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ARTICLE

Effects of pork differentiation strategies in Canada on pig performance and carcass characteristics

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Abstract: Performance and quality traits were measured in carcasses from combinations of genotype, diet supplement, slaughter weight, and carcass chilling regime. Iberian-crossed pigs had lower live animal performance than Duroc and Lacombe. From 70 to 115 kg, Lacombe pigs grew slightly faster than Duroc. Duroc carcasses had a higher lean percentage, heavier ham and picnic primals, and lighter loins and bellies, compared with Lacombe and Iberian. Heavier carcasses had lower lean yield, except those from Iberian-crossed pigs, and bigger bellies. Meat from Duroc-crossed pigs was lighter in colour and higher in marbling, with intermediate values for fat hardness. Iberian carcasses displayed dark meat with intermediate marbling and the hardest fat. Meat from Lacombe pigs was the leanest although, like in all three breeds, marbling scores were higher in heavier carcasses. Generally, supplementing with canola and flax decreased and blast chilling increased fat hardness values. Dietary canola also seemed to affect meat colour traits, but these effects were not consistent among breeds and slaughter weights. The commercial combination of Duroc breed, control diet, and 115-kg slaughter weight showed a balance in terms of performance, carcass, and quality traits. Other combinations evaluated in this study showed potential to efficiently produce differentiated pork.

Key words: canola, cut-out, Duroc, flax, growth, Iberian, Lacombe, pork.

Résumé : La performance et les caractéristiques de qualité ont été mesurées dans les carcasses provenant de combinaisons différentes de génotype, suppléments alimentaires, poids à l'abattage et méthode de refroidissement de la carcasse. Les porcs ibériques croisés ont des performances de leurs vivants moins bonnes que les porcs de race Duroc et Lacombe. De 70 à 115 kg, les porcs Lacombe avaient une croissance légèrement plus rapide que les porcs Duroc. Les carcasses de porcs Duroc avaient un plus grand pourcentage de viande maigre ainsi que des poids plus lourds des découpes de flancs et d'épaules picnic et des poids plus légers de longes et de poitrines, par rapport aux porcs Lacombe et ibériques. Les carcasses plus lourdes avaient des rendements plus faibles en viande maigre, sauf chez les porcs ibériques croisés, et de plus grosses poitrines. La viande des porcs croisés Duroc était de couleur plus pâle et montrait un plus grand persillage et des valeurs intermédiaires de dureté du gras. Les carcasses de porcs ibériques avaient une viande plus foncée, des niveaux intermédiaires de persillage et le gras le plus dur. La viande des porcs Lacombe était la plus maigre, bien que, comme pour les trois races, les cotes de persillage étaient plus élevées dans les carcasses les plus lourdes. De façon générale, les suppléments de canola et de lin diminuaient et le refroidissement rapide augmentait les valeurs de dureté du gras. Le canola

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Abbreviations: ADG, average daily gain; **AFI**, average feed intake.

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alimentaire semblait aussi avoir un effet sur les caractéristiques de couleur de la viande, mais ces effets n'étaient pas consistants parmi les races ni les poids à l'abattage. La combinaison commerciale de la race Duroc, de la diète de contrôle et un poids à l'abattage de 115 kg montrait un équilibre en ce qui a trait à la performance et les caractéristiques de la carcasse et de la qualité. D'autres combinaisons évaluées dans cette étude montraient un potentiel pour la production efficace de porc différencié. [Traduit par la Rédaction]

Mots-clés : canola, découpe, Duroc, lin, croissance, ibérique, Lacombe, porc.

Introduction

Variability in pork quality is due to a combination of genetic, production, and processing factors (Ngapo and Gariépy 2008). Differentiated high-quality pork products are commonly marketed in countries such as Spain (e.g., Iberian pork) or Italy (e.g., Parma ham). Canadian pork, an established commercial crossbred of Yorkshire–Landrace female and Duroc boar, is mainly a commodity product, with little differentiation. Such a situation owes to the genetic selection being applied to a limited number of specialized breeds driven by grading systems encouraging higher carcass yield, which has successfully led to leaner carcasses, faster growth rate, and lower feed conversions in Canada as in many countries (Pommier et al. 2004; Sellier 2007). Consequences of this strategy of selection are as follows: (1) Pig genetic diversity has eroded and (2) the whole meat sensory characteristics and some reproductive and health traits have been undesirably affected (Rauw et al. 1998).

The Canadian pork industry now recognizes the need for differentiation and development of new high-quality products, as well as for adaptability and flexibility to successfully compete in priority markets (Young 2011). Genetics is at the basis of differentiation and studies involving nonselected and selected breeds invariably reported superior meat technological and (or) sensory traits in nonselected breeds over those from selected ones (Labroue et al. 2000; Alfonso et al. 2005; Renaudeau and Mourot 2007). Superior meat technological quality traits have also been reported in Iberian compared with Landrace breed (Serra et al. 1998), supporting further the need to increase genetic variability/diversity. Combining more diverse genetics with dietary treatments, slaughter weight, and (or) chilling regimes would further increase the necessary variability in support of effective differentiation processes and allow for a better identification of the most appropriate source of variation or treatments to efficiently address market needs.

Evaluating the carcass characteristics of pigs is a first step, essential to optimize pork production systems (Schinckel et al. 2008) and even the entire pork marketing chain (Gispert et al. 2007). Pig carcass merit traits usually include composition (yield of lean, fat, and bone), percentage of primal cuts, meat pH value, marbling score, and colour (Marcoux et al. 2007; Ngapo and Gariépy 2008; Uttaro and Zawadski 2010). All these traits have been reported to be influenced by factors such as breed (Sellier 1976; Gispert et al. 2007; Straadt et al. 2013), diet (Dugan et al. 2001; Thacker et al. 2004; Caine et al. 2007), slaughter weight (Martin et al. 1980; Latorre et al. 2004), and chilling regime (Jones et al. 1988; Springer et al. 2003; Juárez et al. 2009). Understanding the potential impact of manipulating each factor, as well as their interactions, would allow the Canadian pork industry to develop differentiated value-added products for a highly competitive market.

The objective of the present study was to evaluate the effects of using integrated strategies for producing differentiated pork quality in Canada, based on combinations of breed, gender, diet, slaughter weight, and chilling regime, on carcass merit traits with economic impact. Duroc, Lacombe, and Iberian breeds form the best model for a study on pork quality as they are genetically both far and equidistant from each other in the phylogenetic tree. Flax was chosen as a dietary source of *n*-3 fatty acids available in Canada (potential differentiation strategy), and canola was chosen as a Canadian source of oleic acid which could be used both to produce Iberian-based products (traditionally rich in oleic acid) or a Canadian heritage pork, using the Lacombe breed and this local product.

Materials and Methods

Experimental design and animal performance

The live animal experimental design for this study consisted of a $3 \times 3 \times 2$ factorial (breed combination, diet, and slaughter weight, respectively). Commercial dams (42 Large White $\times$ Landrace F1; Hypor Inc., Regina, SK, Canada) were inseminated with semen from three different breeds (four boars per breed): Duroc (Peak Swine Genetics, Leduc, AB, Canada), Lacombe (Peak Swine Genetics Inc.), and Iberian (Semen Cardona, Cardona, Spain). When, after following commercial practices, live weight reached 70 kg, animals were transferred to experimental rooms and sorted into pens of three (same breed combination and gender in each pen), and these pens were then assigned to a slaughter weight group (115 or 135 kg) and a dietary treatment (control, canola, or flax). Three replicates of the full design (72 pens and 216 pigs per replicate) resulted in a total of 648 pigs in test. Beginning at 70 kg, all animals were fed a commercial finisher diet (Table 1; Masterfeeds, Winnipeg, MB, Canada) until 4 wk before slaughter. Pigs were then fed the commercial finisher diet (control), a canola (10% ExtraPro; 50% full-fat canola and 50%

Table 1. Ingredient composition and nutrient content of diets.

Ingredient	Control	Canola	Flax
Wheat (%)	44.0	27.8	17.1
Barley (%)	37.7	43.7	56.4
Canola meal (%)	15.0	15.0	14.0
ExtraPro (%)	—	10.0	—
LinPro (%)	—	—	10.0
Calcium carbonate (%)	1.20	1.20	0.95
Soyameal 46% (%)	1.00	1.05	—
Salt (%)	0.43	0.42	0.41
Dicalcium phosphate (%)	0.33	0.25	0.31
Lysine (%)	0.14	0.31	0.38
Threonine (%)	—	0.09	0.13
Methionine (%)	—	—	0.09
Vitamin mix (%)	0.10	0.10	0.10
Mineral mix (%)	0.10	0.10	0.10
Ronozyme (%)	0.02	0.02	0.02
Composition	Control	Canola	Flax
ME (Mcal K^{-1})	3.03	3.13	3.12
Crude protein (%)	15.0	15.0	15.0
Crude fat (%)	2.00	3.94	3.88
Crude fibre (%)	5.00	5.72	5.78
Dry matter (%)	87.8	88.5	88.5
Sodium (%)	0.10	0.19	0.19
Calcium (%)	0.70	0.65	0.65
Phosphorus (%)	0.50	0.50	0.50
Vitamin A (KIU kg^{-1})	8.00	8.00	8.00
Vitamin D (KIU kg^{-1})	1.00	1.00	1.00
Vitamin E (IU kg^{-1})	20.0	20.0	20.0
Zinc (mg kg^{-1})	175	175	175
Copper (mg kg^{-1})	26.8	27.4	26.8
Lysine (%)	0.72	0.97	0.95
Methionine (%)	0.26	0.28	0.37
Threonine (%)	0.53	0.68	0.67
Tryptophan (%)	0.18	0.19	0.18

extruded field peas; O&T Farms Ltd., Regina, SK, Canada), or a flax (10% LinPro; 50% flaxseed and 50% extruded field peas; O&T Farms) diet for the last 3 wk prior to slaughter, with a transitional week (50% commercial and 50% assigned diets) for the canola and flax diets (Table 1). Average pen feed intake was manually measured weekly by subtracting refusals once the animals were transferred to the experimental rooms to calculate average feed intake (AFI). Individual weights were measured weekly from birth to slaughter to calculate average daily gain (ADG). Pigs had ad libitum access to feed and water. In all cases, diets were formulated to meet the nutrient requirements of the pigs and validated by experts from Verus Animal Nutrition (Winnipeg, MB, Canada). All the trials were carried out at the Lacombe Research and Development Centre (Agriculture and Agri-Food Canada, Lacombe, AB) in accordance with guidelines established by the Canadian Council on Animal Care in Science (CCAC 2009).

Carcass evaluation

When average animal weight per pen reached the target weight (115 or 135 kg), animals were shipped to the Lacombe Research and Development Centre Agriculture and Agri-Food Canada federally inspected abattoir (distance: 1.6 km). Pigs were shipped at 0700, not being fed since the previous day. Pigs were stunned (2.1 A for 5 s) and exsanguinated in a manner simulating commercial conditions. Processing of carcasses included pasteurization (16 nozzles at 12 L per nozzle for 10 s with 86.4 °C water for a total of 192 L per carcass), following scalding and before evisceration, using an online stainless steel pasteurizing cabinet (Bryant et al. 2003). Following splitting of carcass, hot side weights were recorded. At approximately 45-min postmortem, an estimated lean yield was determined on the left side between the third and fourth last ribs, approximately 7 cm from the midline, using an Anitech PG100 Grading Probe (Anitech Information Systems Inc., Markham, ON, Canada). Initial (45 min) pH and temperature were also collected between the 10th and 11th ribs on the left and right *longissimus lumborum* (LL) muscles, using a Hanna HI99163 pH meter equipped with a Hanna Smart electrode FC232 (Hanna Instruments, Laval, QC, Canada) and a Mark III, MC4000 (Sumaq Wholesalers, Toronto, ON, Canada), respectively. The right half carcass was blast chilled (–25 °C, 2.5 m s^{-1} wind speed) for 1 h. Both left and right carcass sides were then placed in a cooler at 2 °C.

At 24 h, cold carcass weight, *longissimus* pH, and temperature were recorded. Cooler losses were calculated based on hot and cold carcass weights. Marbling scores from both right and left carcass sides were assessed using the National Pork Producers Council scale (NPPC 2000). Fat hardness was measured on the inner layer of subcutaneous fat above the second thoracic vertebra of the left and right sides using a Rex Durometer (Rex Gauge Company, Buffalo Grove, IL, USA). Left carcass sides were then divided into primal cuts including picnic, butt, ham, loin, and belly. Picnic, butt, ham, and loin were then weighed and dissected into fat (subcutaneous, intermuscular, and body cavity depots), bone and lean according to the procedures described by Martin et al. (1981). Skinned-trimmed belly and rib weights were also recorded. For statistical analysis, fat, bone, and lean values of all primal cuts were combined.

A chop (2.5 cm) was cut from the left and right LL muscles (between eighth and ninth ribs) and allowed to oxygenate for 20 min. Subjective colour of both right and left carcass sides was evaluated using the Japanese (Nakai et al. 1975) and Canadian Pork Quality Standards (CPI 2013). Objective colour measurements (L^*, chroma, and hue; CIE 1978) were determined in duplicate using a Minolta CR-300 with Spectra QC-300 Software (Folio Instruments, Kitchener, ON, Canada).

Fig. 1. Breed effect on average daily gain at different growth stages. Lowercased letters within each growth stage indicate significant differences ($P < 0.05$).

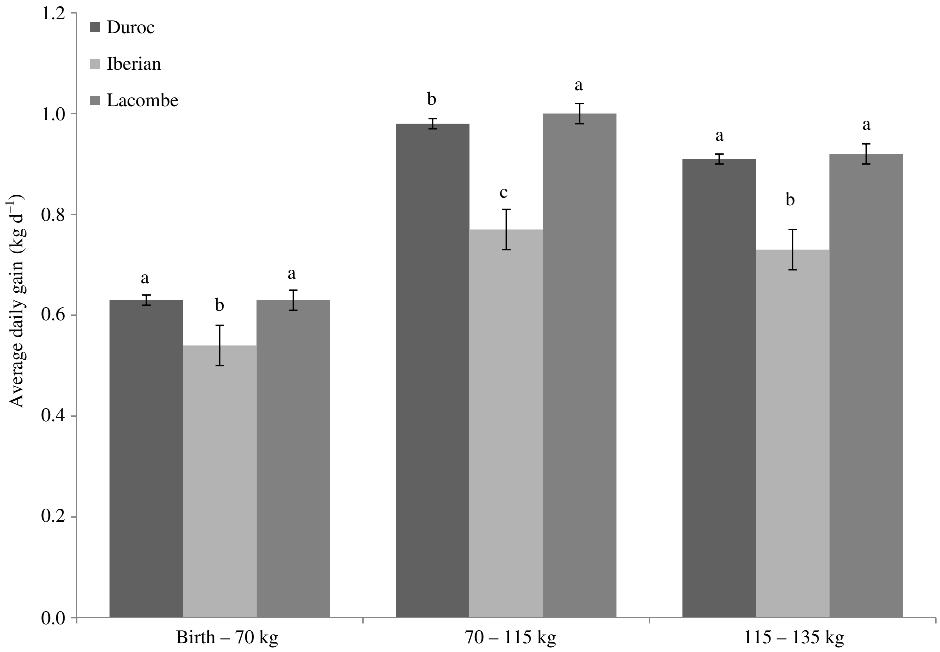


Table 2. Interactive effect of breed and slaughter weight on carcass weight, dressing percentage, cooler loss, and estimated lean yield.

	Duroc		Iberian		Lacombe			*P*-value			
	115 kg	135 kg	115 kg	135 kg	115 kg	135 kg	SEM	Breed (B)	Weight (W)	Diet	B × W
Commercial hot weight (kg)	96.8c	115a	96.8c	115a	96.9c	114b	0.68	0.101	<0.001	0.705	0.022
Hot dressing (%)	82.6b	83.2a	82.8ab	83.3a	83.0ab	82.5b	0.56	0.348	0.240	0.601	0.012
Cooler loss (%)	2.38	2.25	2.25	2.24	2.36	2.30	0.02	0.006	0.001	0.232	0.057
Estimated lean yield (%)	61.6a	60.5b	55.2d	54.4e	59.0c	58.9c	0.34	<0.001	<0.001	0.562	0.003

Note: Values with lowercased letters within the same row indicate significant differences ($P < 0.05$).

Statistical analyses

Data were analysed using the Mixed Model computer algorithm of the SAS Institute, Inc. (SAS 2003) including breed combination, diet, and slaughter weight group, respectively, as fixed factors and replicates blocking effect. Chilling method was also included as a fixed factor for those traits measured in both sides of the carcass. Actual slaughter weight, nested within slaughter weight group and breed, was used as a covariate. When significance was indicated by the model ($P < 0.05$), group means were determined using the LSMEANS statement. Test of multiple comparisons of LSMEANS was separated using the *F*-test protected LSD procedure and adjusted according to the Tukey–Kramer method to ensure the significance of individual comparisons at $P \leq 0.05$. To avoid outliers, sick animals and those out of the target weight groups were not used in the final analyses. The total number for the whole study after removing outliers was 578 animals, with a minimum of 20 animals for any combination of preslaughter treatments.

Results

Animal performance

No interactive effects ($P > 0.05$) between breed and diet were observed for performance traits. While birth weights were not affected by breed ($P > 0.05$), ADG of Iberian pigs, at all growth stages, was significantly ($P < 0.001$) lower than those from Duroc and Lacombe (Fig. 1). From birth to penning (70 kg) and from 115 to 135 kg, no significant differences in ADG were observed between Duroc- and Lacombe-sired pigs. However, from 70 to 115 kg, Lacombe pigs grew slightly faster than Duroc.

Regarding the dietary treatments evaluated in this study, for the last 3 wk before slaughter, AFI was slightly lower ($P < 0.001$; diet effect: data not shown) for the canola (3.36 kg kg^{-1}) and higher for the flax diet (3.57 kg kg^{-1}), compared with the control (3.48 kg kg^{-1}). Thus, ADG was also lower ($P = 0.011$; diet effect: data not shown) for the canola diet (0.81 kg d^{-1}), compared with the control (0.85 kg d^{-1}) and flax (0.86 kg d^{-1}) diets.

Table 3. Interactive effect of breed and slaughter weight on carcass composition.

	Duroc		Iberian		Lacombe			*P*-value						
	115 kg	135 kg	115 kg	135 kg	115 kg	135 kg	SEM	Breed (B)	Weight (W)	Diet (D)	B × W	B × D	W × D	B × W × D
Primal weight, % total carcass weight														
Loin	27.5	27.9	28.4	28.0	28.1	28.1	0.18	0.016	0.980	0.633	0.089	0.609	0.611	0.483
Ham	27.0	26.4	24.2	23.8	26.2	25.8	0.09	<0.001	<0.001	0.192	0.394	0.447	0.533	0.363
Belly	17.6	18.2	20.0	20.6	18.3	18.8	0.11	<0.001	<0.001	0.261	0.944	0.702	0.036	0.622
Picnic	9.96a	9.90a	9.35c	9.67b	9.58b	9.64b	0.07	<0.001	0.061	0.139	0.034	0.046	0.262	0.404
Butt	9.98ab	9.92ab	9.99ab	9.82ab	9.83b	10.04a	0.08	0.843	0.938	0.111	0.034	0.000	0.374	0.001
Tissue weight, % total carcass weight														
Lean	63.5a	62.2b	47.8e	48.0e	57.0c	54.1d	0.60	<0.001	0.004	0.820	0.045	0.042	0.360	0.161
Bone	9.19a	8.77b	8.28c	8.65bc	9.02ab	8.22c	0.15	0.001	0.017	0.300	0.001	0.311	0.395	0.122
SQ	20.2e	21.5d	35.1a	34.9a	26.3c	29.3b	0.57	<0.001	0.002	0.429	0.030	0.067	0.470	0.143
IM	6.44c	6.81b	7.91a	7.54a	6.86b	7.61a	0.16	<0.001	0.041	0.673	0.004	0.016	0.141	0.148
BC	0.70	0.77	0.94	0.90	0.81	0.80	0.03	<0.001	0.700	0.101	0.205	0.777	0.025	0.192

Note: SQ, subcutaneous fat; IM, intermuscular fat; BC, body-cavity fat. Values with lowercased letters within the same row indicate significant differences ($P < 0.05$).

Carcass yield

An interactive effect between breed and slaughter weights was observed for carcass weight (Table 2; $P = 0.022$), hot dressing ($P = 0.012$), and estimated lean yield ($P = 0.003$). As expected, carcass weights were higher from heavier animals (135 kg). However, the heavy carcasses from Lacombe pigs were slightly lighter than those from Durocand Iberian. The dressing percentage of carcasses from 115-kg Duroc and 135-kg Lacombe pigs were lower than those from 135 kg Duroc and Iberian. The light (115 kg) Duroc group had the highest estimated lean yield percentage, followed by its heavy group. The slaughter weight did not affect this trait in Lacombe pigs, while Iberians had the lowest values, especially in heavy carcasses.

The interaction between breed and slaughter weight was only a trend for cooler loss ($P = 0.057$). Iberian carcasses had the lowest values ($P = 0.006$) and were not affected by differences in slaughter weight. Light carcasses from Lacombe and Duroc pigs showed higher cooler losses than heavy ones. The dietary treatments applied during the last 3 wk before slaughter had no effect ($P > 0.05$) on any of these traits.

Carcass cut-out

The percentage of each tissue in carcasses was highly affected by an interaction between breed and slaughter weights (Table 3). As observed for estimated lean yield percentage, due to the effect of this interaction ($P = 0.045$), the actual percentage of lean from manual dissection was highest in carcasses from 115-kg Duroc pigs, followed by the heavier carcasses from the same breed. Lacombe had intermediate values and also higher in light carcasses. Iberian carcasses had the lowest percentage of total lean and slaughter weight did not make any difference for this trait. The opposite interactive effect was observed for subcutaneous fat content ($P = 0.030$), with Iberian carcasses having the greatest amounts and light Duroc carcasses the lowest. Diet only affected the lean content of Lacombe pigs (breed × diet interaction; $P = 0.042$), with higher values in carcasses from animals fed the flax diet (56.4%) compared with the control diet (54.3%).

The highest (breed × weight interaction; $P = 0.004$) percentage of intermuscular fat was observed in carcasses from 115-kg Iberian and 135-kg Iberian and Lacombe pigs (7.69%), followed by 115-kg Lacombe and 135-kg Duroc (6.83%). Light (115 kg) Duroc pigs (6.44%) had the lowest content for this tissue. Carcasses from Duroc pigs fed flax (6.79%) had higher (breed × diet interaction; $P = 0.016$) intermuscular fat content than those from the same breed-cross fed canola (6.37%). On the other hand, pigs fed the control diet (7.65%) had higher intermuscular fat content than those fed canola (6.98%) and flax (7.07%). No diet effect ($P > 0.05$) was observed for Iberian pigs. The percentage of body cavity fat in carcasses from 115-kg pigs fed the control diet (0.78%) was lower (weight × diet interaction; $P = 0.025$) than in carcasses from the flax diet (0.86%). In the heavy group (135 kg), the control diet (0.91%) led to higher content of this tissue than the canola diet (0.76%). Light carcasses from Duroc pigs had the highest percentage of bone, while 115-kg Iberian and 135-kg Lacombe carcasses had the lowest (breed × weight interaction; $P = 0.001$).

Loin percentage was only affected by breed, with Duroc showing the lowest percentage compared with Iberian and Lacombe (Table 3; $P = 0.016$). Breed and weight affected ham percentage, with the highest values being observed on Duroc carcasses, followed by Lacombe and finally Iberian ($P < 0.001$) and relatively heavier hams being observed in lighter carcasses ($P < 0.001$). Carcasses from Iberian-crossbred pigs had the highest percentage

Table 4. Effects of breed, slaughter weight, diet, and chilling method on pig carcass characteristics.

	Breed			Weight		Diet			Chill			*P*-value					
	Duroc	Iberian	Lacombe	115 kg	135 kg	Control	Canola	Flax	Control	Blast	SEM	Breed (B)	Weight (W)	Diet (D)	Chill (C)	B × W	B × W × D
Marbling	1.89a	1.69b	1.41c	1.61b	1.71a	1.66	1.70	1.62	1.66	1.66	0.08	<0.001	0.004	0.166	0.972	0.299	0.395
Fat hardness	76.1b	78.6a	73.9c	75.5b	76.8a	78.8a	74.9b	74.8b	74.2b	78.1a	1.66	<0.001	0.011	<0.001	<0.001	0.002	0.555
pH 24 h	5.53a	5.51b	5.50b	5.52	5.51	5.51ab	5.52a	5.50b	5.51b	5.52a	0.01	0.569	0.111	0.016	0.027	<0.001	0.388
Japanese	3.62b	4.42a	3.67b	3.90	3.91	3.84b	3.92ab	3.95a	3.90	3.91	0.03	<0.001	0.714	0.026	0.797	0.993	0.929
Canadian	3.52b	4.36a	3.53b	3.81	3.79	3.73b	3.82ab	3.86a	3.84	3.77	0.08	<0.001	0.730	0.041	0.090	0.497	0.516
L^*	51.3a	48.5b	51.0a	50.3	50.3	50.4	50.2	50.2	50.4	50.1	0.5	<0.001	0.699	0.334	0.056	0.949	0.004
Chroma	9.32c	10.43a	9.65b	9.79	9.81	9.99a	9.63b	9.78ab	9.89a	9.71b	0.27	<0.001	0.757	0.007	0.044	0.003	0.042
Hue	26.1a	22.5c	24.8b	24.5	24.5	24.8	24.2	24.4	24.5	24.5	0.65	<0.001	0.972	0.068	0.870	0.290	0.018

Note: Japanese refers to Japanese colour score and Canadian refers to Canadian colour score. Values with lowercased letters within the same row and effect indicate significant differences ($P < 0.05$).

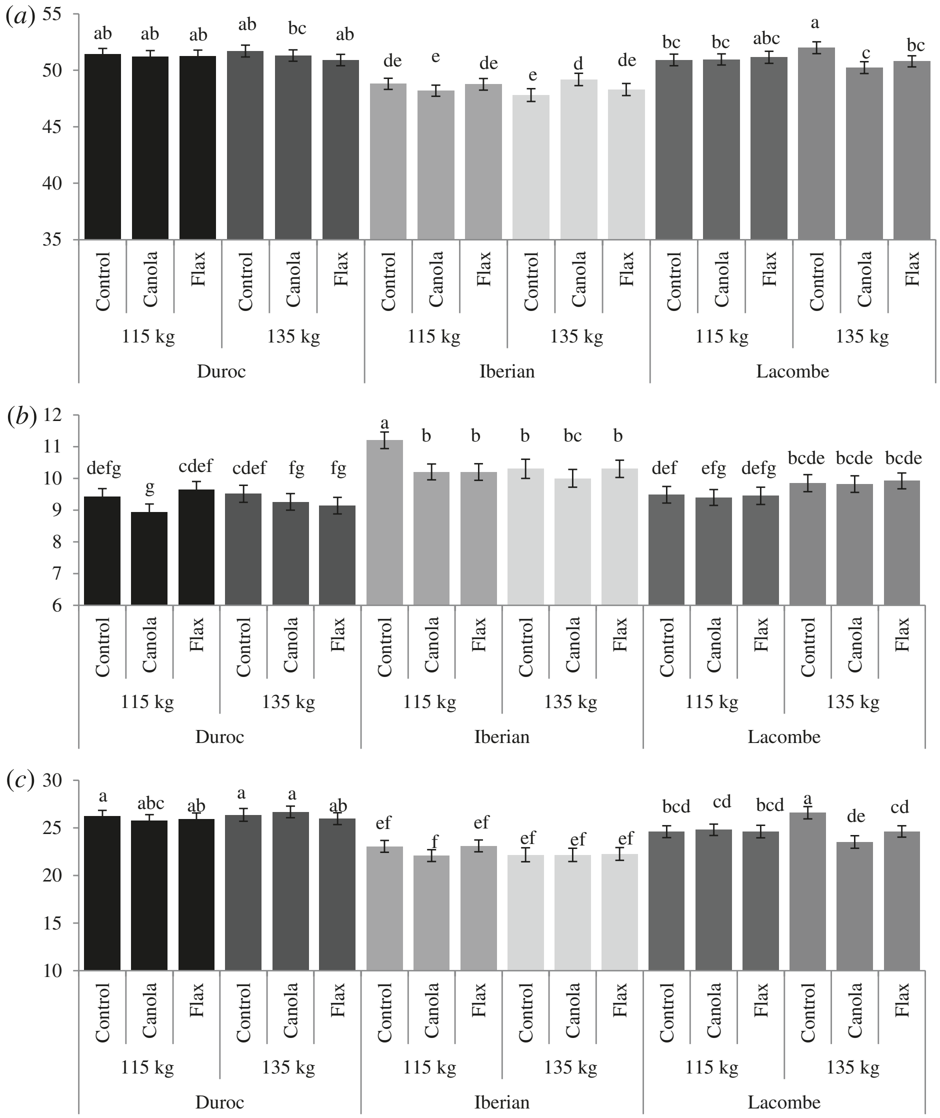
of belly primal, compared with Lacombe and Duroc ($P < 0.001$). The proportion of the belly in the total carcass weight of 135-kg pigs (19.2%) was higher than in 115-kg pigs (18.6%; $P = 0.036$) and was not affected by the diet. However, flax-fed pigs had greater proportion of belly primal (18.8%) than canola-fed pigs (18.4%). Duroc crossbred pigs had the highest percentage of picnic, and light Iberians had the lowest (breed × weight interaction; $P = 0.034$). The percentage of picnic in carcasses from Duroc pigs (9.93%) was the highest and not affected by the dietary treatment (breed × diet interaction; $P = 0.046$). Canola-fed Iberian and Lacombe pigs and flax-fed Iberian pigs showed the lowest picnic percentage (9.42%). Most combinations of weight, breed, and diet had no effect ($P > 0.05$) on the percentage of butt (9.81%). Carcasses from canola-fed 135-kg Iberian pigs and control-fed 135-kg Lacombe pigs showed an increase in the percentage of this primal cut (10.3%). Carcasses from control- and flax-fed 135-kg Iberian pigs showed lower values (9.5%) than the rest of the population (breed × diet interaction; $P = 0.001$).

Carcass quality traits

Marbling was highest in *longissimus* from Duroc crossbred pigs, followed by Iberian and then Lacombe (Table 4; $P < 0.001$), and it was always higher in the 135-kg group ($P = 0.004$). Fat hardness (arbitrary scale from 1 to 100) was highest (breed × weight interaction; $P = 0.002$) in carcasses from 115-kg Iberian pigs (79.1) and lowest in carcasses from 115-kg Lacombe pigs (72.2). No weight effect was observed for fat hardness in carcasses from Duroc pigs, which had intermediate values (76.1). Both experimental diets (canola and flax) decreased fat hardness values when compared with the control diet ($P < 0.05$). As expected, blast chilling resulted in harder fat in all the treatments evaluated. Although diet ($P = 0.016$), chilling regime ($P = 0.027$), and the interaction breed × weight ($P < 0.001$) had statistical significant effects on pH values 24 h after slaughter, the actual differences were minor.

Both breed and diet had the same effect on carcass lean colour evaluated using either the Japanese ($P < 0.001$ and $P = 0.026$, respectively) or the newly developed Canadian ($P < 0.001$ and $P = 0.041$, respectively) colour scales. Lean from Iberian pigs obtained the highest scores (darker). Lean from pigs fed flax got higher scores than lean from pigs fed the control diet. Objective colour traits (L^*, $P = 0.004$; chroma, $P = 0.042$; hue, $P = 0.018$) were affected by a three-way interaction among breed, weight, and diet (Fig. 2). As observed in the Japanese and Canadian colour scores, Iberian carcasses had the darkest meat (lowest L^*), although the canola diet seemed to slightly increase the lightness in heavy Iberian carcasses (Fig. 2*a*). Canola-fed 135-kg Lacombe pigs had darker meat (lower L^*) than those from the same breed and weight group fed the control diet. A very similar interactive effect

Fig. 2. Interactive effect of breed, weight, and diet on colour: (*a*) L^*, (*b*) chroma, and (*c*) hue of pig carcasses. Lowercased letters indicate significant differences ($P < 0.05$).



among breed, weight, and diet was observed for hue (Fig. 2*c*). Iberian pigs fed the control diet had the highest chroma values. The lowest values were observed in carcasses from canola-fed Duroc pigs (Fig. 2*b*). Chroma was also the only colour trait affected by the chilling regime ($P = 0.044$), decreasing with the use of the blast-chilling method (Table 4).

Discussion

When developing differentiated pork and pork products through management strategies, changes in animal growth performance need to be considered to assess their viability in a competitive market. Breed composition has been widely reported to impact animal performance (Sellier 1976; Miao et al. 2004), and directly affects production costs. The Duroc breed is commonly used in crossbreeding programs as a terminal sire to improve performance and meat quality in commercial pork production (McGloughlin et al. 1988; Whittemore and Kyriazakis 2008). The results from the present study show high-performance values for all studied breed combinations, around 1 kg d^{-1} in the finishing phase, similar to those reported in previous studies, such as Bertol et al. (2013). However, the higher ADG observed in Lacombe crossbred pigs during the finishing phase (70–155 kg) would be an advantage for this minority breeding terms of production costs. Fredeen and Stothart (1969) indicated that the Lacombe pig, the only Canadian pig breed, popular in the 1960s for its maternal traits, had higher growth rate compared with Large White. However, no recent information is available in scientific literature regarding the performance of Lacombe crossbred pigs under current commercial conditions. The present results also indicated, as expected, that the growth of Iberian crossbred pigs was slower, which would account for greater production costs. Serra et al. (1998) reported that Iberian pigs, with a significant lower ADG, needed additional 6 wk to reach the 100 kg live weight compared with Landrace. Purebred Iberian and Iberian × Duroc crossbreeding, to enhance performance of this unselected rustic breed, are the typical alternatives for Iberian pork production in Spain (Ibáñez-Escriche et al. 2014). The Iberian breed has been widely reported to produce high-quality (high marbling and dark colour, among other attributes) pork and pork products (Juárez et al. 2009). Thus, although low performance from the Iberian crossbreeding was expected, this alternative was explored due to the potential enhancement of carcass and meat quality.

The results from the dietary treatments also need to be considered from an efficiency point of view. As observed in our study, low levels of dietary flaxseed have been reported to increase AFI with no effect on growth rates (Romans et al. 1995; Juárez et al. 2010), which may be due to an increase in palatability. Higher AFI with no impact on ADG can lead to higher feeding costs. However, this effect on AFI seems to disappear when flaxseed levels increase ≥15% (Thacker et al. 2004; Juárez et al. 2010). Including high levels of canola in the diet of pigs has also been reported to decrease AFI (Dugan et al. 2001; Smit et al. 2014; Woyengo et al. 2014), with no effect (Dugan et al. 2001) or a small decrease in ADG (Woyengo et al. 2014). This may be due to negative effects of canola on diet palatability due to glucosinolate levels (Mawson et al. 1993). In canola-fed pigs, the decrease in AFI and ADG may increase the length of the finishing period, with the subsequent increase in production costs.

The increase in slaughter weight for commercial pigs may benefit slaughter plants by increasing the volume of meat harvested per slaughtered pig. From a production point of view, a recent study (Morin et al. 2015) concluded that, unless feed prices are significantly lower, it is more profitable to produce lighter pigs (~120 kg), as this allows an increase in the number of kilograms of lean meat per pig-place/barn/year. According to previous research, increasing slaughter weight results in higher dressing percentages (García-Macías et al. 1996). Carcasses from Duroc pigs were the only ones to clearly show this effect in our study and were due to differences in the weight of internal organs, such as the liver and large intestine ($P < 0.001$, data not shown).

Hot carcass weight and estimated lean yield are used to determine the commercial value of pig carcasses in Canada (Canada Gazette 1986). Therefore, within a given slaughter weight range, producers benefit from increased lean yield percentages. For Iberian and Lacombe crossbred pigs, estimated lean yield percentage was higher than actual total lean from carcass dissection. For Duroc pigs, the estimated lean yield percentage was lower. These differences were smaller for Duroc and more evident in carcasses from Iberian pigs. This may be due to the fact that the prediction equations were developed using commercial pigs, with a significant influence of the Duroc breed. The high lean and low backfat content of Duroc carcasses is a very positive trait from a production and processing point of view, and leads to higher carcass prices in the form of premiums (Marcoux et al. 2007). At the same time, the levels of lean and fat content observed in Iberian carcasses would lead to great discounts and loss of profitability. Carcasses from Lacombe crossbred pigs, although not as lean as those from Duroc crossbred animals, showed acceptable yield percentages. The lack of effects from the dietary treatments on carcass lean yield is consistent with previous research using similar diets (Caine et al. 2007).

Allometric function explains that fat is a late maturing tissue (Fortin et al. 1987) and usually develops faster when animals are closer to maturity. This explains why heavy carcasses from Duroc and Lacombe pigs showed a decrease in lean content and an increase in the relative contribution of fat depots compared with light carcasses from the same breed. At the same time, Fortin et al. (1987) reported that higher relative deposition rate for subcutaneous fat was an indication of earlier maturity. The Iberian breed is known for its early maturing fat deposition (Daza et al. 2006), explaining the high-fat content in Iberian carcasses and why no differences were observed between slaughter weights.

As previously mentioned, carcass weight and estimated lean yield are the main parameters determining the payment received by producers in Canada. However, the relative percentage of each primal cut may have a large impact on the final value of the carcass for the processing plant. Loin and belly are the two most profitable cuts in North America (Greenwood and Dunshea 2009). Marcoux et al. (2007) reported that the economic contribution of the ham and the loin to total carcass value tended to decrease in favour of the contribution of the belly, while the economic contribution of other cuts has been fairly stable. Therefore, increasing the relative percentage of loin and belly may be desirable. In general, fatter carcasses show a higher proportion of belly (Eikelenboom et al. 2004), as observed in the current study for carcasses from heavier pigs, with the subsequent decrease in relative contribution of ham to the total carcass weight. Gispert et al. (2007) reported that the big differences among genotypes in the proportion of primal cuts are worthwhile to characterize. Carcasses from Lacombe- and, especially, Iberian-crossbred pigs also had a larger proportion of loin and belly compared with Duroc crossbred pigs, which had proportionally heavier hams. This is consistent with results previously reported comparing carcasses from

Duroc and other commercial breeds (Latorre et al. 2003; CCSI 2007). The lack of effect of the dietary treatments on carcass composition also agrees with results from previous studies (Dugan et al. 2001).

Similar to carcass composition, meat quality is not currently used to economically reward or penalize producers in the Canadian pork industry. However, processors classify pork based on quality characteristics, such as fat consistency, meat colour, and marbling. Quality requirements from national, international, and niche markets determine the final value of pork carcasses and primals. Therefore, profitability is directly affected by these traits. Although the impact of marbling scores on pork palatability is not consistent among studies (Ngapo and Gariépy 2008), marbling is one of the main attributes considered by the industry to classify based on quality. The inclusion of flax and canola in the diet may lead to changes in marbling scores (Dugan et al. 2001; Caine et al. 2007). However, these effects have been reported with dietary levels well above those used in this study. Marbling is the last fat depot to develop (Fortin et al. 1983), as observed by the highest scores observed in 135-kg carcasses. In Spain, the Iberian pig is commonly crossed with Duroc to increase productive traits (Utrilla et al. 2010). Iberian pork has been reported to be darker and have higher marbling than Duroc-sired pigs (Juárez et al. 2009; Straadt et al. 2013). High levels of intramuscular fat reported in purebred Iberian pigs under traditional production systems tend to decrease in hybrids (Juárez et al. 2009). In North America, Duroc is widely used as terminal sire by the pork industry due to its potential to improve meat quality traits, especially intramuscular fat content (Mandell et al. 2006), of white breeds. Our results show the highest marbling scores in meat from Duroc-crossed pigs, confirming its ability to enhance this trait. The lower marbling scores observed in Iberian-crossed pork may be due to the interaction genotype × slaughter weight. Iberian pigs usually show their potential for intramuscular fat production when raised as purebred and slaughtered at 160–180 kg (Juárez et al. 2009). Straadt et al. (2013) reported similar intramuscular fat content in meat from the Iberian × Landrace/Large White and Duroc × Landrace/Large White crosses, while meat from Iberian × Duroc hybrids had significantly higher fat content. Meat from Lacombe-crossed pigs was consistently leaner, as expected from this type of breed, selected for maternal and performance traits (Fredeen and Stothart 1969).

Harder fat is desirable for processing of meat products. Softer fat may lead to low fabrication efficiency, oily appearance at retail, and reduced product shelf life (Soladoye et al. 2015). Fatty acid composition has been generally identified as the main factor responsible for fat hardness (Soladoye et al. 2015). Thus, the lower hardness scores observed in carcasses from animals fed the experimental diets (canola and flax) can be explained by the increase in dietary mono- and poly-unsaturated fatty acids (Miller et al. 1990; Dugan et al. 2001; Caine et al. 2007; Juárez et al. 2010). Thicker backfat, as observed in heavy carcasses and carcasses from Iberian-crossed pigs, usually leads to higher fat hardness scores, while leaner carcasses have softer fat (Wood and Riley 1982). However, the low hardness scores observed in carcasses from Lacombe-crossed pigs, which contained medium levels of subcutaneous fat, may be linked to different fat compositions due to differences in Lacombe's fat metabolism and deposition. Regardless of breed, diet, and slaughter weight, blast-chilled carcasses had higher fat hardness scores. Springer et al. (2003) and Jones et al. (1988) also reported higher fat hardness values in blast-chilled compared with conventionally chilled carcasses. The connective tissue lipid composition, matrix of connective tissue, as well as its water content, influence fat firmness (Wood et al. 2004). Blast chilling reduces fat crystal size, increasing fat hardness (Fox and McSweeney 2006).

While the differences observed in pH were minimal and would have no practical consequences, the effects of breed, slaughter weight, and diet on colour traits were significant and need to be considered. Pork colour is one of the main attributes affecting consumer's purchase decisions at retail (Ngapo and Gariépy 2008). Iberian pork has been widely reported to display a characteristic dark red colour (Juárez et al. 2009; Straadt et al. 2013). Serra et al. (1998) indicated that Iberian meat had the lowest L^* due to a higher percentage of pigments. At the same time, other studies have reported a lighter less intense red colour in meat from Duroc-crossed pigs (Bertol et al. 2013). These effects were consistent with our findings using both subjective and objective colour measurements. Springer et al. (2003) and Jones et al. (1988) reported that muscle became darker after blast chilling than after control chilling. Minimum chilling effects were observed on colour traits in the present study, maybe due to different temperature and chilling regimes in others studies. Previous studies have shown that meat lightness was unrelated to carcass weight (García-Macías et al. 1996; Čandek-Potokar et al. 1998). However, the effect of the dietary treatments on pork colour was inconsistent across the study, with canola leading to changes in L^*, chroma, and hue values in certain combinations of breed and slaughter weight only and the highest chroma value being found in 115-kg Iberian pigs fed the control diet. Miller et al. (1990) and Myer et al. (1992) reported a decrease in subjective colour scores in carcasses from canola-fed pigs, while Bertol et al. (2013) found no differences in objective colour traits between control- and canola-fed pigs. Thus, although the levels of the dietary treatments in this study were low, the effects of feeding pigs with diets containing ingredients with high levels of unsaturated fatty acids on meat quality need to be monitored when attempting to produce differentiated pork products.

In conclusion, pork differentiation can be achieved by combining modifications of pre and postslaughter factors. In the present study, the use of Duroc breed, commercial diets, and 115-kg slaughter weight, commonly used by the pork industry, showed a good balance in terms of performance, carcass yield, and quality traits. However, the use of different breeds, diets, and slaughter weights may result in positive changes in some of these attributes, such as ADG, percentage of valuable cuts, or meat colour. The negative impact on other traits needs to be considered to assess potential profitability of meat with differentiated attributes. Using this information, together with market conditions and consumer's preferences, Canadian producers and processors have the opportunity to manipulate pork quality and not be limited to the commodity pork market.

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