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Processing Characteristics, Composition, Shelf-life, and Sensory Attributes of Beef Bacon Manufactured From Seven Value-Added Cuts of Beef

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Abstract: The purpose of this study was to evaluate the influence of different beef cuts on their potential for adding value by assessing processing characteristics, composition, shelf-life, and sensory attributes of these cuts as beef bacon. Six briskets (Institutional Meat Purchase Specification [IMPS]#120), 6 clod hearts (IMPS#114E; divided horizontally into 2 halves: silver-skin side and non–silver-skin side), 6 flanks (IMPS#193), 6 outside flats (IMPS#171B), and 7 short plates (IMPS#121A; cut into a deboned short-rib half and navel half) were sourced commercially from separate Canadian quality grade AA beef carcasses. Data for processing yields, composition, and image analysis were analyzed as a generalized linear mixed model with fixed effect of cut and random effect of replication nested within block (processing group). Sensory data collected using a trained sensory panel were analyzed in the same manner, with an additional fixed effect of storage day and additional random effects of session and panelist. Rested pump uptake, which was targeted at 20%, was not different ($P = 0.21$) among cuts; however, smokehouse cook yield differed ($P < 0.01$) among cuts, with heavier cuts (brisket, plate cuts, and outside flat) generally having greater yields compared with lighter cuts (clod cuts and flank). As expected, composition of bacon slices was affected ($P < 0.01$) by cut, with leaner cuts (clod cuts, flank, and outside flat) having greater moisture, lower lipid levels, and greater protein compared with fatter cuts (brisket and plate cuts). Sensory analysis revealed significant differences in muscle fiber toughness and connective tissue among cuts. The differences that were quantified in this study should allow manufacturers to tailor their cut selection to the processing specifications that may be most profitable and well-suited for the meat industry and its customer base. Overall, this research should help define beef bacon and further indicate that a variety of beef cuts can be used to manufacture beef bacon.

Key words: bacon, beef bacon, beef processing, beef bacon sensory, value-added beef
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Introduction

There is great opportunity for the global beef industry to add value to beef cuts that are currently marketed as low-value cuts (i.e., cuts originating from the chuck, round, and flank/plate primals). One underutilized technique for meat processors to capture more value on undervalued beef cuts is through further processing, a method that is much more common in other sectors of the meat industry. For instance, well over half of pork products are marketed as value-added further processed meat products (National Pork Board, 2009), whereas only a small amount of beef products (excluding ground beef) are regularly marketed as value-added products. Meat processors should work towards techniques that add value to undervalued beef cuts, and one such way is to create innovative products like beef bacon.

While the standard of identity for beef bacon is not available in all countries, there is a standard of identity available in the United States. Beef bacon is specifically described by the US Department of Agriculture (USDA; USDA, 2005) as follows.

> . . . a cured and smoked beef product sliced to simulate regular bacon. It is prepared from various beef cuts and offered with a variety of coined names, including “Breakfast Beef,” “Beef bacon,” etc. A common or usual name is required, e.g., “Cured and Smoked Beef Plate,” and should be shown contiguous to the coined name.

There are multiple challenges with the USDA standard of identity for beef bacon, with the most obvious being product consistency. With no standard cut from which beef bacon is manufactured, great variation in product attributes are expected between products and even within the same product. A preliminary study revealed a great deal of variation in the appearance and composition among different beef bacon products sold commercially in southern Ontario (Chalupa-Krebzdak and Bohrer, 2019). The greatest source of variation was attributed to the beef cut that was used to manufacture beef bacon products. This market variation due to differences in cut was likely caused by the lack of regulated or commonly understood identity. This remains an impediment to the success of beef bacon. Furthermore, academic and marketplace investigations into the optimization of beef bacon processing parameters cannot be currently performed, as there is no base identity or formulation for which modifications can be applied to or compared against.

Although the lack of standard identity for beef bacon currently poses impediments to the widespread market success of beef bacon, this dilemma is not without advantages. Without a universal standard identity, a unique opportunity presents itself in which a thorough analysis of many different formulations that optimize sensorial and economical properties can be manufactured before ascribing an identity to “beef bacon.” Of the many potential parameters that could be ascribed to beef bacon, the cut of beef from which it is manufactured is the most logical starting place for analysis and perhaps the most critical to its success as it will dictate the form, composition, and sensory qualities of the beef bacon product.

For these purposes, the aim of this study was to evaluate the influence of 7 different value-added beef cuts on processing characteristics, composition, shelf-life, and sensory attributes of beef bacon manufactured under a controlled setting (i.e., same production and storage conditions). It was hypothesized that the variation in composition of the cuts used would have significant corresponding effects on the processing, shelf-life, and sensory attributes of the different beef bacon products manufactured in this study.

Materials and Methods

No approval for institutional animal care were required because no live animals were used for this study. Approval from the Research Ethics Board (Human Participants Division) at the University of Guelph (Research Ethics Board #18-05-007) was received, and written informed consent was obtained from each participant.

Raw materials and experimental design

Cuts selected for evaluation in this study were based on assumptions from a preliminary study that focused on variation in the appearance and composition of beef bacon products sold commercially in southern Ontario (Chalupa-Krebzdak and Bohrer, 2019). Based on these assumptions, the following cuts were selected for evaluation in this study: brisket (Institutional Meat Purchase Specification [IMPS]#120), clod heart (IMPS#114E), flank (IMPS#193), short plate (IMPS#121A), and outside flat (IMPS#171B) (NAMP, 2014). Six replications (cuts) were used for the brisket, clod heart, flank, and outside flat, while 7 replications (cuts) were used for the short plate. All cuts were sourced commercially from Canadian quality grade AA beef carcasses. All cuts originated from different cattle processed on the same day at a federally inspected beef processing facility. Cuts were vacuum packaged at approximately 48 h post mortem and were transported to the University of Guelph Meat Science Laboratory under the compliance of federal meat inspection standards (refrigeration between 0°C and 4°C). Once the cuts arrived at the University of Guelph Meat Science Laboratory, the cuts remained vacuum-packaged and were stored at 4°C until fabrication and processing was conducted.

A total of 3 blocks were used in this study. Blocks were defined as the day of fabrication, processing, and smokehouse cooking. Block 1 and block 2 consisted of 2 replications of each cut, whereas block 3 consisted of 2 replications of the brisket, clod heart, flank, and outside flat and 3 replications of the short plate. Block 1 began 6 d after arrival of the cuts to the University of Guelph Meat Science Laboratory, block 2 began 8 d after arrival of the cuts to the University of Guelph Meat Science Laboratory, and block 3 began 12 d after arrival of the cuts to the University of Guelph Meat Science Laboratory. For each block, 3 sequential days were used for completion of the block—day 1 consisted of fabrication and injection of the curing solution, day 2 consisted of cooking in the smokehouse, and day 3 consisted of slicing and sample collection.

It was determined that the clod heart and the short plate cuts required further fabrication before they could be used for beef bacon manufacture. Therefore, the clod heart was divided horizontally into 2 halves, which resulted in a silver-skin side and a non–silver-skin side; the short plate was deboned and separated into a short-rib half and a naval half. Therefore, the following 7 cuts were selected for evaluation and represent the treatments used in this study: (1) Brisket, (2) clod heart silver-skin side (Clod-S), (3) clod heart non–silver-skin side (Clod-NS), (4) Flank, (5) short plate short-rib half (Plate-SR), (6) short plate navel half (Plate-N), and (7) Outside Flat.

External fat was trimmed to a depth of 3 mm for all cuts. Dimensions (length, width, and thickness) of each cut were measured after trimming. Length and width were measured along the longest and widest points across the cut, respectively. Thickness was averaged across 8 measurements (4 measures along the length on each side) for Brisket, Plate-SR, Plate-N, and Outside Flat. Thickness was averaged across 4 measurements (2 measures along the length on each side) for Clod-S, Clod-NS, and Flank. Each cut was weighed before processing began to determine the preprocessing weight (green weight).

Beef bacon processing

Immediately following measurement of dimensions and green weight, each cut was injected using a needle injector (Inject Star Pökelmaschinen Gesellschaft m.b.H; Hagenbrunn, Austria) to a targeted rested pump uptake of 20% (±3%). The injection brine consisted of a standard commercial bacon cure unit (water, salt, sugar, sodium phosphate, sodium erythorbate, sodium nitrite, and less than 2% tri-calcium phosphate; Hela Brine and Cure Unit; Herman Laue Spice Company Inc., Uxbridge, Ontario, Canada). Processing was conducted according to ingredient supplier recommendations of 70.25% cold water, 12.40% ice, and 17.35% of the commercial cure unit. The curing solution was mixed thoroughly before injection began. Calculated levels for individual ingredients were 2.08% salt, 1.00% sugar, 0.38% phosphate, 0.03% sodium erythorbate, and 0.02% sodium nitrite. Cuts were immediately weighed following injection to determine initial pump weight and weighed again after a 30-min rest period to determine rest pumped weight. Initial pump uptake and rested pump uptake were calculated with the following equations:

$$\text{Initial pump uptake \%} = \frac{\text{Initial pump weight} - \text{Green weight}}{\text{Green weight}} \times 100\%$$

$$\text{Rested pump uptake \%} = \frac{\text{Rested pump weight} - \text{Green weight}}{\text{Green weight}} \times 100\%$$

Cuts were then allowed to rest overnight (approximately 18 h) at 4°C. The following day, cuts were weighed once more to obtain precook weight. Cuts were then smoked and cooked to an internal temperature of 62°C in a smokehouse (Scott Mini Single Cage Vertical Air Flow Smokehouse; ScottPec, Guelph, Ontario; Table 1). Cuts were removed as they reached 62°C during step 12 of the cooking cycle due to the varying thickness and size of each cut. After cooking, cuts were sprayed with cold water and rested overnight (approximately 12–16 h) at 4°C. Cooked cuts were then weighed prior to slicing and sample collection. Smokehouse cooking yield was calculated using the following equation:

$$\text{Smokehouse cook yield \%} = \frac{\text{Cooked weight}}{\text{Green weight}} \times 100\%$$

Cuts were sliced into 4.0-mm slices using a deli slicer. Each cut was divided along its length into thirds in order to create a back, center, and front section. The widest end of each cut (longest in terms of slice length) was designated as the back section, and the narrowest end of each cut (smallest in terms of slice length) was

Table 1. Bacon smokehouse cook cycle[1]

Stage	Stage Name	Time (min)	Temperature (°C)	Humidity (%)
1	Preheat	10	54	0
2	Drying	75	54	0
3	Smoke ignition	4	54	0
4	Smoking	14	54	0
5	Smoke discharge	5	54	0
6	Smoking	18	54	0
7	Smoke discharge	8	54	0
8	Cook	15	60	30
9	Cook	15	65	40
10	Cook	15	69	50
11	Cook	15	70	60
12	Cook	Until core temperature of 62°C was achieved	72	60

[1]Products were thermally processed in a smokehouse (Scott Mini Single Cage Vertical Air Flow Smokehouse; ScottPec, Guelph, Ontario) using the same smokehouse cooking cycle and were removed once desired temperature of 62°C was achieved.

designated as the front section. Samples were collected, vacuum-packaged (76-micron-thick transparent poly nylon vacuum pouches; Uline Shipping Supplies; Milton, Ontario, Canada), and allocated to the desired storage period. Back, center, and front slices were collected and immediately frozen (−20°C) for proximate composition analysis (3 slices/section), fatty acid analysis (3 slices/section), and image analysis (3 slices/section). Twelve slices from the center section were collected and used for bacon slice cooking loss and sensory evaluation. These vacuum-packaged samples were stored in sealed boxes without light exposure at 4°C for one of 4 designated storage periods: 0 d, 30 d, 60 d, or 90 d. Once the storage period at 4°C had elapsed, samples were stored at −20°C for future analysis.

Proximate composition

Proximate composition for the identification of moisture, lipid, protein, and ash content was performed as previously described by Sivendiran et al. (2018). Each individual bacon slice was evaluated in duplicate to determine variability between and within cuts (i.e., 3 consecutive slices were selected from each of the 3 sections for each individual cut). Each strip was minced individually in a food processor (KitchenAid 3.5 Cup Food Chopper Model KFC3516ER, Whirlpool Corporation, Benton Harbor, MI) and stored at −20°C until further analysis was conducted, at which point samples were thawed in a refrigerator overnight (approximately 16 h). Moisture content was determined by oven drying at 100°C for 24 h, at which point samples were successively tested for their lipid content via Soxhlet extraction with petroleum ether as the solvent, protein content via Dumas (FP-528, Leco, St. Joseph, MI), and ash content (muffle furnace at 550°C for 24 h).

Fatty acid analysis

The fatty acid profile of beef bacon samples was determined using gas chromatography. Fat was collected from the Soxhlet lipid extraction portion as previously described. The isolated lipid samples underwent the transmethylation procedures specified by Christie and Han (2010). Fatty acid methyl esters were analyzed using capillary gas chromatography equipped with a BPX with 70 columns, an internal diameter of 60 m × 0.22 mm, and 0.25-mm film thickness (SGE Inc., Austin, TX). An Agilent 6890-Series Gas Chromatograph (Agilent Technologies Inc., Wilmington, DE) with a 7683-series autosampler was used to house the column. The oven temperature was programmed to increase from 110°C to 230°C at a rate of 4°C/min and was then maintained at 230°C for 10 min. The injector and detector temperatures were 240°C and 280°C, respectively. Helium was used as the carrier gas at an average velocity of 25 cm/s. Peaks were identified via comparison to fatty acid methyl ester standards (Sigma Aldrich, St. Louis, MO). Results for fatty acids were expressed as milligrams per 100 milligrams of total fatty acids, or simply percentage of total fatty acids.

Image analysis

Image analysis was performed on each of the three slices obtained from each front, center, and back section (i.e., 3 slices were selected from each of the 3 sections for each individual cut). Lean percentage, total area, length and width, and length:width were evaluated. The image analysis method was adapted from previous methods described by Boler et al. (2011), Kyle et al. (2014), and Tavárez et al. (2014). Slices were photographed using a Nexus 5 camera (LG Electronics Inc., Seoul, South Korea) against a black bristol board background alongside a 30-cm ruler. Adobe Photoshop CS5 (Adobe Systems Inc., San Jose, CA) was used to isolate the slices and the ruler from the background of each image to create a TIFF file of the slice and ruler layered on a transparent background. The TIFF files were then imported into the National Institutes of Health's Image J software. Slice dimensions were determined by first defining the number of pixels in a centimeter using the "Set Scale" function and then using the "Threshold" function to create a complete black slice; the straight-line tool was used to measure the slice dimensions. High-contrast black and white images of each bacon slice were created by converting each image to an 8-bit image and using the "Threshold" function to create black pixels for the lean portion of the slice and white pixels for the fat portion of the slice. The "Analyze Particles" function was used to count the number of black (lean) pixels, which was then divided by the number of black pixels in a fully blackened bacon slice image and used to determine the lean percentage of each slice. Total slice area was determined using the freehand selection tool for slices made up of only black pixels, which was then measured with the "Analyze Particles" function. All measured parameters were evaluated in duplicate by 2 technicians and were presented as averages of the 2 evaluations. Length and width were obtained from the longest and widest points along each slice, respectively.

Cooking loss

Three slices from the center portion of each cut were collected for cooking loss (and trained sensory evaluation). Bacon slice cooking loss was determined for each sample. For bacon cooking loss, all bacon slices were gently patted with a paper towel and individually weighed before and after cooking in a convection oven (Frigidaire Professional Model #CPEB30T9FC3; Electrolux Home Products, Augusta, GA) set to 204°C for 15 min on wire rack (Nordic Ware, Minneapolis, MN).

Sensory evaluation

Sensory explanation and training. A trained panel consisting of 10 panelists performed a descriptive analysis of each cut to examine the differences between descriptive sensory properties and oxidative stability of cuts across 4 different storage times at 4°C (0 d, 30 d, 60 d, and 90 d). The sensory properties examined were beef flavor intensity, muscle fiber toughness, connective tissue amount, oxidation aroma, and oxidation flavor.

Panelists participated in 2 training sessions that focused on the panelists ability to recognize and quantify the sensory properties being examined in this study. The training sessions were followed by a screening session that confirmed the panelists' ability to adequately identify and quantify the sensory properties of interest.

Upon arrival to training sessions, panelists received a consent form along with a guiding document for the training session. The consent form was reviewed with the panelists, along with the purpose of the study and panelist expectations. Panelists had each of the sensory properties being examined in this study described to them and were provided with samples that exhibited different degrees of intensity for each sensory parameter. With the guidance of the session instructor, trainees were instructed to consume the provided samples and describe the intensity of the sensory attribute being evaluated by arranging the samples on a line scale. The samples used to train panelists on beef flavor were 3 different dilutions of Campbell's beef broth (1:3, 1:1, and 1:0; Campbell Soup Company, Camden, NJ), Campbell's chicken broth (Campbell Soup Company) for contrast and comparison, and an 80% lean ground beef sample cooked to an internal meat temperature of 72°C. Muscle fiber toughness was evaluated using a beef eye of round (*semitendinosus*) steak cooked to 85°C, a beef strip loin (*longissimus thoracis*) steak cooked to 56°C, and a beef tenderloin (*psoas major*) steak cooked to 56°C. Connective tissue was identified using thick-cut pork bacon samples of different connective tissue amounts, along with connective tissue isolated from beef strip loin (*longissimus thoracis*) steaks. Panelists were instructed to smell fresh soybean oil that was microwaved for 0, 2, or 5 min, which was used to train panelists to recognize and quantify oxidative aroma. Oxidative flavor was taught to trainees by instructing them to consume the soybean oil samples described earlier, along with a freshly prepared 80% lean ground beef sample and 80% lean ground beef sample that was frozen at −20°C for 18 mon. Both ground beef samples were cooked to an internal temperature of 72°C.

All samples used for trainings were cooked in a convection oven (Frigidaire Professional Model #CPEB30T9FC3; Electrolux Home Products) set to 204°C. Following cooking (within 10 min), samples were cut into 1.5 strips (for bacon) or sections (for steaks) and wrapped in aluminum foil. Samples were placed in a warming oven set at 93°C for a maximum of 20 min before being served to panelists. Samples were then served in 118-mL plastic cups with sealed lids in order to collect headspace aroma.

Following the training sessions, panelists were tested on the sensory attributes described during the training sessions. The purpose of this testing was to screen panelists for their ability to understand and quantify differences between the sensory criteria being evaluated in the descriptive panel as well as to verify their ability to follow instructions. The testing form involved a series of questions that tested the panelists' ability to identify and quantify the relevant sensory attributes related to each of the testing parameters—beef flavor intensity, muscle fiber toughness, connective tissue amount, oxidative aroma, and oxidative flavor. Panelists were permitted to participate in the descriptive panel if they were able to correctly answer at least 80% of the questions.

Sensory experimental design and testing. Descriptive analysis panel sessions were conducted to evaluate the effect of each cut across the 4 different storage times, with each treatment combination being replicated 3 times and with the same cut being used across each storage time. The samples were presented to the panelists across 14 sessions (one session per day) in a balanced incomplete block design. Samples were subjectively evaluated by study personnel for microbial spoilage or extreme rancidity before preparation, yet no samples were determined to be spoiled or of unacceptable quality. Each session consisted of 6 to 8 panelists selected at random from the pool of the 10 trained panelists. Panelists were served 6 samples (cut × day combination) labeled with random 3-digit codes under red light, along with unsalted crackers and water for palate cleansing.

Immediately before each sensory session, beef bacon slices were cooked in a convection oven (Frigidaire Professional Model #CPEB30T9FC3; Electrolux Home Products) set to 204°C for 15 min on wire rack (Nordic Ware). Following cooking (within 10 min), samples were patted dry using a paper towel and cut into 1.5-cm strips and wrapped in aluminum foil. Samples were placed in a warming oven set at 93°C for a maximum of 20 min before being served to panelists. Samples were served in 118-mL plastic cups with sealed lids in order to collect headspace aroma.

Beef flavor intensity, muscle fiber toughness, and connective tissue amount were evaluated using unipolar magnitude estimation (American Society for Testing and Materials standard E1697–05) (ASTM, 2008). The reference standard used for the purposes of magnitude estimation for beef flavor intensity was 80% lean ground beef, which was used as a middle anchor in the reference standards developed for quantifying beef flavor identity by Adhikari et al. (2011). In order to make quantitative comparisons between beef bacon and pork bacon. Thick-cut (approximately 4 mm) pork bacon (President's Choice Old-Fashioned Style Bacon; Loblaws Companies Limited, Brampton, Ontario, Canada) was used as the reference standard used for the magnitude estimation of muscle fiber toughness and connective tissue amount.

Oxidative aroma and oxidative flavor were both evaluated using a 4-point nominal scale, with 1 indicating no oxidation, 2 indicating trace amounts of oxidation, 3 indicating some oxidation, and 4 indicating major oxidation. Panelists were provided with an oxidized vegetable oil sample each session to recalibrate their senses and ensure that only oxidized characteristics were being detected.

Statistical analysis

Statistical analyses were performed on the processing characteristics using the PROC GLIMMIX function in SAS version 9.4 (SAS Institute Inc., Cary, NC). Fixed effect was cut, and the random effect of replication nested within block was used. Statistical analysis was performed on proximate composition, fatty acid profile, and image analysis using the PROC GLIMMIX function in SAS with the fixed effect of cut and section and with the random effect of cut replication nested within block and section replication. The LSMEANS statement was used to calculate the F-statistic with the SLICE option using the fixed effect of cut to determine cut × section effects. Statistical analysis was performed on the bacon slice cooking loss using the PROC GLIMMIX function in SAS with the fixed effect of cut, storage day, and their interaction and with the random effects of session and replication. Sensory data for beef flavor intensity, muscle fiber toughness, and connective tissue amount were analyzed as repeated measures using PROC GLIMMIX of SAS with fixed effect of cut, storage day, and their interaction and random effects of session, panelist, and replication. Least-squares differences for all analyses were determined using the LSMEANS statement with a Tukey-Kramer adjustment. Differences for all analyses were considered significant at $P < 0.05$.

Results and Discussion

Processing characteristics

Length, width, and thickness of the unprocessed cuts were different ($P < 0.01$) (Table 2). This was expected but should be considered by processors when manufacturing beef bacon products as these parameters would greatly influence processing capabilities (namely processing yields), as well as final product attributes (namely bacon slice appearance and sensory characteristics). Processing weights were different ($P < 0.01$) among the cuts evaluated in this study. Again, this was expected as integral differences were attributed to the origin and the muscle (or muscle groups) that constitute each of the cuts that were evaluated in this study. While initial pump uptake differed ($P < 0.01$) among the cuts, the rested pump uptake was not different ($P = 0.21$) among the cuts. This was an indication that each of the cuts was successful in its ability to be pumped with the common curing solution that was used in this study. The smokehouse cook yield differed ($P < 0.01$) among cuts. Based on significant differences among the pairwise comparisons, smokehouse cook yield was greater for Plate-N (108.54%), Brisket (106.96%), and Outside Flat (106.79%) compared with Clod-S (99.11%) and Flank (98.95%); Plate-SR (105.61%) and Clod-NS (101.19%) were intermediate. It was obvious that the size of the cuts—or the unprocessed dimensions—contributed to the smokehouse cooking yield, as the larger cuts had greater smokehouse cooking yield and the smaller cuts had lesser smokehouse cooking yield. It is well

Table 2. The effect of beef cut on dimensions of unprocessed cuts and processing weight/yields of beef bacon

	Treatments[1]								
	Brisket	Clod-S	Clod-NS	Flank	Plate-SR	Plate-N	Outside Flat	SEM[2]	***P*** **value**
Replications (cuts), no.	6	6	6	6	7	7	6		
Dimensions of unprocessed cuts									
Length,[3] cm	47.36^{b}	27.62^{c}	29.18^{c}	30.53^{c}	55.49^{a}	52.30^{a,b}	48.00^{b}	1.50	<0.01
Width,[4] cm	26.52^{a}	18.53^{c,d,e}	17.79^{d,e}	15.14^{e}	21.35^{b,c}	19.14^{c,d}	24.66^{a,b}	0.81	<0.01
Thickness,[5] cm	4.76^{b}	3.53^{c}	3.80^{b,c}	2.10^{d}	4.31^{b,c}	3.99^{b,c}	9.05^{a}	0.28	<0.01
Processing weights and yields									
Green weight, kg	4.65^{a,b}	1.51^{c}	1.50^{c}	0.89^{c}	4.46^{b}	4.03^{b}	5.85^{a}	0.29	<0.01
Initial pump weight,[6] kg	5.81^{a,b}	1.86^{c}	1.86^{c}	1.18^{c}	5.64^{b}	5.20^{b}	7.27^{a}	0.36	<0.01
Rested pump weight,[7] kg	5.54^{a,b}	1.78^{c}	1.76^{c}	1.07^{c}	5.37^{b}	4.87^{b}	7.05^{a}	0.36	<0.01
Precooked weight, kg	5.52^{a,b}	1.81^{c}	1.79^{c}	1.09^{c}	5.37^{b}	4.89^{b}	7.04^{a}	0.36	<0.01
Initial pump uptake,[8]%	24.95^{b,c}	22.87^{c}	24.69^{b,c}	32.20^{a}	26.42^{a,b,c}	28.98^{a,b}	24.43^{b,c}	1.56	<0.01
Rested pump uptake,[9]%	18.69	17.70	17.79	19.88	20.47	20.57	20.53	1.26	0.21
Cooked weight, kg	4.98^{a,b}	1.51^{c}	1.52^{c}	0.88^{c}	4.71^{b}	4.38^{b}	6.26^{a}	0.32	<0.01
Smokehouse cook yield,[10]%	106.79^{a}	99.11^{c}	101.19^{b,c}	98.95^{c}	105.61^{a,b}	108.54^{a}	106.96^{a}	1.19	<0.01

[1]Cuts evaluated were beef brisket (IMPS#120; "Brisket"), beef clod heart (IMPS#114E; divided horizontally into 2 halves: silver-skin side ["Clod-S"] and non–silver-skin side ["Clod-NS"]), beef flank (IMPS#193; "Flank"), beef short plate (IMPS#121A; cut into a deboned short-rib half ["Plate-SR"] and navel half ["Plate-N"]), and beef outside flat (IMPS#171B; "Outside Flat").

[2]The maximum standard error of the mean (SEM).

[3]Length was measured at the longest point along the cut.

[4]Width was measured at the widest point along the cut.

[5]Thickness was measured as the average of the thickness (height) measured at multiple locations throughout the cut.

[6]Initial pump weight was measured immediately after injection.

[7]Rested pump weight was measured 30 min after injection.

[8]Initial pump uptake = (pump weight − green weight) ÷ green weight × 100%.

[9]Rested pump uptake = (rested pumped weight − green weight) ÷ green weight × 100%.

[10]Smokehouse cook yield = (cooked weight ÷ green weight) × 100%.

[a,b,c]Least-squares means lacking a common superscript letter within a row are different ($P < 0.05$).

understood that a surface-area-to-volume ratio creates processing yield differences (Barbut, 2016), which aligns with the findings in this study.

In terms of forming a comparison of processing yields of beef bacon products with that of pork bacon, pump uptake and cook yields were roughly similar (Sivendiran et al., 2018). The USDA requirements for pork bacon state that cooked bacon weight must return to green weight (cook yield not exceeding 100%) in order to be labeled as "bacon" (USDA, 2013). This requirement varies from country to country. Yet a recent study conducted by Sivendiran et al. (2018) reported that differences in bacon pump retention levels following thermal processing (exceeding 100% or lower than 100%) had minimal impacts on bacon slice composition and sensory traits. Therefore, it was not assumed that differences in bacon slice composition and sensory traits may only be partially attributed to the observable differences in pump uptake retention and smokehouse cook yield.

An additional criterion of fresh meat quality that was, unfortunately, not measured in this study is pH. pH has been shown to influence fresh beef quality, processing parameters, and storage quality. The most common pH abnormality in beef is an elevated pH (>6.0), which is commonly referred to as dark-cutting beef. In Canada, dark-cutting beef is assigned a quality grade of Canada B4. While pH of the individual cuts was not measured in the current study, only cuts from Canada AA beef were used, so this eliminated the possibility of dark-cutting beef being used in this study.

Composition of beef bacon

The composition of the beef bacon products (which included evaluation of macronutrient composition [moisture, lipid, protein, ash], fatty acid profile, and slice attributes with image analysis) was different ($P < 0.01$) among the cuts evaluated in this study (Table 3).

Moisture content ranged from 52.39% to 69.43%, lipid content ranged from 3.80% to 28.21%, protein content ranged from 14.77% to 21.46%, and ash content ranged from 2.67% to 4.42%. Clod-S, Clod-NS, Outside Flat, and Flank were generally characterized as high moisture (>64%), low lipid (<9%), high protein (>20%), and high ash (>3%), whereas Brisket, Plate-SR, and Plate-N were generally characterized as low moisture (<62%), high lipid (>16%), low protein (<18%), and low ash (<3%). Compared with pork bacon, the lower-moisture, higher-lipid cuts were more similar in their proximate composition, yet there were still differences in this comparison. Previous reports for moisture content in pork bacon was approximately 43%–57%, lipid content was approximately 31%–42%, and protein content was 12%–15% (Kyle et al., 2014; Lowe et al., 2014; Sivendiran et al., 2018). Proximate composition was evaluated on slices from the back, center, and front section within each cut, which revealed that there was considerable variation for proximate composition in several of the cuts (Figure 1). The following differences ($P < 0.05$) were observed within the cuts: Brisket differed in moisture, lipid, and protein; Clod-S differed in ash; Clod-NS differed in ash; Plate-SR differed in moisture and lipid; Plate-N differed in moisture, lipid, protein, and ash; and Outside Flat differed in moisture, lipid, and ash.

Table 3. The effect of beef cut on proximate composition, fatty acid profile, image analysis, and slice cook yield of beef bacon

	Treatments[1]								
	Brisket	Clod-S	Clod-NS	Flank	Plate-SR	Plate-N	Outside Flat	SEM[2]	***P*** **value**
Proximate Composition									
Moisture, %	61.80^{d}	67.98^{a}	69.43^{a}	64.32^{c}	52.39^{f}	55.41^{e}	66.32^{b}	0.58	<0.01
Lipid, %	16.39^{c}	5.27^{e}	3.80^{e}	8.66^{d}	28.21^{a}	25.99^{b}	8.96^{d}	0.76	<0.01
Protein, %	17.79^{c}	21.44^{a}	21.46^{a}	21.11^{a}	15.32^{d}	14.77^{d}	20.00^{b}	0.23	<0.01
Ash, %	2.79^{d}	3.83^{b}	3.84^{b}	4.42^{a}	2.82^{d}	2.67^{d}	3.37^{c}	0.17	<0.01
Fatty Acid Profiles[3]									
Total SFA	46.92^{b,c}	44.28^{c,d}	44.21^{c,d}	48.41^{b}	52.15^{a}	45.41^{b,c}	40.70^{d}	1.18	<0.01
Total MUFA	47.66^{b}	49.25^{a,b}	49.89^{b}	46.50^{b}	40.75^{c}	48.93^{b}	53.95^{a}	1.40	<0.01
Total PUFA	2.21^{d}	3.92^{a}	3.42^{b}	2.28^{d}	2.94^{c}	2.36^{d}	2.30^{d}	0.15	<0.01
MUFA:SFA	1.04^{b,c}	1.12^{b}	1.13^{b}	0.97^{c,d}	0.85^{d}	1.10^{b,c}	1.34^{a}	0.05	<0.01
PUFA:SFA	0.047^{d}	0.090^{a}	0.078^{b}	0.047^{d}	0.058^{c}	0.051^{c,d}	0.058^{c,d}	0.003	<0.01
Image Analysis									
Slice length, cm	18.86^{b}	15.58^{d}	12.81^{e}	12.73^{e}	16.73^{c}	18.29^{b}	18.86^{a}	0.35	<0.01
Slice width, cm	6.48^{c}	4.59^{d}	4.97^{d}	2.87^{e}	6.72^{b,c}	6.92^{b}	7.76^{a}	0.15	<0.01
Slice length:width	3.07^{c}	3.43^{b}	2.60^{d}	4.52^{a}	2.54^{d}	2.70^{d}	2.99^{c}	0.08	<0.01
Total slice area, cm^2	85.41^{c}	52.24^{d}	49.18^{d}	26.73^{e}	81.58^{c}	95.73^{b}	114.26^{a}	2.53	<0.01
Slice lean area, cm^2	63.81^{b}	49.02^{c}	46.39^{c}	24.07^{d}	47.03^{c}	58.95^{b}	104.43^{a}	1.93	<0.01
Slice fat area, cm^2	21.57	3.19	2.76	2.63	34.55	36.77	9.81	1.15	<0.01
Slice lean percentage, %	75.28^{c}	92.69^{a}	93.16^{a}	87.89^{b}	57.42^{e}	61.41^{d}	91.00^{a}	0.78	<0.01
Slice fat percentage, %	24.72^{c}	7.31^{e}	6.84^{e}	12.11^{d}	42.58^{a}	38.59^{b}	9.00^{e}	0.78	<0.01
Slice lean:fat	4.78^{e}	14.23^{b}	17.11^{a}	7.88^{d}	1.41^{f}	1.68^{f}	11.49^{c}	0.59	<0.01
Cook Yield[4]									
Slice cook yield, %	44.45^{b,c}	48.44^{b}	46.73^{b,c}	46.46^{b,c}	39.56^{d}	42.24^{c,d}	54.76^{a}	1.18	<0.01

[1]Cuts evaluated were beef brisket (IMPS#120; "Brisket"), beef clod heart (IMPS#114E; divided horizontally into 2 halves: silver-skin side ["Clod-S"] and non–silver-skin side ["Clod-NS"]), beef flank (IMPS#193; "Flank"), beef short plate (IMPS#121A; cut into a deboned short-rib half ["Plate-SR"] and navel half ["Plate-N"]), and beef outside flat (IMPS#171B; "Outside Flat").

[2]The maximum standard error of the mean (SEM).

[3]Fatty acid values presented in mg/100 mg total fatty acids. Total saturated fatty acid (SFA) content = C14:0 + C16:0 + C18:0 + C20:0; total monounsaturated fatty acid (MUFA) content = C14:1 n-5 + C16:1 n-7 + C18:1 n-9 + C18:1 n-11; and total polyunsaturated fatty acid (PUFA) content = C18:2 n-6 + C18:3 n-3 + C22:5 n-3.

[4]Slice cook yield = (cooked sliced bacon weight ÷ uncooked sliced bacon weight) × 100%.

[a,b,c]Least-squares means lacking a common superscript letter within a row are different ($P < 0.05$).

IMPS = Institutional Meat Purchase Specification.

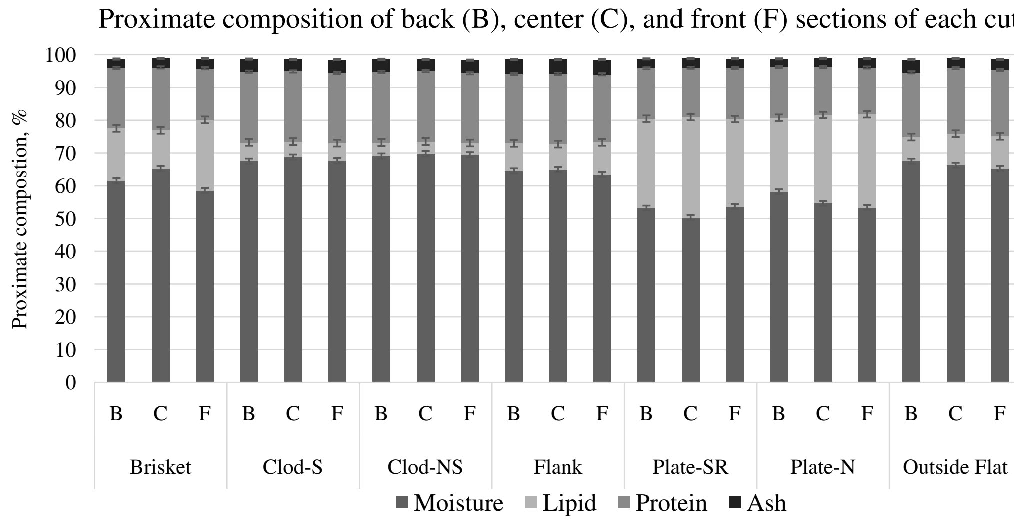

Figure 1. The effect of beef cut on proximate composition of beef bacon slices separated by the back (B), center (C), and front (F) section of each cut.

Percentage of saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs) differed ($P < 0.01$) among cuts. Fatty acid profile is of critical importance for the storage potential of meat products. Irrespective of cut, SFA content of beef bacon was greater, and PUFA content was much less compared with previously reported values for pork bacon, while MUFA content was generally similar to previously reported values for pork bacon. Pork bacon has been reported to have the following fatty acid profile: SFA: 32% to 36%; MUFA: 44% to 50%; and PUFA: 14% to 21% (Kyle et al., 2014; Lowell et al., 2018). Fatty acid profile was evaluated on slices from the back, center, and front section within each cut, which revealed that there was very little variation within the cuts (Figure 2). The following differences ($P < 0.05$) were observed within the cuts: Brisket differed in SFA and MUFA, and Plate-SR differed in PUFA.

The visual properties of packaged, unprepared beef bacon would be among the first properties of the product that consumers would observe when encountering beef bacon in a retail setting. Relative to consumer impressions, the plate seems most similar to traditional bacon in terms of visual appearance. Visual properties would have a critical impact on first impressions and purchase intent of the product, as they can be used to infer the product's nutritional composition, flavor,

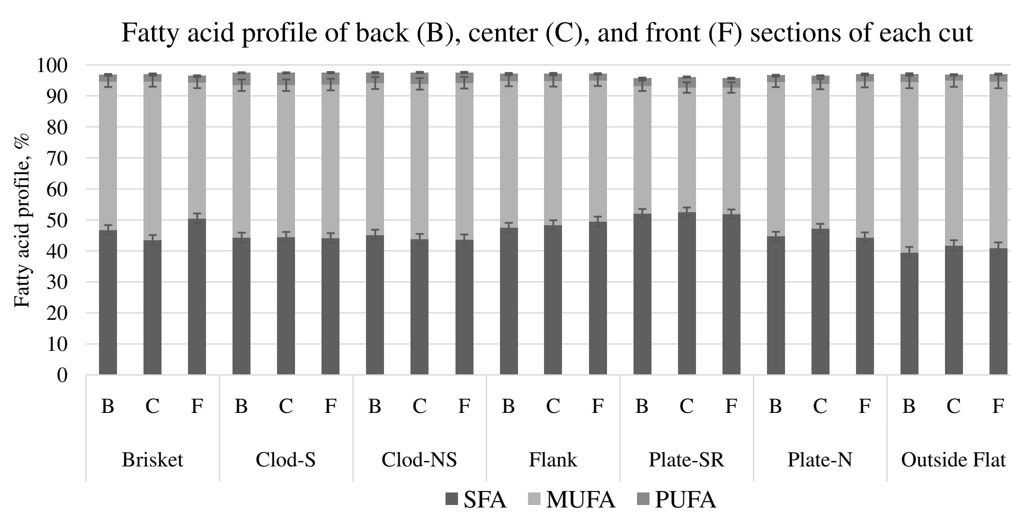

Figure 2. The effect of beef cut on fatty acid profile of beef bacon slices separated by the back (B), center (C), and front (F) section of each cut. Fatty acid values presented in mg/100 mg total fatty acids. Total saturated fatty acid (SFA) content = C14:0 + C16:0 + C18:0 + C20:0; total monounsaturated fatty acid (MUFA) content = C14:1 n-5 + C16:1 n-7 + C18:1 n-9 + C18:1 n-11; and total polyunsaturated fatty acid (PUFA) content = C18:2 n-6 + C18:3 n-3 + C22:5 n-3.

and cooking functionality. Length, width, length: width, total area, lean area, fat area, lean percentage, fat percentage, and lean:fat differed ($P < 0.01$) among cuts evaluated. Slice width and length were obviously influenced by the dimensions of the cuts before processing. Slice width:length of pork bacon was calculated as approximately 5.50 using the least-squares means from a previous study (Kyle et al., 2014). Using this as a standard, all of the cuts in the present study would have lower slice width:length ratios. In addition, the slice width:length was evaluated on slices from the back, center, and front section within each cut, which revealed that there was considerable variation within several of the cuts (Figure 3). Differences ($P < 0.05$) were observed in Brisket, Clod-S, Flank, Plate-N, and Outside Flat. Slice lean:fat was influenced by cut, and these differences were similar to proximate composition. Slice lean:fat of pork bacon was calculated as approximately 1.00 using data from a previous study (Kyle et al., 2014). Using this as a standard, all of the cuts in the present study would have greater slice lean:fat ratios, with some having much greater lean: fat ratios. In addition, the slice lean:fat was evaluated on slices from the back, center, and front section within each cut, which revealed that there was considerable variation within several of the cuts (Figure 4). Differences ($P < 0.05$) were observed in Brisket, Clod-S, Clod-NS, and Outside Flat. Lean:fat in pork

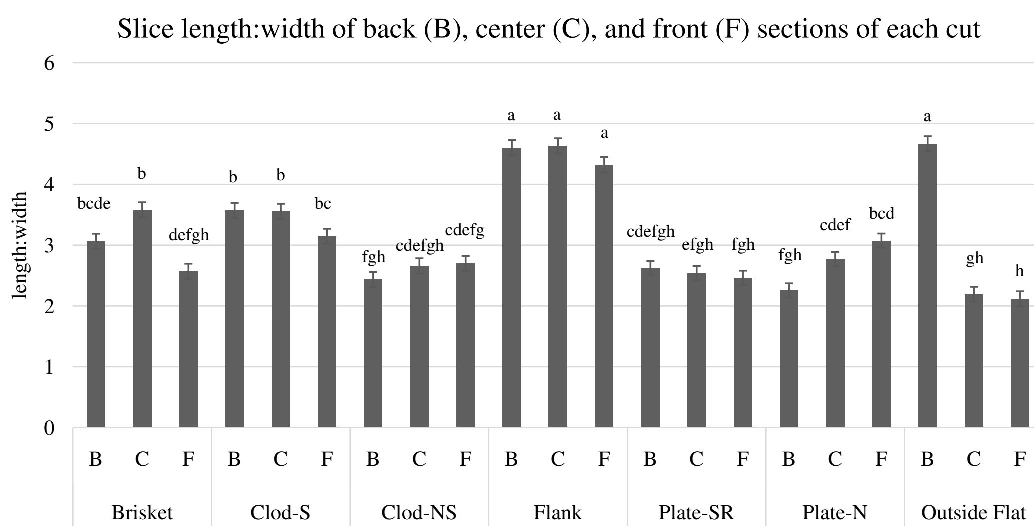

Figure 3. The effect of beef cut on slice length:width as determined by image analysis of beef bacon slices separated by the back (B), center (C), and front (F) section of each cut. [a,b,c]Least-squares means lacking a common superscript letter within a row are different ($P < 0.05$).

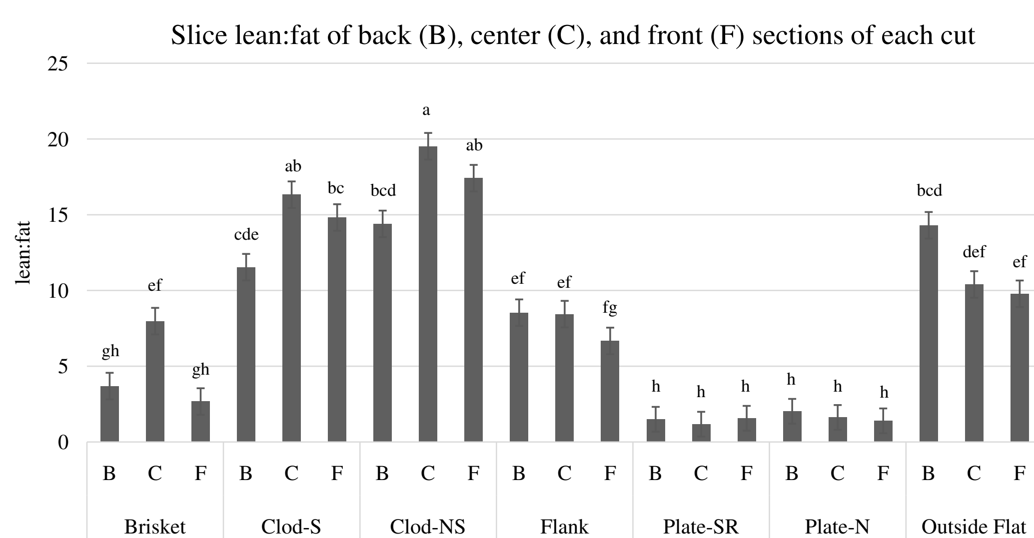

Figure 4. The effect of beef cut on slice lean:fat as determined by image analysis of beef bacon slices separated by the back (B), center (C), and front (F) section of each cut. [a,b,c]Least-squares means lacking a common superscript letter within a row are different ($P < 0.05$).

bacon can vary drastically, with consumers indicating a strong preference for leaner cuts (McLean et al., 2017; Saldaña et al., 2019). A previous study that surveyed consumers for lean percentage preference in pork bacon provided consumers with images of packages of pork bacon ranging from 48% to 81%, with consumers providing greater approval ratings the leaner the bacon was (McLean et al., 2017). With that mentioned, again, the reported averages from a previous study reported lean percentages of approximately 48%–53% and a lean:fat ratio of 1.00 (Kyle et al., 2014). All beef bacon slices averaged well above this range, with the lowest lean percentage being 57% as indicated with image analysis (lean:fat = 1.41), which was sourced from the Plate-SR cut.

Overall, proximate composition and image analysis revealed a clear separation of the cuts used in this study into 2 potential beef bacon product categories: a lean beef bacon product that is approximately 90% lean and fairly homogenous in lean distribution along the different sections of the cut, and a fatty beef bacon product that is approximately 60% lean and more heterogeneous in lean distribution between the front, center, and back sections within the cut. This indicates that 2 different standards of identity may be possible for beef bacon products based on compositional differences. This would certainly be unique for the novel beef bacon products; however, this would not be entirely different than compositional differences observed in streaky bacon (i.e., bacon from the boneless pork belly) and back bacon (i.e., bacon from the boneless pork loin). Greater research efforts are certainly required to determine consumer preference and purchasing habits/attitudes of these 2 categories of beef bacon products as those questions are beyond the scope of this research.

Slice cook yield differed ($P < 0.01$) among cuts, with Outside Flat having the greatest cook yield and Plate-SR having the lowest cook yield. Cook yield was hypothesized to have a strong relationship with the composition of the bacon slices. However, the relationships between slice cook yield and other parameters (slice composition, slice area, and slice lean:fat) were unclear and contradictory. For instance, the Pearson correlation coefficient between lipid content of bacon slices and smokehouse cook yield was moderate and trended in the positive direction ($r = 0.52$; $P < 0.01$), whereas, the Pearson correlation coefficient between lipid content of bacon slices and bacon slice cook yield (cooking loss during final preparation) was strong and trended in the negative direction ($r = -0.70$; $P < 0.01$) (data not presented).

Sensory evaluation

Beef flavor intensity was compared with a reference sample of medium ground beef (approximately 80% lean and 20% fat), perceived muscle fiber toughness and connective tissue amount were compared with a reference sample of thick-cut pork bacon, and oxidative aroma and oxidative flavor were compared on a 1–4 scale (Table 4). In general, beef bacon had greater beef flavor intensity, greater perceived muscle fiber toughness, and less or equal perceived connective tissue amount compared with the reference samples used in this study. Beef flavor intensity was generally twice as great compared with the reference ground beef

Table 4. The effect of beef cut on sensory attributes of beef bacon assessed using a trained sensory panel

	Treatments (cuts)[1]								
	Brisket	Clod-S	Clod-NS	Flank	Plate-SR	Plate-N	Outside Flat	SEM[2]	***P*** value
Beef flavor intensity[3]	1.94	2.17	1.71	2.21	2.13	2.24	2.03	0.15	0.06
Muscle fiber toughness[4]	2.31[a,b]	2.30[a,b]	2.40[a,b]	2.56[a]	2.37[a,b]	1.46[c]	1.88[b,c]	0.17	<0.01
Connective tissue amount[4]	0.60[c,d]	0.70[b,c,d]	0.64[b,c,d]	0.53[d]	0.94[a,b]	1.06[a]	0.88[a,b,c]	0.09	<0.01
Oxidative aroma[5]	1.67	1.62	1.82	1.71	1.66	1.80	1.72	0.23	0.77
Oxidative flavor[5]	1.56[b]	1.90[a,b]	1.97[a,b]	1.84[a,b]	1.67[b]	2.16[a]	1.89[a,b]	0.13	0.01

[1]Cuts evaluated were brisket (IMPS#120), clod heart (IMPS#114E; divided horizontally into 2 halves: silver-skin side [Clod-S] and non–silver-skin side [Clod-NS]), flank (IMPS#193), short plate (IMPS#121A; cut into a deboned short-rib half [Plate-SR] and navel half [Plate-N]), and outside flat (IMPS#171B).

[2]The maximum standard error of the mean (SEM).

[3]Magnitude estimation score relative to a medium ground beef sample anchored at 1.

[4]Magnitude estimation score relative to a thick-cut pork bacon sample anchored at 1.

[5]Oxidative aroma and oxidative flavor were scored on a 1–4 scale, with 1 = no oxidation; 2 = trace amounts of oxidation; 3 = some oxidation; and 4 = major oxidation.

[a,b,c]Least-squares means lacking a common superscript letter within a row are different ($P < 0.05$).

IMPS = Institutional Meat Purchase Specification.

Table 5. The effect of storage day on sensory attributes of beef bacon assessed using a trained sensory panel

	Storage day					
	0	30	60	90	SEM[1]	***P*** value
Beef flavor intensity[2]	2.05	2.07	1.93	2.19	0.13	0.32
Muscle fiber toughness[3]	2.41[a]	2.33[a,b]	1.95[b]	2.05[a,b]	0.15	0.02
Connective tissue amount[3]	0.71	0.75	0.87	0.72	0.08	0.32
Oxidative aroma[4]	1.74	1.73	1.60	1.80	0.10	0.35
Oxidative flavor[4]	1.88	1.83	1.80	1.92	0.10	0.77

[1]The maximum standard error of the mean (SEM).

[2]Magnitude estimation score relative to a medium ground beef sample anchored at 1.

[3]Magnitude estimation score relative to a thick-cut pork bacon sample anchored at 1.

[4]Oxidative aroma and oxidative flavor were scored on a 1–4 scale, with 1 = no oxidation; 2 = trace amounts of oxidation; 3 = some oxidation; and 4 = major oxidation.

[a,b,c]Least-squares means lacking a common superscript letter within a row are different ($P < 0.05$).

sample (medium ground beef; approximately 80% lean and 20% fat). Nonetheless, there was not a difference ($P = 0.06$) in beef flavor intensity among cuts. The perception of muscle fiber toughness differed ($P < 0.01$) among cuts, with Plate-N scoring lower (tougher) compared with all other cuts. Additionally, Outside Flat had lower values for perceived muscle fiber toughness compared with Flank. The perception of connective tissue amount differed ($P < 0.01$) among cuts, with Brisket, Clod-S, Clod-NS, and Flank scoring lower compared with Plate-N. Additionally, Brisket and Flank scored lower for perceived connective tissue amount compared with Plate-SR. Most cuts would be preferential to thick-cut pork bacon in terms of overall texture as the elastic and gummy texture of the connective tissue was reported as the least desirable property of pork bacon (McLean et al., 2017; Saldaña et al., 2019). However, a future consumer evaluation is warranted here to determine whether increased toughness of the muscle fiber component is offset by the lower perception of connective tissue amount and lipid content. Oxidative aroma was not affected ($P = 0.77$) by cut, yet oxidative flavor differed ($P = 0.01$) among cuts. Plate-N had greater oxidative flavor compared with Brisket and Plate-SR.

Samples were evaluated following 0 d, 30 d, 60 d, and 90 d of vacuum-packaged refrigerated storage in an effort to simulate retail settings (Table 5). In general, beef bacon did not undergo greater oxidative aroma or oxidative flavor over the storage period, indicating the feasibility of prolonged storage of beef bacon compared with pork bacon. This could be implied by the study conducted by Lowe et al. (2014), which reported that pork bacon oxidation steadily increased over 90 d of vacuum-packaged refrigerated storage in an effort to simulate retail settings.

Conclusions

Data quantified in this study revealed the differences in the processing, visual, compositional, and sensory properties of beef bacon made with 7 different beef cuts. These data allow the beef industry to tailor their cut selection to an identity most agreeable with the consumer base they wish to target. Leaner cuts also show the possible introduction of new whole-muscle, high-protein, and low–connective-tissue bacon-style products, whereas the higher-fat cuts more closely replicate pork bacon style products. Future work should examine different processing parameters and conduct large-scale consumer panels to identify acceptance within the categories of the higher-fat and leaner cuts used in this study.

Acknowledgments

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Literature Cited

Adhikari, K., E. Chambers IV, R. Miller, L. Vázquez-Araújo, N. Bhumiratana, and C. Philip. 2011. Development of a lexicon for beef flavor in intact muscle. J. Sens. Stud. 26:413–420. https://doi.org/10.1111/j.1745-459X.2011.00356.x.

ASTM. 2008. Standard test method for unipolar magnitude estimation of sensory attributes. In: Annual book of ASTM standards (15.08). American Society for Testing and Materials, Conshohocken, PA. p. 122–131.

Barbut, S. 2016. Poultry products processing: An industry guide. CRC Press, Boca Raton.

Boler, D. D., D. L. Clark, A.A. Baer, D. M. Meeuwse, V. L. King, F. K. McKeith, and J. Killefer. 2011. Effects of increasing lysine on further processed product characteristics from immunologically castrated male pigs. J. Anim. Sci. 89:2200–2209. https://doi.org/10.2527/jas.2010-3641.

Chalupa-Krebzdak, S., and B. M. Bohrer. 2019. A comparison of the composition of beef bacon products sold in southern Ontario, Canada. Meat Muscle Biology. 2(2):72. https://doi.org/10.22175/rmc2018.062.

Christie, W. W., and X. Han. 2010. Lipid analysis: Isolation, separation, identification and lipidomic analysis. Fourth edition. Woodhead Publishing, Cambridge, UK. https://doi.org/10.1533/9780857097866.

Kyle, J. M., B. M. Bohrer, D. D. Boler, A. L. Schroeder, R. J. Matulis, D. D. Boler. 2014. Effects of immunological castration (Improvest) on further processed belly characteristics and commercial bacon slicing yields of finishing pigs. J. Anim. Sci. 92:4223–4233. https://doi.org/10.2527/jas.2014-7988.

Lowe, B. K., B. M. Bohrer, S. F. Holmer, D. D. Boler, and A. C. Dilger. 2014. Effects of retail style or food service style packaging type and storage time on sensory characteristics of bacon manufactured from commercially sourced bellies. J. Food Sci. 79:S1197–S1204. https://doi.org/10.1111/1750-3841.12480.

Lowell, J. E., B. M. Bohrer, K. B. Wilson, M. F. Overholt, B. N. Harsh, H. H. Stein, A. C. Dilger, A. C., and D. D. Boler. 2018. Growth performance, carcass quality, fresh belly characteristics, and commercial bacon slicing yields of growing-finishing pigs fed a subtherapeutic dose of an antibiotic, a natural antimicrobial, or not fed an antibiotic or antimicrobial. Meat Sci. 136:93–103. https://doi.org/10.1016/j.meatsci.2017.10.011.

McLean, K. G., D. J. Hanson, S. M. Jervis, and M. A. Drake. 2017. Consumer perception of retail pork bacon attributes using adaptive choice-based conjoint analysis and maximum differential scaling. J. Food. Sci. 82:2659–2668. https://doi.org/10.1111/1750-3841.13934.

NAMP. 2014. Meat buyer's guide. 8th ed. North American Meat Processors Association (NAMP), Washington, DC.

National Pork Board. 2009. Quick facts: The pork industry at a glance. #09133-12/09. Des Moines, IA. http://porkgateway.org/wp-content/uploads/2015/07/quick-facts-book1.pdf. (Accessed 20 September 2019).

Saldaña, E., L. Saldarriaga, J. Cabrera, J. H. Behrens, M. M. Selani, J. Rios-Mera, and C. J. Contreras-Castillo. 2019. Descriptive and hedonic sensory perception of Brazilian consumers for smoked bacon. Meat Sci. 147:60–69. https://doi.org/10.1016/j.meatsci.2018.08.023.

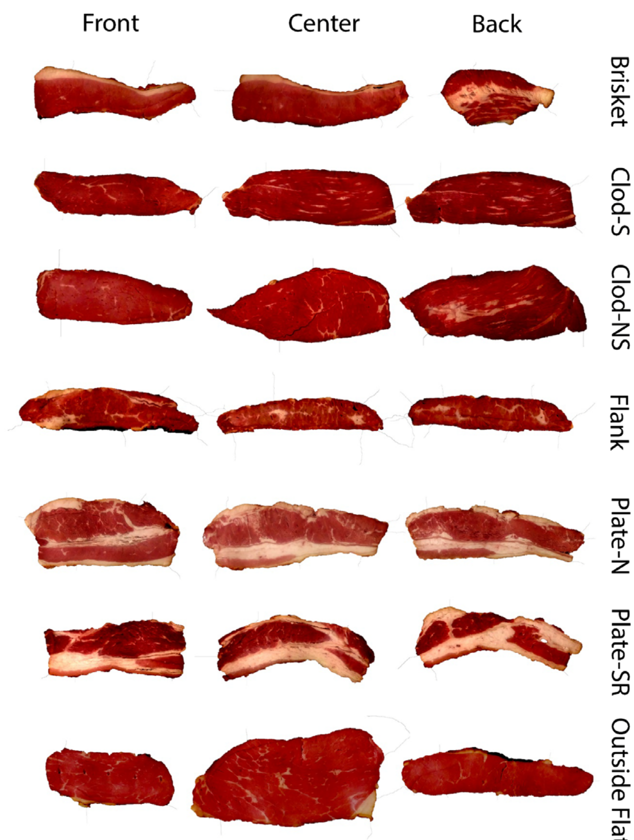
Sivendiran, T., L. M. Wang, S. Huang, and B. M. Bohrer. 2018. The effect of bacon pump retention levels following thermal processing on bacon slice composition and sensory characteristics. Meat Sci. 140:128–133. https://doi.org/10.1016/j.meatsci.2018.03.007.

Tavárez, M. A., B. M. Bohrer, M. D. Asmus, A. L. Schroeder, R. J. Matulis, D. D. Boler, and A. C. Dilger. 2014. Effects of immunological castration and distiller's dried grains with solubles on carcass cutability and commercial bacon slicing yields of barrows slaughtered at two time points. J. Anim. Sci. 92:3149–3160. https://doi.org/10.2527/jas.2013-7522.

USDA. 2005. Food standards and labeling policy book. United States Department of Agriculture-Food Safety and Inspection Service. https://www.fsis.usda.gov/wps/wcm/connect/7c48be3e-e516-4ccf-a2d5-b95a128f04ae/Labeling-Policy-Book.pdf?MOD=AJPERES. (Accessed 24 January 2018). p. 1–202.

USDA. 2013. Bacon and food safety. United States Department of Agriculture-Food Safety and Inspection Service. https://www.fsis.usda.gov/wps/portal/fsis/topics/food-safety-education/get-answers/food-safety-fact-sheets/meatpreparation/bacon-and-food-safety/ct_index. (Accessed 24 January 2018).

Supplementary data



Supplementary Figure 1. Images of slices derived from back, center, and front sections of each cut.

Supplementary Table 1 – The effect of beef cut on proximate composition of beef bacon slices separated by the back (B), center (C), and front (F) section of each cut.[1]

	Brisket			Clod-S			Clod-NS			Flank			Plate-SR			Plate-N			Outside Flat				
	B	C	F	B	C	F	B	C	F	B	C	F	B	C	F	B	C	F	B	C	F	SEM[2]	*P*-value
Moisture, %	61.55^{ef}	65.27^{cd}	58.58^{fg}	67.52^{abc}	68.76^{ab}	67.65^{abc}	69.07^{ab}	69.78^{a}	69.45^{a}	64.53^{cde}	64.94^{cd}	63.47^{de}	53.22^{hi}	50.30^{i}	53.66^{h}	58.21^{g}	54.62^{h}	53.41^{h}	67.49^{abc}	66.24^{bcd}	65.24^{bcd}	0.78	<0.01
Lipid, %	15.98^{c}	11.66^{cd}	21.54^{b}	5.74^{efgh}	4.71^{gh}	5.35^{fgh}	4.10^{gh}	3.71^{h}	3.59^{h}	8.42^{defg}	7.76^{defgh}	9.80^{de}	27.27^{a}	30.66^{a}	26.71^{a}	22.59^{b}	26.98^{a}	28.40^{a}	7.37^{defgh}	9.63^{def}	9.86^{de}	1.04	<0.01
Protein, %	18.45^{d}	19.18^{cd}	15.73^{e}	21.55^{a}	21.41^{a}	21.42^{a}	21.59^{a}	21.48^{a}	21.26^{ab}	21.13^{ab}	21.47^{a}	20.73^{abc}	15.35^{e}	15.06^{e}	15.56^{e}	15.42^{e}	14.61^{e}	14.28^{e}	19.75^{bcd}	20.02^{abcd}	20.22^{abc}	0.35	<0.01
Ash, %	2.69^{f}	2.75^{ef}	2.92^{ef}	3.85^{bc}	3.62^{cd}	4.04^{abc}	3.86^{bc}	3.63^{cd}	4.03^{abc}	4.47^{a}	4.30^{ab}	4.50^{a}	2.87^{ef}	2.78^{ef}	2.82^{ef}	2.51^{f}	2.72^{f}	2.80^{ef}	3.85^{bc}	2.98^{ef}	3.28^{de}	0.19	<0.01

[abc]Least squares means lacking a common superscript letter within a row are different ($P < 0.05$).

[1]Cuts evaluated were beef brisket (IMPS#120, **Brisket**), beef clod heart [IMPS#114E; divided horizontally into two halves; silverskin side (**Clod-S**) and non-silverskin side (**Clod-NS**)], beef flank (IMPS#193; **Flank**), beef short plate [IMPS#121A; cut into a deboned short-rib half (**Plate-SR**) and navel half (**Plate-N**)], and beef outside flat (IMPS#171B; **Outside Flat**).

[2]The maximum SEM (standard error of the mean).

Supplementary Table 2 – The effect of beef cut on fatty acid composition of beef bacon slices separated by the back (B), center (C), and front (F) section of each cut.[1]

	Brisket			Clod-S			Clod-NS			Flank			Plate-SR			Plate-N			Outside Flat				
	B	C	F	B	C	F	B	C	F	B	C	F	B	C	F	B	C	F	B	C	F	SEM[2]	*P*-value
SFA, %	46.73^{abcd}	43.52^{bcd}	50.50^{ab}	44.26^{bcd}	44.48^{bcd}	44.08^{bcd}	45.13^{abcd}	43.84^{bcd}	43.67^{bcd}	47.47^{abc}	48.29^{abc}	49.48^{ab}	52.05^{a}	52.53^{a}	51.89^{a}	44.71^{bcd}	47.26^{abc}	44.27^{bcd}	39.50^{d}	41.73^{cd}	40.86^{cd}	1.87	<0.01
MUFA, %	47.94^{abcde}	51.25^{abc}	43.81^{cdef}	49.20^{abc}	48.98^{abcd}	49.58^{abc}	49.03^{abcd}	50.05^{abc}	50.59^{abc}	47.45^{abcdef}	46.52^{abcdef}	45.53^{bcdef}	41.24^{def}	40.18^{f}	40.82^{ef}	49.80abc	46.58^{abcdef}	50.41^{abc}	55.01^{a}	53.14^{ab}	53.73^{ab}	2.11	<0.01
PUFA, %	2.20^{ef}	2.28^{def}	2.15^{ef}	3.97^{a}	3.96^{a}	3.84^{ab}	3.30^{abcd}	3.68^{ab}	3.29^{abcd}	2.29^{def}	2.41^{cdef}	2.12^{ef}	2.45^{cdef}	3.39^{abc}	2.98^{bcde}	2.14^{ef}	2.62^{cdef}	2.32^{def}	2.58^{cdef}	1.92^{f}	2.39^{cdef}	0.25	<0.01

[abc]Least squares means lacking a common superscript letter within a row are different ($P < 0.05$).

[1]Cuts evaluated were beef brisket (IMPS#120, **Brisket**), beef clod heart [IMPS#114E; divided horizontally into two halves; silverskin side (**Clod-S**) and non-silverskin side (**Clod-NS**)], beef flank (IMPS#193; **Flank**), beef short plate [IMPS#121A; cut into a deboned short-rib half (**Plate-SR**) and navel half (**Plate-N**)], and beef outside flat (IMPS#171B; **Outside Flat**).

[2]The maximum SEM (standard error of the mean).

Supplementary Table 3 – The effect of beef cut on fatty acid profile (presented in mg/100 mg total fatty acids).

	Treatments[1]								
	Brisket	Clod-S	Clod-NS	Flank	Plate-SR	Plate-N	Outside Flat	SEM[2]	*P*-value
C14:0	3.94[a]	3.04[c]	3.09[c]	3.18[c]	3.82[ab]	3.31[c]	3.42[bc]	0.16	<0.01
C14:1 n-5	1.03[ab]	0.51[d]	0.57[cd]	0.64[cd]	0.69[c]	0.87[b]	1.13[a]	0.06	<0.01
C16:0	29.29[ab]	25.58[d]	26.54[d]	29.10[bc]	31.22[a]	27.15[cd]	26.12[d]	0.76	<0.01
C16:1 n-7	4.84[a]	3.42[cd]	3.79[bc]	3.28[d]	3.27[cd]	4.12[b]	5.11[a]	0.24	<0.01
C18:0	13.72[d]	15.60[bc]	14.58[cd]	16.18[ab]	17.07[a]	14.92[bcd]	11.21[e]	0.53	<0.01
C18:1 n-9	39.40[c]	43.35[ab]	43.55[ab]	40.88[bc]	35.06[d]	41.83[abc]	45.13[a]	1.18	<0.01
C18:1 n-11	2.30[ab]	1.97[c]	1.97[c]	1.68[d]	1.66[d]	2.11[bc]	2.49[a]	0.09	<0.01
C18:2 n-6	1.02[c]	3.43[a]	2.95[a]	1.89[b]	1.04[c]	1.53[bc]	1.73[b]	0.16	<0.01
C18:3 n-3	0.06[c]	0.44[a]	0.36[a]	0.23[b]	0.21[b]	0.20[b]	0.41[a]	0.05	<0.01
C20:0	0.02[b]	0.11[a]	0.07[ab]	0.00[b]	0.04[ab]	0.03[b]	0.00[b]	0.02	<0.01
C22:5 n-3	1.13[ab]	0.06[c]	0.12[c]	0.14[c]	1.69[a]	0.63[bc]	0.17[c]	0.20	<0.01

[abc]Least squares means lacking a common superscript letter within a row are different ($P < 0.05$).

[1]Cuts evaluated were beef brisket (IMPS#120, **Brisket**), beef clod heart [IMPS#114E; divided horizontally into two halves; silverskin side (**Clod-S**) and non-silverskin side (**Clod-NS**)], beef flank (IMPS#193; **Flank**), beef short plate [IMPS#121A; cut into a deboned short-rib half (**Plate-SR**) and navel half (**Plate-N**)], and beef outside flat (IMPS#171B; **Outside Flat**).

[2]The maximum SEM (standard error of the mean).