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Influence of Increasing Carcass Weights on Pork Carcass Characteristics and Traditional and Alternative Fabrication Yields

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Abstract: The objective was to characterize the effects of increasing carcass weight on pork carcass characteristics and yields from traditional and alternative fabrication methods, as well as evaluate the size of novel retail cuts. Pigs ($n = 85$) were slaughtered and divided into 3 hot carcass weight (HCW) categories: Average (99 to 109 kg), Heavy (116 to 126 kg), and Very Heavy (134 to 144 kg). Loin muscle area (LMA) and back fat depth were measured on all carcasses. Paired right and left sides were fabricated traditionally and alternatively (shoulder separation at the $4^{th}/5^{th}$ rib), respectively. From the alternative side, the serratus ventralis (SV) was removed from the cellar-trimmed butt, and the triceps brachii (TB) was removed from the picnic shoulder. All individual primals and subprimals were weighed for yield calculations. Data were analyzed using the MIXED procedure in SAS including the main effect of weight class, with sex and sire line as fixed blocking effects. Differences were considered significant at $P \leq 0.05$. Regardless of fabrication method, whole primal and subprimal weights increased ($P < 0.01$) in heavier carcass weight classes compared with lighter classes, but when expressed as a percentage of chilled side weight, these increases did not often translate into meaningful differences in distribution of carcass weight. While the alternative shoulder-loin separation reduced loin and belly length, loins and bellies from heavier carcasses weighed more than those from carcasses typically produced in the U.S. pork industry today. Serratus ventralis weight was increased ($P < 0.01$) approximately 0.28 kg from Average to Very Heavy, while the TB weight was increased ($P < 0.01$) approximately 0.24 kg from Average to Very Heavy. At heavier weights, alternative fabrication of carcasses yielded novel cuts from the shoulder including the SV and TB that were of size to warrant further exploration as retail offerings.

Key words: fabrication, heavy pigs, hot carcass weight, cutability, novel cuts, pork
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Introduction

The average hot carcass weight (HCW) of U.S. pork has increased 17% from 82 kg to 97 kg from 1996 to 2022 (NASS, 2023). Using the current carcass weight increase rate of approximately 0.6 kg per year, the average pork carcass in the U.S. will be over 118 kg by 2050. This trend is projected to continue due to greater efficiency in pork production with increasing economies of scale. Increasing weights of pork carcasses creates the opportunity to reevaluate conventional U.S. pork fabrication specifications; however, alternative fabrication specifications and the resulting primal and subprimal weights from heavier pork carcasses have not been reported.

North American Meat Institute (formerly known as North American Meat Processors; NAMP) fabrication specifications are typically followed by U.S. pork processors with a shoulder-loin separation between the 2nd and 3rd rib to maximize loin and belly yields. Alternative fabrication methods used in other countries, including China, Japan, and South Korea, separate the shoulder and loin primals between the 4th and 5th rib. This change in fabrication increased gross carcass value (Bryan et al., 2018) even without changing carcass weights. Therefore, it is important to understand how altering fabrication methods in heavier carcasses would affect cut weights compared to current U.S. fabrication practices and average pork carcass weights. It is possible that, even with the reduction in loin and belly yield resulting from a change in fabrication method, increasing carcass weights would still result in adequate primal and cut weights.

In the current U.S. pork industry, individual muscles from the pork shoulder are not typically separated and merchandized because the added labor costs associated with their removal is not justified by the small cuts obtained. Additionally, the subsequent portion sizes from individual pork shoulder muscles would likely be too small to gain appeal and acceptance by customers. Instead, pork shoulders provide trim necessary for further processed products. However, as carcass weights increase, pork shoulders may have individual muscles that could be cut into adequate portion sizes similar to novel cuts created from the beef chuck including the top blade steak (NAMP 1114D), under blade steak (NAMP 1116G), and arm steak (NAMP 1114E).

Given the expectation that pork carcass weight will continue to increase, the objective of this study was to characterize the effects of increasing carcass weight on pork carcass characteristics and yields from traditional and alternative fabrication methods. Additionally, the weights of novel cuts from the shoulder from heavier carcasses were determined.

Materials and Methods

All protocols for the live portion of the experiment were reviewed and approved by the Institutional Animal Care and Use Committee at the University of Illinois (Protocol # 23045).

Pig background

In total, 85 pigs from 3 commercial sire lines representing 2 independent finishing trials were harvested on 9 separate d over 10 wk. All pigs were housed in the grower-finisher barn at the University of Illinois Swine Research Center (Champaign, IL). The building was mechanically vented, and pens contained partially slatted concrete floors. Pens were 1.18 m^2/ pig and contained a mounted single-space, dry-box feeder and nipple waterer. Pigs were allocated into pens of 4 at approximately 10 wk of age based on the sire line, sex, and weights at d0. Each pen housed pigs from the same sire line and sex. Pigs had ad libitum access to feed and water throughout the duration of the growth trial and all pigs, regardless of sire line and sex, were fed a common diet. Diets contained no ractopamine or dried distillers grains and were formulated to meet or exceed nutrient requirements for growing-finishing pigs (NRC, 2012). Pigs were fed on a 3-phase feeding program. Pigs were fed a grower diet from d0 to d35, an early finisher diet from d36 to d70, and a late finisher diet d71 to slaughter. All pigs were between 24 and 29 wk of age at the time of slaughter.

Table 1. Distribution of barrows and gilts for each sire line in carcass weight categories

		Carcass Weight Category[1]		
		Average	Heavy	Very Heavy
Sire Line 1	**Barrows, *n***	5	4	8
	Gilts, *n*	5	5	1
Sire Line 2	**Barrows, *n***	6	7	4
	Gilts, *n*	5	4	4
Sire Line 3	**Barrows, *n***	5	8	6
	Gilts, *n*	4	2	2
	Total Pigs, *n*	30	30	25

[1]Carcasses were placed into weight categories based on HCW; Average (99–109 kg), Heavy (116–126 kg), Very Heavy (134–144 kg).

Pigs were harvested under the inspection of the United States Department of Agriculture's Food Safety and Inspection Service at the University of Illinois Meat Science Laboratory (Urbana, IL) abattoir. Pigs were held in lairage for a minimum of 16 h with free access to water but no access to feed. Prior to slaughter, ending live weight (ELW) and sex were recorded. Pigs were immobilized using head-to-heart electrical stunning and terminated via exsanguination. Approximately 45 min postmortem, HCW, which included leaf fat that remained with the carcass, was recorded. Carcass yield (dressing percentage) was expressed as a percentage determined by dividing HCW by ELW. Carcasses ($n = 85$) were divided into 3 categories based on HCW including Average (99 to 109 kg; $n = 30$), Heavy (116 to 126 kg; $n = 30$), and Very Heavy (134 to 144 kg; $n = 25$). Both sexes and all 3 sire lines were represented in each weight category (Table 1).

Carcass characteristics

Carcasses were chilled at 3°C for approximately 22 h before the left side of each carcass was ribbed between the 10^{th} and 11^{th} rib revealing the longissimus thoracis (LTL). Loin muscle area (LMA) surface was traced onto archival polyester film. These tracings were measured twice with a Wacom digital tracing pad (Wacom, Vancouver, WA) and Adobe Photoshop CS6 (Adobe Inc., San Jose, CA, USA). Measurements were averaged for LMA. Tenth-rib back fat was measured 3 quarters of the distance up the LTL face from the dorsal process of the vertebral column. Standardized fat-free lean percentage was calculated using the following equation (Burson and Berg, 2001):

$$Standardized\,fat\text{-}free\,lean,\% = ((8.588 + (0.465 \times HCW, lb) - (21.896 \times fat\ thickness, in) + (3.005 \times LMA, in^2))/HCW, lb) \times 100$$

Traditional carcass fabrication

At 1 d postmortem, left side carcasses were weighed and then fabricated utilizing the method described by Boler et al. (2011) to meet specifications outlined in the NAMP Meat Buyer's Guide (NAMI, 2014). First, leaf fat was removed, and carcasses were standardized by removing any residual fat trim. The weights of these tissues were subtracted from side weight and recorded as chilled side weight. A shoulder-loin separation between the 2nd and 3rd rib and removal of neckbones (NAMP #421) produced a pork shoulder (NAMP #403). The shoulder was split into a bone-in Boston butt (NAMP #406) and a modified skinned bone-in picnic cut similar to NAMP #405. The primals were both deboned and trimmed into a boneless Boston butt (NAMP #406A) and a boneless picnic shoulder (NAMP 4#06B). The skin-on, whole bone-in loin was skinned and trimmed into a bone-in loin (NAMP #410). The loin was then weighed and deboned to meet specifications for boneless Canadian back loin (NAMP #414), tenderloin (NAMP #415), boneless sirloin (NAMP #413D), and back ribs (NAMP #422). The belly primal was fabricated into a skin-on natural fall belly (NAMP #408) and spareribs (NAMP #416).The whole leg (NAMP #401) was weighed before being skinned and trimmed to meet the specifications of a skinned leg (NAMP #402). Trimmed hams were further fabricated into an inside ham (NAMP #402F), outside ham (NAMP #402E), knuckle (NAMP #402H), shank portion, and lite butt. Whole primals, trimmed primals, and subprimal cut weights were recorded throughout fabrication, and weights were expressed as a percentage of chilled side weight.

Alternative carcass fabrication

Immediately following traditional fabrication, the right sides of each carcass were weighed, standardized as above, and fabricated utilizing a shoulder-loin separation between the 4th and 5th rib. Following an alternative shoulder cutout, the remainder of the carcass was fabricated using the same procedure as the traditional cutout. The shoulder was separated between the 4th and 5th rib to meet the specification of long cut pork shoulder (NAMP #403A). The whole shoulder was split into a modified bone-in Boston butt (NAMP #406) and a modified skinned bone-in picnic (NAMP #405). The clear plate and scapula were removed to produce a boneless Boston butt (NAMP #406A). The Boston cap, including the infraspinatus and supraspinatus, was removed to produce a cellar trimmed (CT) shoulder butt (NAMP #407). The serratus ventralis (SV), similar to the under-blade beef chuck (NAMP #116G) and the spinalis dorsi were fabricated from the CT butt and weighed as individual cuts. The remaining CT butt was weighed and recorded. During deboning, the teres major was fabricated from the picnic shoulder. The remaining boneless picnic shoulder (NAMP #405) was further fabricated to remove the triceps brachii (TB) muscle, or picnic cushion (NAMP #405B). The loin primal was fabricated using the same procedure as in the traditional cutout. The Canadian back loin and backribs were shortened due to the alternative shoulder-loin separation. The belly primal was fabricated into a shortened skin-on natural fall belly (NAMP #408) and shortened spareribs due to the alternative shoulder-loin separation. The leg primal was fabricated using the same procedure as the traditional cutout. Whole primals, trimmed primals, and subprimal cut weights were recorded throughout fabrication, and weights were expressed as a percentage of chilled side weight.

Value calculations

The carcass cutout estimates resulting from the current study served as the foundation for economic analysis of packer revenue for carcasses fabricated using traditional and alternative methods. Corresponding price data for pork cutouts were obtained from USDA national weekly negotiated pork report using the USDA mandatory reporting DataMart application (USDA AMS, 2023). The application provided historical weekly pricing values on a century weight basis ($/100 lb of product). Pricing values were converted to price per lb and then to price per kg to be multiplied by cutout primal weight to evaluate total cutout value. Per side carcass value was the sum of each total primal value including trimmed loin, bone-in Boston butt, bone-in picnic, sparerib, whole ham, and natural-fall belly. These values were calculated for each individual side fabricated.

Carcass value was evaluated using 4 pricing scenarios calculated from average primal price values of different time periods: 1) Low total valuation used prices from 2018 to 2019, 2) high total valuation averaged prices from 2021 to 2022, 3) low loin and belly primal valuation used prices from December 2022 where loin and belly primals were similarly priced to shoulder primals, and 4) high loin and belly valuation used prices from February 2022 where loin and belly primals were priced higher than shoulder primals. Scenarios 1 and 2 were used to evaluate the cumulative effects of high or low pork prices across all traditionally- or alternatively-fabricated primals. Scenarios 3 and 4 were used to evaluate the cumulative effects of high vs low price disparity between primal prices across all traditionally- or alternatively-fabricated primals. For all 4 pricing scenarios, a total carcass value was determined as the sum of each primal value for each weight class and each fabrication method.

Statistical analysis

Data were analyzed using the MIXED procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC). Carcass characteristics were analyzed with a model including the main effect of carcass weight category, while sex and sire line were included as random effects. Carcass cutting yields were analyzed with a model that also included the main effect of fabrication method and its interaction with carcass weight category. As hams were cut identically regardless of side, ham primal and subprimal cut weights were averaged between traditional and alternative fabrication sides and analyzed with a model including the main effect of carcass weight category, while sex and sire line were included as random effects. Pork carcass side values were analyzed within a carcass weight category using a model that included the main effect of fabrication method, with sex and sire line included as random effects. Assumptions of ANOVA were tested with Levene's test for homogeneity of variance in the GLM procedure of SAS. Normality of distribution of residuals were tested in the UNIVARIATE procedure of SAS. A Tukey-Kramer adjustment was used for means separation when significant interactions between carcass weight category and fabrication method were observed. The probability of difference (PDIFF) option was utilized to separate least-squares means, which were considered significant at $P \leq 0.05$.

Results

The ELW of Very Heavy pigs was 18.6 kg heavier ($P < 0.01$) than Heavy pigs, which were approximately 20.3 kg heavier ($P < 0.01$) than Average pigs (Table 2). Subsequently, the HCW of Very Heavy carcasses was 16.7 kg heavier ($P < 0.01$) than Heavy carcasses, which was 17.2 kg heavier ($P < 0.01$) than Average carcasses. Carcass yield (dressing percentage) was increased ($P < 0.01$) in heavier carcasses compared with lighter carcasses. It should be noted that differences in slaughter procedure, such as having leaf fat weight included in HCW, resulted in higher carcass yields from these pigs compared with those expected from commercial processing. Loin muscle area was 5.5 cm^2 larger ($P < 0.01$) in Very Heavy carcasses compared with Heavy, which was 5.4 cm^2 larger ($P < 0.01$) than Average. Additionally, 10th rib back fat depth in Very Heavy carcasses was about 0.3 cm greater ($P < 0.01$) compared with Heavy carcasses, which was about 0.4 cm greater ($P < 0.01$) than Average carcasses. Back fat depth of all carcasses ranged between 1.14 and 4.06 cm. Fat-free lean percentage was increased ($P = 0.01$) for Average carcasses (52.7%) compared with Heavy carcasses (51.5%) and Very Heavy carcasses (50.8%), which did not differ ($P = 0.29$) from each other.

Table 2. Effect of carcass weight on carcass characteristics

	Carcass Weight Category[1]				
Item	Average	Heavy	Very Heavy	SEM[2]	*P* Values
Pigs, *n*	30	30	25		
Ending live weight, kg	133.07^a	153.32^b	171.87^c	0.68	< 0.01
HCW[3], kg	104.31^a	121.47^b	138.15^c	0.59	< 0.01
Carcass yield[4], %	78.41^a	79.23^b	80.38^c	0.30	< 0.01
Loin muscle area, cm^2	50.56^a	55.91^b	61.39^c	1.16	< 0.01
10th rib back fat depth, cm	2.09^a	2.47^b	2.79^c	0.11	< 0.01
Standardized fat-free lean[5], %	52.66^b	51.49^a	50.84^a	0.47	0.01

[1]Carcasses were placed into weight categories based on hot carcass weight (HCW); Average (99–109 kg), Heavy (116–126 kg), Very Heavy (134–144 kg).

[2]Greatest standard error of the mean (SEM) occurring among treatments was reported.

[3]HCW includes leaf fat.

[4]Carcass yield = (hot carcass weight/ending live weight) x 100.

[5]Standardized fat-free lean = ((8.588 + (0.465 x HCW, lb) - (21.896 x fat depth, in) + (3.005 x loin muscle area, in^2)) ÷ HCW) x 100 (Burson and Berg, 2001).

[a–c]Means within a row with differing superscripts are statistically different ($P \leq 0.05$).

Whole shoulders from alternative fabrication (4th–5th rib separation) were heavier ($P < 0.01$; Table 3) than shoulders from traditional fabrication (2nd–3rd rib separation). Regardless of fabrication method, absolute weight of whole shoulders increased with increasing carcass weight categories ($P < 0.01$). In traditional fabrication, the percentage of whole shoulder (expressed as a percentage of chilled side weight) was unchanged by carcass weight category. However, in alternative fabrication, percent whole shoulder was slightly increased ($P < 0.01$) for average weight carcasses compared with heavy and very heavy carcasses. Bone-in Boston butt weights increased with increasing carcass weight category ($P < 0.01$) and alternative fabrication ($P < 0.01$). Similar to the whole shoulder, minor differences in percent bone-in Boston were observed between carcass weight categories. Both bone-in and boneless picnic weight increased with increasing carcass weight category ($P \leq 0.01$) and alternative fabrication ($P \leq 0.01$). However, percent bone-in and boneless picnic were unchanged by carcass weight category ($P \geq 0.06$). Minor cuts such as the jowl, neck bones, and clear plate all increased in weight with increasing carcass weight category ($P \leq 0.01$) and alternative fabrication ($P \leq 0.01$). Alternative fabrication also yielded additional cuts including the Boston cap muscle, a portion of the spinalis dorsi muscle, CT butt, supra- and infraspinatus, and SV from the

Table 3. Effect of carcass weight and fabrication method on shoulder primal and subprimal cut weights[1]

	Traditional Fabrication			Alternative Fabrication				P Values		
	Average	Heavy	Very Heavy	Average	Heavy	Very Heavy	SEM[2]	Weight	Fab	Weight × Fab
Pigs, *n*	30	30	25	30	30	25				
Chilled side wt, kg	50.45[a]	58.78[b]	66.99[c]	50.93[a]	59.49[b]	67.90[c]	0.29	< 0.01	< 0.01	0.75
Whole shoulder[3], kg	10.53[a]	12.02[b]	13.78[c]	12.90[a]	14.55[b]	16.67[c]	0.13	< 0.01	< 0.01	0.10
% chilled side wt	21.36[a]	21.01[a]	21.22[a]	25.97[b]	25.12[a]	25.30[a]	0.22	< 0.01	< 0.01	0.26
Jowl, kg	1.35[a,z]	1.67[b,y]	1.81[c,y]	1.3[a,z]	1.72[b,y]	2.02[c,x]	0.04	< 0.01	< 0.01	0.05
% chilled side wt	2.73[a]	2.93[b]	2.79[ab]	2.87[a]	2.97[ab]	3.07[b]	0.06	0.03	<0.01	0.15
Neckbones, kg	0.84[a,v]	0.89[a,w]	1.04[b,x]	1.65[a,y]	1.87[b,yz]	2.07[c,z]	0.05	< 0.01	< 0.01	0.02
% chilled side wt	1.71	1.56	1.60	3.33	3.23	3.14	0.09	0.06	< 0.01	0.62
Clear plate, kg	0.83[a]	0.91[a]	1.20[b]	1.36[a]	1.65[b]	1.93[c]	0.09	< 0.01	< 0.01	0.24
% chilled side wt	1.68[a]	1.61[a]	2.01[b]	2.73[a]	2.90[a]	3.04[a]	0.15	0.01	< 0.01	0.45
Bone-in Boston, kg	4.15[a]	4.69[b]	5.32[c]	5.16[a]	5.75[b]	6.44[c]	0.08	< 0.01	< 0.01	0.72
% chilled side wt	8.42[a]	8.19[a]	8.19[a]	10.38[b]	9.94[a]	9.77[a]	0.14	< 0.01	< 0.01	0.18
Boston cap muscle, kg	—	—	—	3.12[a]	3.57[b]	4.02[c]	0.10	< 0.01	—	—
% chilled side wt	—	—	—	6.29	6.20	5.99	0.18	0.51	—	—
Spinalis dorsi, kg	—	—	—	0.22[a]	0.24[a]	0.28[b]	0.02	< 0.01	—	—
% chilled side wt	—	—	—	0.44	0.41	0.42	0.04	0.14	—	—
CT butt, kg	—	—	—	2.90[a]	3.37[b]	3.71[c]	0.06	< 0.01	—	—
% chilled side wt	—	—	—	5.81	5.82	5.62	0.09	0.23	—	—
Supraspinatus + infraspinatus, kg	—	—	—	0.45[a]	0.52[b]	0.56[b]	0.03	< 0.01	—	—
% chilled side wt	—	—	—	0.90	0.90	0.85	0.05	0.28	—	—
Serratus ventralis, kg	—	—	—	0.92[a]	1.05[b]	1.20[c]	0.02	< 0.01	—	—
% chilled side wt	—	—	—	1.85	1.81	1.80	0.04	0.37	—	—
Bone-in picnic, kg	5.53[a]	6.39[b]	7.25[c]	6.22[a]	6.89[b]	8.21[c]	0.14	< 0.01	< 0.01	0.13
% chilled side wt	11.22	11.18	11.17	12.51	11.93	12.46	0.24	0.19	< 0.01	0.25
Boneless picnic, kg	4.05[a]	4.75[b]	5.42[c]	3.66[a]	4.28[b]	5.03[c]	0.05	< 0.01	< 0.01	0.62
% chilled side wt	8.21	8.31	8.36	7.37	7.39	7.64	0.09	0.06	< 0.01	0.53
Teres major, kg	—	—	—	0.13[a]	0.15[b]	0.18[c]	0.01	< 0.01	—	—
% chilled side wt	—	—	—	0.26	2.26	2.27	0.01	0.93	—	—
Triceps brachii, kg	—	—	—	0.84[a]	0.97[b]	1.08[c]	0.02	< 0.01	—	—
% chilled side wt	—	—	—	1.70	1.69	1.64	0.04	0.35	—	—

[1]Carcasses were placed into weight categories based on HCW; Average (99–109 kg), Heavy (116–126 kg), Very Heavy (134–144 kg).

[2]Greatest standard error of the mean (SEM) occurring among treatments was reported.

[3]Alternative fabrication included shoulder-loin separation between the 4th and 5th rib.

[a–c]Means within a row and fabrication method lacking common superscripts are different ($P \leq 0.05$).

[v–z]Means within a row lacking common superscripts are different ($P \leq 0.05$).

Boston primal. All cuts fabricated from the Boston increased in weight along with carcass weight category ($P \leq 0.01$). However, the percentage of these cuts, relative to side weight, was unchanged by carcass weight category ($P \geq 0.14$). The teres major and TB were also further fabricated from the picnic. Similarly, the weight of the teres major and TB increased along with carcass weight category ($P \leq 0.01$), but were unchanged by carcass weight category when expressed as a percentage of side weight ($P \geq 0.35$).

No interactions were observed between carcass weight category and fabrication method for any loin primal or subprimal cuts ($P \geq 0.10$; Table 4). Whole and trimmed loins from alternative fabrication were lighter than ones from traditional fabrication ($P \leq 0.01$). Similarly, resulting cuts such as the Canadian back, backribs, and backbones were also lighter in weight from the alternative fabrication method ($P \leq 0.01$). Absolute weight of whole and trimmed loins, as well as all resulting cuts, increased along with carcass weight category ($P \leq 0.01$). Although minor differences in percent whole loin and Canadian back were observed between carcass weight categories ($P \leq 0.03$), percent trimmed loin was unchanged by carcass weight category ($P = 0.50$). Tenderloin and sirloins increased in weight with increasing carcass weight categories but were unchanged by carcass weight category when expressed as a percentage of side weight ($P \geq 0.19$). Tenderloin and sirloin were unchanged by fabrication method ($P \geq 0.22$) whether expressed as absolute weights or as a percentage of side weight. No interactions were observed between carcass weight category and fabrication method for the belly primal or subprimal cut. Both whole bellies and spareribs from traditional fabrication were heavier and comprised a greater percentage of side weight than ones from alternative fabrication ($P \leq 0.01$). Whole bellies and spareribs also increased in weight along carcass weight category. While whole belly percentage increased ($P < 0.01$) with carcass weight category, sparerib percentage decreased slightly ($P < 0.01$).

Ham primal and subprimal cut weights were averaged between whole and trimmed hams, as well as all subprimal cuts including the inside, outside, lite butt, knuckle, and inner shank, were heavier with increasing carcass weight category ($P \leq 0.01$; Table 5). However, ham primal and subprimal cuts comprised a smaller percentage of side weight as carcass weight category increased ($P \leq 0.04$).

Table 4. Effect of carcass weight and fabrication method on loin and belly primal and subprimal cut weights[1]

	Traditional Fabrication			Alternative Fabrication[2]				P Values		
Item	Average	Heavy	Very Heavy	Average	Heavy	Very Heavy	SEM[3]	Weight	Fab	Weight × Fab
Carcasses, *n*	30	30	25	30	30	25				
Chilled side wt, kg	50.45^{a}	58.78^{b}	66.99^{c}	50.93^{a}	59.49^{b}	67.90^{c}	0.29	< 0.01	< 0.01	0.75
Whole loin, kg	14.15^{a}	16.61^{b}	19.16^{c}	12.46^{a}	14.82^{b}	17.00^{c}	0.15	< 0.01	< 0.01	0.23
% chilled side wt	28.71^{a}	29.01^{ab}	29.47^{b}	25.06^{a}	25.59^{b}	25.78^{b}	0.22	< 0.01	< 0.01	0.71
Trimmed loin, kg	11.37^{a}	13.22^{b}	14.98^{c}	10.27^{a}	11.97^{b}	13.42^{c}	0.19	< 0.01	< 0.01	0.10
% chilled side wt	23.08	23.12	23.09	20.67	20.68	20.38	0.34	0.50	< 0.01	0.56
Canadian back, kg	3.68^{a}	4.38^{b}	4.84^{c}	3.45^{a}	4.11^{b}	4.53^{c}	0.10	< 0.01	< 0.01	0.74
% chilled side wt	7.47^{a}	7.67^{a}	7.47^{a}	6.94^{ab}	7.11^{b}	6.89^{a}	0.17	0.03	< 0.01	0.95
Tenderloin, kg	0.48^{a}	0.58^{b}	0.67^{c}	0.49^{a}	0.58^{b}	0.64^{c}	0.01	< 0.01	0.49	0.32
% chilled side wt	0.98	1.02	1.03	0.98	1.00	0.97	0.02	0.32	0.22	0.28
Sirloin, kg	0.89^{a}	1.08^{b}	1.19^{c}	0.89^{a}	1.05^{b}	1.20^{c}	0.04	< 0.01	0.63	0.70
% chilled side wt	1.80	1.90	1.83	1.79	1.83	1.81	0.07	0.19	0.27	0.67
Backribs, kg	0.86^{a}	0.99^{b}	1.16^{c}	0.80^{a}	0.94^{b}	1.04^{c}	0.04	< 0.01	< 0.01	0.19
% chilled side wt	1.75	1.75	1.79	1.61	1.62	1.58	0.07	0.99	< 0.01	0.39
Backbone, kg	2.23^{a}	2.32^{a}	2.50^{b}	1.95^{a}	2.13^{b}	2.31^{c}	0.08	< 0.01	< 0.01	0.41
% chilled side wt	4.53^{b}	4.05^{b}	3.84^{a}	3.91^{b}	3.68^{a}	3.50^{a}	0.14	< 0.01	< 0.01	0.11
Whole belly, kg	7.59^{a}	9.11^{b}	10.37^{c}	6.65^{a}	8.11^{b}	9.56^{c}	0.17	< 0.01	< 0.01	0.64
% chilled side wt	15.41^{a}	15.91^{b}	15.95^{b}	13.38^{a}	14.00^{b}	14.50^{c}	0.30	< 0.01	< 0.01	0.20
Spareribs, kg	1.75^{a}	1.96^{b}	2.17^{c}	1.54^{a}	1.80^{b}	2.02^{c}	0.04	< 0.01	< 0.01	0.48
% chilled side wt	3.55^{b}	3.43^{a}	3.35^{a}	3.11^{a}	3.11^{a}	3.07^{a}	0.07	0.02	< 0.01	0.13

[1]Carcasses were placed into weight categories based on HCW; Average (99–109 kg), Heavy (116–126 kg), Very Heavy (134–144 kg).

[2]Alternative fabrication included shoulder-loin separation between the 4th and 5th rib.

[3]Greatest standard error of the mean (SEM) occurring among treatments was reported.

[a–c]Means within a row and fabrication method lacking common superscripts are different ($P \leq 0.05$).

Table 5. Effect of carcass weight on ham primal and subprimal cut weights

	Carcass Weight Category[1]				
Item	Average	Heavy	Very Heavy	SEM[2]	*P* Value
Pigs, *n*	30	30	25		
Whole ham, kg	12.02[a]	13.72[b]	15.25[c]	0.18	< 0.01
% chilled side wt	24.28[c]	23.85[b]	23.32[a]	0.30	<0.01
Trimmed ham, kg	10.16[a]	11.63[b]	12.83[c]	0.09	< 0.01
% chilled side wt	20.52[b]	20.21[b]	19.62[a]	0.18	< 0.01
Inside, kg	1.89[a]	2.13[b]	2.35[c]	0.06	< 0.01
% chilled side wt	3.81[b]	3.72[ab]	3.61[a]	0.11	0.02
Outside, kg	2.57[a]	2.87[b]	3.17[c]	0.04	< 0.01
% chilled side wt	5.18[b]	4.99[a]	4.85[a]	0.07	< 0.01
Lite butt, kg	0.28[a]	0.32[b]	0.33[b]	0.02	< 0.01
% chilled side wt	0.56[b]	0.56[b]	0.50[a]	0.05	0.04
Knuckle, kg	1.48[a]	1.69[b]	1.84[c]	0.03	< 0.01
% chilled side wt	3.00[b]	2.94[b]	2.81[a]	0.06	< 0.01
Inner shank, kg	0.72[a]	0.82[b]	0.86[c]	0.01	< 0.01
% chilled side wt	1.45[b]	1.42[b]	1.32[a]	0.02	< 0.01

[1]Carcasses were placed into weight categories based on HCW; Average (99–109 kg), Heavy (116–126 kg), Very Heavy (134–144 kg)

[2]Greatest standard error of the mean (SEM) occurring among treatments was reported.

[a–c]Means within a row lacking common superscripts are different ($P \leq 0.05$).

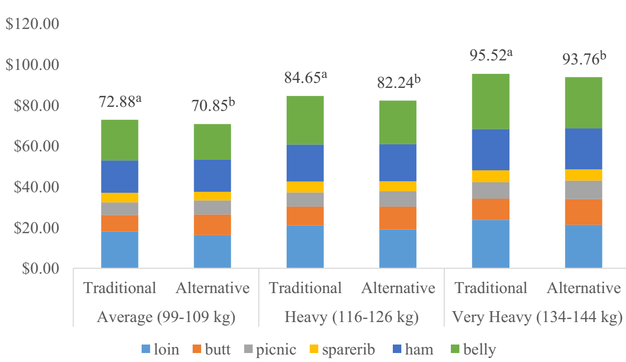

Figure 1. Pork carcass side valuation with low average price (2018–2019) was determined as the sum of each primal value for each carcass weight class and each fabrication method. Traditional fabrication utilized a shoulder separation between the 2nd/3rd rib. Alternative fabrication utilized a shoulder separation between the 4th/5th rib. Values within a carcass weight category with differing superscripts are statistically different ($P \leq 0.05$).

The estimated value of each carcass was determined in a high pork prices and low pork prices scenario by multiplying the cutout weight of each primal by price per kg. The average price values for 2018–2019 were used in the low-price scenario (Figure 1) in which the traditional fabrication method was more profitable in each weight category. Traditional fabricated carcasses had an increased value of $2.03, $2.41, and $1.76 per side compared to sides alternatively fabricated in

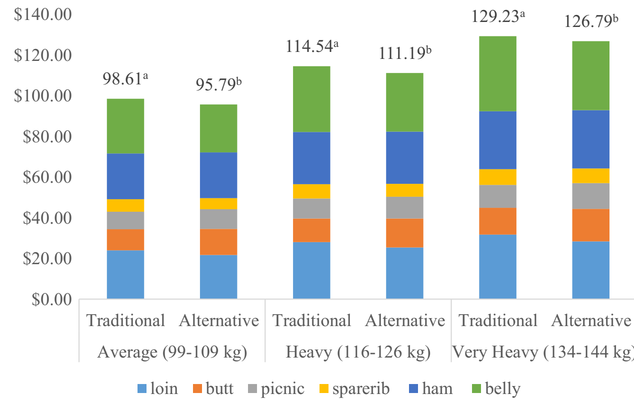

Figure 2. Pork carcass side valuation with high average price (2021–2022) was determined as the sum of each primal value for each carcass weight class and each fabrication method. Traditional fabrication utilized a shoulder separation between the 2nd/3rd rib. Alternative fabrication utilized a shoulder separation between the 4th/5th rib. Values within a carcass weight category with differing superscripts are statistically different ($P \leq 0.05$).

Average, Heavy, and Very Heavy carcasses, respectively. The average price values for 2021–2022 were used in the high price scenario (Figure 2). Traditional fabricated carcasses had an increased value of $2.82, $3.35, and $2.44 per side compared to sides alternatively fabricated in Average, Heavy, and Very Heavy carcasses, respectively.

Approximate value of each carcass was also determined in another pricing scenario considering different primal prices relative to each other. In pricing scenario 3, the value of each carcass was determined for a period where the price of loin and belly primals was considerably higher than shoulder primals. The average primal price values from February 2022 were used to represent a period where loin and belly primals were priced considerably higher than shoulder primals (Figure 3). In this scenario, traditional fabricated carcasses had an increased value of $3.82, $4.40, and $3.47 per side compared to sides alternatively fabricated in Average, Heavy, and Very Heavy carcasses, respectively. In pricing scenario 4, the value of each carcass was determined for a period where prices of shoulder primals were similar to loin and belly primals. The average primal price values from December 2022 were used to represent a period where loin and belly primals were similarly priced to shoulder primals (Figure 4). Traditional fabricated carcass sides had an increased value numerically compared to sides alternatively fabricated in all carcass weight categories. However, carcass value differences were small enough between traditional and alternative fabrication in the Average and Very Heavy carcass weight categories as to not be statistically different ($P \geq 0.18$).

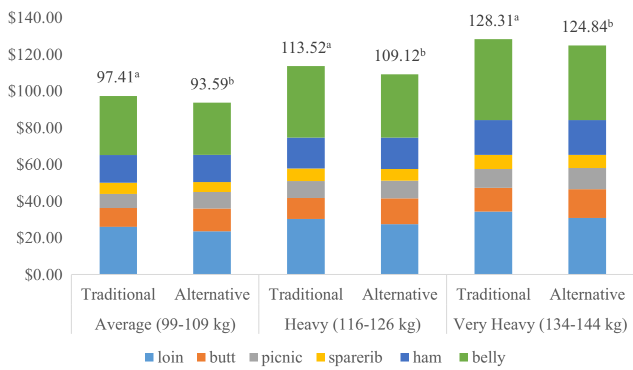

Figure 3. Pork carcass side valuation with high price differential between loin and belly vs. shoulder primals (4 wk average – February 2022) was determined as the sum of each primal value for each carcass weight class and each fabrication method. Traditional fabrication utilized a shoulder separation between the 2nd/3rd rib. Alternative fabrication utilized a shoulder separation between the 4th/5th rib. Values within a carcass weight category with differing superscripts are statistically different ($P \leq 0.05$).

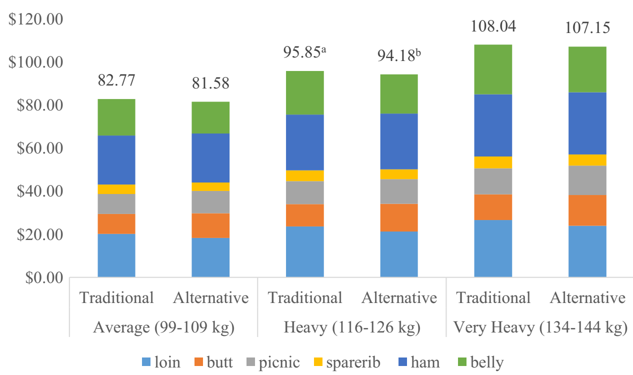

Figure 4. Pork carcass side valuation with low price differential between loin and belly vs. shoulder primals (4 wk average – December 2022) was determined as the sum of each primal value for each carcass weight class and each fabrication method. Traditional fabrication utilized a shoulder separation between the 2nd/3rd rib. Alternative fabrication utilized a shoulder separation between the 4th/5th rib. Values within a carcass weight category with differing superscripts are statistically different ($P \leq 0.05$).

Discussion

Pork HCW have been increasing in the U.S. for more than 20 y and will likely continue to increase in the future due to improved economies of scale. Increasing carcass weights present a need to understand carcass yield with opportunity to reevaluate carcass fabrication specifications to create novel cuts for retail and food service.

Improved lean growth performance genetics have allowed for increased slaughter weights while maintaining carcass composition specifications. In a study evaluating commercial pigs up to 181 kg ELW, Shull (2013) observed limited effects on carcass leanness. Cisneros et al. (1996) reported that pigs with modern genetics could be slaughtered up to 160 kg ELW with limited impact to carcass yield. These results are similar to those reported in the current study. For every 1% increase in HCW, LMA increased by 0.64 percentage units in Heavy pigs. This increase was similar in Very Heavy pigs with every 1% increase in HCW corresponding to a 0.66 percentage unit increase in LMA. Furthermore, back fat depth increased 1.1 percentage units for every 1% increase in HCW for both Heavy and Very Heavy carcass weight categories. It is important to note similar rates of increase for both fat and lean measurements as carcass weight increased as excessive fatness at heavier carcass weights could be a concern.

Some concerns have been expressed that increasing carcass weight in pigs could result in issues similar to those currently observed in the broiler industry such as woody breast and white striping (Tijare et al., 2016; Kuttappan et al., 2016). Genetic selection for faster growth rate in chickens has resulted in unequal distribution of increased carcass weight heavily favoring increased breast weight (Petracci et al., 2015). Allometric (unequal) growth of the breast muscle relative to the rest of the carcass is likely one underlying cause of the current myopathies and poultry meat quality issues in the broiler industry (Kuttappan et al., 2016). Pigs in the current study did not reach heavier weights due to selection for increased weight of one primal compared with another. These findings may indicate that as carcasses get heavier, even up to 136 kg, myopathies like those observed in poultry are unlikely.

As expected, the absolute weights of primals and subprimal cuts increased as carcass weight increased. The 16.5% increase in HCW in Heavy compared to Average carcasses corresponded to an increase of primal weights by 14.2% in the shoulder, 17.4% in the loin, 20.0% in the belly, and 14.3% in the ham. The 32.4% increase in HCW in Very Heavy compared to Average carcasses corresponded to an increase of primal weights by 30.8% in the shoulder, 35.4% in the loin, 36.6% in the belly, and 27.0% in the ham. The trimmed ham as a percentage of chilled side decreased with carcass weight and was the least in Very Heavy carcasses. This was contrary to results of Wu et al. (2017), which observed general decreases in lean primal cut yields with increasing carcass size. However, in the present study, trimmed loin and boneless picnic yields were largely unchanged as carcass weights increased. This is likely due in part to different genetics as well as genetic improvements in lean yields at increased carcass weights. Alternatively, belly yield as a percentage of chilled side also increased slightly in heavier carcasses. This finding is in line with the Wu et al. (2017) review reporting belly primal yield generally increased with increasing weight. Although carcass weight was significant for some cut yields expressed as a percentage of chilled side weight, the magnitude of these differences were minimal. Findings of the present study support the view of approximately equal distribution of carcass weight throughout the entire carcass, highlighting the ability of pigs to be reared to increased weights while maintaining acceptable levels of leanness.

Alternative fabrication including a shoulder-loin separation between the 4th and 5th rib was explored. This fabrication method is utilized by several U.S. export countries, including China, Japan, South Korea, Argentina, Mexico, and Brazil. In 2022, the total U.S. pork export reached \$7.7 billion, with Mexico, China, and Japan buying \$4.9 billion (USMEF, 2022). Ray and Cravens (2002) highlighted the opportunity to further improve U.S. pork value by meeting export market needs including cutting specifications and improved fresh pork quality. However, moving to this alternative fabrication could be met with concern about decreased belly and loin yield compared to a traditional U.S. fabrication method. The alternative shoulder break did reduce loin and belly weights compared with traditional fabrication methods. Loin primal weight was reduced 11%–12% and the whole belly weight was reduced 7%–13% in alternatively fabricated carcasses compared to traditionally fabricated carcasses. However, given the anatomical location of reduced belly yield, the alternative shoulder break would not be expected to alter #1 bacon slices or those center-cut slices most valuable in retail packaging (Person et al., 2005). Furthermore, loin and belly primal weights from alternatively fabricated Heavy carcasses were heavier than traditionally fabricated Average carcasses. Therefore, increased carcass weights could present the opportunity to produce novel retail cuts from the shoulder without compromising loin and belly weights. In both the low total and high total price scenarios, traditional fabrication, regardless of weight category, provided increased carcass value largely due to the increased value of the loin and belly. Similarly, in a scenario where loin and belly prices were substantially higher than shoulder prices, carcass valuation would favor a traditional cutout. However, during a period where shoulder primal prices were similar to loin and belly prices, carcass valuation of a traditional and alternative $4^{th}/5^{th}$ rib fabrication were more similar. Therefore, processors could choose alternative fabrication methods under certain market conditions and gain more value from the fabrication of novel cuts. However, the limitation of this analysis is that primal prices used for all carcass valuation scenarios reflect primal value based on the value of traditional subprimal and retail cuts. The true value of a long-cut shoulder and a shortened loin or belly would be determined by the market and likely be different from prices of currently fabricated primals.

The SV and TB were removed from the alternatively fabricated pork shoulder as individual muscles for exploration as potential novel retail cuts. The weights of both the SV and TB were similar to the boneless sirloin, but the size and number of chops available from each respective muscle should be determined. Additionally, an attractive visual appearance and a high-quality eating experience would be imperative to justify merchandizing these cuts on their own. The SV and TB have been previously shown to have an ultimate pH of 6.26 and 6.10, respectively (Tavárez et al., 2012). As pH may influence pork quality traits including color water-holding capacity (Huff-Lonergan et al., 2002), determining whether or not expected improvements in quality of shoulder chops would translate to a more desirable eating experience would be the next step in developing these novel cuts as alternatives to traditional pork loin chops.

Conclusions

In conclusion, pork carcasses displayed proportional increasing lean and fat accretion with increasing carcass weight. Heavier pork carcasses yielded heavier cuts proportional to the increases in carcass weight. The alternative fabrication of pork shoulders reduced loin and belly length. However, loins and bellies from heavier carcasses weighed more than loins and bellies from carcasses commonly available in the U.S. industry today. Additionally, alternative fabrication of pork shoulders produced 2 muscles, the SV and TB, that warrant further exploration as novel retail cuts.

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