chops cooked to (A) 63 °C or (B) 71 °C. Effect of longissimus dorsi muscle temperature (°C) at 5 h postmortem on slice shear force of chops cooked to (C) 63 °C or (D) 71 °C. Data are depicted as the pooled linear regression of the trait using longissimus dorsi muscle temperature as the independent variable. Depictions of chilling rates (slow, medium, and fast) were provided to illustrate the segregation of carcasses based on chilling rate category.

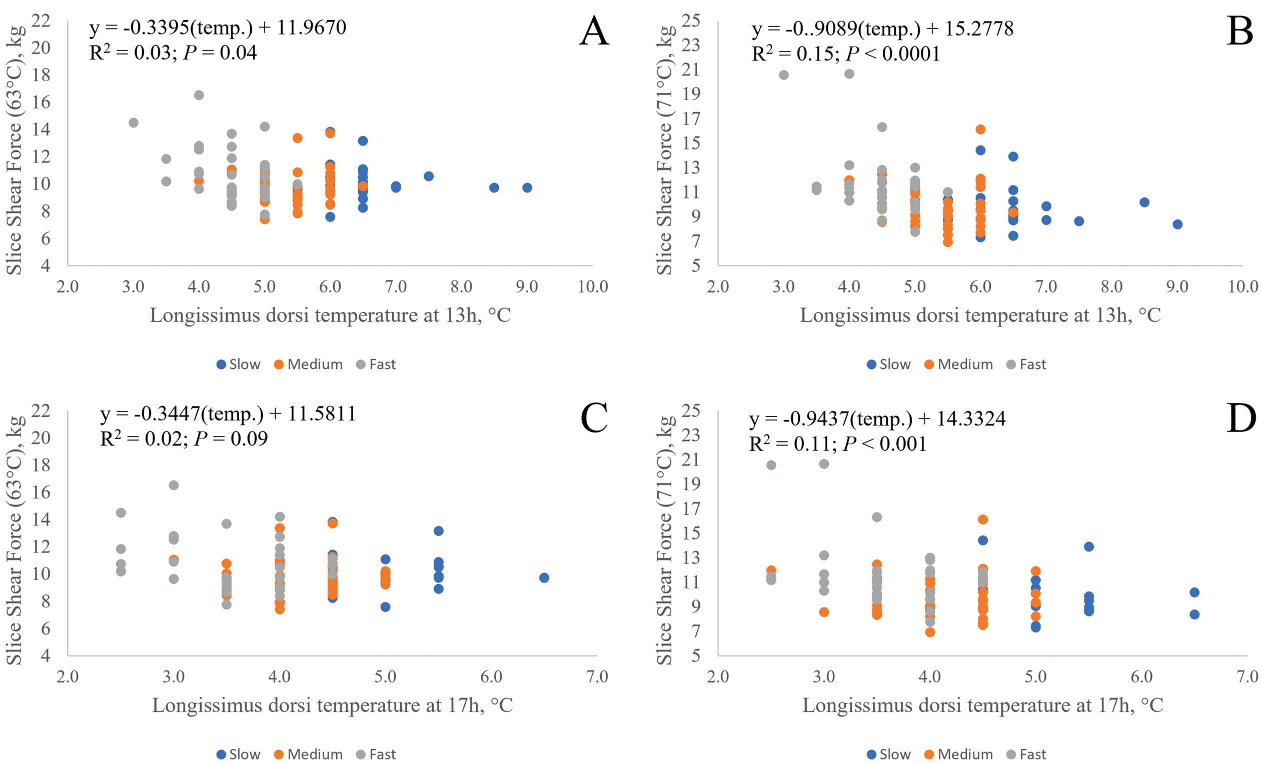


Figure 6. Effect of longissimus dorsi muscle temperature (°C) at 13 h postmortem on slice shear force of chops cooked to (A) 63 °C or (B) 71 °C. Effect of longissimus dorsi muscle temperature (°C) at 17 h postmortem on slice shear force of chops cooked to (C) 63 °C or (D) 71 °C. Data are depicted as the pooled linear regression of the trait using longissimus dorsi muscle temperature as the independent variable. Depictions of chilling rates (slow, medium, and fast) were provided to illustrate the segregation of carcasses based on chilling rate category.

increase in muscle temperature at 13 h postmortem resulted in a 1.72-kg decrease in SSF of chops when cooked to 63 °C and a 4.72-kg decrease in SSF of chops when cooked to 71 °C.

Prediction of sensory traits using carcass weight and chilling information

Because HCW and carcass temperature were correlated (Figure 3A) throughout the chilling period, a stepwise regression analysis was conducted to determine if HCW and temperature or chilling rate were additive in their predictive ability on sensory traits. Knowing the weight of the pork carcass, the temperature of the carcass, or the chilling rate of the carcass was able to explain between 5% and 28% of the variability in various sensory traits (Table 4), but it did not appear that any single trait was consistently more predictive of sensory traits than others. As an example, the combination of HCW and 5 h temperature was able to explain 8.5% (R^2 = 0.085) of the total variability in SSF of chops cooked to 63 °C (Table 4), but 5 h temperature did not add to the predicative ability of SSF when chops were cooked to 71 °C when HCW was known. Interestingly, HCW explained the greatest percentage of the total variability of trained sensory tenderness of any candidate variable for both chops cooked to 63 °C (partial R^2 = 0.100) and 71 °C (partial R^2 = 0.249), but longissimus dorsi temperature at 13 h postmortem explained at least an additional 2% of the variability in sensory tenderness (Table 4).

Discussion

Previous reports from this population of pork carcasses (Price et al., 2019; Rice et al., 2019) suggested that as carcass weight increased, tenderness of chops cooked to 71 °C was improved. Results of the current study were consistent with these previous observations. There was a 0.412-kg decrease in SSF of chops cooked to 63 °C for every 10-kg increase in carcass weight. Chops cooked to 71 °C also exhibited improved tenderness with increasing HCW, but the magnitude of improvement increased to 1.005 kg for every 10-kg increase in carcass weight. Overall, hot carcass weight accounted for a much greater portion of the total variability in chops cooked to 71 °C compared with chops cooked to 63 °C. There are limited published studies that have evaluated sensory traits on heavy pigs, and they have reported contradicting results. Cisneros et al. (1996) observed a 0.15 unit decrease in tenderness, determined by a trained taste panel, for every 10-kg increase in live weight ranging from 100 to 160 kg. Huff-Lonergan et al. (2002) observed a positive correlation between juiciness and carcass weight, but no correlation with tenderness. In both these studies, carcass weights would correspond to the "light" category in the present study. Park and Lee (2011) reported no changes in sensory characteristics on cooked chops with an increase in carcass weight ranging from 116 to 133 kg. However, two meta-analyses (Harsh et al., 2017; Wu et al., 2017) both noted improvements in tenderness with increasing carcass weight at carcass weight ranges that are more consistent with the present study. Thus, the overall conclusion from the present study and other work was that tenderness of pork loin chops is not harmed by increasing carcass weight beyond that of present-day U.S. standards. In fact, tenderness may be marginally improved at carcass weights in excess of 118 kg. The mechanism underlying these improvements is unclear but may relate to differences in rates of carcass chilling.

Table 4. Stepwise regression model and partial coefficients of determination (R^2) of chilling parameter's predictive ability of eating experience

Trait	Model R^2	Partial R^2								Model *P*-value
		Hot carcass weight	45 min temp.	5 h temp.	5 h chilling rate	13 h temp.	5 h to 13 h chilling rate	17 h temp.	13 h to 17 h chilling rate	
Slice shear force (63 °C), kg	0.085	0.014	*	0.071	*	*	*	*	*	0.02
Slice shear force (71 °C), kg	0.245	0.199	*	*	*	0.047	*	*	*	< 0.0001
Trained sensory (63 °C)										
Tenderness	0.126	0.100	*	*		0.026	*	*	*	< 0.01
Juiciness	0.034	*	*	0.017	0.018	*	*	*	*	0.20
Flavor	0.059	*	*	*	0.030	*	0.030	*	*	0.10
Trained sensory (71 °C)										
Tenderness	0.284	0.249	*	*	*	0.035	*	*	*	< 0.0001
Juiciness	0.260	0.225	*	*	*	*	*	0.036	*	< 0.0001

*Chilling parameters did not enter and stay in the final regression model by failing to reach and sustain a SLENTRY and SLSTAY $P < 0.25$.

Concerns over the ability of pig processing plants to effectively chill carcasses as carcass weight increases beyond 130 kg have been noted (Wu et al., 2017). Overholt et al. (2019) provided convincing evidence that heavier carcasses chill more slowly than lighter carcasses and are warmer at the end of the chilling period, even in facilities that use extremely cold, high wind velocity rapid chilling systems. Similarly, in the current study, heavier carcasses were warmer than lighter carcasses throughout the chilling period and especially during the initial period where muscle converts to meat. These changes in early postmortem chilling could alter meat quality and affect meat tenderness. In the present study, all measures of tenderness including SSF and sensory panel tenderness at both 63 and 71 °C cooking temperatures were worse in carcasses that chilled more quickly than those that chilled more slowly. Thus, while chilling rate did affect pork tenderness, more rapid chilling was more of a concern than slower chilling in this study.

The development of tenderness during the conversion of muscle to meat is a multifactorial phenomenon that can be difficult to explain. That said, historically 3 factors have been cited as key contributors to the variation in tenderness of pork muscles. Those factors are collagen content, sarcomere length, and proteolytic enzyme activity (Wheeler et al., 2000). Furthermore, it is well accepted that postmortem metabolism is a key contributor to variability in pork quality, particularly tenderness and water-holding capacity (Barbut et al., 2008). Chilling rate and carcass temperature during the conversion of muscle to meat can impact sarcomere length and proteolytic enzyme activity. Historical reports suggest that the rate of autolysis of u-calpain, an enzyme routinely associated with tenderization, is decreased as temperature decreases, implying that proteolytic activity remains functional longer during the postmortem conversion of muscle to meat (Koohmaraie, 1992). This suggests that fast chilling carcasses (lighter carcasses) should have been more tender. More recently, Pomponio and Ertbjerg (2012) reported that incubating μ-calpain at warmer temperature increased enzyme activity and decreased the activity of the inhibitor enzyme, calpastatin. In other cases, differences in chilling rate of pork carcasses did not result in tenderness differences but did result in differences in inactivation thresholds for μ-calpain (Xu et al., 2012). Although neither of those factors were directly measured in this experiment, it can be speculated that differences in chilling rate, as a result of differences in HCW, could influence these factors that are known to affect tenderness.

Pork carcasses typically enter the onset of rigor mortis between 1 and 3 h postmortem (Aberle et al., 2012) and near completion of rigor at approximately 6 h postmortem (Dransfield and Lockyer, 1985). Pork carcasses are most metabolically active during the onset of rigor and before completion of rigor. Changes to muscle temperature during this time can have negative effects on tenderness by altering sarcomere length. Rapid chilling resulting in muscle temperatures below 14 to 19 °C before the onset of rigor mortis can result in cold shortening, a phenomenon where muscle contracture results in shortened sarcomeres and eventually detriments to tenderness (Savell et al., 2005). In a previous experiment, pork from carcasses chilled at warmer temperatures (14 °C) was more tender after 4 d of postmortem aging than pork from carcasses chilled at 2 °C (Rees et al., 2003). These differences were attributed to differences in sarcomere length and proteolytic enzyme activity (Rees et al., 2003). In the present study, cold shortening may potentially explain the ability of 5 h temperature to predict SSF with some evidence of the most extreme SSF values being among the carcass with the lowest 5 h postmortem temperatures. Although carcass weight differences in this experiment resulted in a 18.3% difference in SSF of chops cooked to 71 °C after a 14-d aging period, chilling rate differences resulted in a 19.1% difference in SSF of chops. The difference in sensory tenderness between chilling categories in the present study (13.6%) is similar to that of Rees et al. (2003) who reported an 18.2% difference in sensory tenderness ratings of pork chops between "warm" and "cold" chilled carcasses. Given these changes, sarcomere length is one potential mechanism to explained differences in tenderness between light and heavy carcasses. It is possible that the industry average carcass weighing 96 kg is actually being chilled too quickly, potentially resulting in cold-shortening and causing loins to become tougher. A similar result was reported by Shackelford et al. (2012) where loins from rapidly chilled carcasses were tougher than those from slower chilled carcasses. However, further experiments to determine the effects of chilling differences in sarcomere length, enzymatic activity, and other biochemical factors are needed to confirm this hypothesis.

Furthermore, a combination of chilling rate and pH can affect water-holding capacity in meat. Elevated muscle temperatures (35 °C) that remain high in the early postmortem period when pH is declining can lead to increased incidence of pale, soft, and exudative (PSE) meat (Fernandez et al., 1994). Although this is an extreme example, the concern was that slower chilling rates in heavier carcasses might compromise water-holding capacity. Increased hot carcass weight was reported to slow chilling rate (Overholt et al., 2019), and it was previously reported that drip loss increased approximately 0.29 percentage units for every 10-kg increase in live weight (Cisneros et al. 1996; Park and Lee 2011) and 0.34 percentage units for every 10-kg increase in carcass weight (Virgili et al. 2003). However, both Durkin et al. (2012) and Harsh et al. (2017) reported a reduction in cooking loss in chops from heavier carcasses. Likewise, both cooking loss and thaw/purge loss were reduced as carcass weight increased in the current study. Furthermore, HCW explained 15% of the variation in improved cooking loss as carcass weight increased in the parent population of these data (Price et al., 2019). Overall, these results should alleviate the concern for potential reduced chilling rates of heavier carcasses negatively affecting water-holding capacity in the loin.

Conclusion

Rapidly chilling pork carcasses has been widely adopted throughout the industry because of the established benefits of reducing microbial growth, protecting food safety, and improvements in fresh meat color. Still, extreme rapid chilling is known to induce cold shortening in some circumstances. In this research population, heavy pigs produced heavy carcasses and heavier carcasses conclusively produced more tender pork chops. The underlying reasons behind the increase in tenderness are still unknown. However, the chilling process and carcass temperatures explain a portion of the variation in various loin chop tenderness estimates. The decreased rate of chilling of heavy carcasses during the first 5 h postmortem led to warmer carcasses at 5 h postmortem, when compared with light- and medium-weight carcass categories. This is a critical period during the conversion of muscle to meat and the warmer temperatures of heavier carcasses may have provided a more optimal metabolic condition that ultimately resulted in an improvement in tenderness of pork chops. Overall, these data confirm that HCW explains a portion of the variation in loin chop tenderness reported in previous reports but also provides evidence that differences in chilling rate due to differences in HCW may be the part of the underlying cause.

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Conflict of Interest Statement

The authors declare no real or perceived conflicts of interest.

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