ONTARIO PORK

Final Report (18-003)

Project Title: Assessing carcass variability in Ontario pork and the potential to increase returns to producers and improve pork quality

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Reporting Date: February 2022

Executive Summary (summarize the project and results to date max 250 words):

The value of Canadian pork carcasses is currently assessed by measuring carcass weight and using probe measurements for fat depth and muscle depth to estimate leanness. These data are then incorporated into a grid for producer payment, providing payment incentives for producing desirable pork carcasses and discounts for undesirable carcasses (excessively light/heavy; excessively trim/fat). While this system provides incentives to produce carcasses that fit within desirable ranges for weight and leanness, overall profitability at both the producer and processor level is greatly influenced by consistency/variability. In addition, quality and consumer perception of pork products are also likely affected by consistency/variability. Thus, there exists great opportunity to evaluate variation in carcass and meat quality parameters at the commercial level.

This project has several overlying goals including specific objectives to assess variability in carcass weights and leanness in the Ontario commercial pork industry, to determine relationships of these parameters with pork quality, and to determine influencers of pork quality variability. To date – this project has completed several initiatives surrounding the central goal of determining variability in the Ontario pork industry. There have been three peer-reviewed papers and six conference abstracts prepared in order to share the research findings of this project.

Detailed Description of the Project:

Objective 1) Assess variability in carcass weights and leanness (using multiple evaluation techniques electronic grading probe, advanced ultrasonic image analysis, and actual cutting yields) for pork processed at a commercial Ontario facility. Providing comprehensive carcass data to producers will provide information needed to develop management and marketing strategies to produce more consistent and profitable pork carcasses.

Activities to date) We have published three peer-reviewed papers focusing on the assessment of carcass weight and leanness in Ontario pork. Other research initiatives within this objective are underway to incorporate advanced ultrasonic image analysis and actual cutting yields into these assessments.

Objective 2) Evaluate ultrasonic image analysis to predict intramuscular fat (IMF) content of pork primals. IMF content is associated with perceived pork quality and export demand of pork, so this will enable value added marketing of pork primals from individual carcasses to meet target markets.

Activities to date) No work was done on this objective due to the limitations of the technology available to us.

Objective 3) Determine relationships between carcass weight and leanness with pork quality attributes and eating experience assessed by a trained sensory panel. This objective will tie together variability at the producer and processor level with variability at the consumer level.

Activities to date) No work was done on this objective at this time due to COVID limiting our activities on campus. We are going to attempt to complete this objective in spring, 2022.

Objective 4) Determine relationships between pork quality in the plant (2-days post-mortem) with quality and eating experience from aged pork (14-days post-mortem). This project presents the unique opportunity to evaluate pork quality early post-mortem and after aging.

Activities to date) This has been done but with only preliminary analysis of the data so far.

Objective 5) Determine relationships of loin quality with shoulder, belly, and ham quality. There are initiatives for the pork industry to implement a quality-based grading system. An important consideration here is where quality should be evaluated, or how well quality assessment of the loin relates to quality assessment of other primals within the pork carcass.

Activities to date) This has been conducted on a limited basis due to COVID.

Summary of the results to date:

Study 1:

The Zhou et al. (2019) study aimed to offer clarification on pig sort loss and associated marketing strategies using a simulated pig marketing model that contemplates both the carcass weight and the predicted leanness of the pig. The objective was to investigate economic variability associated with marketing strategies using simulated pig marketing models. The simulation considered six producers with the presumption that each had a maximum capacity for 4,800 grow-finish pigs, in an attempt to imitate commercial finishing barns with 48 pens of roughly 100 pigs per pen. Under the assumption that variability decreased with the addition of each marketing cut, the simulation incorporated a standard deviation reduction of 20% per increase of one marketing cut for both carcass weight and predicted leanness of the population of pigs marketed. Consequently, it was found that there was an increase in profitability; as well as, a decrease in pig sort loss (defined with both carcass weight and predicted leanness) with each marketing cut, but these improvements would diminish with each additional marketing cut.

Estimated average market premium (US$) of six different marketing phase strategies of pigs using a simulated pig marketing model[a,b].

Day of production when marketed	Producer 1	Producer 2	Producer 3	Producer 4	Producer 5	Producer 6
115 days				$ 5.57 ($12.85)	$ 6.25 ($14.44)	$ 6.55 ($15.09)
120 days			$ 4.67 ($10.68)	$ 5.50 ($12.54)	$ 6.23 ($14.39)	$ 6.54 ($15.09)
122 days		$ 3.35 ($7.76)				$ 6.49 ($14.96)
125 days	$ 1.60 ($3.93)		$ 4.65 ($10.61)		$ 6.14 ($13.96)	
128 days		$ 3.28 ($7.60)				$ 6.51 ($14.83)
130 days			$ 4.53 ($10.33)	$ 5.52 ($12.51)	$ 5.89 ($13.11)	$ 6.16 ($13.70)
135 days				$ 5.03 ($11.15)	$ 6.27 ($13.83)	$ 5.49 (11.87)
Sum of premiums, $	$ 18,861.79	$ 36,863.41	$ 50,585.31	$ 59,291.84	$ 66,943.06	$ 68,435.91
Percent improvement compared to Producer 1, %	-	95.44%	168.19%	214.35%	254.91%	263.83%
Percent improvement compared to Producer 2, %	-	-	37.22%	60.84%	81.16%	85.65%
Percent improvement compared to Producer 3, %	-	-	-	17.21%	32.34%	35.29%
Percent improvement compared to Producer 4, %	-	-	-	-	12.90%	15.42%
Percent improvement compared to Producer 5, %	-	-	-	-	-	2.23%

[a]Costs were calculated using the example of the marketing grid (Table 8) and the pig simulation model for each marketing group.
[b]Data are presented as average premium/cwt (45.4 kg) with the average premium/pig in parentheses.

Study 2:

The Barducci et al. (2020) study aimed to examine the correlation of carcass weight, fat depth, muscle depth, and predicted lean yield in commercial pigs. Data were collected on 850,819 pork carcasses from the same pork processing facility between October 2017 and September 2018. Hot carcass weight was reported following slaughter as a head-on weight; while fat and muscle depth were measured with a Destron PG-100 probe and used for the calculation of predicted lean yield based on the Canadian Lean Yield (CLY) equation [CLY (%) = 68.1863 – (0.7833 × fat depth) + (0.0689 × muscle depth) + (0.0080 × fat depth^2) – (0.0002 × muscle depth^2) + (0.0006 × fat depth × muscle depth)]. Descriptive statistics, regression equations including coefficients of determination, and Pearson product moment correlation coefficients (when assumptions for linearity were met) and Spearman’s rank-order correlation coefficients (when assumptions for linearity were not met) were calculated for attributes using SigmaPlot, version 11 (Systat Software Inc., San Jose, California, USA). Weak positive correlation was observed between hot carcass weight and fat depth ($r = 0.289$; $P < 0.0001$), and between hot carcass weight and muscle depth ($r = 0.176$; $P < 0.0001$). Weak negative correlations were observed between hot carcass weight and predicted lean yield ($r = -0.235$; $P < 0.0001$), and between fat depth and muscle depth ($r = -0.148$; $P < 0.0001$). Upon investigation of relationships between fat depth and predicted lean yield, and between muscle depth and predicted lean yield using scatter plots, it was determined that these relationships were not linear and therefore the assumptions of Pearson product moment correlation were not met. Thus, these relationships were expressed as non-linear functions and Spearman’s rank-order correlation coefficients were used. A strong negative correlation was observed between fat depth and predicted lean yield ($r = -0.960$; $P < 0.0001$), and a moderate positive correlation was observed between muscle depth and predicted lean yield ($r = 0.406$; $P < 0.0001$). Results from this dataset revealed that hot carcass weight was generally weakly correlated ($r < |0.35|$) with fat depth, muscle depth, and predicted lean yield. Therefore, it was concluded that there were no consistent weight thresholds where pigs were fatter or heavier muscled.

Results from this study suggest that there is a high level of variation in carcass weight and leanness parameters in the Ontario pork industry. When the relationship among parameters were evaluated without taking into account the individual pig variation, carcass weight was generally weakly correlated with fat depth, muscle depth, or predicted lean yield. Thus, it can be concluded that pigs do not reach a weight threshold where they consistently become fatter or heavier muscled.

Population summary statistics for carcass traits (n = 850,819 carcasses).

Carcass traits	Mean	SD[1]	Minimum	Maximum
Hot carcass weight, kg	106.30	8.51	44.60	165.80
Fat depth[2], mm	18.11	4.04	4.00	46.00
Muscle depth[2], mm	66.47	8.88	25.00	85.00
Predicted lean yield[3], %	61.13	1.90	52.20	69.80

[1] Standard deviation.

[2] Measured at the 3rd and 4th last rib, and 7 cm off the mid-line.

[3] Predicted lean yield was calculated using the following equation: CLY = (%) = 68.1863 – (0.7833 × fat depth) + (0.0689 × muscle depth) + (0.0080 × fat depth^2) – (0.0002 × muscle depth^2) + (0.0006 × fat depth × muscle depth).

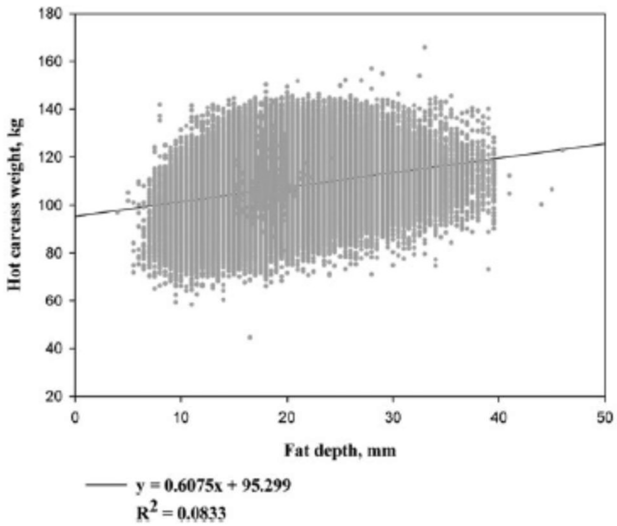


Figure 1. Prediction of hot carcass weight using fat depth as the independent variable (N = 850,819 carcasses).

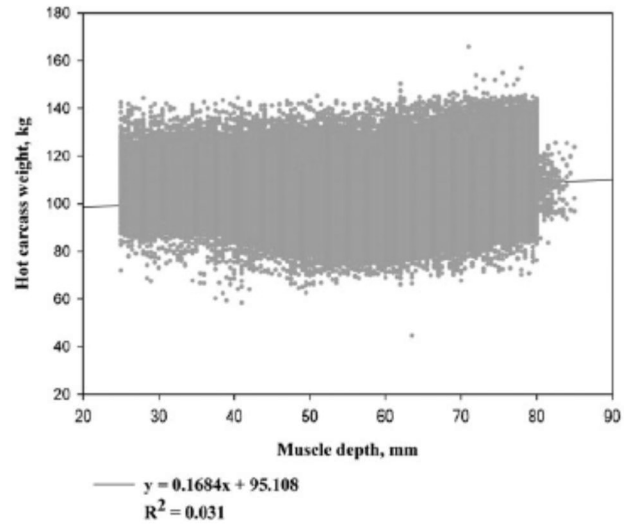


Figure 2. Prediction of hot carcass weight using muscle depth as the independent variable (N = 850,819 carcasses).

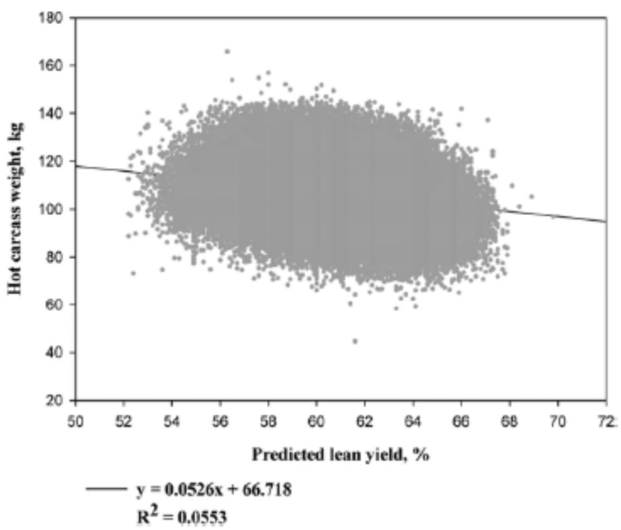


Figure 3. Prediction of hot carcass weight using predicted lean yield as the independent variable (N = 850,819 carcasses).

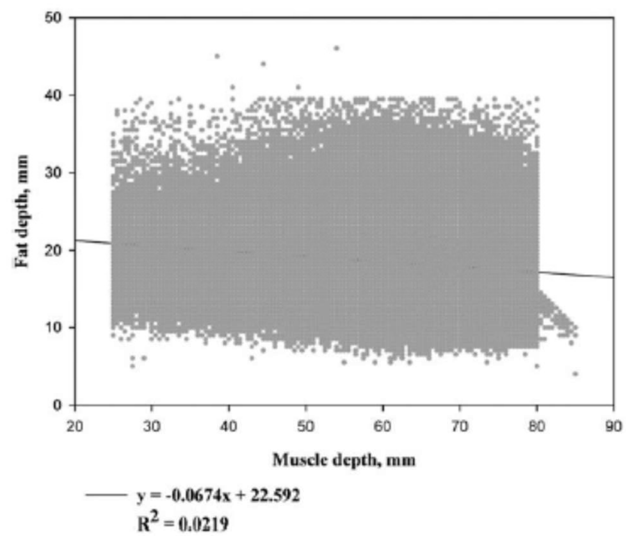
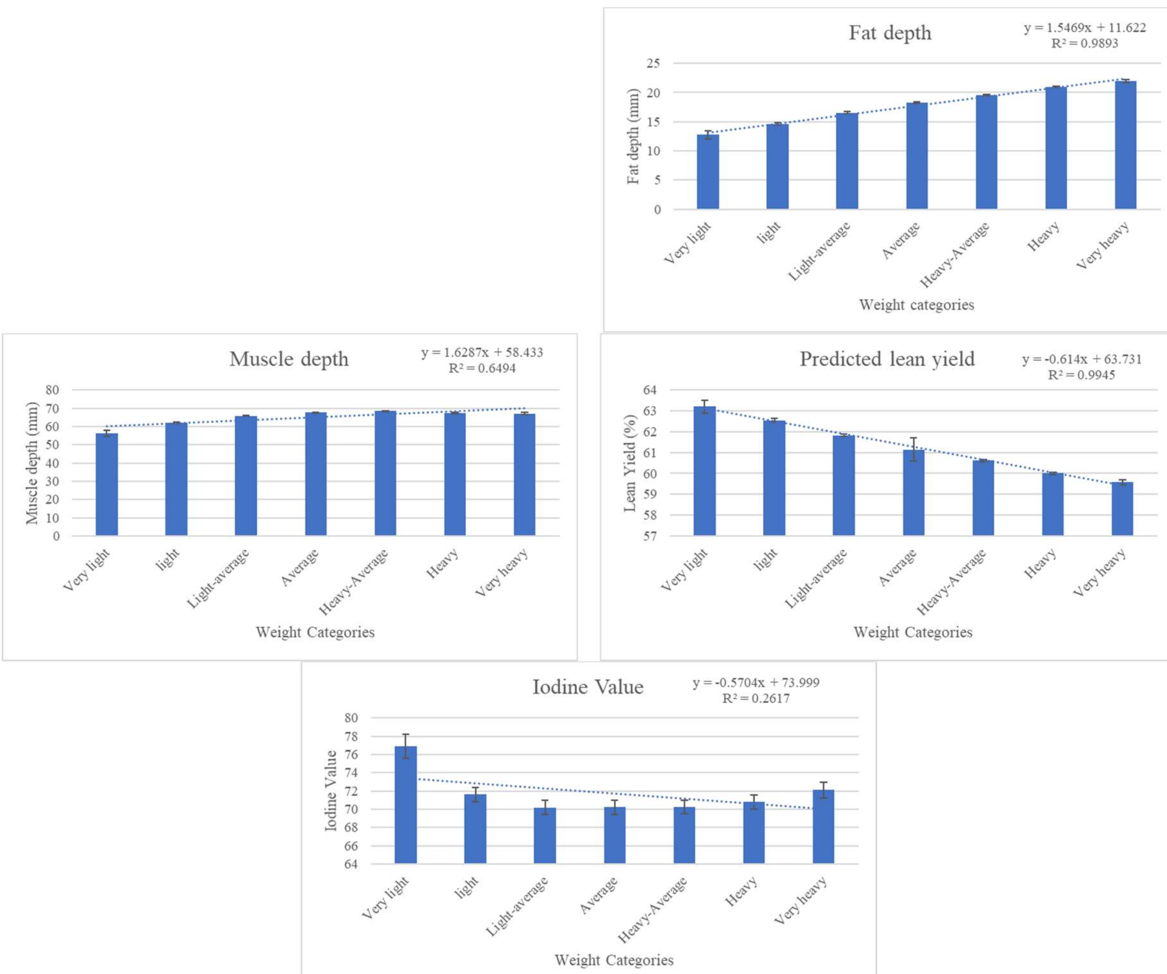


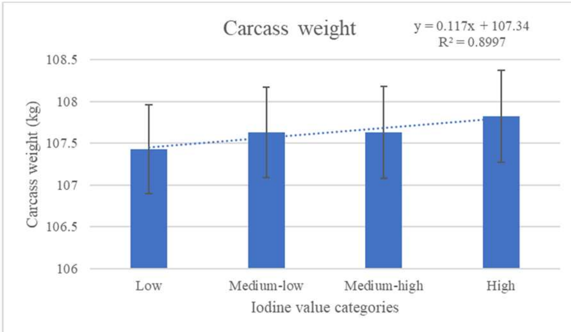
Figure 4. Prediction of fat depth using muscle depth as the independent variable (N = 850,819 carcasses).

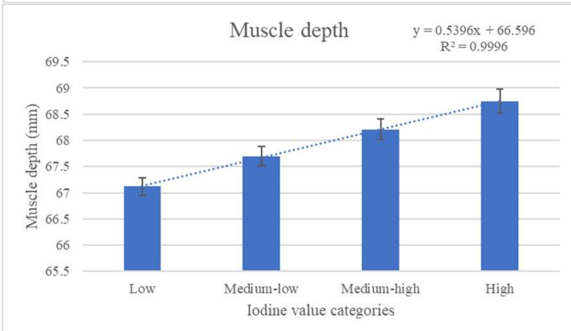
Study 3:

This study examined the relationships among various carcass parameters, specifically carcass weight and iodine value. Data (carcass weight, fat depth, muscle depth, predicted leanness, and iodine value) were collected from 37,488 pork carcasses slaughtered in a commercial pork processing facility located in Ontario during November 2019. The data were first analyzed using simple correlation, and weak correlation coefficients (r < |0.32|) were found between all attributes. Data were then further categorized into meaningful ranges using carcass weight and iodine value. The categories for carcass weight were determined based on 10-kg weight increments beginning at 70.0 kg and ending at 139.9 kg. The categories for iodine value were defined as low (<70), medium-low (70 – 75), medium-high (75 – 80), and high (>80). Eventually, it was concluded that categorical analysis provided stronger correlations as compared to the traditional correlation analysis. Furthermore, when pig carcasses were categorized based on weights in 10-kg increments, heavier carcasses were fatter, heavier muscled, and had a lower predicted percentage lean. Additionally, when pig carcasses were categorized based on iodine value categories, it was concluded that carcasses with greater iodine value were heavier in weight, trimmer, heavier muscled, and had a greater predicted lean yield.



Figures illustrate carcass weight categorized by weight, fat depth categorized by weight, muscle depth categorized by weight, predicted lean yield categorized by weight, and iodine value categorized by weight.





Figures illustrate carcass weight categorized by iodine value, fat depth categorized by iodine value, muscle depth categorized by iodine value, predicted lean yield categorized by iodine value, and iodine value categorized by iodine value.

Study 4: This study was conducted to calibrate an advanced ultrasonic technology (AutoFom III) that scans the entire carcass based on North American cutting specifications for use in a Canadian packing plant for estimating lean yield information for producer settlement. A second objective was to compare the ability of the AutoFom III to predict lean yield versus a commonly used electronic grading probe (Destron PG-100; International Destron Technologies) that predicts lean yield based on fat and muscle depth measurements at one location in the carcass. These lean yield predictions were compared to manual cutting yields from fabricating pork carcass sides according to North American cutting specifications. From approximately April, 2020 to April, 2021 approximately 400 pig carcasses were used to examine the relationships between lean yield determined using the Destron PG-100 optical probe (the standard method for measuring lean yield in many Canadian packing plants), AutoFom III (ultrasound technology that scans the entire carcass for determining lean yield), and a manual cutout of one side from each carcass. In addition, a comprehensive evaluation of meat quality was conducted on the loin from each pig. Results from the study can be found in the table on the following page in which there were no differences ($P > 0.05$) in back fat measurements regardless of the method used. Muscle depths were underpredicted ($P < 0.05$) using the Destron PG-100 and AutoFom III versus manual measurements. There were no differences ($P > 0.05$) in back fat thickness or loin muscle depths between the Destron PG-100 and AutoFom III. Lean yield was over predicted ($P < 0.05$) using the Destron PG-100 and AutoFom III versus a manual cut-out, with greater

(P < 0.05) lean yields using the the Destron PG-100 versus AutoFom III. These results are interesting when considering how packing plants use lean yield information for producer settlement.

Method of measurement differences in back fat thickness, muscle depth, and lean yield						
	Method of Measurement				P-values	
Trait	Cut-out	Destron PG-100	AutoFom III	SEM	Method	Sex × Method interaction
Back fat thickness, mm	17.0^{a}	17.1^{a}	16.7^{a}	0.34	0.2582	0.6682
Muscle depth, mm	70.6^{a}	68.8^{b}	68.5^{b}	0.38	<.0001	0.0834
Lean yield, %	56.2^{c}	61.8^{a}	58.4^{b}	0.28	<.0001	<.0001

A sex by method interaction was present for lean yield (P < 0.0001) as shown in the following table. For each sex, lean yield values were greatest ($P < 0.05$) when the trait was determined using the Destron PG-100 and lowest when using a manual cut-out, with AutoFom III values intermediate to the Destron PG-100 values and the manual cut-out values. While the Destron PG-100 lean yield value for barrows was similar ($P \geq 0.05$) to the AutoFom III lean yield value for gilts, the Destron PG-100 lean yield value for gilts differed ($P < 0.05$) from the AutoFom III lean yield value for barrows. In addition, there were smaller sex differences in lean yield using Destron probe technology than sex differences in lean yield determined using a manual cut-out or the AutoFom III technology.

Method of Measurement by Sex (Barrows, Gilts) Interaction in Lean Yield (P < 0.0001)						
Cut-out		Destron PG-100		AutoFom III		
Barrow	Gilt	Barrow	Gilt	Barrow	Gilt	SEM[4]
54.7^{e}	57.7^{c}	61.1^{b}	62.4^{a}	56.5^{d}	60.3^{b}	0.33

Destron PG-100 lean yield values explained 66% ($R^2 = 0.66$) of the variation for lean yield (RMSE = 2.22%) as determined by the manual cut-out while the AutoFom III had a greater prediction accuracy, explaining 77% of the variation for lean yield. The R^2 values comparing the manual cut-out versus the Destron PG-100 or the AutoFom III were considered strong ($R^2 = 0.88$ and 0.86 respectively) for predicting back fat thickness with low prediction errors (RMSE of 1.63 and 1.74 respectively). Both technologies were very poor for predicting loin muscle depths with an R^2 of 0.25 and RMSE = 4.69% for the Destron PG-100 and an R^2 of 0.32 and RMSE = 4.46% for the AutoFom III although prediction accuracy was greater for the AutoFom III than the Destron PG-100.

Strong inverse relationships ($r > -0.85$; $P < 0.05$) were present between measures of fat thickness and measures of lean yield using all methods of measurement. Back fat ruler thickness was better correlated to AutoFom III muscle depth ($r = -0.49$; $P < 0.05$) than to Destron PG-100 muscle depth ($r = -0.10$; $P > 0.05$). While ruler muscle depth measurements were weakly correlated with lean yield predicted using the Destron PG-100 ($r = 0.26$; $P < 0.05$), there were moderate correlations ($r \leq 0.38$; $P < 0.05$) with cut-out calculated lean yield and lean yield predicted using the AutoFom III. There were strong correlations ($r \geq 0.68$) between actual cut-out lean yield and most Destron PG-100 and AutoFom III parameters. Both the AutoFom III and Destron PG-100 technologies overestimated lean yield which would benefit the producer with the current system that rewards producers for greater carcass lean yield. The AutoFom III improved accuracy for determining lean yield with the advantage of accurately predicting primal weights compared with the Destron PG-100.

Knowledge Transfer:

- **Presentation, poster or abstract from a scientific or industry meeting (copies provided):**

Presentations to industry partners:

Bohrer, B.M. and Z.Y Zhou. 2020. Pork carcass variation and its impact on pork quality. Seminar at Conestoga Meat Packers. Breslau, Ontario. February 25, 2020.

Zhou, Z.Y. and B.M. Bohrer. 2020. The relationship of pork carcass weight, leanness parameters, and iodine values in the Ontario commercial industry. Seminar at Conestoga Meat Packers. Breslau, Ontario. February 25, 2020.

Presentations at scientific or industry meetings:

Zhou, Z.Y., and B.M. Bohrer. 2020. The relationship of pork carcass weight, leanness parameters, and iodine value in the Ontario commercial pork industry. ICoMST/RMC 2020. Virtual Meeting. Meat and Muscle Biology. 5(2). https://doi.org/10.22175/mmb.11683

Barducci, R.S., Z.Y. Zhou, D. Tulpan, and B.M. Bohrer. 2019. Relationship between carcass weight, muscle, fat, and predicted lean yield for commercial pigs in Ontario. Reciprocal Meat Conference 2019. Fort Collins, Colorado. Meat and Muscle Biology. 3(2): 107. https://doi.org/10.22175/mmb.10791

Zhou, Z.Y., and B.M. Bohrer. 2019. Defining pig sort loss with a simulation of various marketing options of pigs with the assumption that marketing cuts improve variation in carcass weight and leanness. ASAS Midwest Section Meetings 2019. Omaha, Nebraska. Journal of Animal Science. 97 (Supp. 2): 228-229. https://doi.org/10.1093/jas/skz122.402

Zhou, Z.Y., and B.M. Bohrer. 2020. Analysis of pork carcass weight and leanness parameters in the commercial pork industry. Banff Pork Seminar 2020. Banff, Alberta.

Zhou, Z.Y., and B.M. Bohrer. 2019. Defining pig sort loss with a simulation of various marketing options of pigs with the assumption that marketing cuts improve variation in carcass weight and leanness. Ontario Swine Research Network University of Guelph Swine Research Day 2019, Guelph, Ontario.

Barducci, R.S., Z.Y. Zhou, D. Tulpan, and B.M. Bohrer. 2019. Relationship between carcass weight, muscle, fat, and predicted lean yield for commercial pigs in Ontario. Ontario Swine Research Network University of Guelph Swine Research Day 2019, Guelph, Ontario.

- **Popular Press Articles and communications (copies provided):**

Peer-reviewed journal articles:

Zhou, Z.Y., L. Wormsbecher, C. Roehrig, M. Smetanin, and B.M. Bohrer. 2021. The relationship of iodine value with pork carcass weight and composition. Canadian Journal of Animal Science. 101(2): 395-399. https://doi.org/10.1139/cjas-2020-0119

Barducci, R.S., Z.Y. Zhou, L. Wormsbecher, C. Roehrig, D. Tulpan, and B.M. Bohrer. 2020. The relationship of pork carcass weight and leanness parameters in the Ontario commercial pork industry. Translational Animal Science. 4(1): 331-338. https://doi.org/10.1093/tas/txz169

Zhou, Z.Y., and B.M. Bohrer. 2019. Defining pig sort loss with a simulation of various marketing options of pigs with the assumption that marketing cuts improve variation in carcass weight and leanness. Canadian Journal of Animal Science. 99(3): 542-552. https://doi.org/10.1139/CJAS-2018-0195

- **Student Theses (copies provided):**

Dorleku, J.B. 2021. Comparison of multiple techniques to determine saleable lean yield in pork carcasses. University of Guelph MSc Thesis. https://atrium.lib.uoguelph.ca/xmlui/handle/10214/26496

Zhou, Z.Y. 2020. Assessing variation in carcass weight and leanness of Ontario pork. University of Guelph MSc Thesis. https://atrium.lib.uoguelph.ca/xmlui/handle/10214/18063

ONTARIO PORK

Ontario Pork Research Final Report (Project #OPPMB 18-003) Executive Summary

Reporting Date: January 31st, 2023

Introduction: The overall goal was to evaluate the impact of carcass traits commonly such as weight, subcutaneous fat thickness, and intramuscular fat on the Canadian consumers pork eating quality perception.

Materials and Methods: A total of 340 untrained panelists received a package containing four sorted pork chops, including two chops from barrow carcasses and two chops from gilt carcasses. Information about the carcasses producing the pork chops were recorded, including carcass weight, back fat thickness, and intramuscular fat content. The pork chops were prepared from the butt and ham ends of the loin with each participant receiving four pork chops from the same anatomical location. Participants were asked to complete and submit a survey regarding the individual cooking method, cooking time, and degree of doneness used to prepare each pork chop. The pork chops were individually rated for pork eating quality by all participants using an 8-point categorical intensity scale for their perception of tenderness, juiciness, flavor, and overall acceptability.

Results: A preliminary analysis of the data revealed that carcass weight, intramuscular fat content, backfat thickness influenced consumer perception of pork eating quality traits. Cooking time also played an important role in how consumers rated eating quality of the pork chops. Due to the interaction of cooking time with the pork eating quality traits that were evaluated, several statistical approaches have been used to develop the most appropriate models to interpret the results more accurately.

Conclusions: Our exploratory descriptive analysis demonstrated that carcass weight had the major effect on the consumers eating quality perception of pork, followed by intramuscular fat and backfat thickness. Due to the complexity of the dataset, we are currently testing several statistical approaches to allow a clear understanding of how these traits affects the consumer perception.

ONTARIO PORK

Ontario Pork Research Final Report (Project #OPPMB 18-003)

Date: January 31st, 2023

1. Introduction

The pig breeding programs for increasing lean yield and feed efficiency have resulted in limited amount of fat in the carcass, which can implicate the consumer satisfaction as fat content plays an important role on pork eating quality (tenderness, juiciness, flavor, overall acceptability) [1,2]. These changes to the pig carcass and efficiency in pork production may have implications on consumer satisfaction when they eat pork as intramuscular fat plays an important role on pork eating quality [1,2]. Since studies have found pork eating quality to be positively correlated to intramuscular fat (IMF) content**,** future genetic selection programs may target increasing IMF deposition in the carcass [3,4] along with improving carcass grading classification and increasing payments for pig producers [5]. Thus, there is a growing interest in the pig industry to find out whether carcass fatness affects consumer perceptions and preferences for the pork they consume.

It has been shown that a greater fat content in the carcass improves sensory or eating quality traits (tenderness, juiciness, flavor, and acceptability) for pork [6]. However, most of the studies used taste panels with trained panelists that were taught to objectively evaluate pork eating quality for pork that was prepared using one standard cooking method to attain a specific degree of doneness, which may not represent the global preferences of consumers who regularly eat pork. Thus, use of a consumer panel where consumers can prepare pork in the manner they prefer may provide more information for determining which carcass quality traits have the greatest influence on pork eating quality, and lead to better decision-making within the pork industry to ensure acceptable pork eating quality. The objective of this project was to conduct a consumer panel by Canadian consumers aiming to evaluate the effect of carcass fatness on pork eating quality.

2. Material and Methods

2.1. Consumer evaluation of pork chops

A total of 340 untrained panelists received a package containing four pork chops including two chops from barrow carcasses and two chops from gilt carcasses. Panelists were recruited from the Guelph community with the major requirement for participation being that participants regularly consume pork. Extensive knowledge was known about the carcasses producing the pork chops including genetics, size of the carcass, amount of carcass fatness, and intramuscular fat content. The pork chops were prepared from the butt and ham ends of the loin with each participant receiving pork chops from the same anatomical location.

Participants were asked to complete and submit a survey regarding the individual cooking method, use of seasonings/sauces, cooking time, and degree of doneness used to prepare each pork chop. Participants received instructions regarding how to record the information they would need to provide in their feedback along with a cooked pork colour guide to help them identify the degree of doneness level for the pork they prepared. The participants were able to evaluate pork eating quality through answering a survey regarding exact cooking method/degree of doneness used, and how each pork chop rated in terms of tenderness, juiciness, flavor, and overall acceptability, using an 8-point categorical intensity scale. The eating quality ratings included: Tenderness level, from 1 = Tough to 8 = Tender; Juiciness level, from 1 = Dry to 8 = Juicy; Flavor level, from 1 = Unpork-like to 8 = Pork-like; and Overall acceptability, from 1 = Dislike to 8 = Like.

2.2.Data analysis

Data analyses to date include exploratory descriptive analysis (EDA) of the database containing all consumer panel responses received. This first evaluation is important because it provides an overview of potential imbalances for qualitative variables (i.e., the number of responses for each category), and to define the possible paths to follow regarding the inferential analyses. In addition to the descriptive analyzes obtained in the EDA, models were also created through a random forest approach for each target variable (flavor, tenderness, juiciness, and overall acceptability). Based on these models, graphs of relative importance were designed to understand which variables (including the carcass traits) have the most impact for each pork eating quality traits evaluated by the participants.

3. Results

The packages were distributed from May to October 2022. Although we initially intended to have a short time-frame to distribute all packages, there were challenges distributing the packages due to the pandemic. Once all packages were distributed, each participant's feedback was monitored with a minimum threshold of receiving 50% of responses used to receive feedbacks before data analysis could begin. From the total of 340 packages distributed, 182 participants submitted completed surveys evaluating pork eating quality (53.5% response rate), totaling 728 observations (Table 1). Since there was missing data for variables such as "degree of doneness" and "cooking method", the total data were unbalanced, which impaired the statistical analysis. To improve the data balance, observations of "medium rare" as degree of doneness, and observations of air fryer, indoor grilling, and roasting for cooking methods were removed due to their lower prevalence in the data set prior to the random forest analysis. As a result, the number of observations decreased from 728 to 646. However, carcass data information for the pork chops used in the random forest analysis were not altered after filtering the data as presented in Table 2.

The results revealed that carcass weight, loin intramuscular fat, backfat thickness and cooking time were the variables that had the greatest impact on pork eating quality attributes (flavor, tenderness, juiciness, and overall acceptability) (Figure 1), demonstrating that carcass traits arising from current Canadian pork production practices can impact consumer ratings for pork eating quality. In contrast, degree of doneness, cooking method, loin cut anatomical position and gender have lower impact on how consumers rate pork eating quality.

4. Conclusions

Results of exploratory descriptive analysis revealed that carcass weight, loin intramuscular fat, backfat thickness affects the perception of untrained panelists regarding pork eating quality. We are currently evaluating different statistical approached that would be applicable to the complexity of the data acquired in the study to understand how these traits affects the consumers' perception. We expect to finish the statistical analysis by end of February 2023, and a scientific article will be submitted to the journal, Meat Science by the end of March.

5. References (by DOI)

[1] DOI: 10.1111/asj.13515; [2] DOI: 10.1016/j.animal.2021.100402; [3] DOI: 10.1093/jas/skz247;

[4] DOI: 10.3390/foods11152280; [5] DOI: 10.1071/AN17360; [6] DOI: 10.1016/j.meatsci.2007.04.001

Table 1. Data summary of survey responses. Unfiltered data includes data from all consumer responses that were received; Filtered data excludes data where consumer responses included "medium rare" for degree of doneness, and observations of air fryer, indoor grilling, and roasting for cooking method.

Item		**Unfiltered data**	**Filtered data**
Total packages (n)		182	162
Total chops (n)		728	646
Gender	Barrow	365 (50.4%)	320 (49.5%)
	Gilt	363 (49.9%)	326 (50.5%)
Loin cut position	Ham	540 (74.2%)	483 (74.8%)
	Butt	188 (25.8%)	163 (25.2%)
Doneness	Well done	321 (44.1%)	294 (45.5%)
	Medium well	243 (33.4%)	228 (35.3%)
	Medium	128 (17.6%)	124 (19.2%)
	Medium rare	36 (4.9%)	-
Cooking method	Grilling	306 (42.0%)	289 (44.7%)
	Fry pan	256 (35.2%)	237 (36.7%)
	Oven broil	120 (16.5%)	120 (18.6%)
	Air fryer	40 (5.5%)	-
	Indoor grilling	4 (0.5%)	-
	Roasting	2 (0.3%)	-

Table 2. Carcass data information for pig carcasses used to provide the pork chops that were evaluated by untrained panelists. Unfiltered data includes data from all consumer responses that were received; Filtered data excludes data where consumer responses included "medium rare" for degree of doneness, and observations of air fryer, indoor grilling, and roasting for cooking method.

Item	**Unfiltered data**[z]			**Filtered data**[z]		
	Mean ± SD	**Max**	**Min**	**Mean ± SD**	**Max**	**Min**
Hot carcass weight (kg)	107.2 ± 7.6	138.0	89.4	107.3 ± 7.7	138.0	89.4
Backfat thickness (mm)	17.0 ± 4.3	34.0	9.0	17.0 ± 4.3	34.0	9.0
Carcass yield (%)	61.8 ± 2.0	66.3	56.0	61.8 ± 2.0	66.3	56.0
Loin IMF (%)	2.2 ± 1.0	7.7	0.7	2.2 ± 0.9	7.7	0.7

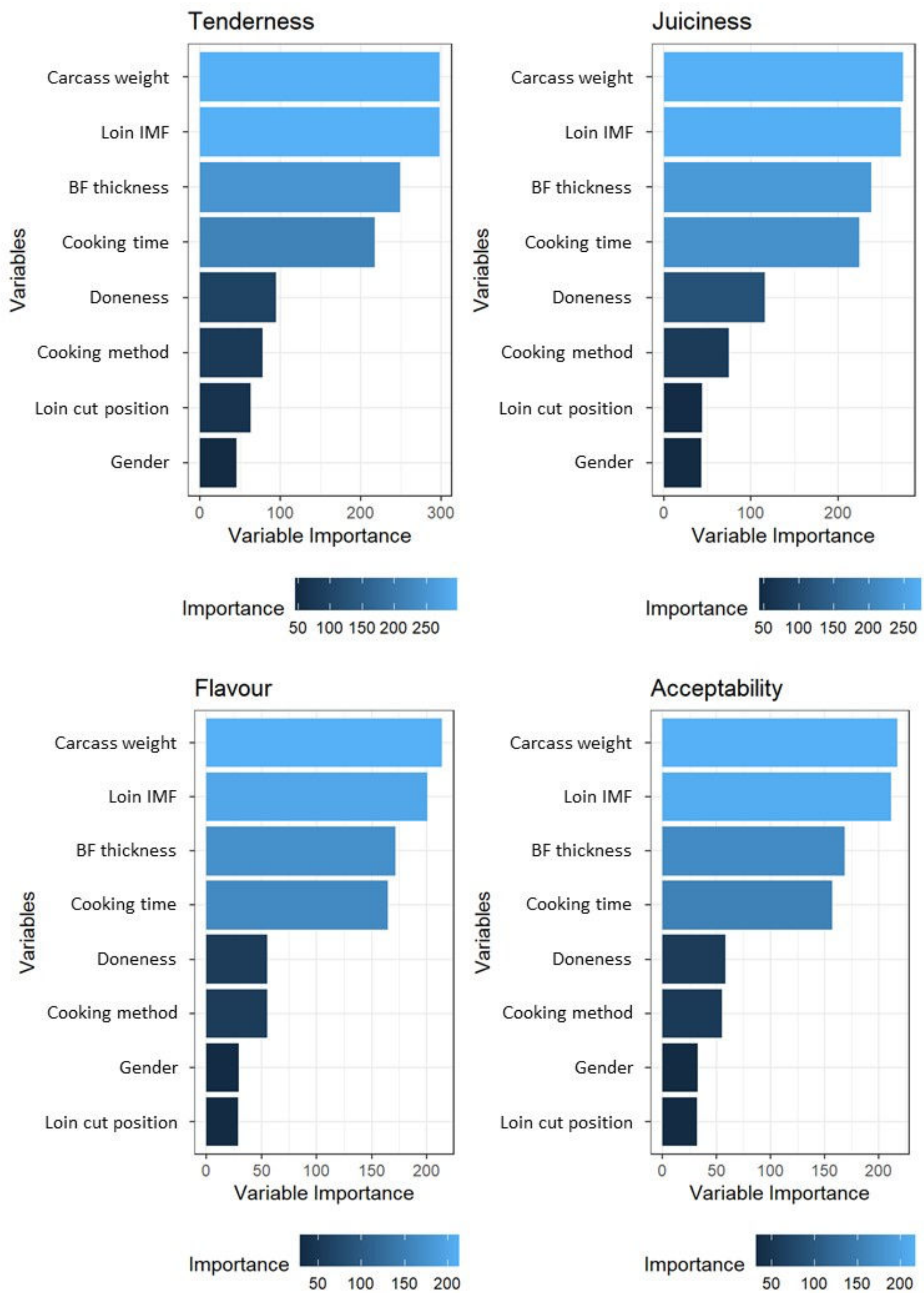


Figure 1. Random forest analysis for each target variable (flavor, tenderness, juiciness, and overall acceptability). The figures show the importance of each variable assessed in the study according to the quality traits evaluated by the participants of the study.

Objective 4) Determine relationships between pork quality in the plant (2-days post-mortem) with quality and eating experience from aged pork (14-days post-mortem).
While many carcass and eating quality traits were evaluated in the study, this objective used the following traits to examine eating quality of the loin:

1) Warner Bratzler shear force (WBSF), an instrumental measure of tenderness with shear force evaluated on chops aged for 2 days or 14 days. 14 days of aging was examined to allow endogenous enzymes in the meat to break down muscle proteins (referred to as post-mortem proteolysis) to enhance tenderness. A low WBSF value is associated with more tender meat while a high WBSF value is associated with tougher meat.
2) The percentage intramuscular fat content or % IMF is the amount of fat within the muscle. IMF is also known as marbling and in the case of pork, the greater amount of IMF in the muscle cut has been shown to be associated with greater consumer rankings for tenderness, juiciness, and flavor.
3) Percentage drip loss which represents the amount of moisture lost in the meat over a set time period. Drip loss also refers to water holding capacity with a high drip loss resulting in a low water holding capacity for the meat. The goal is to have low drip loss (high water holding capacity) as the more water lost before the meat is cooked, the greater chance there will be for less juicy meat (dry meat) to be experienced by the consumer along with decreasing tenderness. Low drip loss is also preferred in the retail setting (by both domestic and international customers) as high level of purge or drip in packages is unattractive to consumers.
4) Percentage cooking loss which represents the amount of moisture lost in the meat during cooking. The goal is to have low cooking losses (more moisture retained in the cooked meat) as the more water lost during cooking, the greater chance there will be for less juicy meat (dry meat) to be experienced by the consumer along with decreasing tenderness. Cooking losses were measured in both 2-day aged and 14-day aged pork chops.
5) Consumer assessment of tenderness, juiciness, flavor, and overall acceptability with consumers rating pork chops for these eating quality attributes.

Materials and Methods for Objective 4 are presented at the end of the report.

Results and Discussion for Objective 4

This study was conducted to sample gilt and barrows carcasses that were representative of the size of pigs and the amount of fatness that commercial pork plants in Ontario process every day. Table 1 provides the distribution of selected carcasses used in the study based on gender, hot carcass weight, and amount of back fat thickness. The effects of gender and carcass weight quartile on eating quality traits for the loin are presented in Table 2. While gilts had less backfat than barrows, most eating quality were unaffected ($P > 0.05$) by gender (Table 2). The greater amount of cooking losses for 14-day aged loin chops for gilts versus barrows is of questionable biological significance. We would expect that as carcass weight increased, the amount of back fat on the carcass would also increase as found in Table 2. Yet there were no effects ($P > 0.09$) of carcass weight quartile on IMF content, shear force values, drip loss, or cooking losses.

Since Objective 4 is to determine relationships between pork quality in the plant (2-days post-mortem) with quality and eating experience from aged pork (14-days post-mortem), we are presenting results from correlation analyses to examine the relationships (Table 3). In this study there were only weak relationships ($r \leq 0.35$) between the amount of intramuscular fat content and eating quality traits, with no relationship ($P > 0.05$) between intramuscular fat content and consumer panel traits. This is most likely due to the low amounts of intramuscular fat found in the pigs from this study (Table 2) where Large white genetics were prevalent on the dam side. Drip loss and cooking losses were only weakly related to each other and to shear force for the most part ($r \leq 0.35$), while 2-day cooking losses were moderately related to 14-day cooking losses ($r = 0.565$). This can be interpreted that low cooking losses for 2-day aged pork chops would be an indicator for low cooking losses for 14-day aged chops while high cooking losses for 2 day aged pork chops would be an indicator for high cooking losses for 14 day aged chops. This makes sense as we would not expect the aging process to affect the retention of moisture in pork loin chops. Warner Bratzler shear force (WBSF) values for 2-day aged chops were moderately correlated ($r = 0.551$) with Warner Bratzler shear force values for 14-day aged chops. This can be interpreted that if the pork is tender or tough with 2 days ageing, it most likely will not change in degree of tenderness with 14 days ageing unless the pork becomes more tender (a lower WBSF value).

For the most part, there was essentially no relationships ($r < 0.11$) between drip loss, cooking losses, or shear force values and any consumer panel assessment of eating quality (Table 2). We attribute this to only 53.5% of the total questionnaires for the consumer panel study being returned for use in statistical analysis. This is one of the challenges that the pandemic caused for this study that was outside of the research team's control.

For consumer panel traits, tenderness was moderately correlated with juiciness ($r = 0.673$) and strongly correlated with overall acceptability ($r = 0.696$). If consumers experience dry meat, they can also find the meat to be tough due to the perception of dryness. So, whatever experience the consumers found for juiciness appeared to also reflect their assessment of tenderness and their individual assessment of tenderness strongly influenced their assessment of overall acceptability for the cooked pork chops. Juiciness was moderately correlated with overall acceptability ($r = 0.679$) indicating the individual assessment of juiciness moderately influenced their assessment of overall acceptability for the cooked pork chops. Flavor was weakly correlated with juiciness, tenderness, and overall acceptability ($r < 0.48$).

Table 1. Distribution of selected carcasses (n = 337) according to gender, hot carcass weight, and back fat thickness.

	Hot carcass weight, kg[1]							
	≤ 102.1		102.2 - 107.5		107.6 - 112.2		112.3 - 138	
Gender	Gilts	Barrows	Gilts	Barrows	Gilts	Barrows	Gilts	Barrows
Total number	49	37	43	41	38	47	41	41
Back fat thickness, mm								
≤ 15	31	12	20	15	19	8	15	5
15.5 – 19	13	13	15	8	14	20	17	15
≥ 19.5	5	12	8	18	5	19	9	21

[1]Hot carcass weight was separated by hot carcass weight quartile for each gender on each slaughter date.

Table 2. Influence of Gender and HCW Quartile on Loin IMF Content, Drip loss, Shear Force (WBSF), and Cooking Losses (Mean ±SEM)[z]

	Gender				Quartiles[y]				*P*-value	
Variable	Back fat[x]	Barrows	Gilts	*P*-value	1	2	3	4	Quartile	G*Q[w]
Backfat thickness, mm		18.67 ±0.49	15.47 ±0.49	<.0001	15.60[b] ±0.62	17.05[ab] ±0.58	17.01[ab] ±0.59	18.62[a] ±0.61	0.0005	0.5742
IMF content, %	<.0001	2.28 ±0.12	2.09 ±0.12	0.0313	2.23 ±0.14	2.20 ±0.13	2.20 ±0.13	2.11 ±0.14	0.8314	0.5110
Drip loss, %	0.1358	3.74 ±0.28	4.02 ±0.28	0.1701	3.65 ±0.33	3.75 ±0.31	3.76 ±0.32	4.35 ±0.33	0.1204	0.6379
2-day WBSF, kg	0.0041	4.61 ±0.13	4.76 ±0.13	0.1133	4.92 ±0.15	4.67 ±0.14	4.60 ±0.15	4.56 ±0.15	0.0902	0.2184
14-day WBSF, kg	0.1141	3.78 ±0.09	3.93 ±0.09	0.0589	3.87 ±0.11	3.80 ±0.10	3.86 ±0.11	3.88 ±0.11	0.8858	0.7648
2-day cooking loss, %	0.7172	22.93 ±0.87	23.47 ±0.87	0.1102	23.26 ±0.92	23.14 ±0.90	23.28 ±0.90	23.11 ±0.92	0.9793	0.2338
14-day cooking loss, %	0.3847	21.58 ±1.02	22.32 ±1.02	0.0355	22.10 ±1.07	21.78 ±1.05	22.08 ±1.05	21.84 ±1.07	0.8742	0.4285

[z] Least square means in the same row without the same superscripts are significantly different ($P < 0.05$). Mean differences for the gender and hot carcass weight (HCW) quartiles were separated by the Tukey's method. Mean ±SEM = mean ± standard error of the mean.

[y] Hot carcass weights were divided into four quartiles: 1 = ≤ 102.1 kg, 2 = 102.2 - 107.5 kg, 3 = 107.6 - 112.2 kg, and 4 = 112.3 - 138 kg.

[x] *P*-value for backfat as a covariate. [w] G*Q = Gender by HCW quartiles interaction.

Table 3. Spearman correlation coefficients between loin intramuscular fat, drip loss, shear force (WBSF), cooking losses and pork eating quality traits for barrows and gilts.[1]

	Loin IMF[2]	Drip loss (%)	WBSF 2d[3]	WBSF 14d[4]	Cook loss 2d[5]	Cook loss 14d[6]	Tenderness	Juiciness	Flavour	Acceptability
Loin IMF	**1.000**	-0.050	**-0.309**	**-0.306**	-0.049	**-0.136**	0.051	0.042	-0.023	0.019
Drip loss (%)	-----	**1.000**	**0.155**	**0.211**	**0.193**	**0.126**	**-0.075**	-0.013	0.056	-0.004
WBSF, 2 days	-----	-----	**1.000**	**0.551**	**0.288**	**0.117**	**-0.083**	-0.044	-0.029	-0.057
WBSF, 14 days	-----	-----	-----	**1.000**	**0.185**	**0.382**	-0.059	-0.012	0.025	-0.054
Cooking losses, 2 days	-----	-----	-----	-----	**1.000**	**0.565**	-0.061	-0.021	0.049	-0.041
Cooking losses, 14 days	-----	-----	-----	-----	-----	**1.000**	**-0.101**	-0.063	-0.045	**-0.104**
Tenderness	-----	-----	-----	-----	-----	-----	**1.000**	**0.673**	**0.338**	**0.696**
Juiciness	-----	-----	-----	-----	-----	-----	-----	**1.000**	**0.32**	**0.679**
Flavour	-----	-----	-----	-----	-----	-----	-----	-----	**1.000**	**0.479**
Acceptability	-----	-----	-----	-----	-----	-----	-----	-----	-----	**1.000**

[1] Significant correlations are shown in bold ($P < 0.05$); The degree of association between two variables was considered (in absolute value) weak for $r \leq 0.35$, moderate for $0.36 \leq r \leq 0.67$, and strong for $r \geq 0.68$.

[2] Loin intramuscular fat (%);

[3] Warner-Bratzler shear force (kg) aged for 2 days;

[4] Warner-Bratzler shear force (kg) aged for 14 days;

[5] Cooking loss (%) aged for 2 days; [6] Cooking loss (%) aged for 14 days.

Objective 5) Determine relationships of loin quality with shoulder and ham quality.

Materials and Methods for Objective 5 are presented at the end of the document

Results and Discussion for Objective 5

Table 4 presents pH and lean colour data in nine different muscles[1] from the pork carcass (measured 24 to 72 hours *post-mortem*). These include the *longissimus* muscle or more specifically *longissimus thoracis* (LT) from the boneless loin, the *triceps brachii* (TB) and the *serratus ventralis* (SV) muscles from the boneless shoulder, and the *biceps femoris* (BF), *semitendinosus* (ST), *semimembranosus* (SM), *adductor* (AD), *rectus femoris* (RF), and *vastus lateralis* (VL) muscles from the boneless ham. While gender differences ($P \leq 0.01$; Table 4) were present for pH, L^*, and a^*, the differences are not biologically meaningful and are likely due to the large number of animals evaluated in the data set which resulted in over 3000 muscle cuts being assessed for pH and lean colour.

The lowest ($P < 0.05$) muscle pH (ultimate pH) was found in the longissimus and biceps femoris muscles with the greatest ($P < 0.05$) muscle pH found in the vastus lateralis muscle (Table 4). Muscle pH levels post-mortem are reflective of the amounts of lactic acid produced in muscles in the conversion of muscle to meat after slaughter. The low values for muscle pH found in the longissimus and biceps femoris muscles are due to much greater amounts of lactic acid being produced in these muscles after slaughter before rigor develops versus lactic acid production in the other muscles evaluated in this study. Consequently, the high muscle pH found in the vastus lateralis muscle is due to much lower amounts of lactic acid being produced in the muscle after slaughter before rigor develops versus the other muscles evaluated in this study. The amounts of lactic acid being produced in the conversion of muscle to meat are due to muscle specific chilling rates for individual muscles after slaughter, muscle fiber composition, individual muscle glycogen levels, and other factors. Muscle fiber composition will vary in this group of muscles studied as all the muscles in the shoulder and ham for this study are involved in locomotion while the longissimus is involved with extending the back and loin, flexing the spine, and aiding respiration.

Lightness (*L^**) values were greatest ($P < 0.05$) for the longissimus and lowest ($P < 0.05$) for the adductor muscle found in the ham. While the rate and amount of lactic acid produced can influence L^* values, this is not always the case as the biceps femoris muscle found in the ham had one of the lowest pH values after the conversion of muscle to meat while the L^* value for the biceps femoris is intermediate for the muscles evaluated in this study. To put these L^* values in perspective, the National Pork Board in the United States has found that Minolta L^* values can be used to identify problems in pork quality; for example, L^* values in the 50's can be found in PSE pork while L^* values in the 30's can be found in DFD pork. The mean L^* value of 47.7 for longissimus muscle is associated with a reddish pink pork that consumers find desirable. The lowest ($P < 0.05$) values for a^* (redness) and b^* (yellowness) were found with longissimus muscle while the greatest ($P < 0.05$) values for these traits were found in the vastus lateralis muscle. Pork is more desirable from an eating quality perspective when it is reddish pink with greater values for a*, with some consumers and companies desiring pork that is dark reddish pink. The functional role of the individual muscle in the body will influence the specific muscle's fiber composition and the percentages of white, red, and intermediate fibers in the individual muscle will affect a* values.

Total colour difference (ΔE^*) was determined to compare the colour of the longissimus muscle with colour for other muscles evaluated in this study. This trait considers all 3 objective measures of lean colour, L*, a*, and b* (Table 5). In the muscles evaluated in this study, the lowest ($P< 0.05$) value for total colour difference from the longissimus was found with the rectus femoris while the greatest ($P< 0.05$) value for total colour difference from the longissimus was found with the vastus lateralis. These 2 muscles are part of the quadriceps femoris or knuckle in which both muscles extend the stifle joint while the rectus femoris also flexes the hip joint.

Correlation analysis was used to determine relationships of loin quality with shoulder and ham quality (tables 6 to 9). The relationship(s) of ultimate pH amongst the 9 muscles evaluated in this study are presented in Table 6. While all correlation coefficients were statistically significant at $P < 0.01$, weak to moderate correlations were present between the longissimus and 3 muscles in the ham, semitendinosus, semimembranosus, and biceps femoris with r values ranging from 0.37 to 0.45. There was no significant relationship for ultimate pH between the longissimus and muscles in the shoulder (TB, SV) and the ham muscles, AD, RF, VL. In contrast, there were at least weak correlations ($r > 0.35$) for ultimate pH between individual muscles in the shoulder and individual muscles in the ham along with moderate ($0.36 \leq r < 0.67$) and strong ($r \geq 0.68$) correlations present (Table 6). The moderate and strong correlations found with some muscles in the ham are most likely due to similar fiber composition and similarities in function.

The relationship(s) of L* amongst the 9 muscles evaluated in this study are presented in Table 7. While all correlation coefficients were statistically significant at $P < 0.01$, moderate correlations were present between the longissimus and 3 muscles in the ham, semitendinosus, semimembranosus, and biceps femoris with r values ranging from 0.42 to 0.46. Similar to ultimate pH correlations, there was no significant relationship for L* between the longissimus and muscles in the shoulder (TB, SV) and the ham muscles, AD, RF, VL. While there were weak to moderate correlations for L* between some individual muscles in the shoulder and some individual muscles in the ham, there was no significant relationship for L* between the ST and most muscles in the ham ($r \leq 0.30$) and for specific comparisons of shoulder muscles and muscles in the ham where $r \leq 0.35$ (Table 7).

In contrast to ultimate pH and L* correlations, weak to moderate correlations ($0.36 \leq r \leq 0.57$), were present for a* between the longissimus and most other muscles evaluated in the study (Table 8). The exception was no significant relationship between a* for the longissimus and a* for the vastus lateralis ($r = 0.24$) which may not be surprising given the large differences in a* values found between these 2 muscles (Table 4). While there were weak to moderate correlations for a* between some individual muscles in the shoulder and some individual muscles in the ham, there was no significant relationship for a* with specific comparisons of shoulder muscles and muscles in the ham with the AD, RF, and VL muscles (where $r \leq 0.36$; Table 8).

Weak to moderate correlations ($0.37 \leq r \leq 0.51$), were present for b* between the longissimus and most other muscles evaluated in the study (Table 9) with 2 exceptions; there were no significant relationship between b* for the longissimus and b* values for the triceps brachii ($r = 0.29$) and the vastus lateralis ($r = 0.30$). While there were weak to moderate correlations for b* between most individual muscles in the ham and shoulder, there was no significant relationship for b* between the vastus lateralis and TB, SV, and ST with $r \leq 0.34$ (Table 9).

In summary there were limited relationships between pH and colour measures in the longissimus and these same measurements in 2 muscles in the shoulder and 6 muscles in the ham. Use of some of these measures in a given muscle to predict trait values in diverse muscles may be problematic given major muscle differences in chilling rates of individual muscles after slaughter, muscle fiber composition, individual muscle glycogen levels, and other factors. Even in the case of muscles in the ham which share many similarities in function, the relationships for the most part were only moderate at best.

In terms of application, these findings are important to further processors who utilize subprimals from the shoulder and ham for the manufacture of processed meat products. Muscle pH has intricate roles in protein functionality and reactivity with non-meat ingredients, while colour of raw materials can have significant impacts on appearance of color for some processed meat products (e.g., two-toning in section-formed hams). To our knowledge, this is the most comprehensive study measuring pH and colour for pork muscles in the last 20 years.

Table 4. Least squares means for pH and objective measures of lean colour in nine different muscles[1] from the pork carcass (measured 24 to 72 hours *post-mortem*).

	Loin	Shoulder		Ham						Main Effect of Gender			*P*-values		
	LT	TB	SV	BF	ST	SM	AD	RF	VL	Barrows	Gilts	SEM[2]	Muscle	Gender	Muscle × Gender
pH	5.59[g]	5.79[d]	5.82[cd]	5.61[g]	5.72[e]	5.66[f]	5.91[b]	5.85[c]	6.00[a]	5.79[a]	5.75[b]	0.016	< 0.01	< 0.01	0.35
*L** (lightness)	47.7[a]	40.7[f]	42.4[d]	44.0[c]	46.8[b]	42.3[d]	39.0[g]	42.5[d]	41.7[e]	43.2[a]	42.9[b]	0.21	< 0.01	< 0.01	0.23
*a** (redness)	6.9[g]	16.8[b]	16.9[b]	12.8[e]	13.6[d]	11.2[f]	15.4[c]	10.9[f]	19.5[a]	13.7[b]	13.8[a]	0.18	< 0.01	0.01	0.20
*b** (yellowness)	3.2[g]	5.6[a]	7.1[b]	6.3[c]	6.4[c]	4.1[e]	4.2[e]	3.6[f]	7.5[a]	5.3	5.3	0.15	< 0.01	0.74	0.28

[abcdefg] Least squares means in the same row without the same superscripts are significantly different ($P < 0.05$); means were separated using the Tukey's method.

[1] Muscles included *longissimus thoracis* (LT), *triceps brachii* (TB), *serratus ventralis* (SV), *biceps femoris* (BF), *semitendinosus* (ST), *semimembranosus* (SM), *adductor* (AD), *rectus femoris* (RF), and *vastus lateralis* (VL).

[2] SEM = Standard error of the mean.

Table 5. Total colour difference (ΔE*) between the *longissimus thoracis* muscle and eight different muscles[1] in the pork carcass (measured 24 to 72 hours *post-mortem*).

	Shoulder		Ham							*P*-value
	TB	SV	BF	ST	SM	AD	RF	VL	SEM[2]	Muscle
Total colour difference (ΔE*) from the LD muscle[3]	12.47[b]	12.19[b]	7.83[c]	7.85[c]	7.26[d]	12.27[b]	6.83[d]	14.81[a]	0.15	< 0.01

[abc] Least squares means in the same row without the same superscripts are significantly different ($P < 0.05$); means were separated using the Tukey's method.

[1] Muscles included *longissimus thoracis* (LT), *triceps brachii* (TB), *serratus ventralis* (SV), *biceps femoris* (BF), *semitendinosus* (ST), *semimembranosus* (SM), *adductor* (AD), *rectus femoris* (RF), and *vastus lateralis* (VL).

[2] SEM = Standard error of the mean.

[3] Total colour difference (ΔE*) from the LD muscle was calculated with the following equation: $\Delta E^* = \sqrt{(L*_2 - L*_1) + (a*_2 - a*_1)) + (b*_2 - b*_1)}$.

Table 6. Spearman rank correlations for pH in nine different muscles[1] from the pork carcass (measured 24 to 72 hours *post-mortem*).

		Shoulder		Ham					
		TB	SV	BF	ST	SM	AD	RF	VL
Loin	LD	0.34	0.26	0.45	0.37	0.41	0.29	0.23	0.15
Shoulder	TB	—	0.65	0.60	0.54	0.59	0.52	0.37	0.41
	SV	—	—	0.60	0.55	0.66	0.54	0.46	0.47
Ham	BF	—	—	—	0.73	0.77	0.62	0.52	0.49
	ST	—	—	—	—	0.70	0.58	0.47	0.45
	SM	—	—	—	—	—	0.65	0.48	0.44
	AD	—	—	—	—	—	—	0.53	0.56
	RF	—	—	—	—	—	—	—	0.70

[*] All values statistically significant at $P < 0.01$. The degree of association between two variables was considered (in absolute value) weak for $r \leq 0.35$, moderate for $0.36 \leq r \leq 0.67$, and strong for $r \geq 0.68$.

[1] Muscles included *longissimus thoracis* (LT), *triceps brachii* (TB), *serratus ventralis* (SV), *biceps femoris* (BF), *semitendinosus* (ST), *semimembranosus* (SM), *adductor* (AD), *rectus femoris* (RF), and *vastus lateralis* (VL).

Table 7. Spearman rank correlations for L^* (lightness) in nine different muscles[1] from the pork carcass (measured 24 to 72 hours *post-mortem*).

		Shoulder		Ham					
		TB	SV	BF	ST	SM	AD	RF	VL
Loin	LD	0.28	0.31	0.46	0.43	0.42	0.31	0.39	0.27
Shoulder	TB	—	0.45	0.44	0.33	0.35	0.45	0.39	0.41
	SV	—	—	0.44	0.34	0.40	0.39	0.45	0.34
Ham	BF	—	—	—	0.39	0.54	0.43	0.53	0.43
	ST	—	—	—	—	0.28	0.30	0.29	0.22
	SM	—	—	—	—	—	0.38	0.47	0.26
	AD	—	—	—	—	—	—	0.48	0.48
	RF	—	—	—	—	—	—	—	0.39

[*] All values statistically significant at $P < 0.01$. The degree of association between two variables was considered (in absolute value) weak for $r \leq 0.35$, moderate for $0.36 \leq r \leq 0.67$, and strong for $r \geq 0.68$.

[1] Muscles included *longissimus thoracis* (LT), *triceps brachii* (TB), *serratus ventralis* (SV), *biceps femoris* (BF), *semitendinosus* (ST), *semimembranosus* (SM), *adductor* (AD), *rectus femoris* (RF), and *vastus lateralis* (VL).

Table 8. Spearman rank correlations for a^* (redness) of nine different muscles[1] in the pork carcass (measured 24 to 72 hours *post-mortem*).

		Shoulder		Ham					
		TB	SV	BF	ST	SM	AD	RF	VL
Loin	LD	0.36	0.43	0.51	0.41	0.57	0.37	0.55	0.24
Shoulder	TB	—	0.49	0.42	0.37	0.41	0.35	0.33	0.32
	SV	—	—	0.53	0.40	0.52	0.38	0.39	0.38
Ham	BF	—	—	—	0.49	0.60	0.39	0.49	0.33
	ST	—	—	—	—	0.51	0.42	0.40	0.32
	SM	—	—	—	—	—	0.55	0.58	0.36
	AD	—	—	—	—	—	—	0.40	0.37
	RF	—	—	—	—	—	—	—	0.27

[*] All values statistically significant at $P < 0.01$. The degree of association between two variables was considered (in absolute value) weak for $r \leq 0.35$, moderate for $0.36 \leq r \leq 0.67$, and strong for $r \geq 0.68$.

[1] Muscles included *longissimus thoracis* (LT), *triceps brachii* (TB), *serratus ventralis* (SV), *biceps femoris* (BF), *semitendinosus* (ST), *semimembranosus* (SM), *adductor* (AD), *rectus femoris* (RF), and *vastus lateralis* (VL).

Table 9. Spearman rank correlations for b* (yellowness) of nine different muscles[1] in the pork carcass (measured 24 to 72 hours *post-mortem*).

		Shoulder		Ham					
		TB	SV	BF	ST	SM	AD	RF	VL
Loin	LD	0.29	0.42	0.51	0.37	0.44	0.40	0.46	0.30
Shoulder	TB	—	0.52	0.51	0.41	0.45	0.40	0.40	0.34
	SV	—	—	0.63	0.43	0.55	0.45	0.57	0.30
Ham	BF	—	—	—	0.53	0.66	0.45	0.61	0.39
	ST	—	—	—	—	0.46	0.40	0.46	0.28
	SM	—	—	—	—	—	0.55	0.63	0.41
	AD	—	—	—	—	—	—	0.48	0.39
	RF	—	—	—	—	—	—	—	0.36

[*] All values statistically significant at $P < 0.01$. The degree of association between two variables was considered (in absolute value) weak for $r \leq 0.35$, moderate for $0.36 \leq r \leq 0.67$, and strong for $r \geq 0.68$.

[1] Muscles included *longissimus thoracis* (LT), *triceps brachii* (TB), *serratus ventralis* (SV), *biceps femoris* (BF), *semitendinosus* (ST), *semimembranosus* (SM), *adductor* (AD), *rectus femoris* (RF), and *vastus lateralis* (VL).

Materials and Methods for Objective 4

For the assessment of pork eating quality for the loin, thirteen 3.0 cm-thick loin chops were cut from the *longissimus* muscle, trimmed of epimysium and external fat, and individually identified for various analyses. The first four loin chops originating from the loin's ham end were designated for consumer sensory panel evaluation. Similarly, the last two loin chops at the butt end were designated for consumer sensory panel evaluation. The samples were individually vacuum packaged and assigned to ageing time (14-days post-mortem chilling at ≤ 4°C) prior to evaluation. The remaining loin chops were assessed at 2-days postmortem ageing and were allocated based on the following arrangement: One loin chop was designated for subjective evaluation (marbling), instrumental colour and ultimate pH measurements determination. This chop was placed on butcher paper and allowed to bloom for 30 minutes in the Meat Lab processing room at ≤10°C for colour development. Immediately after 30 minutes, instrumental colour measurements were taken at 3 different locations on the chop using a Minolta CR-400 with D_{65} light source and a 0° observer with an 8 mm aperture (Minolta Chroma Meter CR-400 colourimeter: Folio Instruments, Kitchener, ON, Canada).National Pork Producers Council (NPPC, 2000) guidelines and Canadian Pork Quality Standards (CPQS; CPI 2013) were used by a trained evaluator in the Meat Lab to subjectively evaluate lean colour.

Subsequently, ultimate pH measurements were taken at different locations on the same loin chop using a smart foodcare spear tipped electrode attached to a Hanna Foodcare Professional Portable pH Meter (Hanna HI 98161: Hanna Instruments, Woonsocket, USA). The three readings would later be averaged to calculate final pH. Prior to the quality measurements, the pH meter was placed in the cooler for at least an hour before calibrating using pH 4 and 7 buffer solutions in order to aid in the accuracy of the measurements.

One chop was used to determine intramuscular fat content in which the epimysium and subcutaneous fat were fully removed prior to cubing and freeze-drying in a Thermo Scientific (Fisher Scientific, ON, Canada) freeze dryer for approximately 96 h. After drying, samples were ground in a commercial coffee grinder and mixed thoroughly before sampling. Dry matter was determined from the difference in weight before and after freeze-drying and corrected by oven drying 1.5 - 2 g samples at 100°C. Intramuscular fat content was determined in the freeze-dried meat samples using the Ankom XT20 Fat Analyzer for ether extraction of fat (AOAC, 2000). 1.5 - 2 g samples were extracted using petroleum ether for 30 min and removed. Then sample bags were re-weighed, and the loss of lipids was determined. To determine the percentage of chemical lipid in each sample, the following equation was used:

$$\%\ Chemical\ Lipid = \left(\frac{Initial\ Weight - Pos\ \ Extraction\ Weight}{Initial\ Wei}\right) * 100$$

Subsequently, two cores were taken from the chop for drip loss determination using the E-Z cup method described by Rassmussen and Andersson (1996). Drip loss containers were sequentially labelled with the sample ID starting from 1 and weighed. Two muscle cores were prepared from the chop using a cork borer (25 mm diameter) that was cored in the directions of the fibres in the middle of the chop. The cores were then placed in a vertical fibre direction in the E-Z funnel-shaped cups and the cup lids were then closed. The cups containing the samples were weighed before and after refrigeration for 48 h at ≤ 4°C. Drip loss was expressed as a percentage relative to the initial weight.

Four chops were individually vacuum sealed and then aged at -1 to 4°C for 2 or 14 d (2 chops/ageing time) and then frozen at -20°C until further analysis. These chops were later thawed over 24 h at -1 to 4°C and used to measure Warner-Bratzler shear force (an instrumental measure of tenderness). After thawing, chops were trimmed of any external fat and epimysium, weighed, and cooked using a Garland Grill (ED-30B broiler: Garland Commercial Range Ltd., Mississauga, Canada) to an internal endpoint temperature of 74°C. Cooking temperatures were continually monitored using a thermocouple inserted in the geometric centre of each chop with initial and final temperatures recorded. Chops were turned after reaching an internal temperature of approximately 40°C. Once the chop was cooked to the target temperature endpoint, the cooked weight was recorded to determine cooking losses. Chops were placed in individual bags, sealed, and immediately chilled in ice water. Chops were stored at 1.5°C for 24 h before coring. Prior to coring, chops were allowed to equilibrate to room temperature (approximately 22°C). Three 1.27 cm meat cores were removed parallel to the muscle fibres from each chop using a drill press-mounted corer. Cores were sheared using a Warner-Bratzler blade on a TA-XT Plus texture analyzer (Texture Technologies Corp., Scarsdale, USA) with a crosshead speed set at 3.3 $mm \cdot s^{-1}$. Peak shear force was determined using a customized macro program in Stable Microsystems Exponent software, and the average of the 6 peak force values was taken as the shear force value for each loin chop.

Consumer panel assessment of tenderness, juiciness, flavour, and overall acceptability have been recently described in a submission to Ontario Pork by Marcio Duarte. To examine the relationships between instrumental measurements of pork eating quality and consumer panel assessments, Spearman rank correlations were performed using PROC CORR in SAS. Correlations were considered significant at $P < 0.05$. The degree of association between two variables was considered (in absolute value) weak for $r \leq 0.35$, moderate for $0.36 \leq r \leq 0.67$, and strong for $r \geq 0.68$ (Taylor, 1990).

Materials and Methods for Objective 5

Pigs were slaughtered under the supervision of the Canadian Food Inspection Agency (**CFIA**) at a federally inspected processing facility. Carcass data from that facility were then shared with the research team that conducted this study. Therefore, Animal Care and Use Committee approval was not required for this study as no live animal data were used by the university research team.

2.1 Data Collection

Pork carcasses used in this study were part of a larger study that consisted of 17 slaughter events over a 9-month time period. Briefly, the 350 carcass sides used in this study originated from nine different pig producers, were of Duroc × Large White genetic lineage, and were slaughtered using industry-standard processing techniques [*i.e.*, group CO_2 stunning and conventional chilling (reefer cooler operating on a specific chill cycle that was proprietary to the commercial packing plant with carcasses chilled for 22 to 24 hours at ambient temperatures ranging from -4 to 2 °C)].

The left side carcasses were fabricated within 24-72 hours post-mortem according to Institutional Meat Purchase Specifications (NAMP, 2006; IMPS, 2014). Immediately following fabrication, the boneless loin, boneless shoulder pieces, and boneless ham pieces were collected for evaluation purposes. One 2.5-cm thick chop from the 10^{th} rib location of the *longissimus thoracis* (LT) was prepared from the boneless loin, while a cut surface was exposed for the *triceps brachii* (TB) and the *serratus ventralis* (SV) muscles from the boneless shoulder pieces and for the *biceps femoris* (BF), *semitendinosus* (ST), *semimembranosus* (SM), *adductor* (AD), *rectus femoris* (RF), and *vastus lateralis* (VL) muscles from the boneless ham pieces. Each muscle sample was allowed to bloom for 30 minutes prior to evaluation of instrumental colour and pH.

Instrumental colour was evaluated with a calibrated, handheld Minolta CR-400 Chroma meter (Konica Minolta Sensing Americas, Inc, Ramsey, New Jersey, USA) with illuminant D_{65}, an 8-mm aperture, and 0° viewing angle settings. Each measurement by the Chroma meter was reported using the $L*$, $a*$, and $b*$ colour space. Three measurements were collected and then averaged to determine instrumental colour values for each sample. Total colour difference ($\Delta E*$) from the LD muscle was calculated for the other eight muscles evaluated in this study with the following equation:

$$\Delta E^* = \sqrt{(L *_2 - L *_1) + (a *_2 - a *_1)) + (b *_2 - b *_1)}\ .$$

pH was measured using a calibrated spear-tipped pH meter (Hanna HI98163; Hanna Instruments, Mississauga, Ontario, Canada). The pH meter was calibrated with 4.01 and 7.01 buffer solutions that were stored at refrigerated temperatures (≤ 4 °C) prior to use and then checked using the buffer solutions at incremental time points during use. Three measurements were collected and then averaged to determine pH values for each sample.

2.2 Statistical Analyses

Two different data analyses were performed for this dataset. The first analysis consisted of a mixed-model analysis with main effects of muscle, Gender (barrow or gilt), and their interaction and a random effect of slaughter event. For this analysis, data were analyzed using the GLIMMIX procedure in SAS version 9.4 (SAS Institute Inc. Cary, North Carolina, USA). Hot carcass weight was determined to be influential and was therefore used as a covariate. Least squares means were separated using with the PDIFF option in SAS and a Tukey-Kramer adjustment was utilized to protect against committing a Type-I statistical error. The second analysis consisted of a correlation analysis. For this analysis, data were analyzed using the CORR procedure of SAS version 9.4 with the Spearman rank option selected for correlation coefficient generation. For discussion purposes, correlation coefficients were considered weak at $r < |0.35|$, moderate at $|0.36| \leq r < |0.67|$, and strong at $r \geq |0.68|$.