The relationship of pork carcass weight and leanness parameters in the Ontario commercial pork industry

Robson S. Barducci,* Ziyu Y. Zhou,* Lisa Wormsbecher,† Colleen Roehrig,† Dan Tulpan,‡ and Benjamin M. Bohrer*,[1]

*Department of Food Science, University of Guelph, Guelph, Ontario, Canada N1G2W1; †Conestoga Meat Packers Ltd., Breslau, Ontario, Canada N0B1M0; and ‡Department of Animal Biosciences, University of Guelph, Guelph, Ontario, Canada N1G2W1

ABSTRACT: This 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, CA). 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 nonlinear 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.

Key words: commercial pork, correlation, fat depth, muscle depth, pork carcass weight

Transl. Anim. Sci. 2020.4:331–338
doi: 10.1093/tas/txz169

[1]Corresponding author: bbohrer@uoguelph.ca

Received August 2, 2019.
Accepted October 21, 2019.

INTRODUCTION

In upcoming years, continued population growth and increased wealth in developing nations will likely increase the global demand for pork (Szymańska, 2018). To increase the quantity of pork produced, while meeting industry (and consumer) demands for more sustainable production systems, utilization of modern technologies is required to lead to the development of a more efficient and profitable global industry. With both efficiency and profitability in mind, pork processors aspire to ensure that pig producers are marketing a consistent product that meets industry standards for weight and yield. At the same time, it is critical that investigations of commonly used technologies be conducted frequently as industry standards can change very quickly. For instance, the weight of pork carcasses has steadily increased over time. In fact, there has been a consistent linear increase in pork carcass weight over the past three decades. This is evident when evaluating historical averages—the average hot carcass weight in 1989 was 81.2 kg, the average hot carcass weight in 1999 was 86.8 kg, the average hot carcass weight in 2009 was 92.2 kg, and the average hot carcass weight to-date in 2019 (through August) was 96.8 kg (USDA ERS, 2019). The changes in carcass weight over time justifies an evaluation of the relationships between carcass weight and predicted leanness of pork carcasses in a commercially representative population of pigs.

Regarding predicted leanness of pork carcasses, many different technologies have been used in the last 30 years for online measurement of lean meat percentage in pork carcasses, with the primary focus of identifying the true commercial value of the pork carcass to the processor and provide proper recommendations for pig producers (Swatland et al., 1994). The most common method for the measurement of carcass lean yield in North America is the use of an optical probe to measure fat depth and muscle depth of the loin, and a subsequent conversion of these measurements presents the designated conversion equations used for the calculation of predicted lean yield (Busk et al., 1999; Zhou and Bohrer, 2019). Thus, fat depth, muscle depth, and predicted leanness are often the only carcass leanness parameters evaluated in commercial pigs. Several research studies have characterized the correlation between pork carcass weight and leanness parameters (Kure, 1997; Ohlmann and Jones, 2011; Plà-aragonés et al., 2013; Rodríguez et al., 2014; Price et al., 2019). However, there still exist many misunderstandings among the relationship of pork carcass weight and leanness parameters, particularly in commercially representative pigs marketed under current times and conditions. Therefore, the objective of this study was to examine the correlation of carcass weight, fat depth, muscle depth, and predicted lean yield in commercial pigs marketed at commercially representative weights and conditions.

MATERIALS AND METHODS

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.

Data Collection

Data were collected at a commercial pig slaughter facility located in southwestern Ontario between October 1, 2017 and September 30, 2018. Information from a total of 850,819 pork carcasses were used for this study. Hot carcass weight, fat depth, and muscle depth of each individual carcass were measured and recorded on the day of slaughter before the animal was chilled. Hot carcass weight was reported immediately following slaughter as a head-on weight. Fat depth and muscle depth were measured with a Destron PG-100 probe (International Destron Technologies, Markham, Canada) inserted perpendicularly between the third and fourth last rib and 7 cm off the mid-line according to Canadian grading standards (Pomar and Marcoux, 2003). Fat depth and muscle depth measurements were used to obtain the predicted lean yield of each individual carcass using the following equation:

$$\begin{aligned}\text{CLY} = (\%) = {} & 68.1863(0.7833 \times \text{fat depth}) \\ & + (0.0689 \times \text{muscle depth}) + (0.0080 \times \text{fat depth}^2) \\ & (0.0002 \times \text{muscle depth}^2) \\ & + (0.0006 \times \text{fat depth} \times \text{muscle depth})\end{aligned}$$

where CLY is the Canadian Lean Yield of the carcasses and fat depth and muscle depth are the backfat thickness (mm) and muscle thickness (mm), respectively (Pomar and Marcoux, 2003).

Statistical Analyses

Data were evaluated thoroughly, and the entire observation was removed in the case of missing data points and extreme outliers. Descriptive statistics for carcass traits (mean, standard deviation, minimum, and maximum) were calculated for all parameters using SigmaPlot, version 11 (Systat Software, Inc., San Jose, CA). Scatter plots were created with SigmaPlot to allow for better visualization of the relationship between all parameters. Further evaluation for linearity and homoscedasticity were evaluated using the scatter plots. When assumptions of linearity and homoscedasticity were met, linear regression equations were created by SigmaPlot. All regression analysis included coefficients of determination (R^2). Coefficients of determination were considered weak at $R^2 < 0.12$, moderate at $0.13 \leq R^2 < 0.45$, and strong at $R^2 \geq 0.46$ (Bohrer and Boler, 2017). For relationships meeting assumptions for Pearson product moment correlation, Pearson correlation coefficients were calculated using SigmaPlot. For relationships failing to meet assumptions for Pearson product moment correlation (nonlinear), Spearman's rank-order correlation coefficients were calculated using SigmaPlot. Correlation coefficients were considered significantly different from 0 at $P < 0.05$. Correlation coefficients were considered weak (in absolute value) for $r < 0.35$, moderate for $0.36 \leq r \leq 0.67$, and strong for $r \geq 0.68$ (Taylor, 1990).

RESULTS AND DISCUSSION

Population Mean and Variation

Means and standard deviation for hot carcass weight (head-on), fat depth, muscle depth, and predicted lean yield were 106.30 ± 8.51 kg, 18.11 ± 4.04 mm, 66.47 ± 8.88 mm, and 61.13 ± 1.90%, respectively (Table 1). It is worth mentioning that it is common practice to include the head in the weight of the carcass in Canada, while this is not generally the case in Europe and the United States. For the purpose of clarity, hot carcass weight will be referred to as head-on or head-off when comparing absolute values throughout the current study. In general, head-on hot carcass weight and muscle depth were greater than historical observations in Canada, while fat depth was closer in value (CPC, 1994; Pomar et al., 2001; Pomar and Marcoux, 2003). Head-on hot carcass weight, fat depth, and muscle depth were similar to values reported in recent studies conducted in Canada (Miar et al., 2014; Zhang et al., 2016). Likewise, hot carcass weight (compared between head-on hot carcass weight and head-off hot carcass weight), fat depth, and muscle depth were similar in value with the values reported in recent studies conducted in Europe (Lisiak et al., 2015; Knecht et al., 2016) and the United States (Wilson et al., 2016; Arkfeld et al., 2017). For example, Wilson et al. (2016) reported population statistics for 1,235 commercial pigs in the United States as: 103.6 kg for head-off hot carcass weight, 22 mm for fat depth, and 67 mm for muscle depth. Furthermore, Arkfeld et al. (2017) reported population statistics for 6,920 commercial pigs in the United States as: 94.50 ± 9.39 kg for head-off hot carcass weight, 15.41 ± 4.00 mm for fat depth, 68.00 ± 8.52 mm for muscle depth, and 57.63% ± 2.76% for predicted lean yield.

The observed differences in parameters over time were likely due to changes in the genotype of pigs, the environment/rearing conditions, and a combination of these things (genotype × environment). The continuous genetic improvement of pigs has resulted in a 41% increase in head-off carcass weight since 1970 (Wilson et al., 2016) and a significant reduction of fat thickness in the global pork population (Adebambo, 1986; Chimonyo and Dzama, 2007; Sellier et al., 2010). As outlined by one highly cited report (Thornton, 2010), livestock production has changed substantially over the past several decades, which has undoubtedly changed the way pigs are raised and marketed. The observed differences in parameters between the current study and recent studies from the United States were likely

Table 1. Population summary statistics for carcass traits (N = 850,819 carcasses)

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

[a]Measured at the third and fourth last rib, and 7 cm off the mid-line.

[b]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).

due to subtle differences in the way that parameters were measured. As previously mentioned, hot carcass weight in Canada (the current study included) is measured as a head-on weight, while studies conducted in the United States (Wilson et al., 2016; Arkfeld et al., 2017) measured hot carcass weight as a head-off weight. While the current study reported an average head-on hot carcass weight of 106.30 ± 8.51 kg, it must be noted that this carcass weight included the head and data reported by United States and most European studies would not have included the head. Boler et al. (2014) reported head weights comprised of 4.47% of ending live weight, or 6.30 kg, for barrows and comprised of 4.50% of ending live weight, or 6.28 kg, for gilts. Using these figures, it can be calculated that the weight of the head was approximately 5.75% of the average carcass weight reported, or 6.11 kg of the reported weight in the current study. Based on these calculations, the current study had an average calculated head-off hot carcass weight of 100.19 kg (106.30 kg − 6.11 kg). This value was less than the head-off hot carcass weight reported by Arkfeld et al. (2017), and greater than the head-off hot carcass weight reported by Wilson et al. (2016). Therefore, the average hot carcass weight for the commercially representative population of pigs in the current study was intermediate to recent scientific studies (Wilson et al., 2016; Arkfeld et al., 2017) and slightly greater than the 2019 head-off hot carcass weight figures reported by the United States Department of Agriculture of 96.8 kg (USDA ERS, 2019).

Correlation among Parameters

Moderate to strong correlation of carcass weight with fat depth, muscle depth, and predicted lean yield was hypothesized. However, few carcass traits demonstrated the strong correlation coefficients that were expected (Table 2).

The weak positive correlation observed between hot carcass weight and fat depth (r = 0.289; P < 0.0001; Figure 1), and between hot carcass weight and muscle depth (r = 0.176; P < 0.0001; Figure 2) were actually similar to previous reported observations (Fix et al., 2010; Miar et al., 2014). Previous studies reported that the combination of hot carcass weight and fat depth accounted for 77% and 83% of the variation in the total weight of carcass lean, respectively (Edwards et al., 1981; Grisdale et al., 1984). Increased growth rate was strongly correlated with greater hot carcass weight and selection for increased growth rate has been hypothesized to increase both fat depth and muscle depth (Miar et al., 2014). Nevertheless, correlation coefficients between growth rate and fat depth have shown a wide range of unpredictability, which may be due to the method of measurement, technician effect, breed differences, and sampling errors (Koots and Gibson, 1994).

Additionally, the weak negative correlation observed between hot carcass weight and predicted lean yield (r = −0.235; P < 0.0001; Figure 3) were similar to previous scientific observations (Fahey et al., 1977; Grisdale et al., 1984; Miar et al., 2014; Bertol et al., 2017). The weak correlation with hot carcass weight demonstrated the poor ability to predict lean yield at both lighter and heavier than average weights. Consequently, it may be possible to consider that less variation in hot carcass weight within a population of pigs (or the marketing of narrower ranges for weights of pigs) would not lead to less variation in predicted lean yield. This would counter the perception that increasing marketing groups by selecting targeted weights of pigs improve predicted lean yield variation as outlined by Zhou and Bohrer (2019).

In addition, weak negative correlation between fat depth and muscle depth was observed (r = −0.148; P < 0.0001; Figure 4). Wilson et al. (2016) reported a similar observation with a weak negative correlation of r = −0.13 between fat depth and muscle depth for the 1,235 pigs in their study. Other previous research studies reported that fat depth and muscle depth had moderate negative correlation (Newcom et al., 2002; Miar et al., 2014) with the implication that increased fat and decreased muscling may be expected when selection was directed toward increased marbling. The growth curve is an important parameter for growth development and muscle biology, where the growth

Table 2. Pearson correlation coefficients (r) for carcass traits (N = 850,819 carcasses)[a]

Carcass traits	Fat depth	Muscle depth	Predicted lean yield[b]
Hot carcass weight	0.289**	0.176**	−0.235**
Fat depth		−0.148*	−0.960**
Muscle depth			0.406**

*$P \le 0.0001$.

**$P \le 0.0001$.

[a]Assumptions for Pearson product moment correlation (linearity) were not met for the relationship between fat depth and predicted lean yield and the relationship between muscle depth and predicted lean yield. Therefore, Spearman's rank-order correlation coefficients were used for these two relationships.

[b]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).

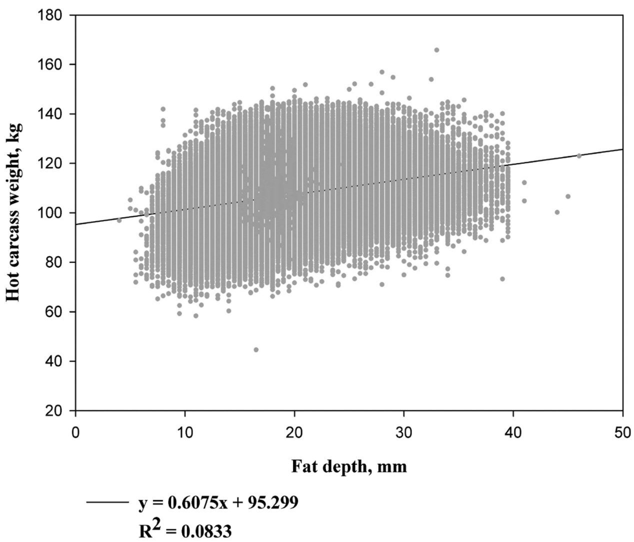

Figure 1. Prediction of hot carcass weight using fat depth as the independent variable (*N* = 850,819 carcasses).

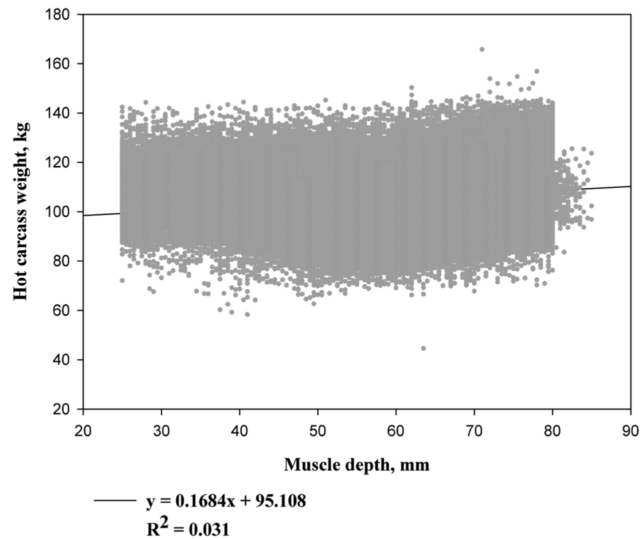

Figure 2. Prediction of hot carcass weight using muscle depth as the independent variable (*N* = 850,819 carcasses).

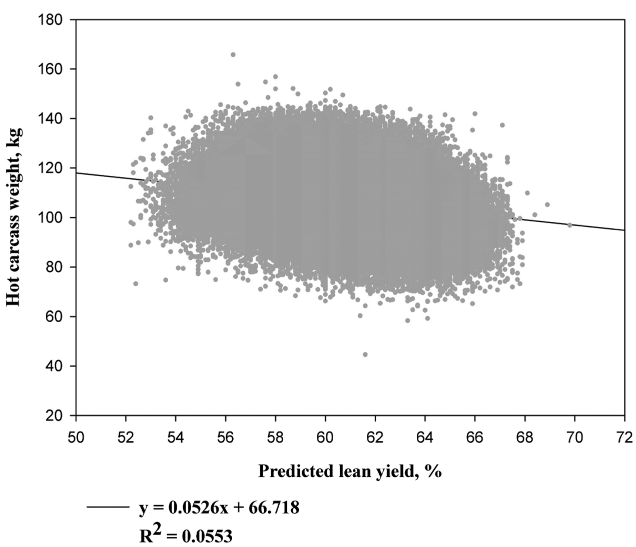

Figure 3. Prediction of hot carcass weight using predicted lean yield as the independent variable (*N* = 850,819 carcasses).

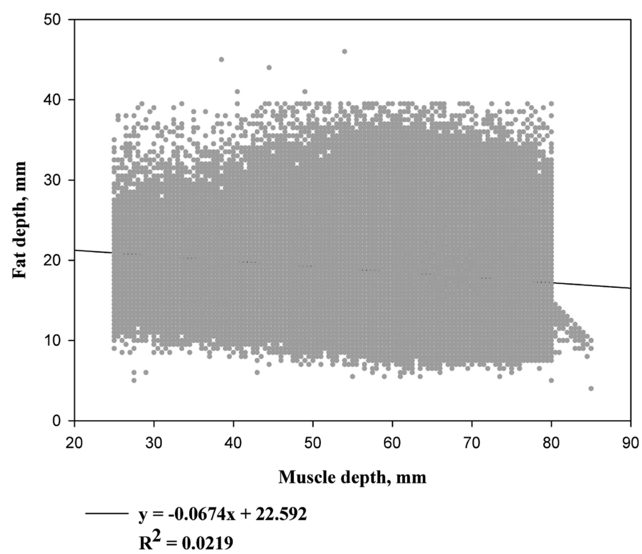

Figure 4. Prediction of fat depth using muscle depth as the independent variable (*N* = 850,819 carcasses).

of muscle tissue during fattening was associated with protein accretion for muscle growth and the deposition of fat in the pig (Schinckel et al., 2001). Consequently, during normal growth muscle mass efficiency decreased and maintenance requirements increased (Owens et al., 1993). Once pigs have reached homeostasis and energy is no longer required for skeletal and muscle growth, it is theorized that fat is first deposited in the form of subcutaneous fat, followed by intermuscular fat, and then intramuscular fat (De Smet et al., 2004). Therefore, genetics companies have shifted their efforts to pigs with a greater mature size and an increasing number of pork processors have begun to focus on the greater slaughter weight, which in turn yields a leaner product while maintaining an acceptable level of fat (Strzelecki et al., 1998; Price et al., 2019).

Impact of Heavier Pork Carcasses

Several recent studies and market assessments have indicated that the weight of pork carcasses is expected to increase in upcoming years (Morin et al., 2015; Harsh et al., 2017; Rice et al., 2018; Gilleland et al., 2019; Price et al., 2019). Harsh et al. (2017) goes as far as to state predictions for carcass weights in the future, which were stated as 104 kg in 2030, 111 kg in 2040, and 118 kg in 2050. These predictions were based on the 0.6 kg/year increase that the United States pork carcass weights are currently experiencing (USDA ERS, 2019).

There are several misunderstandings surrounding the topic of increased hot carcass weight of pigs, particularly that heavy weight pigs are fatter and/or heavier muscled. These data suggests that heavy pigs were not consistently fatter or heavier muscled compared with normal, or even light weight pigs for that matter. Notwithstanding, the fact that there was a high level of variation in fat depth and muscle depth for pigs of all carcass weights makes this study representative of many different situations and may be useful for a variety of pork entities in the future that are concerned with the variation in leanness of heavy weight pigs.

While genetic selection, nutritional improvements, and more efficient production systems have allowed for improved growth rates of pigs over time, it is possible that allometric growth of pigs (i.e., rate of muscle and fat accretion throughout the pig) has remained similar during this change in finishing weight and carcass weight. Beyond genetic improvement over time, it is also important to consider other variables, such as production system, production strategy, sex, season, region, and the method of grading when factoring in relationships of predicted lean yield and carcass weight. These variables can overestimate and/or underestimate the grading indexes and the calculated yields, which could result in significant carcass index differences among a population of pigs (Pomar and Marcoux, 2003; Latorre et al., 2004; Straadt et al., 2013). Moreover, it is important to note that carcass composition traits are typically less affected by environmental variations when compared with other heritable traits like reproduction and growth performance (Akanno et al., 2013). These data along with other recent heavy weight pork carcass data (notably Price et al., 2019) indicate that the relationships between carcass weight and leanness parameters are highly variable at all weights of pigs, and that allometric growth (and composition) is likely not being significantly altered in heavier pigs.

Future Outlook

Insights into the mechanism that affects predicted lean yield were difficult to define with this dataset. Predicted lean yield and the parameters that are used in this equation (fat depth and muscle depth) were generally not greatly influenced by the differing hot carcass weights evaluated in this study. Greater information and stronger relationships may be apparent with a more complex carcass yield evaluation, for example, ultrasonic assessment of the entire carcass or full lean cutting tests when compared with optical probe measurements collected at the loin location.

Although definitive conclusions are not yet plausible, the available data suggest that future increases in carcass weight should not change the assumptions of the predicted lean yield equation. The consideration of allometric growth and lean deposition of pigs at heavier live weights (and the inherent effect on carcass weight) does not seem to be influential when considering the parameters evaluated in this study. This should continue to be explored by the pork industry in the future as pigs continue to be marketed at heavier weights, as changes in allometric growth and lean deposition could have major impacts on all sectors of the global pork industry.

CONCLUSIONS

To begin, the data reported in this study were one contribution to a much larger body of literature, yet this information should provide insight to current grading systems and how heavier pork carcasses in the future may fit within current marketing systems. Results from this dataset revealed that hot carcass weight was generally weakly correlated with fat depth, muscle depth, or predicted lean yield. The conclusion of this study based on the current dataset was that pigs do not reach a weight threshold where they consistently become fatter or heavier muscled, and that current predicted lean yield equations may still be adequate for heavy weight pigs in the same capacity that they are adequate for light weight pigs.

ACKNOWLEDGMENT

The authors would like to acknowledge Conestoga Meat Packers Ltd. for their assistance with the data used in this study. This project was funded wholly or in part by Conestoga Meat Packers, Ontario Pork, and Natural Sciences and Engineering Research Council of Canada.

Conflict of interest statement. None declared

LITERATURE CITED

Adebambo, A. 1986. Selective breeding of the Nigerian indigenous pigs for the rural producer, vol. X. In: Proceedings of the World Congress on Genetics Applied to Livestock Production. Nebraska: Breeding programs for swine, poultry, and fish; p. 70–74.

Akanno, E. C., F. S. Schenkel, V. M. Quinton, R. M. Friendship, and J. A. B. Robinson. 2013. Meta-analysis of genetic parameter estimates for reproduction, growth and carcass traits of pigs in the tropics. Livest. Sci. 152:101–113. doi:10.1016/j.livsci.2012.07.021

Arkfeld, E. K., D. A. Mohrhauser, D. A. King, T. L. Wheeler, A. C. Dilger, S. D. Shackelford, and D. D. Boler. 2017. Characterization of variability in pork carcass composition and primal quality. J. Anim. Sci. 95:697–708. doi:10.2527/jas.2016.1097

Bertol, T. M., A. Coldebella, J. I. S. Filho, and A. L. Guidoni. 2017. Swine carcasses classified by degree of exudation and marbling content. Pesqui. Agropecu. Bras. 52:121–128. doi:10.1590/S0100-204X2017000200006

Bohrer, B. M., and D. D. Boler. 2017. Review: subjective pork quality evaluation may not be indicative of instrumental pork quality measurements on a study-to-study basis. Prof. Anim. Sci. 33:530–540. doi:10.15232/pas.2017-01644

Boler, D. D., C. L. Puls, D. L. Clark, M. Ellis, A. L. Schroeder, P. D. Matzat, J. Killefer, F. K. McKeith, and A. C. Dilger. 2014. Effects of immunologically castration (Improvest) on changes in dressing percentage and carcass characteristics of finishing pigs. J. Anim. Sci. 91:359–368. doi:10.2527/jas2013-6863

Busk, H., E. V. Olsen, and J. Brøndum. 1999. Determination of lean meat in pig carcasses with the Autofom classification system. Meat Sci. 52:307–314. doi:10.1016/s0309-1740(99)00007-8

Canadian Pork Council (CPC). 1994. National pork carcass cutout project (1992): Agriculture and Agri-Food Canada, the Canadian Meat Council and the Canadian Pork Council. Ottawa, ON: CPC.

Chimonyo, M., and K. Dzama. 2007. Estimation of genetic parameters for growth performance and carcass traits in Mukota pigs. Animal 1:317–323. doi:10.1017/S1751731107661849

De Smet, S., K. Raes, and D. Demeyer. 2004. Meat fatty acid composition as affected by fatness and genetic factors: a review. Anim. Res. 53:81–98. doi:10.1051/animres

Edwards, R. L., G. C. Smith, H. R. Cross, and Z. L. Carpenter. 1981. Estimating lean in pork carcasses differing in backfat thickness. J. Anim. Sci. 52:703. doi:10.2527/jas1981.524703x

Fahey, T. J., D. M. Schaefer, R. G. Kauffman, R. J. Epley, P. F. Gould, J. R. Romans, G. C. Smith, and D. G. Topel. 1977. A comparison of practical methods to estimate pork carcass composition. J. Anim. Sci. 44:8. doi:10.2527/jas1977.4418

Fix, J. S., J. P. Cassady, W. O. Herring, J. W. Holl, M. S. Culbertson, and M. T. See. 2010. Effect of piglet birth weight on body weight, growth, backfat, and longissimus muscle area of commercial market swine. Livest. Sci. 127:51–59. doi:10.1016/j.livsci.2009.08.007

Gilleland, H. L., R. Detweiler, M. J. Azain, and D. Pringle. 2019. Effects of sire line, slaughter weight, and gender on pork quality and yield characteristics. Meat Muscle Biol. 1:88. doi:10.221751/rmc2017.083

Grisdale, B., L. L. Christian, H. R. Cross, D. J. Meisinger, M. F. Rothschild, and R. G. Kauffman. 1984. Revised approaches to estimate lean of pork carcasses of known age or days on test. J. Anim. Sci. 58:335–345. doi:10.2527/jas1984.582335x.

Harsh, B. N., E. K. Arkfeld, D. A. Mohrhauser, D. A. King, T. L. Wheeler, A. C. Dilger, S. D. Shackelford, and D. D. Boler. 2017. Effect of hot carcass weight on loin, ham, and belly quality from pigs sourced from a commercial processing facility. J. Anim. Sci. 95:4958–4970. doi:10.2527/jas2017.1674

Knecht, D., K. Duziński, and D. Lisiak. 2016. Accuracy of estimating the technological and economic value of pig carcass primal cuts with an optical-needle device. Can. J. Anim. Sci. 96:37–44. doi:10.1139/cjas-2015-0048

Koots, K. R., and J. P. Gibson. 1994. How precise are genetic correlation estimates? Proc. 5th World Cong. Genet. Appl. Livest. Prod. 18: 353–360.

Kure, H. 1997. Marketing management support in slaughter pig production [PhD thesis]. Copenhagen (Denmark): The Royal Veterinary and Agricultural University Copenhagen, The University of Copenhagen.

Latorre, M. A., R. Lázaro, D. G. Valencia, P. Medel, and G. G. Mateos. 2004. The effects of gender and slaughter weight on the growth performance, carcass traits, and meat quality characteristics of heavy pigs. J. Anim. Sci. 82:526–533. doi:10.2527/2004.822526x

Lisiak, D., K. Duziński, P. Janiszewski, K. Borzuta, and D. Knecht. 2015. A new simple method for estimating the pork carcass mass of primal cuts and lean meat content of the carcass. Anim. Prod. Sci. 55:1044. doi:10.1071/an13534

Miar, Y., G. Plastow, H. Bruce, S. Moore, G. Manafiazar, R. Kemp, P. Charagu, A. Huisman, B. van Haandel, C. Zhang, et al. 2014. Genetic and phenotypic correlations between performance traits with meat quality and carcass characteristics in commercial crossbred pigs. PLoS One 9:e110105. doi:10.1371/journal.pone.0110105

Morin, M., G. Berthiaume, J. Rivest, L. Cloutier, F. Fortin, Y. Allard, and L. Maignel. 2015. Technical and economic study on heavier market pigs (140 kg). Québec, QC: Centre de développement du porc du Québec (CDPQ), Inc.

Newcom, D. W., T. J. Baas, J. W. Mabry, and R. N. Goodwin. 2002. Genetic parameters for pork carcass components. J. Anim. Sci. 80:3099–3106. doi:10.2527/2002.80123099x

Ohlmann, J. W., and P. C. Jones. 2011. An integer programming model for optimal pork marketing. Ann. Oper. Res. 190:271–287. doi:10.1007/s10479-008-0466-3

Owens, F. N., P. Dubeski, and C. F. Hanson. 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci. 71:3138–3150. doi:10.2527/1993.71113138x

Plà-Aragonés, L. M., S. V. Rodríguez-Sánchez, and V. Rebillas-Loredo. 2013. A mixed integer linear programming model for optimal delivery of fattened pigs to the abattoir. J. Appl. Oper. Res. 5:164–175.

Pomar, C. and M. Marcoux. 2003. Comparing the Canadian pork lean yields and grading indexes predicted from grading methods based on Destron and Hennessy probe measurements. Can. J. Anim. Sci. 83:451–458. doi:10.4141/a02-107

Pomar, C., J. Rivest, P. Jean dit Bailleul, and M. Marcoux. 2001. Predicting loin-eye area from ultrasound and grading probe measurements of fat and muscle depths in pork carcasses. Can. J. Anim. Sci. 81:429–434. doi:10.4141/a00-081

Price, H. E., A. B. Lerner, E. A. Rice, J. E. Lowell, B. N. Harsh, K. E. Barkley, L. T. Honneger, E. Richardson, J. C. Woodworth, M. D. Tokach, S. S. Dritz, R. D. Goodband, J. M. DeRouchey, T. G. O'Quinn, M. W. Allerson, B. Fields, D. A. King, T. L. Wheeler, S. D. Shackelford, A. C. Dilger, and D. D. Boler. 2019. Characterizing ham and loin quality as hot carcass weight increases to an average of 119 kilograms. Meat Muscle Biol. 3(1):330–343. doi:10.22175/mmb2019.06.0019

Rice, E. A., A. B. Lerner, H. E. Price, J. C. Woodworth, M. D. Tokach, S. S. Dritz, R. D. Goodband, J, M, DeRouchey, M. W. Allerson, J. M. Gonzalez, and T. G. O'Quinn. 2018. The effect of increased pork hot carcass weights and chop thickness on consumer visual appearance and purchase intent ratings of top loin chops. Kans. Agric. Exp. Stn Res. Rep. 4:40.

Rodríguez, S. V., L. M. Plà, and J. Faulin. 2014. New opportunities in operations research to improve pork supply chain efficiency. Ann. Oper. Res. 219:5–23. doi:10.1007/s10479-013-1465-6

Schinckel, A. P., J. R. Wagner, J. C. Forrest, and M. E. Einstein. 2001. Evaluation of alternative measures of pork carcass composition. J. Anim. Sci. 79:1093–1119. doi:10.2527/2001.7951093x

Sellier, P., L. Maignel, and J. P. Bidanel. 2010. Genetic parameters for tissue and fatty acid composition of backfat, perirenal fat and longissimus muscle in Large White and Landrace pigs. Animal 4:497–504. doi:10.1017/S1751731109991261

Straadt, I. K., M. D. Aaslyng, and H. C. Bertram. 2013. Sensory and consumer evaluation of pork loins from crossbreeds between Danish Landrace, Yorkshire, Duroc, Iberian and Mangalitza. Meat Sci. 95:27–35. doi:10.1016/j.meatsci.2013.04.026

Strzelecki J., K. Borzuta, and D. Lisiak. 1998. Development of the regression equation to estimate the meat content of pig carcases with the Auto-Fom device. Roczniki Instytutu Przemysłu Mięsnego iTłuszczowego 35:35–42.

Swatland, H. J., S. P. Ananthanarayanan, and A. A. Goldenberg. 1994. A review of probes and robots: implementing new technologies in meat evaluation. J. Anim. Sci. 72:1475–1486. doi:10.2527/1994.7261475x

Szymańska, E. J. 2018. The development of the pork market in the world in terms of globalization. J. Agribus. Rural Dev. 16:843–850. doi:10.17306/j.jard.2017.00362

Taylor, R. 1990. Interpretation of the correlation coefficient: a basic review. J. Diagn. Med. Sonogr. 6:35–39. doi:10.1177/875647939000600106

Thornton, P. K. 2010. Livestock production: recent trends, future prospects. Philos. Trans. R. Soc. B Biol. Sci. 365(1554):2853–2867. doi:10.1098/rstb.2010.0134

USDA Economic Research Service (USDA ERS). 2019. Livestock and poultry slaughter. [accessed 14 October 2019]. Available from https://www.ers.usda.gov/data-products/livestock-meat-domestic-data/livestock-meat-domestic-data.

Wilson, K. B., M. F. Overholt, E. K. Hogan, C. Schwab, C. M. Shull, M. Ellis, N. S. Grohmann, A. C. Dilger, and D. D. Boler. 2016. Predicting pork loin chop yield using carcass and loin characteristics. J. Anim. Sci. 94:4903–4910. doi:10.2527/jas.2016-0610

Zhang, H., J. L. Aalhus, C. Gariépy, B. Uttaro, O. Lopez-Campos, N. Prieto, M. E. R. Dugan, Y. Jin, and M. Juárez. 2016. Effects of pork differentiation strategies in Canada on pig performance and carcass characteristics. Can. J. Anim. Sci. 96(4): 512–523. doi:10.1139/cjas-2015-0197

Zhou, Z., 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. Can. J. Anim. Sci. 99(3): 542–552. doi:10.1139/cjas-2018-0195