Published March 3, 2017

Characterization of variability in pork carcass composition and primal quality[1,2,3]

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ABSTRACT: The objective was to characterize the factors and production practices that contribute to variation in pork composition and quality. It is possible the variation in pork quality traits, such as color, marbling, and tenderness, contributes to reduced customer confidence in the predictability of finished product quality and, therefore, pork products becoming less competitive for consumer dollars. Pigs raised in 8 different barns representing 2 seasons (hot and cold) and 2 production focuses (lean and quality) were used in this study. Pigs were marketed in 3 groups from each barn and marketing procedures followed commercial marketing procedures. Data were collected on a total of 7,684 pigs. The mivque0 option of the VARCOMP procedure in SAS was used to evaluate the proportion of variation each independent variable (season, production focus, marketing group, sex, and random variation) contributed to total variance. Random variation including inherent biological differences, as well as factors not controlled in this study, contributed the greatest proportion to total variation for each carcass composition and quality trait. Pig and other factors contributed to 93.5% of the variation in HCW, and marketing group, sex, season, and production focus accounted for 4.1, 1.4, 0.8, and 0.3%, respectively. Variation in percent carcass lean was attributed to production focus (36.4%), sex (15.8%), and season (10.2%). Pig and other factors contributed the greatest percentage of total variation (39.4%). Loin weight variation was attributed to production focus (21.4%), sex (5.4%), season (2.7%), marketing group (1.8%), and pig (68.7%). Belly weight variation was attributed to pig (88.9%), sex (4.1%), marketing group (3.8%), production focus (3.0%), and season (0.1%). Variation in ham weight was attributed to pig and other factors (93.9%), marketing group (2.8%), production focus (2.2%), and season (1.1%). Ultimate pH variation was attributed to pig (88.5%), season (6.2%), production focus (2.4%), marketing group (2.2%), and sex (0.7%). Aside from pig (71.9%), production focus (14.0%) was the next largest contributor to variation in iodine value followed by sex (13.2%) and marketing group (0.9%). Variation in carcass quality and composition could be accounted for, but the greatest percentage of variation was due to factors not accounted for in normal marketing practices.

Key words: composition, pork, quality, variability, variation

 J. Anim. Sci. 2017.95:697–708
doi:10.2527/jas2016.1097

INTRODUCTION

Pork quality is inherently variable (Cannon et al., 1996; Stetzer and McKeith, 2003; Klinkner, 2013). Specifically, loin chop color (27.12% CV) and marbling (38.14% CV) scores were highly variable (Klinkner, 2013). Pork consumers make purchasing decisions based on pork color, discriminating against pork perceived as very light pink (Brewer and McKeith, 1999). Greater marbling in pork results in consumers rating product as more tender, juicy, and flavorful (Brewer et al., 2001). This coupled with the 8.6% decline in

[1]Funding, wholly or in part, was provided by The National Pork Board.

[2]Mention of trade names, proprietary products, or specified equipment does not constitute a guarantee or warranty by the USDA and does not imply approval to the exclusion of other products that may be suitable. The authors gratefully acknowledge the technical support of Casey Trambly, Trent Ahlers, Patty Beska, Kristen Ostdiek, Peg Ekeren, Nancy McCully, Neil Hofer, and Glenda Lovell and the secretarial support of Jody Gallagher.

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Received October 5, 2016.
Accepted December 22, 2016.

per capita consumption of pork retail cuts in the United States from 2000 to 2013 (23.2 to 21.2 kg; NPB, 2014) leads to speculation that variation in pork quality traits (i.e., color, marbling, and tenderness) contributed to reduced customer confidence in the predictability of finished product quality and, thus, pork products becoming less competitive for consumer dollars.

Producers are focused on minimizing variation, as increased variation in a pork carcass population results in missed opportunities to reach premium grid qualifications. Specifically, minimizing variation in sort loss increased the total value of pigs in a barn (Hinson et al., 2012). Additionally, the majority of pigs in the United States are marketed on matrices targeting carcass weight and percent lean specifications (Meyer, 2005); reduction of variation in BW at marketing has the potential to result in increased value. Before the processor can capture this value, the industry must first estimate total variation of pork quality traits and contributors to that variation. Due to the use of marketing groups by producers to specifically minimize variation in BW, it was hypothesized that marketing group would not contribute to variation in carcass weight, primal weight, or quality traits. However, it was hypothesized that sex, season in which the pigs were raised, and production focus would contribute variation to weight and quality traits in a population of carcasses.

MATERIALS AND METHODS

Pigs were slaughtered under the supervision of the USDA Food Safety Inspection Service at a federally inspected facility. Postmortem meat samples were purchased from that facility and transported to the University of Illinois Meat Science Laboratory (Urbana, IL) or the USDA Meat Animal Research Center (Clay Center, NE). Therefore, Institutional Animal Care and Use Committee approval was not necessary.

Pigs raised in 8 different barns representing 2 seasons and 2 production focuses were used in this study. Pigs from half of the barns were raised and slaughtered in a cold season (February and March) and pigs from the other half of the barns were raised and slaughtered in a hot season (July through September). Half of the pigs slaughtered within each season were from the production focus aimed at meat quality and half were produced with a focus aimed at lean growth. Pigs selected for the meat quality focus were pigs that were identified by the packer from proprietary suppliers to provide proprietary genetics that resulted in loins with increased intramuscular fat compared with pigs in the lean growth focus. Loins from pigs in this population from the meat quality focus had 0.95 subjective units more ($P < 0.0001$) marbling, were predicted to be more tender ($P = 0.04$) using visible and near-infrared reflectance spectroscopy, and had less purge loss ($P = 0.03$) than loins from pigs in the lean growth focus group (data not shown in tabular form). Similarly, pigs selected for the lean growth focus were pigs that were identified by the packer from proprietary suppliers to provide proprietary genetics that resulted in larger loins and greater estimates for carcass lean. Carcasses from pigs in the lean growth focus had 5.21 mm greater ($P = 0.02$) loin depths and 2.54 greater ($P < 0.01$) carcass lean estimates (data not shown in tabular form). Pigs in the lean growth production focus for the cold season were fed ractopamine during finishing of the live phase portion of the trial. Ractopamine does not influence color (7 of 8 studies reported no difference) or marbling (9 of 10 studies reported no difference) when fed at approved doses for use in the United States (Apple et al., 2007), so differences in variability among selection focuses or marketing groups were not anticipated due to ractopamine. No other dietary, antibiotic, or management history was known about the pigs.

Processing Facility Data Collection

Lairage procedures followed normal operating procedures of the abattoir. Pigs of the quality production focus were lairaged overnight at the abattoir (approximately 13 h), and pigs selected for lean growth program arrived at the abattoir approximately 7 h prior to slaughter. These differences were routine for those types of pigs at that abattoir because of the need to slaughter pigs whose meat qualified for a particular program at the same time. Pigs were rendered insensible by carbon dioxide stunning and terminated via exsanguination. Immediately after evisceration, carcasses were assigned a sequence number on the shoulder and ham, and each pig's respective lot tattoo was recorded (tattoos corresponded to both barn of origin and the truck on which the pig was transported). Data were collected on 7,684 carcasses at the production facility (7,684 was the number of carcasses on which at least 1 data point was recorded; 100% data collection was not achieved for any specific trait, leading to the discrepancy in total number of observations for HCW, LM depth, fat depth, and leg primal weight). Immediately after evisceration, a target of 10% of pigs delivered to the abattoir were selected for in-depth quality analyses of loins and hams. All carcasses were weighed to determine HCW. Fat depth and LM depth were evaluated using a Fat-O-Meater probe (SFK Technology A/S, Herlev, Denmark). Percent lean was calculated using an abattoir-proprietary equation. Carcasses were blast-chilled for approximately 100 min. After exiting the chiller, adipose tissue cores, approximately 3.81 cm in diameter, were collected from the right side of every carcass from the clear plate (adipose

tissue located over the scapula and cervical vertebra) near the dorsal midline using a core and drill. Vertebrae of all loins and bellies from odd numbered carcasses were labeled with sequence numbers consistent with both the ham and shoulder while carcasses were stored in carcass equilibration bays.

Approximately 22 h postmortem, carcasses were fabricated into primal pieces. Bellies (North American Meat Processors [**NAMP**] #408; NAMP, 2007) and hams (modified NAMP #401) were collected and placed into combos for further analyses that same day. Loins were fabricated into boneless Canadian back loins (NAMP # 414). Fresh loin muscle marbling (1–10 subjective scale) was evaluated using National Pork Producers Council standards on the boning and trimming line at the time of cutting by an industry professional with over 10 yr of pork quality research experience (NPPC, 1999). A subset (approximately 50%) of the loins was placed in a combo for collection of ultimate pH and instrumental measurements.

Loins. Approximately 50% of the entire population of loins (odd numbered carcasses from above) were selected for further quality analyses and boneless primal weight. Instrumental L*, a*, and b* color evaluations were conducted on the ventral side at approximately 25 and 75% the length of the loin using a Hunter Miniscan XE Plus colorimeter (HunterLab, Reston, VA) with a D65 light source, 10° observer, and 25-mm port. Ultimate pH was recorded using a pH meter. For data collected during the first week of the cold season, a REED SD-230 m (Wilmington, NC) fitted with a PHE-2385 glass combo electrode (Omega Engineering, Inc., Stamford, CT) was used. For all remaining ultimate pH measurements, data were collected with a HI 98160 Microprocessor Logging pH/ORP Meter (Hanna Instruments, Woonsocket, RI). Loin weight was recorded. Loins of the select 10% were vacuum-packaged and transported (1°C) to the Meat Animal Research Center (Clay Center, NE). Within 58 h of carcass cutting, loins arrived at USMARC (Clay Center, NE). Loins were immediately place on carts in a single layer and ventral side up and aged (1°C). Loins were weighed (tared for vacuum packaging bag) to record initial loin weight. At 20 d postmortem, loins were removed from their packaging and weighed to determine aged weight, and purge loss was calculated: ([(initial weight, kg − aged weight, kg)/initial weight, kg] × 100). Loins were then prepared for slicing with a Grasselli NSL 400 portion meat slicer (Grasselli, Albinea, Italy). The posterior end of the loin (approximately 4 cm long) was removed by a straight cut perpendicular to the length of the loin at a point 5 cm posterior to the anterior tip of gluteus accessories. The anterior end of the loin was removed by a second cut made 396 mm anterior to the first cut, leaving a 396-mm-long center-cut loin section that fits the width of the Grasselli NSL 400 portion meat slicer. This approach maximized the yield of chops with the highest proportion of their mass/cross-sectional area comprising longissimus and excluded chops with a high proportion of their mass/cross-sectional area comprising other muscles (spinalis dorsi, multifidus dorsi, gluteus medius, and gluteus accessorius). Additionally, this approach standardized anatomical location of chop assignment across loins. Chops 5 and 6, which correspond approximately to the 11th rib region of the loin, were used for determination of slice shear force (**SSF**). Immediately after cutting, fresh (never frozen) chops were weighed to record initial weight. The following day (21 d postmortem), chops were cooked using a belt grill (Magigrill, model TBG-60; MagiKitch'n Inc., Quakertown, PA) to a desired internal temperature of 71°C. Cooked chops were weighed and cooking loss was calculated: [(initial weight, g − cooked weight, g)/initial weight, g] × 100. Slice shear force was measured using the procedures of Shackelford et al. (2004) on 2 chops. The 2 SSF values were then averaged.

Hams. Whole leg primal weight was recorded, and instrumental L*, a*, and b* (Konica Minolta CR-400 colorimeter; Minolta Camera Company, Osaka, Japan; D65 light source, 0° observer, and 8-mm aperture) measures were recorded on the gluteus medius and gluteus profundus of the ham face on approximately 100% of the hams in the population. Select hams (targeted 10%) were transported in combos via refrigerated (≤4°C) truck to the University of Illinois Meat Science Laboratory where they were fabricated following procedures of Boler et al. (2011). Briefly, a modified NAMP number 401 (rectus abdominus attached) leg was trimmed similar to a NAMP # 402 . Hams were then separated into 5 pieces: inside ham (NAMP # 402F), outside ham (NAMP # 402D), knuckle (NAMP # 402H), inner shank portion, and lite butt. Instrumental L*, a*, and b* values (Konica Minolta CR-400 colorimeter; Minolta Camera Company; D65 light source, 0° observer, and 8-mm aperture) and ultimate pH (MPI pH meter; Meat Probes Inc., Topeka, KS; 2 point calibration at pH 4 and 7) were collected on the semimembranosus muscle (blonde spot, medial side).

Bellies. Skin-on bellies (NAMP number 408) were weighed, and measurements of belly length, depth, and width were recorded on approximately 50% of the bellies (odd-numbered carcasses from above). Belly depth (thickness) was measured at 25, 50, and 75% of the distance from the anterior toward the posterior end. Average belly depth was determined by averaging the 3 depth values.

Iodine Value. Iodine value (**IV**) was calculated for the adipose tissue sample from the clear plate using gas chromatography on the select 10% carcasses.

Table 1. Number, mean, and variance of each trait used in this study

Variable	No.	Mean	SD	SEM	Variance (s^2)	CV
HCW, kg	7,576	94.50	9.39	0.11	88.13	9.93
Fat depth, mm	6,920	15.41	4.00	0.05	15.96	25.93
Loin depth, mm	6,920	68.00	8.52	0.10	72.62	12.53
Percent lean, %	6,920	57.63	2.76	0.03	7.63	4.79
Iodine value (g/100 g of fatty acid methyl esters)	848	75.78	3.63	0.12	13.17	4.79
Loin weight, kg	3,973	3.75	0.49	0.01	0.24	13.07
Loin L*[1]	3,937	52.66	2.49	0.04	6.21	4.73
Loin a*[1]	3,937	7.40	1.15	0.02	1.32	15.55
Loin b*[1]	3,937	13.64	1.04	0.02	1.08	7.61
Ultimate pH	3,990	5.69	0.15	0.002	0.02	2.56
Slice shear force, kg	818	14.80	5.50	0.19	30.24	37.16
Marbling score	7,381	2.13	0.92	0.01	0.85	43.35
Belly weight, kg	3,648	7.43	1.15	0.02	1.32	15.48
Belly length, cm	3,648	69.24	4.13	0.07	18.59	6.23
Belly width, cm	3,647	35.91	2.45	0.04	5.98	6.81
Average belly depth, cm	3,648	2.53	0.42	0.01	0.18	16.59
Ham weight, kg	7,539	11.74	1.10	0.01	1.20	9.33
Semimembranosus pH	842	5.66	0.28	0.01	0.08	4.97
Semimembranosus L*[1]	840	46.57	3.14	0.11	9.83	6.73
Semimembranosus a*[1]	841	9.53	1.86	0.06	3.47	19.53
Semimembranosus b*[1]	839	1.54	1.56	0.05	2.42	101.22

[1]L* measures darkness to lightness (greater L* value indicates a lighter color), a* measures redness (greater a* value indicates a redder color), and b* measures yellowness (greater b* value indicates a more yellow color).

Fatty acid methyl esters were converted from lipid using the AOAC International official method C3 2-66 (AOAC, 2000). The resulting fatty acid methyl esters were analyzed using the procedures of Arkfeld et al. (2015). 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 American Oil Chemists' Society (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 (0.723).

Statistical Analyses

Means, variances, and CV of variables were calculated using the MEANS procedure in SAS (version 9.4; SAS Inst. Inc., Cary, NC). The mivque0 option of PROC VARCOMP was used to evaluate the proportion of variation each independent variable (marketing group, sex, season of production/slaughter, and production focus) contributed to total variance. Variance that could not be attributed to an independent variable (error) was attributed to biological differences between pigs as well as other factors not controlled for in this study (e.g., diet, barn type, etc.). Computed negative variance estimates were treated as contributing zero variation to the population. Due to the nature of the statistical analysis used in this study, variation percentages total to 100% (subtle deviations may occur due to rounding).

RESULTS AND DISCUSSION

Population statistics indicate carcasses used in this study were representative of current commercial pork (Table 1). Hot carcass weight (94.50 ± 9.39 kg) was similar to the 96-kg dressed weight observed in all barrows and gilts slaughtered in the United States in 2014 (USDA AMS, 2014). Variance for HCW was 88.13 kg. Historically, variation in a population of pigs is not commonly addressed in peer-reviewed literature. However, in the 1992 pork quality audit, Cannon et al. (1996) reported estimated U.S. market swine live weight. Over 83% of pigs had a final BW in the 3 middle groups of 8-kg categories (100 to 108, 109 to 117, and 118 to 126 kg BW). To compare this with the current data set, data were sorted into 6-kg bins (to account for a 74% dressing percentage from BW to HCW; 8 kg × 0.74 = 5.92 kg, rounded to 6 kg). The middle 3 bins of the current data set (89–107 kg) contained 67.8% of the population. Using this information, it could be extrapolated that variation has increased in the U.S. pork population since 1992. However, there are no direct data available to support or refute that conclusion.

Hot Carcass Weight and Carcass Composition

Given that over 95% of pigs in the United States are sold on matrices targeting optimal carcass weight

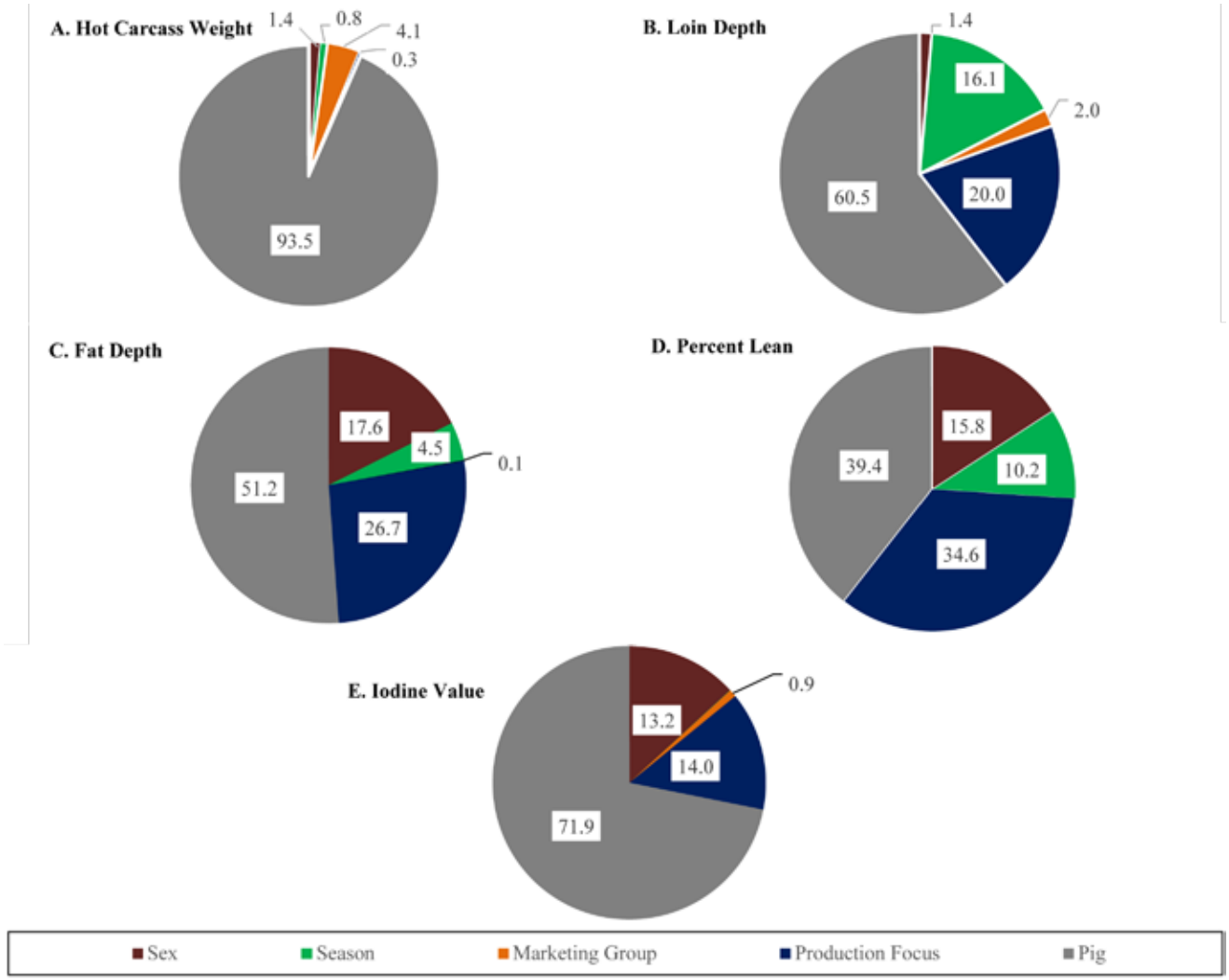

Figure 1. Percent of total variation that sex, season, marketing group, production focus, and pig (random error) contributed to HCW (A), loin depth (B), backfat (C), percent lean (D), and iodine value (E).

and percent lean (Meyer, 2005), producers use marketing groups to minimize BW variation and achieve the maximum number of pigs at a target HCW. The hypothesis was that variation in HCW would be due to pig and other factors; however, given that pigs are selected for marketing group at a target final BW, it was anticipated that marketing group would contribute the least of all independent variables to total variation. Variation in HCW (93.5%) was indeed attributed largely to pig and other factors (Fig. 1). Marketing group (4.1%), sex (1.4%), season (<1%), and production focus (<1%) also contributed variation to HCW. Because these results indicate that only a small amount of variation in HCW was due to marketing group, producers in this study properly managed this independent variable to contribute little variation.

Pig and other factors contributed the largest variation to carcass composition traits (51.2% fat depth, 60.5% loin depth, and 39.4% percent lean). Remaining variation in fat depth was attributed to production focus (26.7%), sex (17.6%), season (4.5%), and marketing group (0.1%). Total variation in loin depth was attributed to production focus (20.0%), season (16.1%), marketing group (2.0%), and sex of the pig (1.4%). Given that percent lean is the other large driving factor in marketing matrices (Meyer, 2005), it is of interest that marketing group did not contribute to total variation of percent lean. In other words, marketing group strategies used by producers to limit HCW variation were successful in limiting variation in percent lean as well. Variation that was present in percent lean could be attributed to production focus (36.4%), sex (15.8%), and season (10.2%). Seasonality encompasses a variety of factors; for example, during summer months, factors such as temperature, relative humidity, etc., have the potential to result in an animal that is heat stressed. Although pigs that are heat stressed during the finishing phase (≥14 wk of age; 32°C and 35 to 50% relative humidity) have decreased separable fat and increased lean tissue as a percentage of side weight compared with pigs that have not been heat

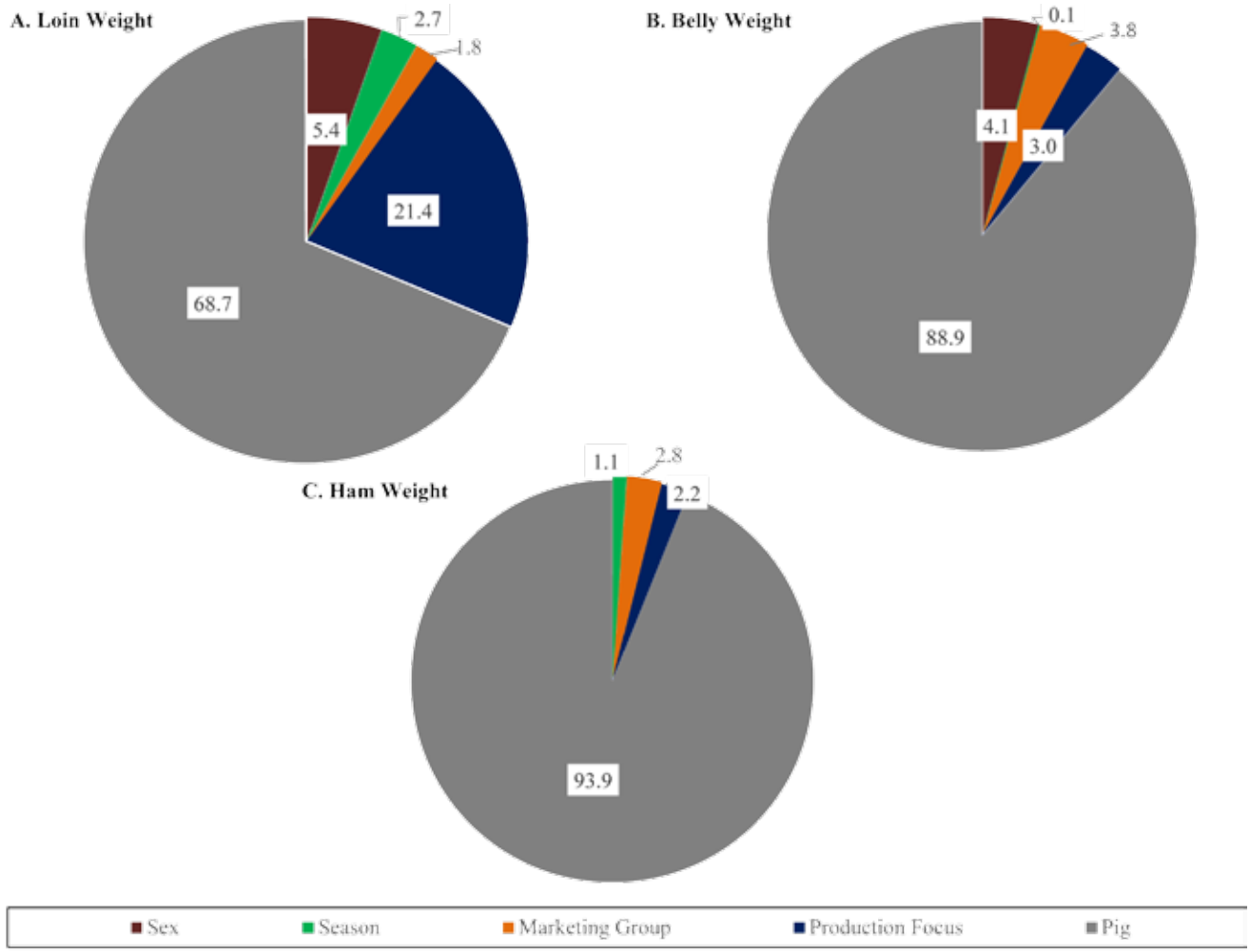

Figure 2. Percent of total variation that sex, season, marketing group, production focus, and pig (random error) contributed to boneless loin weight (A), belly weight (B), and ham weight (C).

stressed (Cruzen et al., 2015), variances between the 2 treatments do not necessarily differ. Therefore, seasonality did contribute to total variation but it cannot be determined if one season produces pork carcasses with more variation in percent lean than the other season. The variation differences that are understood are those due to sex. Overholt et al. (2016) reported a greater variance, and therefore greater variation, in barrows compared with gilts for estimated carcass lean. Therefore, it was not surprising that sex contributed to overall variation in percent lean of these carcasses.

Iodine Value

It was expected that marketing group would contribute little to total variation in IV. Previous literature has reported a lack of mean differences between marketing groups for SFA, MUFA, PUFA, and IV of belly and jowl adipose tissue measured by gas chromatography (Shircliff et al., 2015). A lack of mean differences between marketing groups would not directly translate into differences in variation. However, consistency in IV means across marketing groups lead to the hypothesis that marketing group would contribute minimal variation to the overall variation in IV. In contrast to the weakness in the literature in regards to IV variation due to marketing group, there is literature that concluded that variation is different between barrows and gilts for IV. Specifically, gilts from this population of pigs had greater variation in IV compared with barrows (Overholt et al., 2016). Therefore, it was anticipated that sex would contribute to total variation in IV. Pigs used in this study were produced targeting different value-added pork programs and therefore were produced with differing production focuses. This differing focus resulted in numerically different back fat depths between the 2 populations (14.30 mm lean vs. 17.40 mm quality; data not presented). Although mean values would not necessarily translate into variation differences, it was anticipated that the production of pigs with such a range in back fat depths would lead to great variation in the overall population. Increased back fat thickness is related to increased SFA and MFA and reduced PUFA content (Lo Fiego et al., 2005). Pigs that are genetically leaner had lower de novo fatty acid synthesis and greater lipolysis

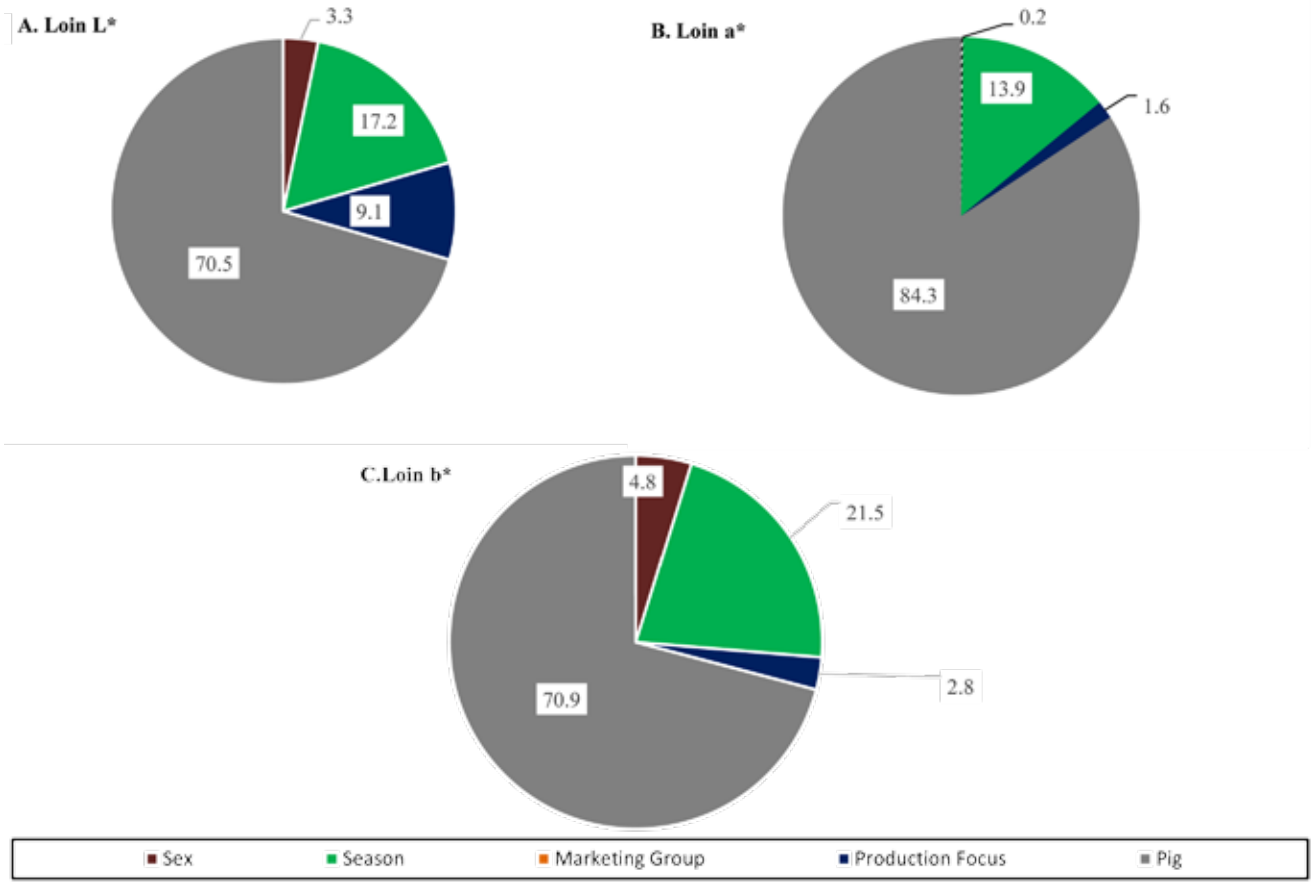

Figure 3. Percent of total variation that sex, season, marketing group, production focus, and pig (random error) contributed to loin L* (A), loin a* (B), and loin b* (C).

than fatter pigs (Scott et al., 1981a,b). Therefore, it was expected that production focus would contribute variation to IV. In the current study, marketing group contributed little variation to IV (0.09%; Fig. 1). Furthermore, season had no effect on variation, contributing less than 0.1% of the total variation in IV. However, production focus (14.0%) and sex (13.2%) did contribute to variability in IV. In line with all other traits in this study, pig and other factors in this study contributed the greatest variation in IV (71.9%). These results agree with previously stated hypotheses. Iodine value not only has consistent means across marketing groups (Shircliff et al., 2015), but data from the current study allow for the conclusion that marketing group had virtually no (<1%) impact on total variation of IV. Furthermore, differences in IV variation between barrows and gilts reported by Overholt et al. (2016) resulted in sex contributing to overall variation in IV.

Primal Weights

Due to the manner in which pigs are marketed in the United States, reduced variation of carcass composition traits directly benefits the pork producer, whereas reduced variation of primal weight and pork quality traits offers value to the pork processor. Variation in boneless loin weight, belly weight, and ham weight was largely accounted for by pig and other factors not controlled for in this study at 68.7, 88.9, and 93.9%, respectively (Fig. 2). Further variation in loin weight was accounted for by production focus (21.4%), sex (5.4%), season (2.7%), and marketing group (1.8%). Remaining variation in belly weight was attributed to sex (4.1%), marketing group (3.8%), production focus (3.0%), and season (0.1%). Finally, the remaining 6.1% of variation in ham weight was accounted for by marketing group (2.8%), production focus (2.2%), and season (1.1%). Sex did not contribute any variability to ham weight. Because marketing group contributed ≤3.8% of the variation in primal weights, the use of marketing groups contributed little variation to pork primal weights. Largely, the proportion that each independent variable contributed to individual primal weight variation was in line with HCW variation results, with the exception of the contribution of production focus to loin weight variation. Furthermore, there was not a large numerical difference in boneless loin weight between the 2 production focuses (3.95 kg for the lean focus and 3.55 kg for the quality focus; data not presented in tabular form). Bone-in loin weights were not recorded in this study, so it is uncertain if primal weights were different from each other. If it is assumed

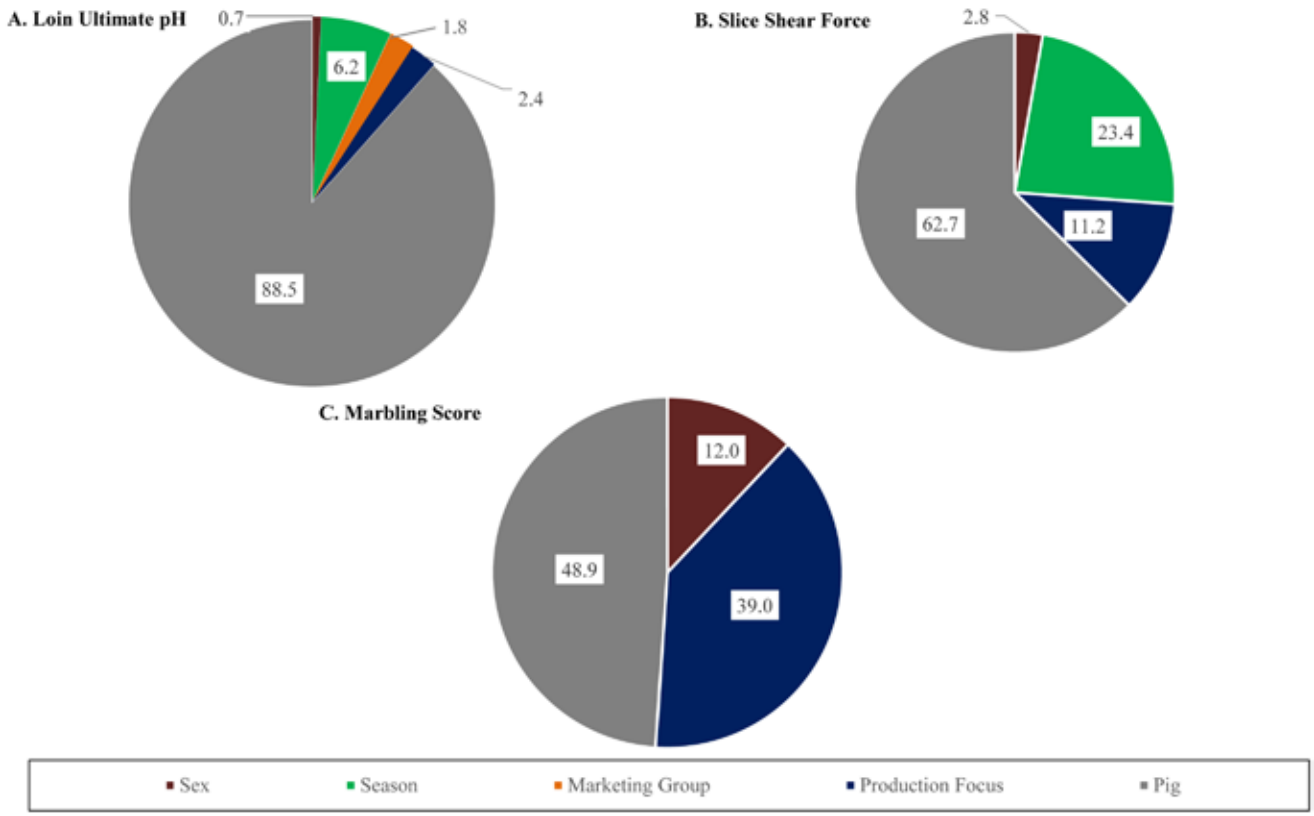

Figure 4. Percent of total variation that sex, season, marketing group, production focus, and pig (random error) contributed to loin ultimate pH (A), loin slice shear force (B), and loin marbling score (C).

that bone-in primal weights were relatively equal, the increased fat depth (14.30 mm for the lean focus and 17.40 mm for the quality focus) in the quality focus could have resulted in greater variability due to trimming. However, concrete conclusions on this hypothesis cannot be drawn, as bone-in primal weights were not recorded and variability differences in loin weights between production focuses were not evaluated in this study.

Loin Quality

Recent research suggested there is variation present in pork loin chops in the retail case (Klinkner, 2013), specifically in measures of L* (SEM = 3.70, CV = 6.69%), a* (SEM = 3.11, CV = 52.87%), b* (SEM = 1.84, CV = 49.19%), pH (SEM = 0.30, CV = 5.03%), and Warner-Bratzler shear force (SEM = 6.70 kg, CV = 28.68%). Variation in the current study was not as large (Table 1) as that previously reported. The differences in variation of the 2 populations could be attributed to both uncertainty and variability, the 2 components of variation (van Belle, 2008). Uncertainty refers to precision associated with measurement. Given that protocols differed between Klinkner (2013) and the present study, differences in both uncertainty and variability are likely present between studies. Klinkner (2013) evaluated pork from a much broader genetic, production, and processing background likely with differences in factors that impact pork quality: genetics (Brewer et al., 2002), production system (Honeyman and Harmon, 2003; Lebret et al., 2006), diet (Benz et al., 2010; Leick et al., 2010; Xu et al., 2010), feed additives (Leick et al., 2010; Hinson et al., 2011, 2012), marketing group (Lowe et al., 2014, 2016), transportation procedures (Carr et al., 2008; Ritter et al., 2009; Correa et al., 2013), lairage time (Gajana et al., 2013; Dokmanović et al., 2014), and carcass chilling procedures (Springer et al., 2003; Shackelford et al., 2012; Blakely, 2014). Using carcass chilling as an example, Shackelford et al. (2012) observed differences in pigs sourced from a single barn and genetic line: pigs with carcasses that were chilled more rapidly (blast chill) had greater loin purge loss percentages and were less tender (15 d postmortem) than carcasses chilled in a conventional spray chill system. Furthermore, SD for loin SSF was numerically greater in plants with blast chilling compared with the plant with spray chilling (Shackelford et al., 2012).

Similar to other traits in this study, the biological variation in pig and other factors accounted for the majority of total variation in loin composition and quality traits (Fig. 3 and 4). Pig and other factors were the overwhelming contributor to variation in objective loin color (Fig. 3): 70.5% of L* variation, 84.3% of a* variation, and 70.9% of b* variation. Marketing group did not

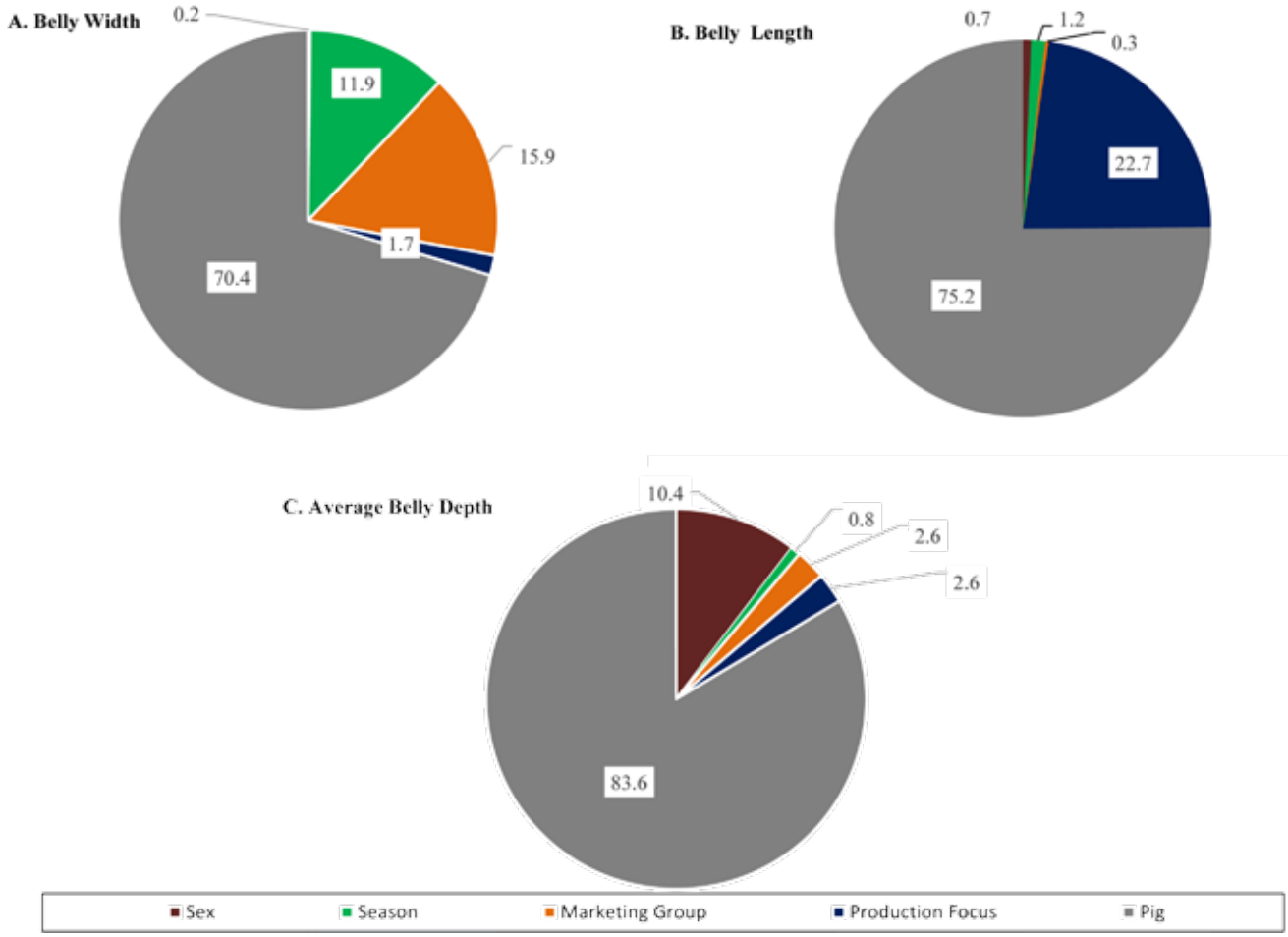

Figure 5. Percent of total variation that sex, season, marketing group, production focus, and pig (random error) contributed to belly width (A), belly length (B), and average belly depth (C).

contribute to total variation of instrumental loin color. It is interesting to find that an indirect result of selecting for consistent carcass composition traits through multimarketing group strategies was to eliminate variation in color caused by marketing group. This was surprising, as previous research reported a 1.41 and 1.51 unit increase in L* value from marketing group 1 to marketing groups 2 and 3, respectively (Lowe et al., 2014). Furthermore, a 0.35 unit decrease and a 0.75 unit increase were observed in loin a* value from marketing group 1 to marketing groups 2 and 3, respectively (Lowe et al., 2014). The remaining variation in loin L* was attributed to season (17.2%), production focus (9.1%), and sex (3.3%); the remaining variation in loin a* was attributed to season (13.9%), production focus (1.6%), and sex (0.2%); and the remaining variation in loin b* was attributed to season (21.5%), sex (4.8%), and production focus (2.8%).

Mean loin pH differences among marketing groups have been reported (Lowe et al., 2014) as well as among season of transport (Correa et al., 2013). Less than 15% of the variation in loin ultimate pH was attributed to factors other than pig (Fig. 4). This indicates that producers are currently using management steps that contribute little variation in loin ultimate pH or that variation in ultimate pH is due to practices at the abattoir. D'Souza et al. (1998) reported that pigs aggressively handled at the plant had a decreased pH (pooled effects of the longissimus thoracis and biceps femoris) at 45 and 70 min postmortem but not at 24 h postmortem when compared with minimally handled pigs. Although this study did not specifically test differences in rate of pH decline, it is highly likely that there were differences in pH measures at 45 and 70 min. These differences resulted in increased exudate in the longissimus thoracis and biceps femoris as well as an increased percentage of pale, soft, and exudative (PSE) loins due to negative handling (D'Souza et al., 1998). Additionally, increased time (70 min) of a carcass on the processing floor before chilling did not significantly affect pH at any time point but did result in paler pork when compared with carcasses that spent a shorter time (45 min) on the processing floor (D'Souza et al., 1998). In the current study, variation in ultimate pH was attributed to pig (88.5%), season (6.2%), production focus (2.4%), marketing group (2.2%), and sex (0.7%; Fig. 4). However, the same is not true for pork tenderness. Although 62.7% of the variation in SSF was

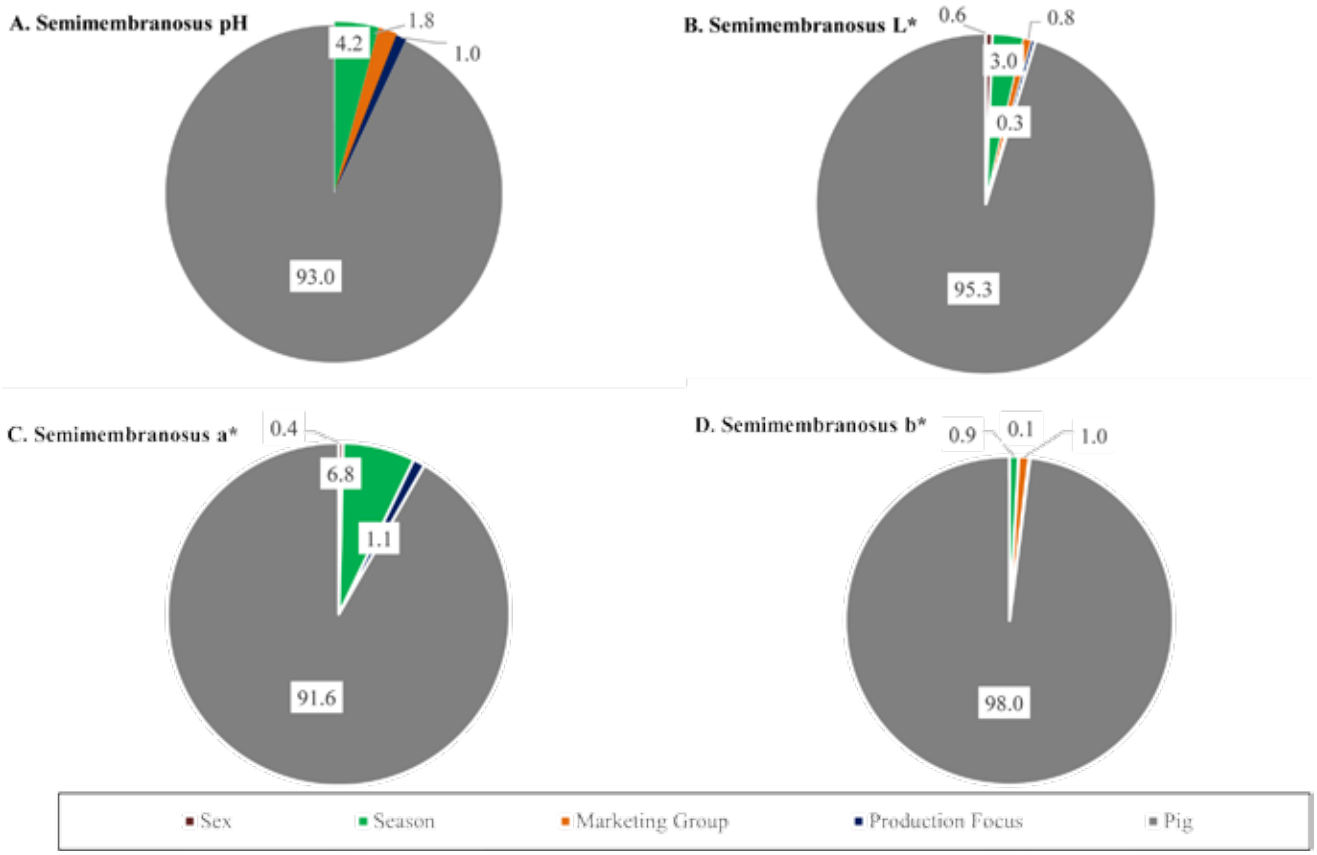

Figure 6. Percent of total variation that sex, season, marketing group, production focus, and pig (random error) contributed to semimembranosus pH (A), semimembranosus L* (B), semimembranosus a* (C), and semimembranosus b*(D).

accounted for by pig, 23.4% was attributed to season, 11.2% was attributed to production focus, and 2.8% was attributed to sex. No variation in SSF could be attributed to marketing group. Season contributed no variation to subjective marbling score and marketing group contributed less than 0.1%. Variation in subjective marbling score was accounted for by pig (48.9%), production focus (39.0%), and sex (12.0%). Use of marketing groups by pork producers results in minimal contribution of variation to loin quality traits.

Belly and Ham Quality

Sliced bacon has increased sharply in value since 2010 and is the most expensive pork product (Bureau of Labor Statistics, 2016). Therefore, minimizing variation in raw belly characteristics offers the potential to further capture value from the pork belly. Pig and other factors contributed the largest variation to belly width, length, and average depth: 70.4, 75.2, and 83.6%, respectively (Fig. 5). Remaining variation in belly weight was attributed to sex (4.1%), marketing group (3.8%), production focus (3.0%), and season (0.1%). Belly width variation was attributed to marketing group (15.9%), season (11.9%), production focus (1.7%), and sex (0.2%). Production focus had a large impact on belly length and accounted for 22.7% of total variation, whereas remaining variation was accounted for by season (1.2%), sex (0.7%), and marketing group (0.3%). Average belly depth variation was attributed to sex (10.4%), marketing group (2.6%), production focus (2.6%), and season (0.8%).

Pig accounted for greater than 91% of variation in semimembranosus pH and semimembranosus objective color (Fig. 6), indicating that sex, season, and the management techniques of marketing group and production focus are all working to manage ham variation. Relatively small variation was present in semimembranosus pH, L*, and a*, as indicated by a low CV (Table 1). Yet semimembranosus b* had a CV of 101.22%. The factor or factors driving the variation are largely due to pig and/or a production practice not evaluated in the present study. Nonetheless, independent variables of the current study still offered an avenue to reduce variation (Fig. 6). Ninety-three percent of the variation in semimembranosus pH was accounted for by pig, 4.2% by season, 1.8% by marketing group, 1.0% by production focus, and less than 0.1% by sex. Pig and other factors accounted for 95.3% of semimembranosus L*; further variation was accounted for by season (3.0%), marketing group (0.8%), sex (0.6%), and production focus (0.3%). Semimembranosus a* variation was attributed

to pig (91.6%), season (6.8%), production focus (1.1%), and sex (0.4%). Marketing group did not contribute variation to semimembranosus a*. Similarly, sex did not contribute to total variation in semimembranosus b*. Variation in this trait was accounted for largely by pig (98.0%) but additionally by marketing group (1.0%), season (0.9%), and production focus (0.01%). Overall, similar to loin instrumental color, marketing group did not account for much of the variation in ham color. This was again surprising, as peer-reviewed literature indicated that although mean L* value is not affected by marketing group, mean a* and b* values were affected (Lowe et al., 2016). However, the statistical inference space of the Lowe et al. (2016) study included only barrows (both immunologically and physically castrated) of one genetic background. Furthermore, SEM were greater for L*, a*, and b* in the study of Lowe et al. (2016) compared with the current, study indicating differences in overall variation between studies.

Conclusions

Variation exists in the pork industry. Management of this variation offers great potential to add value to the U.S. pork industry by reducing the number of carcasses falling outside of premium qualifications and minimizing the amount of fresh meat that misses quality specifications. With the exception of belly width, marketing group attributed ≤4.1% of the total variation of HCW, fat depth, loin depth, percent lean, iodine value, loin weight, loin instrumental color measures, loin pH, slice shear force, marbling score, belly weight, belly length, belly depth, ham weight, ham pH, and ham instrumental color, indicating that use of marketing groups by producers to control variation in final BW is effective in controlling variation in primal weights and quality characteristics. For all traits measured in this experiment, pig and other factors accounted for the majority of variation. Independent variables other than pig and other factors accounted for less than 8.5% of the total variation in carcass weight, ham weight, and ham quality traits. Because the total contribution of independent variables for these traits is low, it indicates that producers are effectively managing the independent variables evaluated in this study. However, for carcass composition traits and loin and belly quality traits, the independent variables of production focus, season, and sex contribute to overall variation. An understanding of the sources of variation in the U.S. pork supply provides a foundation for further research into addressing variation reduction.

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