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Pork Ham and Belly Processing Traits With Increasing Carcass Weight

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Abstract: The objective of this study was to determine the effect of increasing hot carcass weight (HCW) on pork ham and belly processing characteristics. Pigs ($n = 85$) were slaughtered and divided into 3 HCW categories: Average (99 to 109 kg), Heavy (116 to 126 kg), and Very Heavy (134 to 144 kg). Fresh hams were fabricated and further processed as 3-piece (inside, outside, and knuckle) boneless cured hams. Fresh belly quality measurements were taken before bacon processing. Data were analyzed using the MIXED procedure in SAS including the main effect of weight class, with sex and sire line as random blocking effects. Means were considered significant at $P \leq 0.05$. There were no differences ($P = 0.08$) in ham processing characteristics including pump uptake, retention, and cook yield. However, cured hams from heavier carcasses were less red and less yellow ($P < 0.01$). Heavier carcasses produced longer, thicker, and wider bellies ($P < 0.01$), but bellies did not differ in firmness ($P = 0.16$). Despite reduced pump uptake ($P < 0.01$), bellies from heavier carcasses had greater cooked yield than those from lighter carcasses ($P < 0.01$). Total area of sliced bacon increased with increasing carcass weight. Bacon slice lean area percentage decreased ($P < 0.01$) in bacon from Very Heavy carcasses compared to lighter carcasses. Iodine value was decreased ($P = 0.04$) approximately 2.5 units from 68.6 in fresh bellies from Average carcasses to 66.2 in bellies from Very Heavy carcasses. Overall, processing characteristics of hams and bellies were not impaired at heavier carcass weights, though the consumer acceptability of larger slices of bacon from heavier carcasses should be determined.

Key words: heavy pigs, carcass weight, processing, yield, bacon, ham
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Introduction

There has been a steady rise in average U.S. pork hot carcass weight (HCW), including a 17% increase from 82 kg to 97 kg from 1996 to 2022 (NASS, 2023). At the current rate of increase of approximately 0.6 kg per year, the average pork carcass in the U.S. would be projected to reach 118 kg by 2050. Carcass weights will likely continue to trend upward due to greater throughput efficiency with economy of scale (Park and Lee, 2011). As marketing and primal weights increase (Metz et al., 2024), these things may pose challenges for further processing of ham and belly primals.

Increased carcass weights have been shown to slow carcass cooling (Overholt et al., 2019) and lead to quality concerns related to low ultimate pH, decreased water holding capacity, and paler color (Savell et al., 2005). These detriments to fresh pork quality are a source of concern for the 2 driving factors of further processing profitability, yield and quality. McKeith and Pringle (2013) observed that poor quality fresh hams were more likely to display the two-toning ham quality defect. Further, selecting poor quality raw pork materials has demonstrated a negative impact to processing yields and consumer appeal (Person et al., 2005a). Conversely, increased carcass weights would likely benefit bacon processors as increased fat deposition is typically associated with greater saturation of fatty acids and decreased iodine value (IV) (Correa et al., 2008). The firmness and solidity of saturated fats when chilled are important traits lending to greater bacon sliceability, higher quality slice appearance, and increased shelf life compared to bellies with higher degrees of unsaturated fatty acids (Wood et al., 2004).

Nearly 80% of the pork consumed in the U.S. is further processed. This includes bacon and ham, which make up over 60% of the further processed pork consumed in the U.S. (Pork Checkoff, 2011). Increased bacon demand in recent decades has made the belly the most valuable pork carcass primal (USDA, 2023). Similarly, average sliced bacon prices have increased 38% from \$11.66/kg in 2013 to \$14.67/kg in 2023. During that same time period, the average ham price has increased 47% from \$6.17/kg to \$9.79/kg (U.S. Bureau of Labor Statistics, 2024). Both these increases have outpaced average rate of inflationary increases during this period. Although less valuable per kg than the belly, fresh ham comprises nearly 25% of carcass weight, thus supporting the total value of the pork carcass (USDA, 2023).

Given the expectations of increasing carcass weight as well as ham and belly value, the objectives of this study were to determine the effect of HCW on fresh ham component yields, ham processing characteristics and quality, fresh belly dimension and composition, and belly processing characteristics.

Materials and Methods

All animal care and use procedures were approved by the Institutional Animal Care and Use Committee at the University of Illinois (Protocol #23045) and followed standard practices described in the Guide for the Care and Use of Agricultural Animals in Research and Teaching (American Society of Animal Science (ASAS), 2020).

Pig background

In total, 85 pigs from 3 commercial sire lines representing 2 independent finishing trials were harvested on 9 separate days over 10 weeks. The full experimental design used in this study is described in detail by Metz et al. (2024). All pigs were housed in the grower-finisher barn at the University of Illinois Swine Research Center (Champaign, IL). Pigs were allocated into pens of 4 at approximately 10 wk of age based on the sire line, sex, and weights at d 0. Diets contained no dried distillers grains and were formulated to meet or exceed nutrient requirements for growing-finishing pigs (NRC, 2012). 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. Approximately 45 min postmortem, HCW, which included leaf fat that remained with the carcass, was recorded. Carcass characteristics were reported by Metz et al. (2024). 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 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). 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, subrprimal cuts, ham trim (external fat and gracilis muscle), and ham bone weights were recorded throughout fabrication, and weights were expressed as a percentage of chilled side weight.

Fresh belly characteristics

Approximately 48 h postmortem, fresh belly characteristics were collected from skin-on natural fall bellies using procedures outlined by Kyle et al. (2014). A sample from the dorsal edge of the anterior end of each belly containing all 3 layers of adipose tissue, free of lean tissue, was removed and frozen for fatty acid profile analysis. A sample from the ventral edge of the anterior end of each belly was removed and frozen for proximate analysis. Belly length was measured at the midpoint of the latitudinal axis, and belly width was measured at the midpoint of the longitudinal axis. Belly thickness was evaluated at 8 individual locations along the belly by inserting a probe through the lean side of each belly. Measurements 1 to 4 were collected at the midpoint between the latitudinal axis and the dorsal edge at approximately 20%, 40%, 60%, and 80% of the length of the belly beginning at the anterior edge. Measurements 5 to 8 were collected at the midpoint between the longitudinal axis and the ventral edge at approximately 20%, 40%, 60%, and 80% of the length of the belly starting at the anterior end. Average belly thickness was calculated from the mean of the 8 individual measurements. Flop distance was measured by setting the bellies with skin side down over a bar. The distance between the inside edges of the bellies was measured and recorded. After fresh belly characteristics were evaluated, bellies were vacuum packaged and stored at −34°C until further processing.

Fatty acid profile

Belly adipose tissue samples were used to prepare fatty acid methyl esters (FAME) using the procedure outlined by Lepage and Roy (1986). Samples were analyzed in duplicate and followed standardized procedures. The long chain fatty acids (LCFA) were analyzed using Hewlett-Packard 5890 Series II and Hewlett-Packard 6890 gas chromatography equipment. A glass column (Supelco SP-2560, 100 M × 0.25 mm × 0.2 μm film) was used in each chromatographer. The oven temperature, detector temperature, and injector temperature were 240°C, 245°C, and 240°C, respectively. The concentration of LCFA were calculated as the LCFA content of substrate-containing tubes minus the LCFA content of blank tubes divided by substrate weight expressed on a dry matter basis. Values were corrected for differences in total fatty acid content of each sample by expressing them as g LCFA per 100 g of FAME.

Belly proximate composition

Belly fat samples were allowed to thaw for at least 60 min before being homogenized in a food processor (Hamilton Beach, model 70720, Glen Allen, VA, USA). Duplicate 5 g samples were placed in aluminum tins, covered with 2 filter papers (Cytiva, Marlborough, MA, USA), and then dried in a convection oven set to 110°C oven for a minimum of 24 h. Moisture and extractable lipid content were determined using the chloroform-methanol solvent method described by Novakofski et al. (1989). Both moisture and fat were reported as a percentage of the sample wet weight.

Ham processing characteristics

Inside, outside, and knuckle ham pieces from each individual trimmed ham were placed in nylon netting with identification and weighed to determine the initial (green) weight. Three-piece hams (NAMP #402G) were multi-needle injected with a cure solution to target pump uptake of 120% of the initial weight using a Schroder Injector Marinator model N50 (Wolf-Tec Inc., Kingston, NY). The cure solution was formulated to target 1.52% salt, 0.33% sodium tripolyphosphate, 0.014% sodium nitrite, and 0.05% sodium erythorbate in the completed ham product. Hams were weighed immediately after injection to determine the pumped ham weight and percent pump uptake. Hams were then placed on a rack and allowed to drain for 30 min before being weighed again to determine final pumped ham weight and final percent pump uptake (pump retention). Percent uptake (both initial and final) were calculated as [(pumped weight – initial weight)/initial weight] * 100. Hams were allowed to equilibrate for at least 2 h. After equilibrating, the hams were removed from the nylon netting and macerated using a Belam macerator (Wolfking Meat Processing Equipment, Slagelse, Denmark). Hams were macerated twice in a crisscrossing pattern with each pass through the macerator penetrating the ham approximately 5 mm. Three-piece hams were placed in plastic bags with identification being maintained and then tumbled under a vacuum for 2 h. After tumbling, ham pieces were stuffed into netting, with the inside ham placed on top of the outside ham and the knuckle placed in front towards the factory clipped end. Hams were weighed to determine stuffed weight. Hams were cooked in an Alkar smokehouse (Lodi, WI) for 10 h to a targeted internal temperature of 65.6°C. After cooking, hams were showered with cold water and moved to a 4°C cooler, where they were chilled for at least 24 h. Hams were weighed with the casing removed to determine a final cooked weight. Final cook yield was calculated as (cooked weight/initial weight) * 100.

Cured ham color

Using a method described by Arkfeld et al. (2016), a 2.54 cm ham steak was cut from each 3-piece ham using a Bizerba SE 12 deli slicer (Bizerba GmbH & Co., Balingen, Germany) at approximately 75% of the distance from the factory clipped end with no knuckle portion visible on the steak. Instrumental Commission Internationale de l'Eclairage (CIE) L^* (lightness), a^* (redness), and b^* (yellowness) measurements (CIE, 1976) were measured on 4 visually divided quadrants on the surface of the ham steak using a Minolta CR-400 Chroma meter (Konica Minolta, Osaka, Japan) with a 2° observer, an 8 mm closed aperture, a D65 illuminant, and calibrated with a machine-specific white tile. Reported values were the average of the 4 measurements (King et al., 2023).

Bacon processing characteristics

Natural fall bellies that were vacuum sealed and frozen were thawed at 4°C for approximately 4 d. Identification was maintained throughout bacon processing. After proper thawing, initial (green) belly weights were recorded, and bellies were then multi-needle injected with a cure solution to target pump uptake of 113% the initial weight using a Schroder Injector Marinator model N50 (Wolf-Tec Inc., Kingston, NY). The standard cure solution included a formulation of water, sugar, salt, sodium nitrite, sodium phosphates, and sodium erythorbate. Following injection, bellies were weighed again to determine pumped weight and pump uptake using the following equation:

$$Pump\ Uptake = [(pumped\ weight - initial\ weight)/initial\ weight] \times 100$$

Bellies were hung in the smokehouse by inserting bacon combs into the posterior medial end and cooked to an internal temperature of 60.0°C. After cooking, bellies were chilled to an internal temperature between 1.0°C and 3.0°C for approximately 24 h. Prior to slicing, bellies were weighed again with the skin on to calculate cooked yield using the following equation:

$$Cooked\ yield = [cooked\ weight/initial\ weight] \times 100$$

Bellies were weighed again after the skin was removed from the belly. Bellies were standardized with the removal of the teat line and bootjack. An approximately 12-cm-wide slab was hand cut at approximately 50% the length of the belly from the anterior end. The belly slab was vacuum-sealed and frozen for further bacon slice image analysis.

Bacon slice image analysis

Bacon slabs were thawed at 4°C for approximately 1 d. Each bacon slab was sliced with a Bizerba SE 12 deli slicer (Bizerba GmbH & Co., Balingen, Germany). The initial slice from the anterior end was discarded. The next 3 slices were labeled and laid out for photographing. A camera was used at a standardized distance from the slices. Images were analyzed with Adobe Photoshop CS6 (Adobe Systems Inc., San Jose, CA). A ruler was included in each image as a known distance for measurement scale. The measurement was set for each image using Adobe Photoshop to determine the pixel to inch ratio. Slices images were outlined using the magnetic lasso tool to determine area. Total slice length and width were determined using the ruler tool within Adobe Photoshop CS6. The following equations were used:

$$Total\ lean\ area = primary\ lean\ area + \sec ondary\ lean\ area.$$

$$Percent\ lean\ area = (total\ lean\ area/total\ slice\ area) \times 100.$$

$$Lean\ to\ fat\ ratio = total\ lean\ area/(total\ slice\ area - total\ lean\ area).$$

Statistical analysis

Data were analyzed with the Mixed procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC). The model included the main effect of carcass weight class (Average: 99 to 109 kg; Heavy: 116 to 126 kg; and Very Heavy: 134 to 144 kg). Sex and sire line were included in the model as random effects. As the effect of sex and sire line were outside the scope of this work, only the main effect of weight class was reported. 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. The probability of difference (PDIFF) option was utilized to separate least-squares means, which were considered significant at $P \leq 0.05$.

Results

Initial 3-piece ham weight increased ($P < 0.01$) as carcass size increased (Table 2). Similarly, ham pumped weight, final pumped weight, stuffed weight,

Table 2. The effect of increasing carcass weight on ham yield and quality

	Carcass Weight Category[1]				
Item	Average	Heavy	Very Heavy	SEM[2]	*P* Value
Initial weight, kg	5.50[a]	6.10[b]	6.38[c]	0.13	<0.01
Pumped weight, kg	6.72[a]	7.41[b]	7.70[b]	0.17	<0.01
Pump uptake, %	22.24	21.31	20.53	0.69	0.08
Final pumped weight[3], kg	6.50[a]	7.16[b]	7.46[b]	0.16	<0.01
Pump retention[4], %	18.07	17.1	17.03	0.62	0.15
Stuffed weight, kg	6.39[a]	7.02[b]	7.30[b]	0.15	<0.01
Casing-off cooked weight, kg	5.61[a]	6.23[b]	6.43[b]	0.15	<0.01
Cooked yield[5], %	101.9	102.11	100.75	0.76	0.23
Cured color[6]					
Lightness[7], L^*	64.61	64.14	64.26	0.59	0.68
Redness[8], a^*	12.65[b]	11.92[a]	11.78[a]	0.30	<0.01
Yellowness[9], b^*	6.38[b]	5.55[a]	5.84[a]	0.35	<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.

[3]Weight 30 min post injection.

[4]Pump percentage after 30 min where excess brine was allowed to drain off.

[5]Cook yield determined with ((casing-off cooked weight ÷ initial weight) * 100).

[6]Calculated as the average of 4 measurements per ham slice.

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

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

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

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

Table 3. The effect of increasing carcass weight on fresh belly quality and bacon processing[1]

	Carcass Weight Category[2]				
Item	Average	Heavy	Very Heavy	SEM[2]	*P* Value
Bellies, *n*	30	30	25		
Belly dimensions					
Length, cm	70.63[a]	73.35[b]	75.64[c]	0.75	<0.01
Width, cm	27.87[a]	29.54[b]	30.35[b]	0.49	<0.01
Thickness[3], cm	3.94[a]	4.19[b]	4.71[c]	0.20	<0.01
Flop, cm	27.90	28.08	32.09	2.72	0.16
Belly processing traits					
Green weight, kg	7.15[a]	8.63[b]	9.89[c]	0.13	<0.01
Pumped weight, kg	8.00[a]	9.65[b]	10.90[c]	0.20	<0.01
Pump uptake[4], %	11.84[b]	11.84[b]	10.36[a]	1.07	<0.01
Cooked weight skin-on, kg	7.11[a]	8.69[b]	9.93[c]	0.17	<0.01
Cooked weight skin-off, kg	6.68[a]	8.21[b]	9.41[c]	0.15	<0.01
Cooked yield[5], %	99.47[a]	100.61[b]	100.49[b]	0.78	<0.01
Belly proximate composition[6]					
Moisture, %	53.84[c]	51.40[b]	48.31[a]	0.01	<0.01
Fat, %	29.83[a]	31.78[a]	37.09[b]	0.02	<0.01

[1]Different superscript letters within the same row reflect carcass weight category treatment differences ($P \leq 0.05$).

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

[3]Average of 8 individual thickness measurements on fresh belly.

[4]Pump uptake determined with (((pumped weight − green weight) ÷ green weight) * 100).

[5]Cooked yield calculated for skin-on cooked belly.

[6]Proximate analysis was performed on fresh, uncured pork belly.

and cooked weight all increased ($P < 0.01$) in hams from Very Heavy and Heavy carcasses compared to Average carcasses. There was a tendency for decreased pump uptake ($P = 0.08$) with increasing carcass weight categories; however, no differences in pump retention or cooked yield were observed between carcass weight categories ($P \geq 0.15$). Cured ham steak instrumental lightness (L^*) was unchanged by carcass weight categories ($P = 0.68$). Cured ham instrumental redness (a^*) and yellowness (b^*) were decreased ($P \leq 0.03$) from Heavy and Very Heavy carcasses compared with Average carcasses. However, no differences in cured ham redness or yellowness ($P \geq 0.27$) were observed between Heavy and Very Heavy carcasses.

Both belly length and thickness increased ($P < 0.01$) with increasing carcass weight (Table 3). Bellies from Very Heavy carcasses were approximately 0.52 cm thicker than those from Heavy carcasses and 0.77 cm thicker than those from Average weight carcasses ($P \leq 0.01$). Belly width also increased ($P < 0.01$) in bellies from Heavy and Very Heavy carcasses compared to Average carcasses. However, no differences in belly width ($P = 0.13$) were observed between Heavy and Very Heavy carcasses. Belly flop distance did not differ ($P = 0.16$) between carcass weight categories. Both initial (green) belly weight and pumped belly weight increased ($P < 0.01$) with increasing carcass weight. Pump uptake was decreased ($P < 0.01$) in bellies from Very Heavy carcasses compared with bellies from Average and Heavy carcasses, which did not differ from each other ($P = 0.99$). Despite greater pump uptake by bellies from lighter carcasses, both skin-on and skin-off cooked weight increased ($P < 0.01$) as carcass weight category increased. Cooked yield percentage was increased ($P < 0.01$) in slab bacon from Heavy and Very Heavy carcasses compared to slab bacon from Average carcasses. There was no difference ($P = 0.66$)

Table 4. Effect of carcass weight on cured sliced belly characteristics

Item	Carcass Weight Category[1] Average	Heavy	Very Heavy	SEM[2]	P Value
Bacon Slabs, n	30	30	25		
Average Slice[3]					
Length, cm	24.77[a]	25.97[b]	27.15[c]	0.38	<0.01
Width, cm	4.49[a]	4.87[b]	5.16[c]	0.16	<0.01
Total Slice Area, cm^2	106.48[a]	120.07[b]	134.85[c]	2.66	<0.01
Primary Lean Area, cm^2	25.55[a]	28.95[b]	28.79[b]	0.90	<0.01
Secondary Lean Area, cm^2	17.37[a]	19.26[b]	19.31[b]	0.73	<0.01
Lean Area, %	40.58[b]	40.37[b]	35.78[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.

[3]Average slice image analysis was the mean of the image analysis evaluated on 3 consecutive slices from center section.

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

Table 5. Effect of carcass weight on fatty acid profile (g/100 g of FAME) of belly adipose tissue[1]

Item	Carcass Weight Category[2] Average	Heavy	Very Heavy	SEM[2]	P Value
Pigs, *n*	30	30	21		
SFA					
C14:0	1.22	1.25	1.26	0.03	0.28
C16:0	22.39	22.76	23.09	0.29	0.08
C18:0	11.53	11.92	12.48	0.45	0.28
C20:0	0.18	0.19	0.20	0.02	0.08
Total SFA[3]	35.90	36.77	37.64	0.63	0.11
MUFA					
C16:1	2.41	2.66	2.36	0.18	0.08
C18:1*n*-9	42.57	41.8	42.15	0.41	0.29
Total MUFA[4]	49.49	49.03	48.94	0.58	0.72
PUFA					
C18:2*n*-6	13.43	13.15	12.46	0.48	0.06
C18:3*n*-6	0.03	0.03	0.03	<0.01	0.36
C18:3*n*-3	0.07	0.06	0.06	<0.01	0.48
C20:2*n*-6	0.56	0.54	0.54	0.24	0.35
C20:3*n*-6	0.09	0.09	0.08	<0.01	0.30
C20:3*n*-3	0.13	0.12	0.12	0.02	0.13
C20:4*n*-6	0.19[b]	0.18[ab]	0.16[a]	0.01	0.01
Total PUFA[5]	14.36	14.4	13.35	0.52	0.06

[1]Abbreviations: FAME: fatty acid methyl esters; IV: iodine value; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; SFA: saturated fatty acids; UFA: unsaturated fatty acids.

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

[3]Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C15:0] + [C16:0] + [C17:0] + [C18:0] + [C19:0] + [C20:0] + [C21:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[4]Total MUFA = ([C14:1] + [C16:1] + [C18:1*trans*-9] + [C18:1*n*-9] + [C18:1*n*-7] + [C19:1] + [C20:1] + [C21:1]); brackets indicate concentration.

[5]Total PUFA = ([C18:2*n*-6] + [C18:3*n*-6] + [C18:3*n*-3] + [C20:2*n*-6] + [C20:3*n*-6] + [C20:3*n*-3] + [C20:4*n*-6] + [C20:5*n*-3] + [C22:5*n*-3] + [C22:6*n*-3]); brackets indicate concentration.

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

in slab bacon cooked yield percentage between Very Heavy and Heavy carcass weight categories.

Bacon slice length and width increased ($P < 0.01$) with increasing carcass weight categories (Table 4). Given increases in length and width, total slice area of bacon also increased with carcass weight categories ($P < 0.01$). Both the primary lean and secondary lean areas of bacon slices were increased ($P \leq 0.01$) in Heavy and Very Heavy carcasses compared to Average carcasses, with no differences ($P \geq 0.86$) between Very Heavy and Heavy carcasses. Slice lean area percentage was decreased ($P < 0.01$) in bacon slices from Very Heavy carcasses compared to bacon from Average and Heavy carcasses, which did not differ from each other ($P = 0.85$). Fresh pork belly proximate composition showed a decrease in moisture content ($P \leq 0.05$) with increasing carcass weight categories. Fat content of fresh belly was increased ($P \leq 0.01$) in Very Heavy carcasses compared to Average and Heavy carcasses, which did not differ ($P = 0.23$) from each other in fat content.

Total saturated fatty acid (SFA) content of adipose tissue was not different ($P = 0.11$) between carcass weight categories (Table 5). A tendency was observed for increased C16:0 concentration ($P = 0.08$) with increasing carcass weight categories. Likewise, a numerical increase in C20:0 was observed with increasing carcass weights. However, no differences in C18:0 or C14:0 concentration were observed ($P \geq 0.28$) as carcass weight increased. Concentrations of C8:0, C10:0, C12:0, C15:0, C22:0, and C24:0 were each less than 0.1% of total fatty acids for all carcass weight categories, and C17:0 comprised less than 1% of total fatty acids for all carcass weight categories.

Total monounsaturated fatty acid (MUFA) content of adipose tissue, including oleic acid (C18:1*n*-9) concentrations, did not differ ($P \geq 0.29$) between carcass weight categories. A tendency for greater C16:1 content was observed in adipose tissue from Heavy carcasses compared with Average and Very Heavy carcasses. There were no differences in adipose tissue concentrations of C18:1*n*-7 between carcass weight categories ($P = 0.60$). Concentrations of C14:1, C18:1 *trans*-9, C20:1*n*-15, C20:1*n*-9, C20:1*n*-7, and C22:1 were each less than 1% of total fatty acids for all carcass weight categories. A tendency for total polyunsaturated fatty acid (PUFA) concentrations to decrease with increasing carcass weight categories was observed ($P = 0.06$). Accordingly, a tendency for decreasing linoleic acid (C18:2*n*-6) concentrations was also observed with increasing carcass weight categories. Percentages of γ-linolenic acid (C18:3*n*-6), α-linolenic acid (C18:3*n*-3), C20:2*n*-6, C20:3*n*-6, and C20:3*n*-3 in adipose tissue were unchanged by carcass weight categories ($P \geq 0.13$). C20:4*n*-6 concentration in adipose tissue decreased ($P < 0.01$) in Very Heavy carcasses compared to Average carcasses.

In total, there were no differences in the ratio of total unsaturated (MUFA + PUFA) fatty acids to SFA between carcass weight categories ($P = 0.12$; Table 6). However, adipose tissue from Very Heavy carcasses contained more SFA relative to PUFA than adipose tissue from Average carcasses as indicated by decreased PUFA:SFA ratios ($P < 0.01$). Changes to the degree of saturation in the belly fat were reflected in IV differences. The IV of adipose tissue from Very Heavy carcasses was reduced ($P \leq 0.01$) compared with Average weight carcasses, with IV of Heavy carcasses intermediate but not different from either extreme ($P \geq 0.13$).

Table 6. Effect of carcass weight on fatty acid ratios and iodine values of belly adipose tissue[1]

	Carcass Weight Category[2]				
Item	Average	Heavy	Very Heavy	SEM[2]	*P* Value
Calculations					
UFA:SFA[3]	1.79	1.73	1.67	0.05	0.12
PUFA:SFA[4]	0.40[b]	0.39[ab]	0.36[a]	0.02	0.03
IV AOCS[5]	66.20[b]	65.29[ab]	63.94[a]	0.84	0.04
IV Meadus[6]	68.64[b]	67.61[ab]	66.19[a]	0.88	0.04

[1]Different superscript letters within the same row reflect dietary treatment differences ($P \leq 0.05$); Abbreviations: AOCS: American Oil Chemist Society; FAME: fatty acid methyl esters; HCW: hot carcass weight; IV: iodine value; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; SFA: saturated fatty acids; UFA: unsaturated fatty acids.

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

[3]Unsaturated fatty acids (UFA):SFA = (total MUFA + total PUFA)/total SFA.

[4]PUFA:SFA = total PUFA/total SFA.

[5]Iodine value AOCS = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723) (AOCS, 2009).

[6]Iodine value Meadus = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C20:2 (1.57) + C20:3 (2.38) + C20:4 (3.19) + C20:5 (4.01) + C22:4 (2.93) + C22:5 (3.68) + C22:6 (4.64) (Meadus et al., 2010).

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

Discussion

Pork HCW are projected to continue increasing in the U.S. due to greater production efficiencies associated with raising fewer animals to produce the same amount of meat. Given the economic value of ham and belly products to pork carcass total value, there is a need to understand the impact of increasing carcass weights on ham and belly fresh and further processed characteristics. Pork carcasses used in this study presented proportional increasing lean and fat accretion with increasing carcass weight (Metz et al., 2024). Unsurprisingly, heavier pork carcasses yielded heavier lean cuts proportional to the increases in carcass weight (Metz et al., 2024). Therefore, it is likely that improved lean growth performance genetics have enabled producers to raise pigs to increased slaughter weights while maintaining acceptable carcass composition.

The importance of fresh ham quality, specifically pH, on cured ham processing yield and quality has been well documented (Kemp et al., 1974; Person et al., 2005a; McKeith and Pringle, 2013). However, few studies have evaluated ham further processing characteristics from heavy weight pigs. Overholt et al. (2019) observed that hams from carcasses weighing 105 kg chilled slower than hams from carcasses weighing 85 kg. The ability to properly chill hams could be compromised with increased carcass weights, which could potentially impact processing characteristics and cured ham quality. Price et al. (2019) reported no relationship between HCW and fresh ham (*gluteus medius*) quality from pork carcasses with an average weight of 119 kg, but cured ham characteristics were not evaluated.

Ham processing yield is greatly dependent on the ability of the ham to hold water (Lebret and andek-Potokar, 2022). The tendency for decreased pump uptake of hams from heavier weight carcasses observed in the present study is not unexpected as previous studies have demonstrated a reduction in pump uptake of cuts from fatter pigs, likely caused by decreased water holding capacity due to the hydrophobic nature of fat tissue compared to lean tissue. Further, decreased processing yields with slower chilling rates in larger carcasses have previously been demonstrated (Overholt et al., 2019), likely due to reduced protein functionality. However, this was not observed in the current study as ham pump retention and final cooked yields did not differ between weight classes. Similarly, Cisneros et al. (1996) observed no effect of increasing slaughter weight on cured ham yields from pigs with an average HCW of 98 kg. Despite similarities in cured ham yields, minor changes in cured ham slice instrumental color from Heavy and Very Heavy were observed. This finding was unexpected as Harsh et al. (2017) observed no relationship between HCW and cured ham slice instrumental color. However, carcasses evaluated in Harsh et al. (2017) represented pigs indicative of present marketing weights (80–130 kg) rather than future marketing weights as considered in the present study. Although redness differences in the present study were slightly greater than the reported perceptible visual difference in redness of approximately 0.6 units in beef (Zhu and Brewer, 1999), these differences in cured ham color should not be a source of concern to processors given the small unit differences and the lack of differences in instrumental lightness.

Belly characteristics have been poorly defined at weight ranges indicative of future marketing weights. In commercial pigs with a mean carcass weight of 95 kg, Harsh et al. (2017) reported that carcass weight was a moderate predictor of belly quality traits with heavier carcasses producing thicker and firmer bellies. Belly dimensions associated with increasing carcass weight will likely increase to a point that exceeds the ability to fit in current belly presses or present sliced bacon that is less suitable for current packaging. Understanding belly dimension and composition change with increasing carcass weight will allow processors to anticipate future production challenges.

Belly length of Heavy pigs increased 0.16 cm/kg of HCW. Belly length of Very Heavy pigs increased 0.14 cm/kg of HCW. Bellies from heavier carcasses were approximately 6% wider than bellies from lighter carcasses. Belly thickness of Heavy pigs increased 0.01 cm/kg of HCW. Belly thickness of Very Heavy pigs increased 0.03 cm/kg of HCW. Increases in belly thickness reported in the present study were consistent with previous research evaluating the relationship between carcass weights and belly thickness (Correa et al., 2008; Harsh et al., 2017). Interestingly, there was no statistical relationship between belly firmness (flop) and increasing carcass weight, which conflicted with previous studies (Harsh et al., 2017). However, belly flop distance has been demonstrated to have a relatively weak correlation ($r = 0.18$) with commercial bacon slicing yield (green weight; Kyle et al., 2014).

In a study evaluating belly thickness in bacon production, Person et al. (2005b) sorted the bellies into 3 thickness categories: thin (approximately 2.0 cm), average (approximately 2.5 cm), and thick (approximately 3.0 cm). All bellies in the present study, which represent current and future carcass weight increases, would be categorized as thick. Increased belly thickness observed in heavier carcasses may benefit processors as thicker bellies are typically associated with increased processing yields and greater total profitability (Soladoye et al., 2015). Similar observations were observed in the present study, as despite reduced pump uptake in bellies from Very Heavy carcasses, heavier carcasses still had increased cook yields compared with lighter carcasses. This is important to note as the U.S. standard of identity for bacon indicates that the weight of cured pork bellies ready for slicing shall not exceed the weight of fresh uncured pork bellies (Definitions and Standards of Identity or Composition, 2024). Pump uptake will need to be closely monitored in bellies from heavier carcasses to ensure the final cook weight does not exceed green weight. Person et al. (2005b) reported that bacon produced from thick bellies had “less than ideal” cured color and lacked flavor compared to bacon from thin and average bellies. Achieving a desirable cured color and flavor could become a concern in bellies from heavier carcasses due to limits on final cook yield.

Given the increases in fresh belly dimensions, it was unsurprising that bacon slices were longer and wider and had an overall greater area as carcass size increased. The lack of differences in both primary and secondary lean area between Very Heavy and Heavy carcasses, as well as a 4.6% unit decrease in total lean area, highlighted a decrease in lean accretion and an increase in fatness of bacon slices from Very Heavy carcasses. Decreases in lean to fat ratio have been shown to negatively influence consumer acceptability (Person et al., 2005b). Further work is needed to determine consumer acceptability of bacon slices from heavy weight pigs. It is presumed this is due to a perception of reduced healthfulness, as Saldaña et al. (2020) demonstrated healthfulness was the most important non-sensory factor in consumer purchase intent of bacon. Fresh belly proximate analysis results were in alignment with bacon slice image analysis, with bellies from Very Heavy carcasses having 5.3% unit and 7.3% unit increased percent fat compared to Heavy carcasses and Average carcasses, respectively. As percent fat increased, it was unsurprising that percent moisture decreased in Very Heavy carcasses compared to lighter carcasses.

Minimal differences in fatty acid composition of bellies were observed in the present study as evidenced by no differences in total SFA and total MUFA with increasing carcass weight. However, the decreased PUFA:SFA ratio in heavier carcasses compared to lighter carcasses was likely the culmination of minute changes within each concentration, as a tendency for reduced total PUFA concentration was observed in adipose tissue from Very Heavy carcasses. Additionally, the PUFA:SFA ratio differences could be attributed to the decrease of arachidonic acid (C20:4n-6) concentration in bellies from heavier pigs compared to lighter pigs. These results were consistent with Raj et al. (2010), where the PUFA:SFA ratio was reduced in heavier pigs (130 kg ending live weight (ELW)) compared to lighter ones (90 and 110 kg ELW).

Cumulative differences in fatty acid composition were calculated together as IV, which decreased in bellies from heavier carcasses compared to lighter carcasses. Nonetheless, bellies from all 3 carcass weight categories would still be considered acceptable under the typical industry IV maximum set at 74 g/100 g (Seman et al., 2013). Previous studies have reported HCW to account for only 7–10% of variation in IV in pork fat (Harsh et al., 2017; Price et al., 2019).

Conclusion

In conclusion, minimal differences in both ham and belly cooked yields were observed with increasing carcass weights despite reduced pump uptake. Increases in belly dimensions and thickness were present with increased carcass weight but did not result in meaningful differences in fat composition. Increased sliced bacon dimensions and fatness, as well as decreased cured ham redness, at heavier carcass weights warrant further study for impacts on consumer acceptability.

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