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Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition, and eating quality of pork[1]

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ABSTRACT: The objective of this study was to investigate the relationships among birth weight, birth order, or litter size on growth performance, carcass quality, and eating quality of the ultimate pork product. Data were collected from 98 pig litters and, with the addition of recording birth weight and birth order, farrowing and piglet management were according to normal barn practices. In the nursery and during growout, the pigs received the normal feeding program for the barn and, with the addition of individual tattooing, were marketed as per standard procedure. From 24 litters, selected because they had at least 12 pigs born alive and represented a range of birth weights, 4 piglets were chosen (for a total of 96 piglets) and sent to Agriculture and Agri-Food Canada–Lacombe Research Centre (Lacombe, Alberta, Canada) when they reached 120 kg for extensive meat quality and sensory analysis. Individual BW was measured at birth, on the day of weaning, 5 wk after weaning, at nursery exit, at first pull, and at the time of marketing. Litter sizes were divided into 3 categories: small (3 to 10 piglets), medium (11 to 13 piglets), and large (14 to 19 piglets). There were 4 birth-weight quartiles: 0.80 to 1.20, 1.25 to 1.45, 1.50 to 1.70, and 1.75 to 2.50 kg. Increased litter size resulted in reduced mean birth weight ($P < 0.05$), but had no effect on within litter variability or carcass quality ($P > 0.05$) when slaughtered at the same endpoint. Lighter birth-weight pigs had reduced BW at weaning, 5 and 7 wk postweaning, and at first pull and had increased days to market ($P < 0.05$). Birth weight had limited effects on carcass quality, weight of primal cuts, objective quality, and overall palatability of the meat at the same slaughter weight ($P > 0.05$). In conclusion, increased litter size resulted in decreased mean birth weight but no change in days to market. Lighter birth-weight pigs took longer to reach market. Despite some differences in histological properties, birth weight had limited effects on carcass composition or final eating quality of the pork when slaughtered at the same BW and large litter size resulted in more pigs weaned and marketed compared with the smaller litters. We concluded that based on the conditions of this study, other than increased days to market, there is no reason based on pig performance or pork quality to slow down the goal of the pork industry to increase sow productivity as a means to increase efficiency.

Key words: birth weight, carcass quality, litter size, pig performance, pork quality

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INTRODUCTION

Birth weight and litter size are important traits in pig production. Rapid increases in litter size and annual sow productivity have resulted in increased numbers of light-birth-weight piglets. Lighter birth weight in piglets has been associated with greater preweaning mortality, slower growth rates, and decreased pork quality (Herpin et al., 2002; Quiniou et al., 2002; Rehfeldt et al., 2008), possibly a result of fewer total and primary muscle fibers (Quiniou et al., 2002; Rehfeldt and Kuhn, 2006). Although poorly studied, there is an indication that birth weight is related to birth order with heavier piglets born earlier (Friend and Cunningham, 1966; Motsi et al., 2006). Although litter size and birth weight are related, it remains uncertain if the effects of light birth weight can also be attributed to increased litter size. Therefore, the objectives of this project were to 1) determine if birth weight affects the

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eating quality of pork through changes in muscle fiber number and type; 2) determine if birth weight or birth order was the more critical factor in determining ultimate pig performance, explaining the number and type of muscle fibers at birth, and predicting the final eating quality of pork; and 3) determine if birth weight could be employed as a practical criterion to select pigs early in life that are more or less likely to produce a superior final meat product. It was our hypothesis that because larger litters result in a lighter mean birth weight, the impact of increased litter size would mirror effects previously observed due to reduced birth weight.

MATERIALS AND METHODS

This experiment was conducted under animal care protocol 970019, approved by the University of Saskatchewan Committee on Animal Care and Supply, ensuring adherence to the principles of the Canadian Council on Animal Care (1993).

Animal Care

Data were collected from 98 litters for a total of 1,114 pigs born alive (1,200 born total). The barn was transitioning its sow herd, and thus piglets were born to Camborough Plus, C-22, or F_2 sows; all were sired by PIC 337 sires (PIC Canada, Winnipeg, Manitoba, Canada). A technician was present from 0800 h Tuesday until 1600 h Saturday for 5 consecutive weeks to provide attendance at all farrowings. Farrowing and piglet management followed normal barn procedures. Piglets were cross-fostered within 3 d of birth, although piglet identification was by litter of birth; cross-fostering occurred across all litter sizes because the focus of the study was the impact of prenatal influences on subsequent performance and meat quality. Iron injections, castration of male pigs, and tail clipping were completed within 48 h of birth. At the time of farrowing, each live-born piglet was identified individually using an ear notch that recorded litter number and order of birth within litter. Notching preceded any cross-fostering. Litter of origin and litter of nursing were recorded for each pig.

The number of mummies and stillborn piglets were also recorded, but not weighed and not included in the birth order. Piglets were weighed to the nearest 50 g when dry and were reweighed on the day of weaning 21.1 ± 2.2 d of age), 5 wk after weaning, at nursery exit (7 wk of age), at first pull, and at the time of marketing. First pull was defined as the date when the first pig in any given pen was marketed, based on reaching the minimum market weight. Three litter size categories were used, defined as small litters (3 to 10 pigs born alive), medium litters (11 to 13 pigs), and large litters (14 to 19 pigs), and 4 birth-weight categories were used (0.80 to 1.20, 1.25 to 1.45, 1.50 to 1.70, and 1.75 to 2.50 kg). Consistent with commercial practice on many farms, piglets with a birth weight of 750 g or less were considered nonviable and removed from the experiment after the recording of their birth weight.

In the nursery and during growout, the pigs received the normal feeding program, which included 5 phases in the nursery and 4 phases in growout, and was designed to meet or exceed the nutrient requirements of the pig for maximum BW gain (NRC, 1998).

Market Pigs

All pigs, with the exception of 24 select litters (described below), were randomly weaned into mixed pens. Marketing occurred twice a week; any pig weighing at least 118 kg was identified for shipping on the next marketing day. These pigs were marketed through Mitchell's Gourmet Foods (Saskatoon, Saskatchewan, Canada). Carcass weight (head on), backfat thickness, loin thickness, and estimated percent lean yield were collected at slaughter, and the carcass index was calculated, all according to the Canadian Hog Carcass Grading Settlement System (Canadian Pork Council, 1986). Dressing percent was calculated based on BW at shipping and the subsequent carcass weight.

Select Pigs

Twenty-four litters were selected at weaning to provide the best distribution of the number of piglets within the 4 defined birth-weight quartiles described above. These select litters were housed in intact groups in discrete pens until marketed. Select litter pens contained barrows and gilts and received the gilt feeding program. One pig from each of the 4 birth-weight quartiles (4 pigs per litter, n = 96 pigs) was randomly selected for transport to the Agriculture and Agri-Food Canada–Lacombe Research Centre (Lacombe, Alberta, Canada) for a detailed evaluation of pork quality and muscle histology. All other pigs were marketed in the manner described for the market pigs.

Slaughter. At the time of slaughter, final BW were recorded, and animals were stunned, exsanguinated, and dressed in a simulated commercial manner. Weights were recorded for the kidneys, leaf lard, feet, and head. After splitting of the carcass, hot side weights were recorded. At 45-min postmortem, an estimated lean yield was determined on the left side between the third and fourth anterior rib approximately 7 cm from the midline (Anitech PG100 Grading Probe, Anitech Information Systems Inc., Markham, Ontario, Canada). At the same time, pH and temperature were recorded on the left longissimus thoracis between the 11th and 12th vertebrae (Accumet AP72 pH meter, Fisher Scientific, Mississauga, Ontario, Canada; equipped with an Orion Ingold electrode, Udorf, Switzerland).

Meat Quality. At 24 h, carcass sides were weighed to determine cooler shrink loss. Fat hardness readings (0 to 100 durometer units) were determined on the right sides of the carcasses at the 1st and 2nd thoracic vertebrae on the second subcutaneous fat layer (Rex Durometer LG2400, Rex Gauge Company, Buffalo Grove, IL) in accordance with specification standard D2240-05 (ASTM, 2008). The left sides of the carcasses were separated into primals (picnic, butt, loin, hock, and ham) and subsequently dissected into lean, bone, and fat (subcutaneous, intermuscular, and body cavity) as described by Martin et al. (1981).

The right and left longissimus lumborum (**LL**) and semitendinosus (**STM**) muscles were collected and labeled. At 24-h, pH and temperature were recorded on the posterior end of the left LL and proximal end of the left STM. This portion was discarded and a chop (25 mm) was removed and exposed to atmospheric oxygen for 20 min. Objective color measurements using a Minolta CR-300 with Spectra QC-300 Software (Minolta Canada Inc., Mississauga, Ontario, Canada) were collected from 2 locations and converted to hue and chroma (Commission Internationale de l'Eclairage, 1978; Murray, 1995). One color reading was taken from the visibly lighter area of the STM muscle and one from the darker area to determine the average. Chops were then preweighed in a polystyrene tray with a dri-loc pad, overwrapped with oxygen-permeable film (8,000 $mL \cdot m^{-2} \cdot 24\ h^{-1}$ Vitafilm choice wrap, Goodyear Canada Inc., Toronto, Ontario, Canada) and stored at 1°C for 2 d to determine gravimetric drip loss. The remainder of the muscle was stored in a cooler at 2°C with air speeds of 0.5 m/s until 48 h postmortem quality determinations.

A chop (50 mm) was removed from the mid-portion of the right LL and STM muscles for subsequent histological determinations. A cross-sectional area image of each chop was captured with a digital Canon Power Shot G6 camera (Canon Inc., Tokyo, Japan) and the cross-sectional area analyzed with Image J Software (Bethesda, MD). Both light and dark areas of the STM chop were determined individually. After image capture, 2-g samples from the LL chop and from the light and dark areas of the STM chop were hand-minced with a surgical scalpel, avoiding connective tissue and large deposits of fat. The minced samples were prepared for determination of sarcomere lengths (Aalhus et al., 1999). In addition, a 1.0-cm^3 muscle sample from the LL and from the light and dark area of the STM were mounted, flash-frozen, sectioned (11 μm), and stained according to Solomon and Dunn (1988). Fiber counts (slow oxidative, fast oxidative glycolytic, and fast glycolytic fibers) and fiber areas were analyzed using an image analysis system (Axioscope, Zeiss, Göttingen, Germany; equipped with a Sony DXC 930 Color Video Camera, Sony Corporation, Tokyo, Japan, and Image Pro-Plus software V4.0, Mediacybernetics, Silver Spring, MD) similar to other published methods (Dwyer et al., 1993; Bee, 2004). Total numbers of primary and secondary muscle fibers within the muscle cross-sectional area were also estimated.

At 48 h, the right and left LL and STM muscles were removed from the cooler, and pH and temperature readings were collected from the posterior end of the left LL muscles and the proximal end of the left STM muscles. Four chops, each 25-mm thick, were removed from left muscles only. The first chop was used for objective color measurements as previously outlined. Raw weights were then collected on the first and second chops from both muscles before cooking for shear force analyses as described by Juarez et al. (2009) with the exception that chops were cooked to an internal temperature of 35°C, then turned and cooked to a final internal temperature of 70°C. Raw and final chop weights were used to determine cooking loss and cooking time per gram expressed as the average of the 2 chops. Peak shear force was also expressed as the average of the 2 chops. The remaining 2 chops were labeled, vacuum-packaged (Multivac AGW, Multivac Inc., Kansas City, MO), and stored at −35°C for subsequent sensory analysis.

Right muscles were trimmed of all extraneous fat and connective tissue and subjective color and structure were evaluated on the LL muscles as a consensus of 3 experienced raters using the Agriculture Canada Pork Quality Standards (Agriculture Canada, 1984). Color and structure standard scores ranged from 1 (extremely pale, soft, and exudative with an open grainy texture) to 5 (extremely dark, firm, and dry with a closed grainy texture). Subjective marbling scores were assessed on the cut surface of the LL muscles after color and structure scoring using the National Pork Producers Council scale (NPPC, 2000) with assigned numbers corresponding to estimated percentages of intramuscular fat (100 being devoid of marbling and 600 having abundant marbling). The remaining portions of the right LL and STM muscles were then ground 3 times through a 3.2-mm plate and subsampled for proximate analyses and soluble proteins as described by Juarez et al. (2009).

Sensory Analysis. Preparation procedures for sensory analyses were similar to those described by Juarez et al. (2009), with the exception that chops were cooked to a final internal temperature of 70°C. Eight 1.3-cm cubes from each sample (4 per chop in the case where chops were too small to obtain 8 cubes) were randomly assigned to an 8-member trained taste panel. Samples were placed in glass jars in a circulating water bath (Lindberg/Blue model WB1120A-1) and allowed to equilibrate to 70°C before evaluation. Attribute ratings were electronically collected using Compusense 5 computer software (Compusense Inc., Guelph, Ontario, Canada) with 8-point descriptive scales for initial and overall tenderness (8 = extremely tender; 1 = extremely tough), initial and sustained juiciness (8 = extremely juicy; 1 = extremely dry), pork flavor intensity (8 = extremely intense pork flavor; 1 = extremely bland pork flavor), and amount of connective tissue (8 = none detected; 1 = abundant). Flavor desirability and overall palatability were rated on an 8-point hedonic scale (8 = extremely desirable; 1 = extremely undesirable). Initial tenderness was rated on the first bite through the cut center surface with the incisors; initial juiciness was rated after 3 to 5 chews with the molars; pork flavor,

flavor desirability, and amount of connective tissue between 10 to 20 chews and sustained juiciness; overall tenderness and overall palatability were rated before expelling. All panel evaluations were conducted in well-ventilated, partitioned booths, under 882 lx of incandescent and fluorescent white light. Distilled water and unsalted soda crackers were provided to purge the palate of residual flavor notes between samples (Larmond, 1977).

Statistical Analysis

Within litter variation in BW is reported using the SD and CV. Birth order is expressed as both (order; absolute position within the litter) or the rank (order divided by the number born alive). Growth data, which utilized all piglets in the experiment, were subjected to ANOVA using the MIXED procedure (SAS Inst. Inc., Cary, NC). The model included the effect of litter size or birth-weight quartile, and if found significant ($P < 0.05$), means were separated using the PDIFF procedure of SAS. Because no effect or interactions of dam line was detected, these data were removed from the model.

Carcass quality, histology, and sensory data, utilizing the 96 piglets selected to represent the birth-weight quartiles, were analyzed using the MIXED procedure of SAS, with final BW as a covariate and kill date as a random variable. The model included birth-weight quartile (carcass data), or birth-weight quartile and muscle type (quality, sensory, and histological data). When significant, the PDIFF procedure was used for means separation.

Correlation analysis, using the CORR procedure of SAS, related birth weight, birth order, and litter size to growth and carcass outcomes. Differences with a P-value of less than 0.05 were considered to be statistically significant; trends were defined as a P-value between 0.05 and 0.10.

RESULTS

Effects of Litter Size

Of the total pigs born, 89% were born alive in the small and medium, whereas greater than 98% were born alive in the large litters (Table 1). Average birth weight decreased by approximately 33 g per pig with increasing litter size ($P < 0.001$; Figure 1). The variation in BW within a litter, whether expressed as the SD or CV, was not affected by litter size ($P > 0.05$). The increased number of pigs per litter, defined by treatment at birth, persisted through to first pull; however, the average piglet weight advantage for the smaller litters at birth was undetected by the time of weaning ($P > 0.05$; Table 1). Conversely, total litter BW increased as litter size increased at all stages of growth ($P < 0.05$). Average days to market was not affected by litter size ($P > 0.05$; Table 1). There was no effect of litter size on dressed weight, yield percentage, loin and fat proportions or index ($P > 0.05$; Table 2). However, pigs from large litters tended to produce slightly fatter carcasses ($P < 0.10$).

Effects of Birth Weight

As mandated by the experimental design, BW increased across quartiles on d 0. This BW advantage was maintained through to first pull ($P < 0.001$; Table 3). Average daily gain from d 0 to weaning and from weaning to 5 wk postweaning increased as birth weight increased ($P < 0.001$). Average daily gain was least in the lighter birth-weight pigs in the period from 5 to 7 wk postweaning and in the 2 least birth-weight categories from 7 wk postweaning to market ($P > 0.05$; Table 3).

Average days to market was reduced with increasing birth-weight category ($P < 0.001$). Although not analyzed statistically, it can be observed that the range in days to market was numerically greater in the lightest birth weight (64 d) than those pigs in the heaviest birth-weight category (44 d). This can be attributed to differences in the time taken by slower pigs to reach market weight.

Birth-weight category had no effect on any carcass quality variables for the pigs marketed through a commercial processor ($P > 0.10$; Table 4). The carcass data for the subset of 96 pigs sent to the Lacombe Research Centre for detailed analysis are reported in Table 5. Consistent with the data obtained from a commercial abattoir (Table 4), birth-weight quartile had no effect on lean yield or dressing percentage; neither did it affect loss in the cooler, fat hardness, or grade site pH and temperature ($P > 0.05$). However, there was a small difference in final BW ($P = 0.05$), the effect of which was accounted for by identifying final BW as a covariate in the other data sets. Similarly, the yields of primal cuts were similar, with the exception of the butt primal, which was greatest in the lightest and heaviest birth-weight quartiles, intermediate in the second lightest birth-weight quartile, and least in the second heaviest birth-weight quartile (Table 6). Overall totals for the proportions of lean, bone and total fat, total body cavity fat, and subcutaneous fat were similar regardless of birth-weight quartile ($P > 0.10$). There was a tendency for intermuscular fat to differ among birth-weight quartiles with the lightest birth-weight quartile having the numerically greatest proportion of intermuscular fat ($P < 0.10$).

The proportion of lean, bone, and fat within each of the primal cuts showed few differences (Table 7). In the picnic, loin, and hock, there was no effect of birth-weight quartile on primal composition ($P > 0.10$). Within the butt, the proportion of bone was elevated in pigs in the heaviest birth-weight quartile, whereas the proportion of intermuscular fat was least in the second

Table 1. The effect of litter size on BW, variability in BW, and days to market[1]

	Pigs per litter[2]				
Item	3 to 10	11 to 13	14 to 19	SEM	P-value
Litters, total n	38	39	21		
Piglets, total n					
Total born	357	528	330		
Born alive					
Including ≤750 g at birth	318	472	324		
Excluding ≤750 g at birth	313	453	301		
n, litter average					
d 0	8.4[a]	12.1[b]	15.4[c]	0.41	<0.001
Wean	7.3[a]	10.4[b]	13.2[c]	0.49	<0.001
5 wk	7.2[a]	10.2[b]	13.0[c]	0.48	<0.001
7 wk	7.1[a]	10.2[b]	12.8[c]	0.48	<0.001
1st pull[3]	6.9[a]	10.0[b]	12.2[c]	0.46	<0.001
Average individual BW, kg					
d 0	1.57[a]	1.37[b]	1.27[b]	0.04	<0.001
Wean	6.81	6.45	6.49	0.19	0.17
5 wk	22.88	22.01	22.71	0.51	0.24
7 wk	32.94	31.65	32.82	0.59	0.10
1st pull[3]	97.55	96.44	98.42	1.31	0.45
SD of individual BW, kg					
d 0	0.30	0.25	0.26	0.02	0.09
Wean	1.28	1.06	1.28	0.11	0.16
5 wk	3.23	2.80	3.00	0.24	0.23
7 wk	4.16	3.62	4.08	0.30	0.21
1st pull[3]	8.99	8.90	10.14	0.78	0.40
CV of individual BW, %					
d 0	23.99[a]	18.73[b]	16.9[b]	1.48	0.001
Wean	19.17	16.77	18.82	1.86	0.43
5 wk	13.43	12.98	13.43	1.17	0.46
7 wk	12.88	11.60	12.46	1.03	0.49
1st pull[3]	9.38	9.33	10.38	0.87	0.58
Total litter BW, kg					
d 0	12.99[c]	16.58[b]	19.70[a]	0.64	<0.001
Wean	49.32[a]	66.69[b]	84.75[c]	3.53	<0.001
5 wk	162.80[a]	223.16[b]	293.49[c]	11.21	<0.001
7 wk	232.26[a]	313.38[b]	421.13[c]	16.05	<0.001
1st pull[3]	672.03[a]	961.94[b]	1,206.87[c]	46.73	<0.001
Shipped	792.27[a]	1,090.31[b]	1,390.33[c]	56.6	0.001
Days to market					
Average	154.3	155.3	153.5	1.3	0.52

[a–c]Within a row, means without a common superscript differ ($P < 0.05$).
[1]Data include pigs selected to go to Lacombe Research Centre but do not include pigs that weighed ≤750 g at birth.
[2]Average sow parity was 3.97 (1 sow was parity 12), 3.13, and 3.24 for groups small, medium, and large, respectively.
[3]Time at which first pigs were removed from pens for marketing.

heaviest birth-weight quartile and greatest in the least birth-weight quartile ($P < 0.05$). In the ham, the portion of body cavity fat was least in pigs from the second greatest birth-weight quartile and greatest in the heaviest birthweight quartile ($P \leq 0.05$).

The effect of birth weight on objective quality characteristics (Table 8) was limited to a significant effect on the muscle composition and cook time ($P < 0.05$). Crude protein content was similar regardless of birth weight ($P > 0.05$); however, moisture increased and intramuscular fat decreased as birth weight increased ($P < 0.05$). Temperature, pH, objective color, shear force, soluble protein, and driploss as indicators of pork quality were unaffected by birth weight ($P > 0.05$). Cooktime was shortest in the 2 intermediate quartiles ($P = 0.03$) and longest in lightest and heaviest birth-weight quartiles. Marbling, color, and structure, measured in the LL only, were unaffected by birth weight ($P > 0.05$).

Similar to the lack of effect on objective quality, birth-weight quartile had no effect on initial tenderness or juiciness, flavor intensity, sustained juiciness, amount of connective tissue, overall tenderness, or overall palatability (Table 9; $P > 0.05$). However, flavor desirability was greatest for the lightest and the heaviest birth-weight quartiles ($P < 0.05$).

There was a significant birth-weight quartile × muscle interaction for sarcomere length (<0.05; data not shown). In the heaviest birth quartile weight, sarcomere length was longer in the light and dark areas of the STM. In the LL, sarcomere length was not affected by birth-weight quartile (Table 10). Although the proportion of fiber types did not differ ($P > 0.10$), the mean fiber area or the slow oxidative fibers was significantly

Table 2. The effect of litter size on carcass composition of marketed pigs[1]

Item	Pigs per litter 3 to 10	11 to 13	14 to 19	SEM	*P*-value
Dressed wt, kg	94.5	94.3	94.6	0.41	0.82
Yield, %	60.3	60.5	60.2	0.23	0.64
Loin, mm	66.4	66.9	66.6	0.73	0.81
Fat, mm	19.8	19.7	20.2	0.53	0.09
Index[2]	109.4	108.8	108.6	0.57	0.46

[1]Data do not include pigs selected to go to Agriculture and Agri-Food Canada–Lacombe Research Centre.

[2]Carcass index represents the basis for establishing carcass value according to the Canadian Hog Carcass Grading Settlement System (Canadian Pork Council, 1986).

greater in the least birth-weight quartile than in the second greatest and greatest birth-weight quartiles. Numerically, fiber areas for the fast oxidative glycolytic and fast glycolytic fibers were greater in the lighter birth-weight quartiles than in the heavier birth-weight quartiles. These differences in mean fiber areas led to a tendency for the calculated number of secondary fibers to be less ($P = 0.06$) in the least birth-weight quartile. As well, there were numerically fewer primary fibers in the lightest birth-weight quartile.

Correlation analysis (Table 11) revealed a significant negative relationship between number born and sow parity, birth weight, and weaning weight ($P < 0.05$) and a positive correlation with birth order. Birth weight was positively correlated with BW at weaning, at 5 and 7 wk of age, and at first pull and was negatively correlated with days to market. However, Figure 1 clearly illustrates that there is a relationship between litter size and birth weight; however, the relationship is weak due to the high degree of variation in birth weight.

DISCUSSION

The pork industry has achieved tremendous gains in litter size, through genetic selection and the introduction of hyperprolific dam lines into commercial production, along with improvements in nutrition, housing, and herd health management. Larger litters, however, result in lighter birth weights (Quiniou et al., 2002), which have been associated with early mortality, decreased growth performance, and decreased eating quality of pork (Herpin et al., 2002; Quiniou et al., 2002; Rehfeldt et al., 2008), prompting some (Foxcroft et al., 2006) to express caution about the use of hyperprolific sow lines in commercial pork production. The increase in uterine blood flow is insufficient to compensate for the increased number of fetuses, which results in a reduced nutrient supply for each fetus (Père and Etienne, 2000). The decreased blood flow can negatively affect the number of muscle fibers, restricting postnatal lean growth, causing increased fat deposits, and resulting in

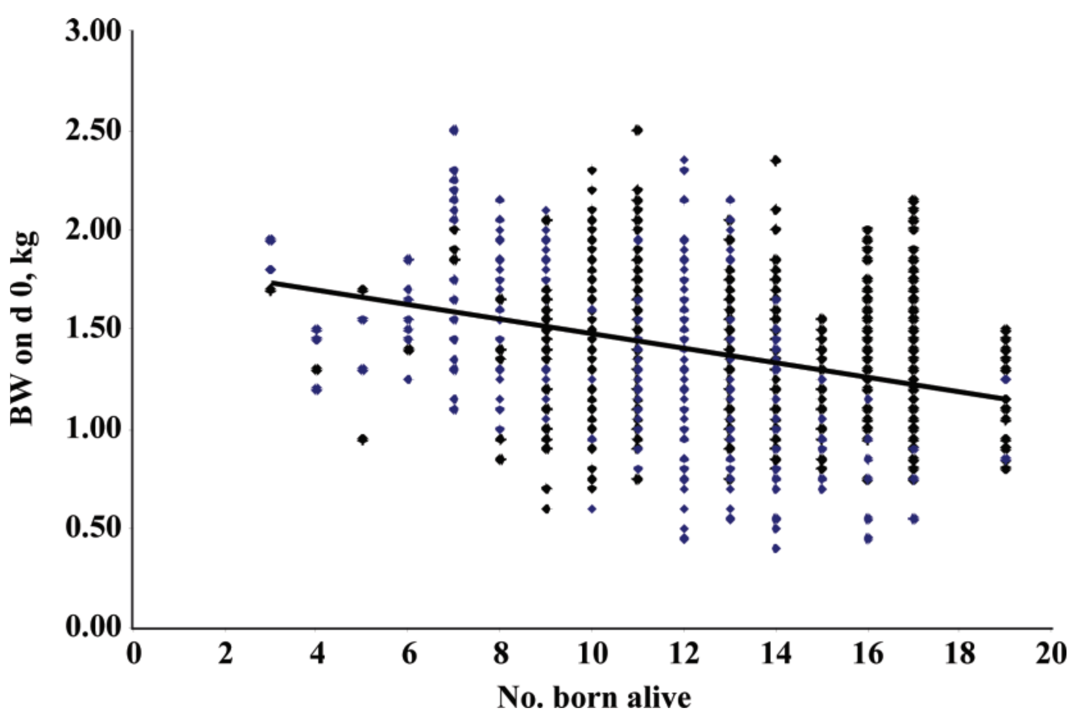

Figure 1. Regression of number born alive per litter and birth weight (kg). All data: y = −0.0374x + 1.85, $R^2 = 0.092$; remove ≤750 g pigs: y = −0.0330x + 1.823, $R^2 = 0.086$. Color version available in the online PDF.

Table 3. The effect of birth weight on BW, ADG, and days to market[1]

	Birth weight, kg					
Item	0.75 to 1.20	1.25 to 1.45	1.50 to 1.70	1.75 to 2.50	SEM	*P*-value
n, born alive	296	309	277	185		
BW, kg						
d 0	1.04[a]	1.35[b]	1.59[c]	1.93[d]	0.008	<0.001
Weaning	5.48[a]	6.30[b]	7.04[c]	7.68[d]	0.09	<0.001
5 wk	19.92[a]	21.95[b]	23.56[c]	24.63[d]	0.30	<0.001
7 wk	29.60[a]	31.78[b]	33.77[c]	34.74[d]	0.32	<0.001
1st pull[2]	92.18[a]	96.81[b]	99.74[c]	101.82[d]	0.79	<0.001
Shipping	119.31	119.23	119.68	119.47	0.39	0.78
ADG, kg/d						
Day 0 to wean	0.21[a]	0.23[b]	0.26[c]	0.27[d]	0.004	<0.001
Wean to 5 wk	0.42[a]	0.45[b]	0.47[c]	0.49[d]	0.006	<0.001
5 wk to 7 wk	0.68[a]	0.71[ab]	0.73[b]	0.72[b]	0.01	0.002
7 wk to market	1.02[a]	1.04[b]	1.06[bc]	1.07[c]	0.008	<0.001
Days to market						
Mean	159.3[a]	154.9[b]	152.3[c]	149.6[d]	0.8	<0.001
Range	139 to 203	138 to 195	137 to 194	137–181		
n shipped[3]	206	250	224	147		

[a–d]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Includes pigs selected for shipment to Lacombe Research Centre. Pigs weighing ≤750 g at birth were excluded from the data set.

[2]Time at which first pigs were removed from pens for marketing.

[3]Number of pigs included in data set.

Table 4. The effect of birth weight on carcass quality of marketed pigs[1]

	Birth weight, kg					
Item	0.75 to 1.20	1.25 to 1.45	1.50 to 1.70	1.75 to 2.50	SEM	*P*-value
Dressed wt, kg	94.2	94.2	94.6	94.5	0.34	0.65
Lean yield, %	60.3	60.4	60.7	60.2	0.17	0.16
Loin, mm	66.8	66.3	67.1	66.6	0.58	0.66
Fat, mm	20.1	19.8	19.3	20.3	0.40	0.20
Index[2]	109.0	108.7	109.4	108.8	0.62	0.75

[1]Data include pigs marketed through Mitchell's Gourmet Foods in Saskatoon, Canada, and exclude pigs sent to Agriculture and Agri-Food Canada–Lacombe Research Centre for meat quality analysis.

[2]Carcass index represents the basis for establishing carcass value according to the Canadian Hog Carcass Grading Settlement System (Canadian Pork Council, 1986).

Table 5. The effect of birth weight on carcass quality of select pigs[1]

	Birth weight, kg					
Item	0.75 to 1.20	1.25 to 1.45	1.50 to 1.70	1.75 to 2.50	SEM	*P*-value
Final BW, kg	105.91[a]	106.06[a]	106.71[ab]	109.15[b]	1.82	0.05
Hot dressing, %	82.80	82.34	82.30	81.93	0.31	0.31
Lean yield, %	59.45	60.24	60.73	59.61	0.61	0.42
Cooler loss, g/kg	22.79	24.05	25.62	23.95	0.94	0.21
Fat hardness	65.7	64.3	62.1	63.8	1.3	0.38
Grade site pH, 45 min	6.43	6.43	6.37	6.41	0.03	0.48
Grade site temperature, 45 min	38.0	37.3	37.6	38.1	0.15	0.15

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Data obtained from 96 pigs, 1 pig within each birth-weight quartile from 24 litters, selected for slaughter at Agriculture and Agri-Food Canada–Lacombe Research Centre.

Table 6. The effect of birth weight on dissected yields of primal cuts,[1] and total lean, bone, and fat[2,3]

	Birth weight, kg					
Item	0.75 to 1.20	1.25 to 1.45	1.50 to 1.70	1.75 to 2.50	SEM	*P*-value
Primal cuts, g/kg						
Picnic	105.6	105.7	108.5	107.9	1.3	0.24
Hock	25.6	26.5	26.6	25.6	0.4	0.19
Ham	271.4	274	277.1	270.8	2.3	0.19
Loin	264.8	262.2	263.3	262.5	2.3	0.86
Butt	108.8[b]	107.7[ab]	104.9[a]	108.6[b]	1.1	0.05
Belly	670.3	674	655.3	671.9	10.2	0.51
Composition, g/kg						
Total lean	631.1	643.1	651.2	638.1	7.97	0.31
Total bone	90.6	92.1	92.8	91.6	1.55	0.76
Total fat	208.1	198.7	194.5	202.7	6.10	0.40
Body cavity	8.0	8.1	7.3	8.2	0.34	0.17
Intermuscular	62.3	58.0	54.3	59.4	2.28	0.09
Subcutaneous	278.4	264.8	256.0	270.3	7.96	0.22

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Expressed per kilogram of total side weight.

[2]Expressed per kilogram of total lean cuts (loin, ham, butt, and picnic).

[3]Data obtained from 96 pigs, 1 pig within each weight quartile from 24 litters, selected for slaughter at Agriculture and Agri-Food Canada–Lacombe Research Centre.

poorer pork quality (Rehfeldt and Kuhn, 2006). Rehfeldt et al. (2008) reported optimal pork quality from middle-birth-weight pigs (1.23 to 1.53 kg) and poor meat quality from lighter birth-weight pigs (0.80 to 1.23 kg) with respect to pH and drip loss. This poor quality was attributed to excessive fiber hypertrophy

Table 7. The effect of birth weight on the proportion ($g \cdot kg^{-1}$) of lean, bone, and fat within each primal cut[1]

	Birth weight, kg					
Item	0.75 to 1.20	1.25 to 1.45	1.50 to 1.70	1.75 to 2.50	SEM	*P*-value
Picnic						
Lean	683.62	689.55	695.01	675.31	7.96	0.33
Bone	78.91	80.00	81.12	81.79	2.03	0.76
Subcutaneous fat	128.31	125.27	126.94	135.79	4.88	0.44
Body cavity fat	11.75	11.04	11.32	10.75	0.70	0.77
Intermuscular fat	97.40	94.13	85.61	96.36	4.15	0.15
Hock						
Lean	385.69	392.93	387.50	387.15	6.14	0.83
Bone	367.49	366.35	369.79	368.82	5.19	0.97
Subcutaneous fat	202.37	198.15	196.32	203.58	4.83	0.66
Intermuscular fat	44.45	42.57	46.39	40.45	196.96	0.95
Ham						
Lean	680.38	684.38	688.45	681.82	6.06	0.77
Bone	84.57	87.27	88.37	89.26	1.59	0.18
Subcutaneous fat	189.59	185.58	181.63	184.28	5.06	0.71
Body cavity fat	4.33[ab]	4.79[ab]	3.84[a]	5.26[b]	0.37	0.04
Intermuscular fat	41.32	37.99	37.71	39.35	1.61	0.34
Loin						
Lean	567.82	588.22	597.58	584.52	10.04	0.18
Bone	120.85	122.22	121.07	116.90	2.83	0.57
Subcutaneous fat	251.50	233.97	228.80	242.31	8.36	0.21
Body cavity fat	13.52	13.38	11.89	13.29	0.65	0.22
Intermuscular fat	46.28	42.19	40.65	43.07	2.32	0.34
Butt						
Lean	619.85	633.59	647.93	630.29	9.69	0.21
Bone	42.80[ab]	42.24[a]	45.17[bc]	46.00[c]	0.95	0.01
Subcutaneous fat	222.00	215.73	209.61	215.36	6.46	0.58
Intermuscular fat	115.35[b]	108.44[ab]	97.29[a]	108.36[ab]	4.55	0.04

[a–c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Data obtained from 96 pigs, 1 pig within each birth-weight quartile from 24 litters, selected for slaughter at Agriculture and Agri-Food Canada–Lacombe Research Centre.

Table 8. The effect of birth weight on average objective quality characteristics of the longissimus lumborum and semitendinosus muscles[1]

	Birth weight, kg					
Item	0.75 to 1.20	1.25 to 1.45	1.50 to 1.70	1.75 to 2.50	SEM	*P*-value
pH, 24 h	5.69	5.71	5.67	5.68	0.03	0.70
pH, 48 h	5.70	5.71	5.65	5.65	0.03	0.39
Temperature, 24 h	6.54	6.33	6.49	6.30	0.26	0.89
Temperature, 48 h	3.52	3.73	3.74	3.96	0.12	0.10
L*, 24 h	50.45	50.39	50.77	50.84	0.49	0.89
L*, 48 h	52.68	51.96	52.09	52.72	0.52	0.64
Chroma, 24 h	12.58	12.45	12.34	12.99	0.29	0.42
Chroma, 48 h	13.52	13.47	13.37	13.08	0.31	0.77
Hue, 24 h	25.93	25.54	25.66	25.80	0.57	0.96
Hue, 48 h	30.61	29.48	29.80	29.31	0.63	0.49
Proximate analysis						
Moisture, mg/g	743.80[a]	746.43[ab]	749.76[b]	749.31[b]	1.41	0.01
Intramuscular fat, mg/g	35.12[a]	30.07[b]	25.75[b]	29.09[b]	0.18	0.01
CP, mg/g	218.99	220.34	220.21	217.49	0.11	0.23
Shear, kg	5.61	5.22	5.66	5.24	0.17	0.13
Cook loss, mg/g	195.13	182.58	188.87	190.60	4.43	0.25
Cook time, s/g	7.41[a]	6.88[ab]	6.57[b]	7.52[a]	0.25	0.03
Soluble protein, mg/g	157.98	157.51	157.55	160.27	1.51	0.54
Drip loss, mg/g	28.36	28.88	26.14	26.48	2.10	0.74
Subjective scoring, LL only[2]						
Marbling	1.91	1.79	1.56	1.78	0.12	0.22
Color	3.04	3.08	3.13	3.04	0.08	0.85
Structure	3.00	3.04	3.00	3.00	0.06	0.94

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Data obtained from 96 pigs, 1 pig within each weight quartile from 24 litters, selected for slaughter at Agriculture and Agri-Food Canada–Lacombe Research Centre. There were no significant muscle × birth-weight quartile interaction effects ($P > 0.05$).

[2]Longissimus lumborum muscle.

and the formation of giant fibers. Conversely, Berard et al. (2008) reported that overall effects of litter size and birth weight on meat quality traits were minimal. The differences observed among studies may be attributed to the genetic lines employed. For example, we did not observe giant fibers, a characteristic often associated with lines that are positive for the porcine stress syndrome gene. The pigs used in our study were negative for the porcine stress syndrome gene. Although increased litter size in our study resulted in decreased

Table 9. The effect of birth weight on average sensory qualities of the longissimus lumborum and semitendinosus muscles[1]

	Birth weight, kg					
Item	0.75 to 1.20	1.25 to 1.45	1.50 to 1.70	1.75 to 2.50	SEM	*P*-value
Initial tenderness						
Mean	5.16	5.16	5.09	5.39	0.11	0.25
Initial juiciness						
Mean	4.80	4.68	4.80	4.91	0.09	0.38
Flavor intensity						
Mean	4.31	4.22	4.20	4.16	0.06	0.39
Flavor desirability						
Mean	4.40[a]	4.09[b]	4.19[b]	4.26[ab]	0.07	0.02
Sustained juiciness						
Mean	4.66	4.57	4.61	4.76	0.08	0.42
Connective tissue						
Mean	6.97	6.99	7.01	7.07	0.05	0.61
Overall tenderness						
Mean	5.33	5.38	5.33	5.55	0.11	0.46
Overall palatability						
Mean	4.04	3.85	3.94	4.07	0.08	0.16

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Data obtained from 96 pigs, 1 pig within each weight quartile from 24 litters, selected for slaughter at Agriculture and Agri-Food Canada–Lacombe Research Centre. There were no significant muscle × birth-weight quartile interaction effects ($P > 0.05$).

Table 10. The effect of birth weight on the average histological properties of the longissimus lumborum and the light and dark regions of the semitendinosus muscle[1]

	Birth weight, kg					
Item	0.75 to 1.20	1.25 to 1.45	1.50 to 1.70	1.75 to 2.50	SEM	*P*-value
Sarcomere length, μm	2.00[a]	1.97[a]	1.97[a]	2.06[b]	0.02	0.01
Proportion of different fibers, %						
Slow oxidative	18.35	17.91	19.53	18.75	0.58	0.23
Fast oxidative glycolytic	27.13	27.33	26.53	26.95	0.94	0.94
Fast glycolytic	54.54	54.76	53.93	54.29	0.97	0.94
Mean fiber area, μm²						
Slow oxidative	3,958.86[a]	3,877.86[ab]	3,419.64[c]	3,470.21[bc]	164.87	0.05
Fast oxidative glycolytic	3,639.20	3,707.73	3,315.57	3,318.71	143.53	0.11
Fast glycolytic	4,567.44	4,594.26	4,390.39	4,079.84	191.31	0.24
Cross sectional area (CSA), cm²	25.95	26.78	26.57	25.88	0.60	0.64
Primary fibers in CSA	16,928	18,147	18,423	18,857	614	0.17
Secondary fibers in CSA	416,594	451,374	450,700	476,572	14,863	0.06

[a–c]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Data obtained from 96 pigs, 1 pig within each weight quartile from 24 litters, selected for slaughter at Agriculture and Agri-Food Canada–Lacombe Research Centre. The only significant muscle × birth-weight quartile interaction effect was for sarcomere length ($P < 0.05$).

birth weight, our hypothesis was proved to be incorrect; birth weight did not affect the final eating quality of pork, and moreover, larger litters per se did not result in reduced meat quality.

Effects of Litter Size

There is no evidence from our data that increasing litter size results in increased variability in birth weight within a litter. Quiniou et al. (2002) reported a decline in mean birth weight of 35 g for each additional piglet born. In this study, the increase in average litter size from 8.4 to 15.4 piglets resulted in a mean decline in birth weight of 300 g, or 43 g per piglet.

It should be noted that the decision to remove all pigs with a birth weight less than or equal to 750 g may have affected this conclusion somewhat. Very light birth-weight piglets were removed because they were deemed to be nonviable and would in all likelihood be killed in a commercial setting. However, the decision to remove nonviable piglets resulted in the removal of 1.6% of pigs from the small litter size group, 4.0% of pigs born alive in the intermediate litter size group, and 6.8% of the piglets from the large litter size group. Removing different portions of the tail of the distribution curve could have affected variation later in the study.

Whereas mean birth weight declined as litter size increased, the SD for birth weight was identical across litter size categories. We conclude, therefore, that increased litter size will result in more light-birth-weight piglets simply because there are more pigs produced per litter, thus increasing the number of piglets in all BW categories. The decline in the mean birth weights with increased litter size will shift the normal distribution curve toward lighter BW; however, the shape of that curve would remain unchanged.

Milligan et al. (2002) reported that larger litters did not wean more pigs compared with smaller litters;

Table 11. Correlation coefficients comparing the number born alive, birth order, and BW variables

				BW, kg					
Item	Parity	Order	Rank	Birth	Wean	5 wk	7 wk	First pull	Age at market, d
No. born[1]	–0.145*	0.37*	0.03	–0.29*	–0.10*	–0.06	–0.04	0.02	–0.006
Parity		–0.04	0.02	0.17*	0.20*	0.05	0.03	–0.09*	0.02
Order[2]			0.89*	–0.04	0.05	0.04	0.04	–0.003	0.02
Rank[3]				0.09*	0.10*	0.07	0.07	–0.007	0.02
BW, birth					0.55*	0.46*	0.43*	0.33*	–0.32*
BW, wean						0.70*	0.65*	0.41*	–0.35*
BW, 5 wk							0.88*	0.62*	–0.50*
BW, 7 wk								0.67*	–0.56*
BW, first pull[4]									–0.83*

[1]Number born alive.

[2]Order = birth order.

[3]Rank = order ÷ number born alive in litter.

[4]Time at which first pigs were removed from pens for marketing.

*Numbers with asterisks are significant at $P < 0.05$ (n = 833).

however, in the present study, more pigs were weaned and marketed from the large litters compared with the small and medium litters. In agreement with Clowes et al. (2007), larger litters, thus, have the potential to provide more pork per sow per year; if the marginal cost of producing the extra pigs is less than the market price, then increased profits will ensue.

Total litter BW was increased with litter size, an indication that the decreased average BW with increasing litter size was more than compensated for by the extra pigs produced. Additionally, litter size had no effect on days to market or carcass composition, which suggests increased litter size can be utilized by producers to produce more pork per sow without negatively affecting pork quality. Berard et al. (2008) also concluded that the effect of litter size on growth performance and on carcass and meat quality is minor.

Effects of Birth Weight

The increased BW at birth across birth-weight quartiles was observed through to market and the light-birth-weight piglets took almost 10 more days to reach market weight than the pigs from the heaviest birth-weight quartile. This is in agreement with previous research that states light birth-weight pigs do not compensate for their lighter birth weight during postnatal growth (Rehfeldt and Kuhn, 2006).

It has been known for many years that light-birth-weight piglets differ biologically from their heavier litter mates. Wigmore and Stickland (1983) reported the same number of primary fibers, but fewer secondary fibers in small, as compared with large, birth-weight piglets. Later, Dwyer et al. (1993) concluded that whereas birth weight influenced growth up to 70 d of age, muscle fiber number was an important determinant of the rate and efficiency of BW gain thereafter

Several more recent studies have concluded that light birth weight is associated with fatter carcasses (Bee, 2004; Gondret et al., 2006; Rehfeldt et al., 2008), attributing these results to a smaller total number and larger size of myofibrils. The fiber size and number were in turn associated with poorer meat quality. Gondret et al. (2005) compared pigs of light (0.75 to 1.25 kg) and heavy (1.75 to 2.05 kg) birth weight and reported reduced lean meat content, more backfat, and a decreased proportion of ham, loin, and belly in the carcasses from lighter birth-weight piglets. Gondret et al. (2006) reported no impact of birth weight on drip loss or flavor, but lighter birth-weight piglets produced less tender meat, although it tended to be juicier. Berard et al. (2008) reported decreased carcass yield and smaller kidneys and livers in pigs with low birth weights, but interestingly, also saw that pigs with medium birth weights produced more tender pork than light or heavy birth-weight pigs. In the present study, only flavor desirability was related to birth weight, with the greatest and least birth-weight pigs preferred; this may be related to the observed differences in cooktime because flavor development will be greater with longer cooktimes (Aalhus et al., 2009).

In the present study, we found limited evidence of increased carcass fatness associated with light birth weight. The 2 exceptions were the amount of intermuscular fat, which tended to be greater in the lightest birth-weight quartile, in the butt, and the greater intramuscular fat in the lightest birth-weight quartile. Similar to other published results (Wigmore and Stickland, 1983; Bee, 2004; Gondret et al., 2006; Rehfeldt et al., 2008), we found both an increase in the mean fiber area, particularly in the slow oxidative fibers, and a decrease in the number of secondary fibers in the lightest birth-weight quartile. The longer sarcomere length in the heaviest birth-weight quartile is probably due to the slightly greater carcass weight in this quartile, which would provide an increased stretch in the STM when suspended on the rail during chilling. However, despite these differences, objective and subjective assessment did not show any disparity in meat quality attributable to birth weight. Whereas this may appear to contrast with the European research, cited above, the development of quality in the final product also is breed-dependent and can be affected by the rate of chilling in the postmortem environment. In cases in which genetic predisposition to PSE meat is not controlled adequately through chilling (potentially due to differences in carcass fatness or final weight arising from initial differences in birth weight), differences in quality may result. Regardless of the reason for differences among published research, Based on the results of this study, the same quality of pork can be produced by pigs with lighter birth weights as compared with heavier birth weights.

In conclusion, increased litter size resulted in reduced average birth weight, but there was no effect on within-litter variability in BW or performance. Lighter birth-weight pigs had reduced BW at each phase of measurement and increased days to market compared with heavier birth-weight pigs. However, there were very limited effects of birth weight on carcass quality, physical properties of the meat, and overall eating quality of the pork. Histological changes indicating larger fiber areas and fewer numbers of secondary fibers were consistent with published literature. Furthermore, birth order had no effect on BW at birth, growth, or final eating quality of the meat. Selecting pigs at birth based on BW would allow producers to sort pigs based on days to market, but would not be an effective criteria to predict final eating quality of the meat. Increased litter size will allow producers to wean and market more pigs; however, these decreased birth-weight pigs need to be kept longer until reaching market weight. Increased litter size can be utilized by producers to increase productivity with no adverse effect on pig performance or carcass quality. Therefore, our hypothesis was proven incorrect because the present study demonstrates that the effects of increased litter size do not mirror effects of reduced birth weight.

LITERATURE CITED

Aalhus, J. L., D. R. Best, F. Costello, and L. E. Jeremiah. 1999. A simple, on-line processing method for improving beef tenderness. Can. J. Anim. Sci. 79:27–34.

Aalhus, J. L., M. Juárez, N. Aldai, B. Uttaro, and M. E. R. Dugan. 2009. Meat preparation and eating quality. Int. Congr. Meat Sci. Technol. 55:1058–1062.

Agriculture Canada. 1984. Pork Quality–A guide to understanding colour and structure of pork muscles. Publ. 5180/B. Agriculture Canada, Ottawa, Ontario, Canada.

Annual Book of ASTM Standards (ASTM). 2008. Test Method for Rubber Property/Durometer Hardness. In Rubber, Natural and Synthetic—General Test Methods. Vol. 9.01. ASTM Int., West Conshohocken, PA.

Bee, G. 2004. Effect of early gestation feeding, birth weight, and gender of progeny on muscle fiber characteristics of pigs at slaughter. J. Anim. Sci. 82:826–836.

Berard, J., M. Kreuzer, and G. Bee. 2008. Effect of litter size and birth weight on growth, carcass and pork quality, and their relationship to postmortem proteolysis. J. Anim. Sci. 86:2357–2368.

Canadian Council on Animal Care. 1993. Guide to the Care and Use of Experimental Animals. 2nd ed. E. D. Olfert, B. M. Cross, and A. A. McWilliam, ed. Can. Counc. Anim. Care, Ottawa, Ontario, Canada.

Canadian Pork Council. 1986. The Canadian Hog Carcass Grading/Settlement System. Canadian Pork Counc., Ottawa, Ontario, Canada.

Clowes, E., A. Gamroth, M. Young, M. Duggan, J. Patience, and L. Goonewardene. 2007. Litter size and parity affect sow performance. Adv. Pork Prod. 18:A–3. (Abstr.)

Commision Internationale de l'Éclairage. 1978. Recommendations on uniform color spaces-colour difference equations-psychometric color terms. Pages 8–12 in Publ. No. 15, Suppl. No. 2. CIE, Paris, France.

Dwyer, C. M., J. M. Fletcher, and N. C. Stickland. 1993. Muscle cellularity and postnatal growth in the pig. J. Anim. Sci. 71:3339–3343.

Foxcroft, G. R., W. T. Dixon, S. Novak, C. T. Putnam, S. C. Town, and M. D. A. Vinsky. 2006. The biological basis for prenatal programming of postnatal performance in pigs. J. Anim. Sci. 84:E105–E112.

Friend, D. W., and H. M. Cunningham. 1996. Piglet birthweights and the order of farrowing. Can. J. Comp. Med. Vet. Sci. 30:179–182.

Gondret, F., L. Lefaucheur, H. Juin, I. Louveau, and B. Lebret. 2006. Low birth weight is associated with enlarged muscle fiber area and impaired meat tenderness of the longissimus muscle in pigs. J. Anim. Sci. 84:93–103.

Gondret, F., L. Lefaucheur, I. Louveau, B. Lebret, X. Pichodo, and Y. Le Cozler. 2005. Influence of piglet birth weight on postnatal growth performance, tissue lipogenic capacity and muscle histological traits at market weight. Livest. Prod. Sci. 93:137–146.

Herpin, P., M. Damon, and J. Le Dividich. 2002. Development of thermoregulation and neonatal survival in pigs. Livest. Prod. Sci. 78:25–45.

Juarez, R. E. M., W. R. Caine, I. L. Larsen, W. M. Robertson, M. E. R. Dugan, and J. L. Aalhus. 2009. Enhancing pork loin quality attributes through genotype, chilling method and ageing time. Meat Sci. 83:447–453.

Larmond, E. 1977. Laboratory methods for sensory evaluation of foods. Publ. 1637. Canada Dep. Agric., Ottawa, Ontario, Canada.

Martin, A. H., H. T. Fredeen, G. M. Weiss, A. Fortin, and D. Sim. 1981. Yield of trimmed pork product in relation to weight and backfat thickness of the carcass. Can. J. Anim. Sci. 61:299–310.

Milligan, B. N., D. Fraser, and D. L. Kramer. 2002. Within-litter birth weight variation in the domestic pig and its relation to pre-weaning survival, weight gain, and variation in weaning weights. Livest. Prod. Sci. 76:181–191.

Motsi, P., C. Sakuhuni, T. E. Halimani, E. Bhebhe, P. N. B. Ndiweni, and M. Chimonyo. 2006. Influence of parity, birth order, litter size and birth weight on duration of farrowing and birth intervals in commercial exotic sows in Zimbabwe. Anim. Sci. 82:569–574.

Murray, A. C. 1995. The evaluation of muscle quality. Chapter 4 in Quality and Grading of Carcasses of Meat Animals. S. D. Morgan Jones, ed. CRC Press, New York, NY.

NPPC. 2000. Pork Composition and Quality Assessment Procedures. Natl. Pork Producers Counc., Des Moines, IA.

NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

Père, M. C., and M. Etienne. 2000. Uterine blood flow in sows: Effects of pregnancy stage and litter size. Reprod. Nutr. Dev. 40:369–382.

Quiniou, N., J. Dagorn, and D. Gaudre. 2002. Variation of piglets; birth weight and consequences on subsequent performance. Livest. Prod. Sci. 78:63–70.

Rehfeldt, C., and G. Kuhn. 2006. Consequences of birth weight for postnatal growth performances and carcass quality in pigs as related to myogenesis. J. Anim. Sci. 84:(E. Suppl.):E113–E123.

Rehfeldt, C., A. Tuchscherer, M. Hartung, and G. Kuhn. 2008. A second look at the influence of birth weight on carcass and meat quality in pigs. Meat Sci. 78:170–175.

Solomon, M. B., and M. C. Dunn. 1988. Simultaneous histochemical determination of three fiber types in single sections of ovine, bovine, and porcine skeletal muscle. J. Anim. Sci. 66:255–264.

Wigmore, P. M. C., and N. C. Stickland. 1983. Muscle development in large and small fetuses. J. Anat. 137:235–245.