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Running head: Correlation of loin firmness with pork quality

Correlation of fresh muscle firmness with sensory characteristics of pork loins destined for a quality focused market[1]

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ABSTRACT: Production of pork for quality driven export markets offers economic incentive. Pork processors use subjective firmness as a sorting tool for loins intended for high-quality export. The objectives of this study were to determine: 1) durometer efficacy in muscle, 2) if firmness on one portion of the loin is indicative of other locations, 3) if 1 d firmness is related to export quality traits, and 4) if variation in firmness is explained by mechanistic measures. Subjective firmness scores (1 = extremely soft; 5 = extremely firm) were determined by a trained individual d 1 (initial time point) postmortem. Loins (NAMP #414 Canadian back, N=154) were wet aged for 28 d at 1.7°C. On d 28, a panel of 4 individuals assigned firmness scores on the ventral side of the loin at the area of the 10th rib, the anterior half, and the posterior half of the loin. Durometer readings were collected at the area of the 10th rib on the dorsal and ventral side of the loin. Spearman correlation coefficients were computed in SAS (v. 9.3) to account for non-normality of categorical data. Subjective firmness measures at d 28 at the 10th rib and on the anterior portion of the loin did not correlate ($P \geq 0.21$) with whole loin durometer readings on the dorsal or ventral portion of the loin, nor the average of the whole loin values. Subjective firmness (d 28) at the 10th rib accounted for 38.44% (r = 0.620) and 48.30% (r = 0.695) of the variation in firmness at the anterior portion of the loin and the posterior portion of the loin, respectively ($P \leq 0.05$). One d subjective firmness measures correlated with 28 d WBSF measures (r = 0.174; $P = 0.03$), but did not significantly correlated with sensory characteristics ($P \geq 0.08$). Purge tended to correlated with 1 d firmness (r = 0.136; $P = 0.10$), however drip and cooking loss, 24 h and 28 d pH, and soluble and insoluble collagen content were not correlated ($P \geq 0.34$). Firmness measures collected in the production facility (d 1) negatively correlated with IV (r = -0.199; $P = 0.02$) yet no 28 d subject firmness measures were correlated with IV ($P \geq 0.33$). When loins not achieving export standards are removed from the population, 1 d firmness was not correlated to

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export quality or sensory characteristics (d 28). Differences in firmness were not explained by mechanistic measures. Inconsistencies among subjective and objective firmness measures suggest the durometer may not be an appropriate way to determine firmness.

Key words: export, firmness, loin, pork, quality, sensory

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INTRODUCTION

In 2014, Mexico imported the greatest amount of us pork (680,842 metric tons; $1.558 billion), while Japan was the largest importer of U.S. pork on a value basis (468,561metric tons; $1.932 billion; Masker, 2015). Japanese meat processors rank pork eating quality second only to food safety (Murphy et al., 2015). Therefore, one challenge for U.S. pork processors seeking to export to high-quality markets like Japan is to determine eating quality of the product prior to shipping without harming the integrity of whole muscle products.

A variety of mechanical methods are available to predict quality (pH meter, colorimeter, etc.), but these methods are not a viable option at production speed (> 1000 pigs/h) in a U.S. production facility. Consequently, many quality decisions for fresh loins are based on assessments of subjective color, marbling, and firmness by facility personnel. Studies have evaluated the correlations of subjective firmness to other pork quality traits (Huff-Lonergan et al., 2002; Boler et al., 2010). However, these studies have not focused on subjective firmness as a determining factor for palatability of loins destined for export. Others have evaluated mechanical firmness of muscle (Rincker et al., 2007) and adipose tissue (Seman et al., 2013). Seman et al. (2013) demonstrated that durometers are effective at evaluating tissue firmness in pork bellies, but less is known about the durometers efficacy in muscle tissue. As such, little information exists regarding appropriateness of using loin firmness as a sorting tool to predict quality of exported loins.

Therefore, this study had four primary objectives: 1) to determine if durometer measures correlate with subjective firmness scores, and thus have potential efficacy in a commercial facility, 2) to determine if firmness at various anatomical locations throughout the loin is an accurate predictor of firmness in other loin locations, 3) to determine if firmness 1d postmortem

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is related to export quality traits, and 4) to determine if variation in firmness can be attributed to variability in mechanistic measures. Although correlations have been made between firmness and other quality traits, we hypothesize that by removing the lowest quality loins from a population of loins, variation in firmness will be reduced. Thus, in high-quality export loins, firmness is not an accurate indicator of pork quality and may not be the most appropriate way to select pork loins for export.

MATERIAL AND METHODS

Postmortem samples were obtained from a federally inspected slaughter facility therefore no Institutional Animal Care and Use Committee approval was necessary.

Processing Facility Data Collection

Loins (N = 154) selected for this experiment were derived from PIC337-sired pigs (PIC, Pig Improvement Company, Hendersonville, TN). Hot carcass weight, backfat depth, and loin depth were measured after slaughter of the pigs using a Fat-O-Meater system (Fat-O-Meater measurements, SFK Technology Fat-O-Meater, Herlev, Denmark). Estimated percent lean was calculated using a proprietary facility equation. Carcasses were fabricated into primal cuts at approximately 24 h postmortem. Boneless loins were evaluated for subjective quality measures online 1 d postmortem on the ventral surface of the loin after the backribs were removed. Color was evaluated online approximately 3-5 min after backribs were removed using a 6 point scale (Japanese color scale), marbling was evaluated using a 10 point scale (NPPC, 1999; 1 = 1.0% intramuscular lipid, 10 = 10.0% intramuscular lipid), and firmness was evaluated using a 5 point scale (NPPC, 1991; 1=soft; 5=very firm) through standard facility procedures of folding the whole loin. Objective L*, a*, and b* measurements were collected using a Minolta CR400 Colorimeter (C light source, 2˚ observer, 10 mm aperture). Ultimate pH was recorded using a

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MPI pH meter with glass tipped electrode (Meat Probes Inc., Topeka, KS), the probe was inserted at approximately the 10th rib location on the boneless loin. Iodine value of jowl and belly adipose tissue was measured using a Bruker NIR (Billerica, MA). Loins were individually packed in vacuum-packaging and shipped under refrigeration to the University of Illinois Meat Science Laboratory.

Aged Loin Evaluation

Loins arrived at the University of Illinois Meat Science Laboratory under refrigeration at 1.7 ˚C. Loins were aged, in vacuum-sealed packages, until 28 d postmortem at 4 ˚C to account for an estimated time it would take loins to arrive at their final export destination. Aged loins were weighed in their package and weighed after removal from their package. Dried package weight was determined as the average of a random selection of 10% (16 packages) of the vacuum-packaged bags used in the study and subtracted from the packaged loin weight. Purge loss was calculated as weight lost in purge as a percentage of packaged weight.

Fresh Loin Firmness Measurements

Loin flop distance was determined by placing the loin, ventral side down, on a bar and measuring the distance between the inside edges of both ends of the loin. A trained panel (n=4) assigned firmness scores to whole loins on a scale of 1 to 5; with one being very soft and 5 being very firm (NPPC, 1991). Aged (28 d) fresh loin firmness was evaluated at several location of the loin and on multiple, individual chops to gain an understanding of the variation on firmness throughout the loin. Subjective firmness of the ventral side of the loin was assessed at three locations: mid-point (at approximately the 10th rib), anterior (half the distance between the 10th rib and anterior end of the loin), and posterior (half the distance between the 10th rib and

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posterior end of the loin). Durometer measurements (objective firmness with greater numbers indicating a firmer product; DD-100-000-S with removable stainless steel barrel; Check-Line, Cedarhurst, NY) were determined at approximately the 10th rib on both the dorsal and ventral sides of the loin with an approximate temperature of 4 °C. Durometer measures on the ventral portion of the loin were evaluated on fresh muscle tissue and measures on the dorsal portion of the loin were evaluated on loins trimmed to the epimysium. Dorsal and ventral durometer measures were averaged for a whole loin durometer firmness score. Loins were trimmed to expose a fresh cut surface at approximately the 10th rib, where the trained panel evaluated firmness on the cut surface. Chops (2.54 cm thick) were cut assigned to assays (Warner-Bratzler shear force and sensory evaluation) in a consistent order to minimize variation due to loin location among loins. Subjective firmness and durometer readings were collected on lean tissue of these chops and then, they were held frozen at -4˚ C in a vacuum package bag for further analyses. Additionally, 1.25 cm thick chops were collected for drip loss and 7.6 cm section was collected for intramuscular fat iodine values.

Color, Marbling, and pH Measurements

Objective and subjective color readings were collected on the cut surface of the loin immediately after facing the loin (pre-bloom) at approximately the 10th rib. Objective L*, a*, and b* measurements were collected using a Konica Minolta CR-400 colorimeter (Minolta Camera Company, Osaka, Japan; D65 light source, 0˚ observer, 8 mm aperture). Subjective color scores were assigned on a scale of 1 to 6 (NPPC, 1999), were 1 represented a pale pinkish-grey color and 6 a dark purplish-red color. Loins were then allowed to bloom (to allow for the conversion of deoxymyoglobin to oxymyoglobin) for at least 20 min, and color was measured again using the same protocol as above. Subjective marbling scores were assigned to loins after

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the 20 min bloom time using a scale of 1 to 10 (NPPC, 1999), where 1 = 1.0% intramuscular lipid and 10 = 10.0% intramuscular lipid. Ultimate pH was measured using a MPI pH meter (Meat Probes Inc., Topeka, KS; 2 point calibration at pH 4 and 7). The pH probe was inserted on the cut surface towards the posterior end of the loin.

Drip Loss

Chops cut 1.25 cm thick were used for determination of drip loss. An initial weight was recorded, and chops were suspended in Whirl Pak bags for 24 h at 4 ˚C. Final weight was collected after 24 h and drip loss was calculated as: [(initial weight – final weight) / initial weight] x 100.

Warner-Bratzler Shear Force (WBSF) and Cook Loss

Samples for WBSF were thawed at 4˚ C for 24 h. Chops were trimmed of excess subcutaneous fat, weighed, and cooked to 70˚C on Faberware open hearth grills (Model 455 N, Walter Kiddie, Bronx, NY. Internal temperatures were monitored using thermocouples (Type T, Omega Engineering, Stanford, CT) connected to a digital scanning thermometer (Model 92000-00 Barnant Co., Barington, IL). Chops were weighed after tempering to approximately room temperature and cook loss was calculated as: [(raw weight – cooked weight) / raw weight] x 100. After cooling to approximately 22 ˚C, six 1.25 cm cores were removed parallel to the orientation of muscle fibers and sheared using a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/Stable Microsystems, Godalming, UK) with a blade speed of 3.3 mm/s and 100 kg load cell capacity. The average of the 6 cores were reported as WBSF values.

Sensory Panel

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Trained panelists (n=6) evaluated samples for tenderness, chewiness, juiciness, and off flavor. Chops were trimmed of subcutaneous fat and cooked in the same manner as chops for WBSF. No greater than 8 samples were served per panel; allotment of chops to panel was random. Two cubes (1 cm x 1 cm x 2.54 cm) were served to each panelist under red lighting. A 15 cm anchored scale was used with a low degree of each trait on the left side of the scale (0) and a high degree of each trait on the right side (15; Smith et al., 2011; Arkfeld et al., 2015).

Proximate Composition

Chops for proximate composition were thawed, trimmed of subcutaneous fat, and homogenized in a food processor (Cuisinart, East Windsor, NJ). Methods were followed as described by Novakofski et al. (1989). Briefly, moisture and extractible lipid analyses were performed in duplicate. Samples were dried at 110˚ C for at least 24 h and extracted in an azeotropic mixture of warm chloroform:methanol. Protein concentrations were determined by measuring N content using the combustion method (Association of Official Analytical Chemists, 2000; model TruMac, method 990.03, LECO Corp., St. Joseph, MI).

Soluble and Insoluble Collagen Content

Chops for collagen determination were trimmed of external fat, frozen in liquid nitrogen, and then ground to a powder using a blender (Waring Commercial Blender Model HGB2WT53, Stamford, CT). Soluble and insoluble collagen content procedures were adapted from protocol outlined by Hill (1966). Duplicate 3.0 gram samples were weighed into 50 mL polyethylene tubes, 16 mL of ¼ strength Ringer's solution was added. Samples were placed in a 77 ºC water bath for 70 min, with samples shaken every 10 min. Next, samples were centrifuged at 5200 x g for 10 min and the soluble fraction was decanted into a flask labeled soluble fraction through

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filter paper (Qualitative P8, 15.0 cm diameter, Fisher Scientific, Pittsburgh, PA). Eight mL of ¼ strength Ringer's solution was added to the remaining sample in the polyethylene tube and sample was centrifuged and decanted in the same manner. Sample remaining in the tube (insoluble fraction) was removed using a metal spatula into a flask labeled as insoluble fraction. One-half of an extra low lint task wipe (Kimwipe EX-L, Kimberly-Clark; Dallas, TX) was used to remove any remaining insoluble fraction from the polyethylene tube. The Kimwipe and filter paper used to decant the soluble fraction were placed in the insoluble flask for their respective sample. Twenty-five mL of 6 N HCl were added to each flask and the flasks were placed in a 110 ºC oven for at least 12 h. After 12 h 1.0 gram of charcoal was added to the flask, flask was shaken, and then contents were filtered through filter paper (Whatman 2, 150 mm, Sigma-Aldrich, St. Louis, MO). The pH of each sample was buffered to 6.0 ± 0.1 and samples were volumized through Qualitative P8 filter paper. One mL of each sample was combined with 2 mL of isopropanol and vortexed. One mL of oxidant solution (1 volume chloramine T to 4 volumes of acetate citrate buffer) was added to each sample and vortexed. Exactly 4 min later, 4 mL of Elrich's solution (15.8% dimethylaminobenzoaldehyde·HCl_4 and 84.2% isopropanol) was added to the sample and vortexed. Samples were placed in a 60 ºC water bath for 25 min, and then a cool water bath for 5 min. Two hundred µl of each tube was plated along with hydroxyproline standards of 0, 4, 8, 12, 16, 20, 24, 28, 32, and 36 µg/mL prepared in the same manner as samples. Plates were read at an absorbance of 558 nm, and collagen content was determined as [(µg/mL) (dilution factor) (constant)] / [sample weight x 1000], with constants of 7.52 and 7.25 for soluble and insoluble samples, respectively.

Intramuscular Fat Iodine Value

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Intramuscular lipid was extracted from muscle tissue using the procedure of Folch et al. (1957). Fatty acid methyl esters (FAME) were converted from lipid using the AOAC official method C3 2-66 (1998). The resulting FAME were analyzed using a gas chromatograph (Hewlett Packard 5890 series II) equipped with and auto-sampler and a DB-wax capillary column (30m x 0.25mm x 0.25µm film coating; Agilent Technologies, Santa Clara, CA). The equipment was operated under constant pressure (1.30 kg/cm^2) using helium as the carrier gas and a 100:1 split ratio. Temperature of the injector was held constant at 250 ºC and temperature of the flame-ionization detector was held at 260 ºC. The oven was operated at 170 ºC for 2 min and then increased 2 ºC per min up to 240 ºC when this temperature was maintained for 8 min. Chromatographs were integrated using Agilent Chemstation Software for gas Chromatographs systems (Version B.01.02, Agilent Technologies, Inc.). Peaks were identified using a gas chromatograph reference standard (GLC 461 A, Nu-check-prep, Elysian, MN). Fatty acids were normalized such that the area of each peak was represented as the percentage of the total area. Iodine values were calculated using fatty acid profile data with the following AOCS (1998) equation: IV = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.785).

Statistical Analysis

Data were analyzed using the correlation procedure of SAS (v. 9.3, SAS Institute Inc., Cary, NC). There were 154 replications in this study. Spearman correlation coefficients were used to account for the non-normality of categorical firmness data. Percent variation accounted for by firmness scores was calculated as the correlation coefficient (r), raised to the second power and multiplied by 100 (r^2 * 100). Relationships were considered statistically significant at the $P \leq 0.05$ level, and trending at the $P > 0.05$ to $P \leq 0.10$ level.

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RESULTS AND DISCUSSION

Loins used in the study were representative loins selected for export in regards to 1 d color (range 2.5-4), marbling (range 1-3), and firmness (range 2-5; Table 1). Although carcass weight of the current population was similar to previous work investigating pork quality correlations by Huff-Lonergan et al. (2002), carcasses from pigs of the current population had approximately 15 mm less fat over the 10th rib. Further, subjective color and firmness scores (both 1 d postmortem) were similar in both populations, but the mean marbling score was 1.85 units greater and pH was 0.21 units greater in the Berkshire x Yorkshire F1 population used by Huff-Lonergan et al. (2002). Due to differences in sensory scales used between the two projects direct comparison of sensory data cannot be made.

Durometer Efficacy

Processing facility decisions of which loins to export to quality driven markets are based on the following quality criteria 1) lean color, 2) firm muscle, and 3) sufficient marbling (Johnson, 2008). While validated objective measures exist to determine both loin color and lipid percentage, no objective measures to determine muscle firmness have been readily adopted by industry. Durometers have been used to determine fat firmness in bellies (Seman et al., 2013), but results of durometer use on muscle have not been reported. Therefore, in order to validate use of the durometer for loin firmness evaluation, durometer measurements were correlated with subjective firmness measurements.

Day 1 subjective firmness (determined at the processing facility) did not correlate with durometer measures of the whole aged loin muscle ($P \geq 0.12$; Table 2). Subjective d 1 firmness tended to correlate with durometer readings on chops used for sensory ($P = 0.07$; r = 0.146), but

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279 did not correlate with chops used for WBSF ($P = 0.49$). Subjective firmness measures at d 28 at
280 the 10th rib and on the anterior portion of the loin did not correlate with whole loin durometer
281 readings on the dorsal or ventral portion of the loin, nor the average of the whole loin values ($P \geq$
282 0.21). There was, however, a tendency for the subjective measures on the posterior portion of
283 the loin to correlate with mid-point (10th rib) dorsal ($P = 0.08$; r = 0.142) and ventral ($P = 0.06$; r
284 = 0.151) durometer readings which contributed to a significant correlation of subjective firmness
285 of the posterior portion of the loin with average whole loin durometer measures ($P = 0.04$; r =
286 0.170).

287 In general, durometer readings from the area of the 10th rib either individually or when
288 averaged are not well-correlated with subjective firmness scores on any portion of the loin (Table
289 2). A similar result was observed by Swatland (1998), when creating an objective firmness
290 measure using vacuum-induced changes in reflectance of pork loins. Those authors attributed
291 the lack of a relationship between reflectance and firmness to either that objective or subjective
292 measures accounted for different portions of firmness (i.e. elasticity and viscosity), or there was
293 bias in subjective firmness scores by the evaluator due to inconsistencies in pork color
294 (Swatland, 1998). In the present data set, loins were "normal" in color (NPPC color score range:
295 2-4) and neither pale nor dark as in the previous work. Also, a panel of 4 evaluators was used for
296 subjective firmness measures to further eliminate bias. Therefore, while this study does rule out
297 bias as a potential impact on firmness measures, it does not rule out that different portions of
298 firmness (i.e. elasticity and viscosity) may be measured by objective and subjective firmness
299 measures. In the context of the current subjective firmness rating system, the lack of correlation
300 between durometer readings and subjective firmness measures leads to the conclusion that the
301 durometer may not be an appropriate tool for online firmness estimation of pork loins.

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A widely used commercial application to assess firmness and quality of pork bellies is by the use of belly flop firmness measures. Similar to bellies, it was expected that decreased flop distances would indicate less firm loins. Initial (1 d) and aged (28 d) whole loin subjective firmness traits were correlated with 28 d loin flop ($P \leq 0.01$; Table 3), but no objective firmness measures were related ($P > 0.35$) to loin flop. Subjective and objective whole loin measures are inconsistent with each other, so, the lack of significant correlations between loin flop and objective measures ($P \geq 0.35$) agrees with previous data regarding correlation of belly flop measurements. Trusell et al. (2011) reported no correlation between belly flop measures skin side up, and negative, but inconsistent results across different regions of the belly when measured skin side down compared with mechanical compression measures.

Variation in Firmness Due to Anatomical Location

Firmness determination protocols are plant specific, and therefore a variety of locations are potentially used when determining firmness of loins in the export selection procedure. It is known that firmness varies throughout the loin. Waylan et al. (1998) reported that chops from more posterior portions of the loin are firmer than chops from the anterior portions of the loin. However, it is not well understood if one location within the loin is an accurate predictor of other locations. Therefore, one objective of this project was to determine if firmness in one location of the loin was indicative of firmness in other locations of the loin. Subjective firmness measures at 28 d postmortem were significantly correlated with each other. Specifically, firmness at the 10^{th} rib accounted for 38.44% (r = 0.620) and 48.30% (r = 0.695) of the variation in firmness at the anterior portion of the loin and the posterior portion of the loin, respectively ($P \leq 0.05$; Table 2). Subjective firmness measures on the anterior portion of the loin accounted for 24.4% (r = 0.494) of the variation in subjective firmness measures on the posterior portion of the loin. Similarly,

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durometer readings on the dorsal portion of the loin accounted for 7.1% (r = 0.266) of the variation in durometer readings on the ventral portion of the loin ($P < 0.01$). It can be concluded that firmness in one location does predict firmness in other locations of the loin, however this relationship is moderate, and caution should be exercised when comparing results of studies where firmness may be measured in different locations.

Relationship of Export Selection Criteria with 28 d Quality Measures

Firmness and Sensory Characteristics. Of all firmness traits measured in this study, initial (1 d) firmness measures are arguably the most important in commerce. Firmness assessed at the processing facility is used in selecting loins for export to high-quality markets. However, few studies have correlated firmness with loins aged over 21 d. In the current study, initial subjective firmness accounted for 3.0% of the variation in WBSF measures ($P = 0.03$; Table 4) while objective durometer readings on the ventral portion of the loin and average whole loin durometer measures tended to correlated with WBSF measures ($P \leq 0.09$). Warner-Bratzler shear force correlated with subjective firmness measures on the chop used to determine WBSF ($P = 0.01$; r = 0.211). Average whole loin durometer measures and sensory chop objective firmness measures each accounted for 2.7% of the variation in WBSF measures ($P = 0.04$). Previously, WBSF values were correlated with sensory tenderness: sustained tenderness sensory measures correlated with WBSF measures at r = -0.60, while initial tenderness sensory measures correlated with WBSF at r = - 0.61 (Caine et al., 2003). Therefore, the lack of similar correlations in the current study was surprising. In the present study, WBSF was correlated with sensory tenderness at r = -0.32 ($P < 0.0001$; data not presented). There was not a significant correlation between sensory tenderness and subjective initial firmness ($P = 0.79$; r = -0.022; Table 4), but a significant correlation was present between sensory tenderness and subjective firmness of the

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anterior portion of the loin ($P = 0.03$; r = 0.170). Whole loin objective firmness measures using the durometer did not correlate to sensory tenderness ($P \geq 0.83$). Chewiness, or sustained tenderness, was not correlated with subjective firmness on the posterior portion of the loin ($P = 0.39$), yet, was correlated with firmness measures at the 10th rib ($P = 0.03$; r = -0.180) and on the anterior portion of the loin ($P = 0.02$; r = -0.189). Objective durometer readings from both whole loin and chop measures did not correlate with sensory chewiness ($P \geq 0.14$). Initial firmness tended to explain 2.0% of the variability in sensory juiciness. No significant correlation was observed for sensory juiciness and firmness at the 10th rib and on the posterior portion of the loin, but firmness measures of the anterior portion of the loin tended to account for 1.7% of the variability in sensory juiciness ($P = 0.10$). No subjective firmness measures on the whole loin or on chops were significantly correlated with sensory off-flavor ($P \leq 0.32$). Average whole loin durometer readings accounted for 5.2% of the variation in sensory off-flavor ($P < 0.01$).

Davis et al. (1975) proposed correlations between firmness and sensory characteristics. In that study of 403 loins, subjective firmness measures explained between 9.6 to 18.49% of the variation in sensory juiciness, 1.2% of the variation in flavor, 1.4 to 7.8% of the variation in tenderness and 8.4 to 13.7% of the variation in overall satisfaction (Davis et al., 1975). In general, these correlations are greater than correlations presented in the current study, likely due to the added variation of kill location and differing genetics imposed in the Davis et al. (1975) study. In the present study, some firmness measures did account for small variation in sensory characteristics, but these correlations are inconsistent. Consequently, firmness, measured at either 1d or 28 d postmortem with a variety of techniques, is not an accurate predictor of aged pork loin sensory characteristics.

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370 ***Firmness, Subjective Color, and Marbling.*** Color is a large determining factor in sorting
371 loins destined for quality driven export markets. Though color can be measured objectively with
372 various colorimeter systems, for sorting, it is measured subjectively. At 1 d color was not
373 correlated with any whole loin subjective firmness measures ($P \geq 0.19$), but was significantly
374 correlated to durometer readings on the dorsal portion of the loin ($P = 0.03$; Table 5).
375 Traditionally, literature reports pork color after a bloom period, however bloom time does not
376 allow for color measurements at line speed, consequently both pre- and post-bloom color were
377 measured at 28 d in this study. No subjective whole loin ($P \geq 0.38$; Table 4) or objective ($P \geq$
378 0.21) firmness measures correlated with pre-bloom color. Pre-bloom subjective color scores
379 were related to durometer measures for texture and sensory chops ($P \leq 0.02$; r = 0.206 and 0.192,
380 respectively), and tended to be related to firmness of the raw WBSF chops ($P = 0.07$; r = 0.192).
381 In regards to subjective firmness measures, firmness of WBSF chops and texture chops were
382 correlated with pre-bloom color ($P < 0.04$; r = 0.227 and 0.164, respectively). Neither whole loin
383 or chop subjective firmness measures correlated with subjective color after a 20 min bloom time
384 ($P \geq 0.19$). Objective sensory chop measures were weakly, but significantly correlated ($P \leq$
385 0.01) to color after the blooming period but the tendency observed pre-bloom for the WBSF
386 chop was no longer present ($P \geq 0.87$). However, these correlations are not as strong as those
387 reported by Huff-Lonergan et al. (2002), who suggested positive correlations between firmness
388 and color of r = 0.27, or Boler et al. (2010), who suggested a positive correlation of r = 0.41.

389 The final component in evaluating quality of loins for export is marbling, which can be
390 objectively measured by percent extractable lipid, but in commerce, is estimated by visual
391 appraisal. In this population of loins subjective marbling scores ranged from 1 to 3 and
392 extractable lipid from 0.47% to 4.18%. Correlation between these two measures was significant

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but weak ($P < 0.01$; r = 0.233; data not presented). No significant correlations existed between extractable lipid and whole loin subjective firmness measures ($P \geq 0.11$; Table 3). Durometer readings on the dorsal portion of the loin accounted for 2.7% of the variation in extractable lipid ($P = 0.04$), while durometer readings on the ventral portion of the loin and average whole loin durometer measures were not significantly correlated to extractable lipid ($P \geq 0.38$).

Although not the emphasis of this experiment, Spearman correlation coefficients are presented on the two remaining export selection criteria (color and marbling) and sensory characteristics (Table 6). Huff-Lonergan et al. (2002) reported significant positive correlations between color and sensory tenderness, as well as color and flavor ratings. Further, in that study, off-flavor was correlated with color. However, in the present study, no significant correlations were reported between 1 d or 28 d color and tenderness, chewiness, and juiciness ($P \geq 0.18$). Similar to Huff-Lonergan et al. (2002) results, a tendency for a negative correlation was present between 1 d color score and sensory off flavor ($P = 0.07$; r = -0.148), however this same result was not present between 28 d color and sensory off flavor ($P = 0.90$). Previously, marbling was correlated with tenderness (r = 0.21), flavor (r = 0.20) and off flavor (-0.15; Huff-Lonergan et al., 2002). However, in the present study, sensory characteristics were not correlated with color at either 1 or 28 d of aging ($P \geq 0.33$). Although ranges are not included in the study by Huff-Lonergan et al. (2002), the standard deviations in the present study were lower for 1 d color, marbling and firmness, indicating less variability in the current study and a potential explanation for the lack of correlations between sensory characteristics, and color, marbling, and firmness.

Relationship Between Mechanistic Traits and Firmness. Mechanistic measures are used as indicators of overall quality, palatability, or further processing characteristics. Ultimate pH (24 h postmortem) correlates with color (r = 0.50) and marbling (r = 0.25; Boler et al., 2010). Previous

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work suggested that increased pH would result in a swelling of myofibrils (Huff-Lonergan and Lonergan, 2005), which would ultimately result in a firmer product. However, no subjective or objective firmness correlations were observed with 1 d pH ($P \geq 0.13$; Table 5) and no subjective firmness measures were correlated with aged pH measures ($P \geq 0.17$; Table 4). This contrasts with research by both Boler et al. (2010) and Huff-Lonergan et al. (2002) who reported significant, positive correlations between firmness and pH.

Firmness has been demonstrated to be negatively correlated with purge loss of pork loins aged for 21 d (Boler et al., 2010). Initial (1 d) firmness measures tended to correlate with aged loin purge ($P = 0.10$; r = 0.136; Table 4) such that loins that were firmer on d1 had increased amounts of purge during storage. As loins age and postmortem proteolysis occurs inherent variation in moisture loss occurs (Melody et al., 2004), and may result in a less firm product. It is therefore unsurprising that whole loin subjective firmness measures from the 10th rib, anterior portion, and posterior portion of the loin accounted for 7.2% (r = -0.268), 12.2% (-0.349), and 9.2% (-0.304), respectively, of the variation of aged loin purge loss ($P < 0.01$). However, at 28 d postmortem, it is expected that the majority of postmortem proteolysis and consequent free water loss is likely nearing completion. This is reflected in the low population average of drip loss percentage in the current project (0.78 ± 0.23 %; Table 1) and the lack of significant correlations between drip loss and subjective whole muscle firmness ($P \geq 0.10$; Table 4). Similar to other traits in this study, durometer readings on the dorsal and ventral portions of the loin did not account for any significant variation in drip loss or purge ($P \geq 0.11$). Furthermore, loin moisture content was not correlated with any firmness measures ($P \geq 0.18$).

Collagen content is known to contribute to the variability in tenderness of pork (Wheeler et al., 2000). However, soluble and insoluble collagen content were poor indicators of firmness,

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439 with only subjective WBSF chop firmness being correlated with insoluble collagen content (P =
440 0.01; r = 0.220; Table 4), but no other chop or whole loin measurement of firmness. Excessive
441 unsaturated fatty acids in loins are of concern because they may cause visual detection of
442 marbling to be more difficult, and loin chops may have a more oily appearance (Johnson, 2008).
443 However, though unsaturated fatty acids would be oilier and less firm than saturated fatty acids,
444 little research has been conducted to understand the relationship between fatty acid composition
445 of pork loin extractable lipid and firmness of pork loins. Of all subjective and objective firmness
446 traits, only initial firmness was significantly but inversely correlated with iodine value (IV; P =
447 0.02; r = -0.199; Table 7) such that as iodine value increased (fatty acids are more unsaturated),
448 firmness score decreased. Initial subjective firmness measures were not significantly correlated
449 with the total percentage of MUFAs or PUFAs ($P \geq 0.13$), however, initial subjective firmness
450 was positively correlated with total percentage of SFAs ($P < 0.01$; r = 0.231), negatively
451 correlated with unsaturated:saturated fatty acid ratio ($P < 0.01$; r = -0.231) and tended to
452 negatively correlate with the ratio of PUFA:SFA ($P = 0.06$; r = -0.154), all in agreement with
453 observations of correlations between initial firmness and IV. The variation in subjective cut
454 surface firmness measures at 28 d postmortem can be explained partially by unsaturated fatty
455 acid content; 4.4% by total percentage of MUFAs ($P = 0.01$) and 3.1% ($P = 0.03$) by total
456 percentage of PUFAs. Further, subjective cut surface firmness measures tended to be correlated
457 with SFA ($P = 0.06$; r = -0.151) and the ratio of unsaturated:saturated fatty acids ($P = 0.06$; r =
458 0.151). Durometer readings on the dorsal region of the loin were correlated with total percentage
459 of MUFAs ($P = 0.01$; r = 0.203), PUFAs ($P < 0.01$; r = -0.238) and the ratio of PUFA:SFA (P =
460 0.04; r = -0.167). The weak correlation between IV and initial firmness and the lack of
461 correlation between firmness and 28 d aged pork IV could be due to the fact that this population

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of loins had a low extractable lipid content (0.47% - 4.18%, Table 1) compared to pork bellies or because fatty acid profile is not related with pork loin firmness.

Conclusions

When loins not achieving export standards are removed from the population, initial (1 d postmortem) firmness was not correlated to aged (28 d postmortem) pork quality. Given the lack of correlation between firmness and sensory characteristics, selecting only the firmest loins of a population will likely not improve eating quality. Further, at 28 d postmortem, firmness does explain a small portion of the variation in quality and sensory characteristics; however these measures are not consistent throughout the entire loin. Inconsistencies among subjective and objective firmness measures suggest that use of the durometer may not be the most appropriate way to evaluate fresh pork firmness. Differences in firmness were not explained by mechanistic measures. Further work is needed to determine the most appropriate way to evaluate quality while maintaining the whole muscle integrity of loins destined for export to Japan and other quality driven markets if better selection criteria to improve the eating quality of loins is desired.

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Table 1. Characteristics of loins used in the experiment

Variable	N	Mean	Std Dev	Median	Minimum	Maximum
Back Fat, mm	135	17.12	3.86	17	8	28
Loin Depth, mm	135	55.13	7.82	56	36	73
Percent Lean, %	135	52.88	2.37	53.1	46.77	58.57
HCW, kg	152	89.42	6.82	90.29	71.84	107.48
1 d Color	151	3.20	0.30	3	2.5	4
1 d Marbling	151	1.57	0.57	1.5	1	3
1 d Firmness	151	3.19	0.55	3	2	5
1 d L*	151	44.29	2.32	44.45	38.52	52.08
1 d a*	151	6.31	1.01	6.16	4.17	8.79
1 d b*	151	0.14	0.74	0.11	-1.75	2.86
Ultimate pH, 24 h	151	5.57	0.05	5.56	5.45	5.75
28 d Loin pH	154	5.55	0.07	5.55	5.37	5.74
1 d Jowl IV	149	67.63	2.53	67.20	61.00	75.00
1 d Belly IV	151	64.78	3.68	64.90	55.30	74.60
28 d Purge, %	153	2.86	1.45	2.64	0.19	8.11
28 d Drip Loss, %	154	0.78	0.23	0.75	0.37	1.42
Length, cm	154	60.97	2.38	60.96	54.61	66.29
Flop, cm	154	18.46	2.50	18.54	7.11	23.88
Circumference, cm	154	29.37	1.63	29.53	20.73	33.93
NPPC Pre-Bloom Color	154	2.56	0.50	3	2	3
Japan Pre-Bloom Color	154	2.56	0.50	3	2	3
Aged Loin Marbling	154	1.43	0.55	1	1	3
NPPC Post-Bloom Color	154	2.73	0.47	3	2	4
Japan Post-Bloom Color	154	2.73	0.47	3	2	4
10th Rib Subjective Firmness	154	3.05	0.49	3	2	4
Anterior Subjective Firmness	154	3.03	0.51	3	2	4
Posterior Subjective Firmness	154	3.05	0.51	3	2	4
Cut Firmness	154	2.87	0.52	3	2	4
WBSF Chop Subjective Firmness, kg	154	2.63	0.48	2.58	1.61	5.54
Texture Chop Subjective Firmness	154	2.94	0.47	3	2	4
Sensory Chop Subjective Firmness	154	2.99	0.47	3	2	4
Dorsal Durometer	154	53.84	6.30	54.35	36.6	67.9
Ventral Durometer	154	56.03	8.70	55.45	35.6	88.7
Average Whole Loin Durometer	154	54.93	5.98	55.01	40.81	73.10
WBSF Chop Durometer	154	39.45	6.69	39.35	21.6	55.5
Texture Chop Durometer	154	41.18	7.50	41.15	23.5	58
Sensory Chop Durometer	154	42.09	7.12	42.3	20.2	59.9

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28 d WBSF, kg	154	2.63	0.48	2.58	1.61	5.54
28 d Moisture, %	154	0.74	0.01	0.74	0.72	0.75
28 d Extractable Lipid, %	154	1.77	0.62	1.69	0.47	4.18
28 d Protein, %	154	21.71	0.43	21.72	20.42	22.74
28 d Sensory Tenderness	154	8.82	1.11	8.93	5.65	11.98
28 d Sensory Chewiness	154	7.26	1.15	7.13	4.33	9.82
28 d Sensory Juiciness	154	7.36	1.00	7.28	5.03	9.75
28 d Sensory Off-Flavor	154	0.01	0.03	0	0	0.24
Soluble Collagen, µg/gram of meat	154	3.95	2.23	3.51	0.65	10.71
Insoluble Collagen, µg/gram of meat	154	23.69	7.75	23.41	2.38	38.24
28 d Cook Loss, %	150	21.37	4.15	21.86	10.96	34.26
Pre-Bloom L*	154	51.22	2.08	51.43	46.23	56.53
Pre-Bloom a*	154	6.64	1.09	6.56	4.1	9.06
Pre-Bloom b*	154	0.19	0.61	0.18	-1.47	1.68
Post-Bloom L*	154	51.36	2.16	51.48	44.47	56.3
Post Bloom a*	154	7.73	1.23	7.7	4.01	10.83
Post Bloom b*	154	3.19	0.81	3.17	0.10	5.14
C 14:0, %	150	1.23	0.12	1.22	0.89	1.61
C 14:1, %	150	0.01	0.02	0	0	0.07
C 15:0, %	150	0.10	0.04	0.09	0	0.23
C 16:0, %	150	21.44	2.64	22.16	10.05	27.52
C 16:1, %	150	3.07	0.57	3.08	1.52	4.54
C 17:0, %	150	0.26	0.07	0.25	0.09	0.48
C 17:1, %	150	0.01	0.08	0	0	0.672
C 18:0, %	150	12.05	2.15	12.30	5.27	16.28
C 18:1 n9, %	150	43.57	5.26	43.64	27.82	56.97
C 18:2 n6, %	150	12.99	2.61	12.83	7.93	21.95
C 18:3 n6, %	150	0.09	0.03	0.09	0	0.17
C 18:3 n3, %	150	0.24	0.04	0.23	0.16	0.41
C 20:0, %	150	0.12	0.03	0.13	0	0.18
C 20:1 n9, %	150	0.51	0.09	0.51	0.31	0.77
C 20:2 n6, %	150	0.28	0.05	0.27	0.17	0.44
C 20:3 n6, %	150	0.37	0.10	0.37	0.14	0.69
C 20:4 n6, %	150	2.83	0.81	2.82	0.50	5.36
C 20:3 n3, %	150	0.05	0.38	0	0	3.965
C 20:5 n3, %	150	0.07	0.03	0.07	0	0.16
C 22:4 n6, %	150	0.41	0.11	0.40	0.18	0.82
C 22:5 n3, %	150	0.24	0.07	0.23	0.08	0.47
C 22:6 n3, %	150	0.08	0.05	0.08	0	0.22
SFA, %	150	35.20	4.63	36.18	16.69	43.58

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MUFA, %	150	47.17	5.75	47.31	30.34	62.13
PUFA, %	150	17.63	3.65	17.39	10.15	29.96
UFA:SFA	150	1.91	0.51	1.76	1.29	4.99
PUFA:SFA	150	0.51	0.16	0.49	0.27	1.47
AOCS IV	150	64.14	4.47	63.21	54.51	84.03

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Table 2. Spearman correlation coefficients of firmness traits with other firmness traits

	Subjective							Objective				
	1 d	10th	Anterior	Posterior	Cut Surface	WBSF Chop	Sensory Chop	Dorsal[1]	Ventral[1]	Avg. Durometer[2]	WBSF Chop	Sensory Chop
	--	**0.141**	0.101	0.121	**0.195**	**0.242**	0.113	0.126	0.110	0.124	0.057	**0.146**
1 d		0.08	0.22	0.14	0.02	<0.01	0.17	0.12	0.18	0.13	0.49	0.07
		--	**0.620**	**0.695**	**0.156**	0.096	0.055	0.102	0.068	0.082	**-0.132**	-0.095
10th			<0.0001	<0.0001	0.05	0.23	0.50	0.21	0.41	0.31	0.10	0.24
			--	**0.494**	0.062	**0.151**	0.054	0.069	0.043	0.051	-0.042	-0.074
Anterior				<0.0001	0.44	0.06	0.51	0.40	0.60	0.53	0.60	0.36
				--	**0.154**	0.123	0.053	**0.142**	**0.151**	**0.170**	**-0.149**	-0.040
Posterior					0.06	0.13	0.52	0.08	0.06	0.04	0.06	0.62
					--	**0.202**	**0.147**	**0.197**	**0.140**	**0.201**	**0.179**	**0.184**
Cut Surface						0.01	0.07	0.01	0.08	0.01	0.03	0.02
						--	**0.484**	0.112	0.116	**0.144**	**0.325**	0.050
WBSF Chop							<0.0001	0.17	0.15	0.07	<0.0001	0.54
Sensory Chop							--	0.082	0.042	0.081	**0.141**	0.085
								0.31	0.60	0.32	0.08	0.29
								--	**0.266**	**0.721**	-0.036	0.034
Dorsal									<0.01	<0.0001	0.66	0.68
									--	**0.844**	0.036	0.081
Ventral										<0.0001	0.66	0.32
Avg. Durometer[2]										--	0.005	0.078
											0.95	0.34
											--	**0.401**
WBSF Chop												<0.0001

[1] Durometer readings were determined at approximately the 10th rib on both the dorsal and ventral sides of the loin.

[2] An average whole loin durometer reading was calculated as the average of the durometer readings on the dorsal and ventral sides of the loin.

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Table 3. Spearman correlation coefficients of firmness traits with 28 d aged meat quality

	Subjective							Objective				
	1 d	10th	Anterior	Posterior	Cut Surface	WBSF Chop	Sensory Chop	Dorsal[1]	Ventral[1]	Avg. Durometer[2]	WBSF Chop	Sensory Chop
	-0.022	-0.028	**-0.232**	-0.043	0.026	-0.050	-0.028	-0.053	0.104	0.039	0.091	0.049
Loin Length	0.79	0.73	<0.01	0.59	0.75	0.53	0.73	0.51	0.20	0.63	0.26	0.54
	0.443	**0.268**	**0.216**	**0.222**	0.112	0.049	0.019	0.076	0.034	0.049	-0.027	0.064
Loin Flop	<0.0001	<0.01	0.01	0.01	0.17	0.54	0.82	0.35	0.68	0.55	0.74	0.43
NPPC Color	0.065	0.001	0.071	-0.068	**0.147**	**0.227**	0.115	0.032	0.080	0.102	**0.148**	**0.192**
Pre-Bloom	0.43	0.99	0.38	0.40	0.07	<0.01	0.16	0.69	0.32	0.21	0.07	0.02
Japan Color	0.065	0.001	0.071	-0.068	**0.147**	**0.227**	0.115	0.032	0.080	0.102	**0.148**	**0.192**
Pre-Bloom	0.43	0.99	0.38	0.40	0.07	<0.01	0.16	0.69	0.32	0.21	0.07	0.02
NPPC Color	0.113	-0.006	0.000	0.002	0.115	0.049	0.014	0.070	0.055	0.106	0.053	**0.257**
Post-Bloom	0.17	0.94	1.00	0.98	0.16	0.54	0.87	0.39	0.50	0.19	0.51	<0.01
Japan Color	0.113	-0.006	0.000	0.002	0.115	0.049	0.014	0.070	0.055	0.106	0.053	**0.257**
Post-Bloom	0.17	0.94	1.00	0.98	0.16	0.54	0.87	0.39	0.50	0.19	0.51	<0.01
	0.013	-0.035	-0.030	-0.071	**0.166**	0.024	-0.005	**0.236**	0.005	0.125	0.043	-0.075
Aged Marbling	0.87	0.66	0.71	0.38	0.04	0.77	0.95	<0.01	0.95	0.12	0.59	0.36
	-0.025	0.036	0.062	0.028	-0.096	0.030	-0.090	-0.109	0.093	-0.0001	-0.101	-0.091
Moisture	0.76	0.66	0.45	0.73	0.23	0.72	0.26	0.18	0.25	1.00	0.21	0.26
Extractable	0.071	-0.080	-0.128	-0.059	**0.138**	-0.042	**0.151**	**0.165**	-0.071	0.034	**0.178**	**0.210**
Lipid	0.39	0.32	0.11	0.47	0.09	0.61	0.06	0.04	0.38	0.67	0.03	0.01
	0.013	0.099	0.070	0.048	0.004	0.010	-0.122	-0.056	-0.045	-0.054	**-0.154**	-0.046
Protein, %	0.87	0.22	0.39	0.56	0.96	0.90	0.13	0.49	0.58	0.51	0.06	0.57
	-0.137	-0.056	-0.095	-0.099	-0.088	-0.023	-0.039	**-0.166**	-0.030	-0.125	0.094	-0.117
L* Pre-Bloom	0.09	0.49	0.24	0.22	0.28	0.77	0.63	0.04	0.71	0.12	0.25	0.15
	0.050	**0.145**	0.054	**0.157**	**0.175**	0.067	0.044	0.042	0.087	0.102	-0.023	0.099
a* Pre-Bloom	0.54	0.07	0.50	0.05	0.03	0.41	0.59	0.61	0.28	0.21	0.78	0.22

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	-0.122	0.092	0.013	0.043	0.086	-0.071	-0.075	**-0.136**	0.056	-0.024	0.062	-0.074
b* Pre-Bloom	0.14	0.26	0.87	0.59	0.29	0.38	0.35	0.09	0.49	0.77	0.45	0.36
	-0.101	-0.061	-0.042	-0.067	-0.059	-0.074	-0.009	-0.111	0.044	-0.035	0.000	-0.069
L* Post-Bloom	0.22	0.45	0.60	0.41	0.47	0.36	0.92	0.17	0.59	0.66	1.00	0.39
	0.036	0.123	0.084	0.069	**0.181**	0.039	0.088	0.020	0.080	0.074	0.058	0.090
a* Post-Bloom	0.66	0.13	0.30	0.39	0.02	0.63	0.28	0.80	0.33	0.36	0.47	0.27
	-0.068	0.104	0.033	0.063	0.116	-0.064	**0.132**	-0.027	**0.138**	0.088	0.015	0.014
b* Post-Bloom	0.41	0.20	0.69	0.44	0.15	0.43	0.10	0.74	0.09	0.28	0.85	0.87

[1] Durometer were determined at approximately the 10th rib on both the dorsal and ventral sides of the loin.

[2] An average whole loin durometer reading was calculated as the average of the durometer readings on the dorsal and ventral sides of the loin.

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Table 4. Spearman correlation coefficients of firmness with pH, WHC measures, sensory characteristics, and collagen content

	Subjective							Objective				
	1 d	10th	Anterior	Posterior	Cut Surface	WBSF Chop	Sensory Chop	Dorsal[1]	Ventral[1]	Avg. Durometer[2]	WBSF Chop	Sensory Chop
	0.174	-0.074	-0.005	-0.053	0.071	**0.211**	0.016	0.031	**0.142**	**0.135**	0.131	**0.164**
WBSF	0.03	0.36	0.95	0.52	0.38	0.01	0.85	0.70	0.08	0.09	0.11	0.04
	-0.022	0.129	**0.170**	0.008	**-0.140**	-0.076	**-0.164**	0.009	0.018	-0.011	-0.022	**-0.134**
Tenderness	0.79	0.11	0.03	0.92	0.08	0.35	0.04	0.92	0.83	0.90	0.78	0.10
	0.057	**-0.180**	**-0.189**	-0.070	-0.028	0.117	**0.144**	0.072	-0.006	0.056	-0.030	0.119
Chewiness	0.49	0.03	0.02	0.39	0.73	0.15	0.07	0.37	0.94	0.49	0.71	0.14
	0.143	0.070	**0.132**	0.056	-0.092	0.063	-0.009	**-0.190**	-0.087	**-0.176**	0.018	-0.098
Juiciness	0.08	0.39	0.10	0.49	0.26	0.44	0.91	0.02	0.28	0.03	0.82	0.23
	0.081	-0.021	-0.012	-0.023	-0.063	-0.030	0.007	-0.129	**-0.254**	**-0.229**	0.025	0.066
Off Flavor	0.32	0.80	0.88	0.78	0.44	0.71	0.93	0.11	<0.01	<0.01	0.76	0.42
	0.058	0.111	0.086	0.111	0.038	0.015	-0.108	**0.197**	0.104	**0.183**	-0.123	-0.061
Aged pH	0.48	0.17	0.29	0.17	0.64	0.86	0.18	0.01	0.20	0.02	0.13	0.46
	0.136	**-0.268**	**-0.349**	**-0.304**	-0.0028	0.101	0.094	0.029	-0.131	-0.068	**0.168**	0.093
Purge	0.10	<0.01	<0.0001	0.0001	0.73	0.21	0.25	0.72	0.11	0.41	0.04	0.25
	-0.028	-0.100	**0.134**	-0.039	**-0.213**	0.027	-0.079	-0.068	-0.083	-0.099	0.036	0.026
Drip Loss	0.73	0.22	0.10	0.63	0.01	0.74	0.33	0.40	0.31	0.22	0.66	0.75
	-0.028	-0.001	0.054	-0.032	0.002	0.103	0.077	-0.076	0.023	-0.018	0.019	0.054
Cook Loss	0.73	0.99	0.51	0.69	0.98	0.21	0.35	0.36	0.78	0.83	0.81	0.51
Soluble Collagen	-0.078	-0.105	-0.047	-0.026	-0.058	0.069	**0.144**	-0.019	0.011	0.005	0.024	0.052
	0.34	0.19	0.56	0.74	0.47	0.39	0.08	0.81	0.89	0.96	0.76	0.53
Insoluble Collagen	0.060	0.004	0.081	0.036	-0.078	**0.220**	0.043	-0.117	-0.106	-0.130	0.025	-0.130
	0.47	0.96	0.32	0.66	0.33	0.01	0.60	0.15	0.19	0.11	0.76	0.11

[1] Durometer were determined at approximately the 10th rib on both the dorsal and ventral sides of the loin.

[2] An average whole loin durometer reading was calculated as the average of the durometer readings on the dorsal and ventral sides of the loin.

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Table 5. Spearman correlation coefficients of firmness traits with production facility data

	Subjective							Objective				
	1 d	10th	Anterior	Posterior	Cut Surface	WBSF Chop	Sensory Chop	Dorsal[1]	Ventral[1]	Avg. Durometer[2]	WBSF Chop	Sensory Chop
Back Fat, mm	**0.158**	**0.206**	0.055	0.167	**0.258**	**-0.167**	-0.071	**0.145**	0.104	0.117	-0.062	0.000
	0.07	0.02	0.53	0.05	<0.01	0.05	0.41	0.09	0.23	0.18	0.48	1.00
Loin Depth, mm	**0.182**	-0.029	0.088	-0.009	-0.100	-0.017	-0.048	**0.156**	-0.019	0.077	**-0.155**	-0.004
	0.04	0.74	0.31	0.92	0.25	0.85	0.58	0.07	0.82	0.36	0.07	0.96
Percent Lean, %	-0.046	**-0.152**	0.013	**-0.143**	**-0.228**	0.041	-0.005	0.047	-0.077	-0.004	-0.081	-0.030
	0.60	0.08	0.89	0.10	0.01	0.63	0.95	0.59	0.37	0.96	0.35	0.73
HCW, kg	**0.325**	**0.150**	0.012	0.092	0.127	0.055	0.047	0.061	0.106	0.096	0.057	0.029
	<0.0001	0.06	0.88	0.26	0.12	0.50	0.57	0.45	0.19	0.24	0.49	0.73
Color	0.095	0.080	0.108	0.086	**0.149**	0.104	**0.143**	**0.175**	0.000	0.114	-0.041	0.041
	0.24	0.33	0.19	0.29	0.07	0.20	0.08	0.03	1.00	0.16	0.62	0.62
Marbling	0.060	0.042	0.121	0.077	**0.182**	0.058	-0.013	**0.173**	**0.140**	**0.194**	0.069	0.005
	0.47	0.61	0.14	0.35	0.03	0.48	0.87	0.03	0.09	0.02	0.40	0.95
L*	-0.006	-0.059	-0.093	-0.020	-0.062	-0.114	-0.118	0.061	0.087	0.096	-0.110	-0.032
	0.94	0.47	0.25	0.81	0.45	0.16	0.15	0.45	0.29	0.24	0.18	0.69
a*	0.058	**0.207**	**0.141**	**0.139**	0.118	**0.148**	0.127	0.037	-0.072	-0.023	0.072	0.017
	0.48	0.01	0.09	0.09	0.15	0.07	0.12	0.65	0.38	0.76	0.38	0.84
b*	-0.018	0.105	-0.046	0.076	0.060	-0.049	-0.087	0.060	0.123	0.125	0.026	-0.077
	0.83	0.20	0.57	0.35	0.47	0.55	0.29	0.46	0.13	0.13	0.75	0.35
24 h pH	0.040	0.050	0.060	0.082	0.143	0.069	0.042	0.060	-0.003	0.036	-0.031	-0.093
	0.63	0.54	0.46	0.32	0.08	0.40	0.61	0.47	0.97	0.66	0.71	0.26
Jowl IV	-0.127	-0.048	-0.023	-0.018	0.028	0.039	-0.013	0.111	-0.118	-0.017	-0.013	-0.037
	0.12	0.56	0.78	0.83	0.73	0.63	0.88	0.18	0.15	0.83	0.87	0.65
Belly IV	-0.082	-0.053	-0.049	-0.060	0.131	0.037	-0.056	0.073	-0.118	-0.030	0.008	-0.038
	0.32	0.52	0.55	0.46	0.11	0.65	0.49	0.37	0.15	0.72	0.93	0.65

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[1] Durometer were determined at approximately the 10th rib on both the dorsal and ventral sides of the loin.
[2] An average whole loin durometer reading was calculated as the average of the durometer readings on the dorsal and ventral sides of the loin.

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Table 6. Spearman correlations coefficients of color, marbling, and sensory characteristics

	1 d color score	28 d color score	1 d marbling score	28 d marbling score
	-0.019	-0.059	-0.055	-0.049
Tenderness	0.82	0.47	0.50	0.54
	0.088	0.109	-0.065	-0.041
Chewiness	0.28	0.18	0.43	0.61
	-0.039	0.014	-0.064	-0.028
Juiciness	0.63	0.86	0.43	0.73
	-0.148	-0.010	-0.080	-0.054
Off Flavor	0.07	0.90	0.33	0.51

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Table 7. Spearman correlation coefficients of firmness traits with fatty acid methyl ester profile (FAME) and iodine value (IV)

	Subjective							Objective				
	1 d	10th	Anterior	Posterior	Cut Surface	WBSF Chop	Sensory Chop	Dorsal[1]	Ventral[1]	Avg. Durometer[2]	WBSF Chop	Sensory Chop
	-0.015	-0.063	-0.001	-0.004	-0.012	-0.116	-0.004	0.108	0.022	0.096	-0.054	0.034
C 14:0, %	0.86	0.44	0.99	0.96	0.88	0.16	0.96	0.19	0.79	0.24	0.52	0.68
	-0.140	0.079	0.033	**0.154**	0.052	0.041	0.099	0.017	0.035	0.034	-0.053	-0.092
C 14:1, %	0.09	0.34	0.69	0.06	0.53	0.62	0.23	0.84	0.67	0.68	0.52	0.26
	0.035	-0.118	-0.073	-0.078	-0.051	0.099	-0.005	-0.073	0.065	-0.007	0.052	0.045
C 15:0, %	0.67	0.15	0.38	0.34	0.54	0.23	0.95	0.38	0.43	0.93	0.53	0.58
	0.214	-0.004	-0.057	0.091	-0.103	0.017	-0.025	-0.014	0.049	0.017	-0.049	-0.031
C 16:0, %	0.01	0.96	0.49	0.27	0.21	0.84	0.76	0.87	0.55	0.83	0.55	0.71
	-0.127	0.093	0.062	0.042	0.189	-0.065	-0.003	**0.252**	0.022	**0.163**	0.001	0.010
C 16:1, %	0.13	0.26	0.45	0.61	0.02	0.43	0.97	<0.01	0.79	0.05	0.99	0.90
	0.030	**-0.162**	**-0.164**	-0.091	**-0.198**	-0.003	-0.044	**-0.148**	0.035	-0.085	-0.011	**-0.135**
C 17:0, %	0.72	0.05	0.04	0.27	0.01	0.97	0.59	0.07	0.67	0.30	0.90	0.10
	0.134	-0.018	-0.010	0.062	-0.120	0.078	0.011	-0.078	-0.130	-0.132	-0.055	-0.048
C 17:1, %	0.11	0.83	0.90	0.45	0.15	0.34	0.90	0.34	0.11	0.11	0.51	0.56
	0.204	-0.095	-0.073	-0.031	-0.173	0.020	-0.034	**-0.160**	0.056	-0.064	-0.029	-0.030
C 18:0, %	0.01	0.25	0.38	0.71	0.03	0.81	0.68	0.05	0.49	0.44	0.73	0.71
C 18:1 n9, %	-0.122	0.069	0.073	-0.033	**0.202**	0.006	0.095	**0.197**	-0.085	0.059	0.056	0.081
	0.14	0.40	0.38	0.69	0.01	0.94	0.25	0.02	0.30	0.47	0.49	0.33
C 18:2 n6, %	-0.108	-0.028	-0.017	-0.009	**-0.221**	-0.051	-0.090	**-0.256**	-0.042	**-0.163**	-0.036	0.016
	0.19	0.74	0.84	0.92	<0.01	0.53	0.27	<0.01	0.61	0.05	0.66	0.85
C 18:3 n6, %	-0.045	-0.043	-0.093	-0.052	0.078	0.008	-0.073	-0.068	0.006	-0.051	0.024	0.014
	0.59	0.60	0.26	0.53	0.34	0.92	0.37	0.41	0.95	0.54	0.77	0.86
C 18:3 n3, %	**-0.150**	-0.028	0.059	-0.046	**-0.181**	0.016	-0.038	**-0.190**	**-0.138**	**-0.194**	0.011	0.008
	0.07	0.74	0.47	0.58	0.03	0.85	0.64	0.02	0.09	0.02	0.89	0.92

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	0.199	-0.076	0.002	-0.019	**-0.165**	0.065	-0.011	0.007	0.019	0.004	0.012	-0.020
C 20:0, %	0.02	0.36	0.98	0.81	0.04	0.43	0.89	0.93	0.81	0.95	0.89	0.81
C 20:1 n9, %	-0.032	-0.042	-0.008	-0.075	0.121	0.074	0.108	0.083	-0.041	0.024	0.087	0.072
	0.70	0.61	0.92	0.36	0.14	0.37	0.19	0.31	0.62	0.77	0.29	0.38
C 20:2 n6, %	**-0.200**	-0.113	-0.059	-0.122	**-0.209**	0.060	0.049	**-0.222**	-0.125	**-0.193**	0.043	0.047
	0.02	0.17	0.48	0.14	0.01	0.47	0.55	<0.01	0.13	0.02	0.60	0.57
C 20:3 n6, %	-0.077	0.008	-0.055	-0.011	-0.111	0.005	-0.030	**-0.168**	-0.036	-0.120	-0.031	-0.014
	0.36	0.92	0.50	0.89	0.18	0.95	0.72	0.04	0.66	0.14	0.71	0.87
C 20:4 n6, %	-0.102	0.003	-0.099	-0.009	-0.061	0.005	-0.040	**-0.191**	-0.046	**-0.141**	-0.020	-0.052
	0.22	0.97	0.23	0.92	0.45	0.95	0.62	0.02	0.58	0.09	0.81	0.53
C 20:3 n3, %	-0.115	-0.081	-0.068	-0.058	0.007	0.073	0.089	0.050	-0.107	-0.024	-0.054	0.036
	0.17	0.32	0.41	0.48	0.93	0.37	0.28	0.54	0.19	0.77	0.51	0.66
C 20:5 n3, %	-0.012	-0.051	-0.086	-0.051	-0.040	0.061	-0.037	-0.107	0.045	-0.036	0.026	0.009
	0.89	0.54	0.30	0.53	0.63	0.46	0.66	0.19	0.58	0.67	0.76	0.92
C 22:4 n6, %	-0.069	-0.012	**-0.138**	0.002	-0.054	0.029	-0.056	**-0.175**	-0.040	-0.117	-0.006	-0.037
	0.41	0.89	0.09	0.98	0.51	0.73	0.49	0.03	0.62	0.15	0.95	0.65
C 22:5 n3, %	-0.043	-0.032	-0.098	-0.019	-0.096	0.005	-0.061	**-0.200**	-0.036	-0.127	-0.041	-0.011
	0.60	0.70	0.23	0.82	0.24	0.95	0.45	0.01	0.66	0.12	0.62	0.89
C 22:6 n3, %	-0.051	-0.043	-0.058	-0.027	-0.026	**0.168**	0.058	-0.056	-0.045	-0.037	0.023	-0.004
	0.54	0.60	0.48	0.74	0.75	0.04	0.48	0.49	0.58	0.66	0.78	0.96
SFA, %	**0.231**	-0.062	-0.074	0.028	**-0.151**	0.028	-0.026	-0.092	0.049	-0.029	-0.024	0.038
	<0.01	0.45	0.37	0.73	0.06	0.74	0.75	0.26	0.55	0.72	0.77	0.65
MUFA, %	-0.125	0.070	0.072	-0.027	**0.209**	0.005	0.096	**0.203**	-0.079	0.066	0.058	0.054
	0.13	0.39	0.38	0.74	0.01	0.96	0.24	0.01	0.34	0.42	0.48	0.51
PUFA, %	-0.107	-0.024	-0.038	-0.011	**-0.175**	-0.018	-0.062	**-0.238**	-0.044	**-0.153**	**-0.160**	-0.042
	0.20	0.77	0.65	0.90	0.03	0.83	0.45	<0.01	0.59	0.06	0.05	0.61
Ratio Unsaturated FA:SFA	**-0.231**	0.062	0.074	-0.028	0.151	-0.028	0.026	0.092	-0.049	0.029	0.024	-0.038
	<0.01	0.45	0.37	0.73	0.06	0.74	0.75	0.26	0.55	0.72	0.77	0.65
Ratio	**-0.154**	0.006	-0.008	-0.008	-0.083	-0.029	-0.051	**-0.167**	-0.073	-0.132	-0.151	-0.036

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PUFA:SFA	0.06	0.94	0.92	0.92	0.31	0.73	0.53	0.04	0.38	0.11	0.06	0.66
	-0.199	0.045	0.079	-0.015	0.016	-0.043	-0.010	-0.023	-0.065	-0.047	0.021	0.055
AOCS IV	0.02	0.59	0.33	0.85	0.84	0.60	0.91	0.78	0.43	0.57	0.79	0.51

[1] Durometer were determined at approximately the 10th rib on both the dorsal and ventral sides of the loin.
[2] An average whole loin durometer reading was calculated as the average of the durometer readings on the dorsal and ventral sides of the loin.