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The effect of Piétrain sire on the performance of the progeny of two commercial dam breeds: a pig intervention study

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Genetic evaluation of Piétrain sires in Flanders occurs under standardized conditions, on test stations with fixed dam breeds, standardized diets and uniform management practices. As environmental conditions vary on commercial farms and differ from the test stations, this study aimed at understanding to what extent the sire, the dam breed and the interaction between both affects the translation of breeding values to practice. Dams of two commercial breeds were inseminated with semen from one of five different sires selected for contrasting breeding values (daily gain, feed conversion ratio and carcass quality). For each sire by dam breed combination, six pen replicates (with three gilts and three barrows per pen) were evaluated for growth performance from 9 weeks of age (20 kg) to slaughter (110 kg), and for carcass and meat quality. In our experimental setup, both sire and dam breed affected growth, carcass and meat quality traits. No significant sire × dam breed interactions on performance could be detected. Though a tendency for interaction on average daily feed intake between 20 and 110 kg ($P = 0.087$*), and on pork colour (lightness) (*$P = 0.093$*) was present. In general, offspring of all tested sires behaved similarly in both dam breeds, indicating that estimated breeding values for Piétrain sires determined in one dam breed are representative in other dam breeds as well.*

Keywords: breeding value estimation, growth, carcass and meat quality, genotype by environment interaction, swine

Implications

High feed prices, low pig prices and high manure processing costs drive margins down for pig producers. As differences between sires could contribute to farm profitability, careful selection of terminal sires is essential. This study shows that the current estimated breeding values (EBVs) for Piétrain sires in Flanders, obtained in test station conditions, remain valid in commercial conditions where different dam breeds are used.

Introduction

While dam genetics is usually fixed at farm level, sire choice is more flexible, especially when applying artificial insemination (AI) with semen provided by AI-stations. Careful selection of the sire may be a simple and efficient way to improve production results, which is particularly important when profit margins are under pressure. Estimated breeding values are commonly used to support decision making. Sires of the Flemish pig book are evaluated by raising 18 to 21 crossbred offspring in test stations under standardized conditions such as a fixed dam breed (Large White × Landrace), standardized (high energy and amino acid level) diets and uniform management practices designed to allow the pigs to reach their full genetic potential. Estimated breeding values for daily gain (DG), daily feed intake (DFI) and carcass quality (CQ) are obtained applying an animal model (Henderson, 1973) on live weight gain on test (20 to 115 kg), average feed intake on test and CQ at slaughter. Carcass quality is expressed on a scale from 0 to 200 which reflects both conformation and lean meat percentage of the carcass. Estimated breeding values are also combined in a total index by multiplying the EBVs with the corresponding economic weight. Various studies have shown that growth performance, carcass and/or meat quality in pigs can be influenced by diet (Wood *et al.*, 2004; Millet and Aluwe, 2014; Zhou *et al.*, 2016), housing strategy (Gonyou and Stricklin, 1998; Street and Gonyou, 2008; Brandt *et al.*, 2009), or dam breed (Bereskin *et al.*, 1976; McLaren *et al.*, 1987a; Oliver *et al.*, 1994). As a consequence, farmers question whether EBVs obtained on test stations remain representative for commercial farms (Merks, 1989; Knap and Su, 2008; Wallenbeck

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et al., 2009) and specifically if the EBVs obtained with progeny from one dam breed are valid for other dam breeds as well. Sire breed × dam breed interactions have been reported among Yorkshire, Spotted, Landrace and Duroc breeds (Hutchens *et al*., 1982; McLaren *et al*., 1987a and 1987b) and among Minnesota no 1, Piétrain and Yorkshire breeds (McKay *et al*., 1984a and 1984b), but no study has explored whether such interactions are observed within a breed, in this case a set of Piétrain sires. In Flanders, the Belgian Piétrain is the predominant terminal sire for production of growing-finishing pigs because of its low feed conversion ratio (FCR) and extreme leanness (Lean *et al*., 1972; Labroue *et al*., 1999; Department Agriculture and Fisheries, 2016). Although some commercial companies claim that the performance of a particular Piétrain sire depends on the dam breed, this has not been scientifically validated. Therefore, the aim of this study was to assess to what extent the sire, the dam breed and the interaction between both affects the translation of breeding values to practice.

Material and methods

Animals and management

This study compared performances of offspring resulting from crossings of five different Piétrain sires (breeding values computed and published online by the Flemish pig book in 2014) in two dam breeds (i.e. DanBred and Topigs 20, referred to as breed A and breed B). The experiment was blocked in two rounds. In the first round, 25 sows per dam breed were selected and inseminated twice with semen of one of the five selected sires (five dams per sire × dam breed combination). In the second round, the same dams were allocated at random for insemination by the sires while ensuring that for all dams, the sire used in the second round was different from the sire used in the first round. Eight dams were replaced in the second round due to fertility problems or lameness.

Piétrain sires were selected amongst the available AI sires based on their EBV for DG, FCR and CQ, with a minimal total index of 100 (Table 1). Sire 1 had an average EBV for DG, FCR and CQ. Sire 2 was characterized by a good breeding value for CQ, but a poor breeding value for DG and FCR. Sire 3 was selected for a good breeding value for DG and FCR, but a poor breeding value for CQ, whereas sire 4 was chosen based on a good breeding value for CQ and a moderate breeding value for DG and FCR. Finally, sire 5 was selected for a good breeding value for DG and FCR, and a moderate breeding value for CQ. As this boar was no longer available at the start of the second round, sire 5 was replaced by sire 6, having a comparable EBV. All Piétrain sires used in this study were homozygous stress positive for the halothane locus, whereas both dam breeds were homozygous stress negative. As a result, all progeny were heterozygous for the halothane locus.

All pigs were born on a commercial pig farm (Agro De Gaai, Deerlijk, Belgium). Since the farm was switching dam breed from A to B, breed A had a lower parity compared to breed B. At the age of 9 weeks, six littermates (three gilts and three barrows of average BW) of three dams per sire × dam breed combination were transferred to the pig experimental facility at Flanders Research Institute for Agriculture, Fisheries and Food (ILVO) (Melle, Belgium) for the growing-finishing phase. This resulted in a total of 354 experimental animals: 180 piglets in round 1 and 174 piglets in round 2 as only two matings of sire 1 in dam breed A were successful. At ILVO, finishing pigs were housed with six full sibs per pen. Finishing pigs were fed *ad libitum* with a three phase feeding strategy: growing (20 to 40 kg), early finishing (40 to 70 kg) and late finishing (70 to 110 kg) (Supplementary Tables S1 and S2).

Table 1 *Estimated pig breeding values for daily gain (DG), feed conversion ratio (FCR) and carcass quality (CQ) of the selected Piétrain sires[1] and the corresponding code for growth performance (P, based on DG and FCR) and carcass quality (Q), varying from poor (−), average (0), moderate (+) to good (++)*

Sire	Code	DG (g/day)	FCR (g/kg)	CQ (points)	Accuracy	Index
1	P_0Q_0	37	0	1.1	0.858	105.4
2	P_-Q_{++}	−42	81	28.8	0.856	116.6
3	$P_{++}Q_-$	117	−178	−10.5	0.840	123.8
4	P_+Q_{++}	16	−55	18	0.848	125.5
5	$P_{++}Q_+$	73	−103	1.9	0.863	121.7
6[2]	$P_{++}Q_+$	85	−165	0.6	0.848	128.8

[1]Breeding values computed and published online by the Flemish pig book in 2014.
[2]In the second round, sire 5 was replaced by sire 6.

Growth performance

All pigs were weighed individually and feed consumption per pen was recorded weekly to determine average DFI, average DG and FCR per feeding phase, and for the total growing-finishing period. Average daily lean meat gain (DLMG) was calculated as (lean meat at slaughter – lean meat at the beginning of the growing-finishing phase) / (number of days between the beginning of the growing-finishing phase and slaughter). The amount of consumed lysine per kilogram lean gain was calculated as total consumed digestible lysine / (lean meat at slaughter – lean meat at the beginning of the growing-finishing phase). Lean meat at slaughter was defined as lean meat percentage × cold carcass weight. Lean meat at the beginning of the growing-finishing phase was assumed to be 45% BW (Susenbeth and Keitel, 1988). To better understand the observed growth performance results, serum urea and creatinine levels, two parameters of muscle metabolism, were determined additionally.

Carcass quality

At an average live weight of 110 kg, all pigs in the pen were slaughtered in a commercial slaughterhouse by exsanguination after carbon dioxide stunning. As 12 pigs were euthanized or removed due to illness or lameness, 342 pigs remained in the experiment. Animals were fasted 16 h before slaughter. Muscle and fat thickness were measured using the AutoFOM III (Carometec A/S, Smørum, Denmark) and values were converted into lean meat percentage by the equation approved by the regulation 2012/416/EU. Dressing percentage was calculated as cold carcass weight, recorded in the slaughterhouse, divided by the BW recorded immediately before transport to the slaughterhouse and multiplied by 100.

Meat quality

Meat quality parameters were assessed in the first round ($n = 175$). At 45 min *postmortem*, pH (pH_{45}) was measured in the *musculus longissimus thoracis et lumborum* (LM) (around the 13th rib of the right carcass side) using a Knick Portamess, Type 911 pH with a Xerolyt puncture-type electrode (Mettler Toledo, Columbus, OH, USA) and a Testo 230 with a NTC-sensor (Testo, Ternat, Belgium). One-day *postmortem*, a piece of the LM of the right side of the carcass (30 cm around the 13th rib) was sampled at the slaughterhouse. Samples were trimmed for intermuscular and subcutaneous fat and sliced (2.5 cm thickness).

On one slice, the ultimate pH (pH_u) was measured 24 h *postmortem* using a Knick Portamess, Type 911 pH with a Xerolyt puncture-type electrode. A second slice was used to assess drip loss, based on the method described by Honikel (1987). The weight of the slice (approximately 150 g) was measured, and the slice was then placed in a plastic bag and suspended for 48 h at 4°C using a nylon cord. After 48 h, the slice was weighed again after wiping the sample dry, and the proportionate weight loss was calculated. Color was determined on a third slice in duplicate after 15 min blooming time with a reflection spectrophotometer (HunterLab Miniscan, Reston, VA, USA), giving the color coordinates *L* (lightness), *a* (redness) and *b* (yellowness). Average values were used for further statistical analysis.

Before the other analyses (intramuscular fat (IMF) content and shear force), slices were vacuum packed and stored at − 18°C. The amount of IMF was calculated based on the total amount of lipids (slice with all intermuscular and subcutaneous fat removed) as determined using the modified Bligh and Dyer method (Bligh and Dyer, 1959). Tenderness was evaluated by shear force determination. A slice was heated in a plastic bag at 75°C for 60 min in a hot water bath and cooled in a bath of cold tap water. Cooking loss was recorded as weight loss during cooking of this slice. The cooked slice rested for 24 h at 4°C. Shear force of the cooked samples was determined with a triangular Warner–Bratzler shear force measurement device (Boccard *et al*., 1981). Ten cylindrical samples (diameter 1.27 cm) were taken parallel to the fiber direction and were sheared, during which the shear force was recorded. The lowest and highest values of each sample were excluded to determine the average shear force.

Metabolic parameters

Blood samples were collected from 166 pigs in the second round, the day after the average weight in the pen reached at least 105 kg. Blood samples were taken via venipuncture of the jugular vein and were collected in a 10 ml serum tube with a silicone-coated interior (Terumo Europe, Leuven, Belgium). Serum was obtained by centrifugation at 1499 rpm for 10 min at 4°C and stored at −80°C until analysis. Urea and creatinine concentrations were determined by using the commercial Cobas Ureal kit and Cobas CreJ kit, respectively (both kits made by Roche, Basel, Switzerland). The limits of detection were 3.0 mg/dl for urea and 0.17 mg/dl for creatinine.

Statistical analysis

Statistical analysis was performed using R (R Core Team, 2017) with general linear mixed-effect models (nlme package). Performance parameters (DG, DFI and FCR) were analyzed using a longitudinal model. The pen was considered as the experimental unit. For individually assessed parameters (DLMG, serum concentrations, meat and CQ traits), pen was included as random factor to correct for repeated measures within the same pen. Round was included as fixed factor to model the differences between weaning rounds, except for serum concentrations and meat quality parameters as these parameters were only measured in one round. All fixed and random effects that were included in the initial models to analyze the different parameters, are shown in Table 2. For final models, interaction terms with *P*-values above 0.1 were excluded. Differences in main effects were considered significant if $P < 0.05$ based on the Type III Anova table (car package). A Tukey's *posthoc* test was used to compare treatment means (lsmeans package).

A *posthoc* power calculation with 10 000 simulations was performed (simr package), based on the observed values in this study. Assuming a difference of 75 g in DG, 0.3 in FCR and 3% in lean meat percentage, a power of 71%, 85% and 88% for the effect of sire × dam breed was calculated, respectively.

Correlation coefficients (Pearson correlation) were calculated between IMF and lean meat percentage, fat thickness and muscle thickness, in both barrows and gilts. Results were considered significant if $P < 0.05$.

Results

Performance

For average DFI, sire and dam breed tended to interact when considering the trajectory 20 to 110 kg ($P = 0.087$) (Table 3, Supplementary Tables S3, S4 and S5). Offspring of sire 3, sire 4 and sire 5 in dam breed A ate more compared to offspring of sire 2, whereas no differences between sires were observed for dam breed B. Overall, sire significantly affected DG: sire 5 offspring grew faster than offspring of sire 2 ($P < 0.001$). There was no effect of dam breed on DG. Average DLMG was significantly affected by the sire ($P = 0.031$), yet no differences between individual sires could be determined with Tukey's *posthoc* tests. Dam breed also had a significant effect ($P < 0.001$), with offspring of breed A having a higher DLMG compared to offspring of breed B. Feed conversion ratio tended to be affected by dam breed (lower for breed A in phase 2 and phase 3) ($P = 0.063$), and was significantly reduced in sire 1 and sire 5 pigs compared to sire 2 pigs ($P = 0.002$), independent of dam breed. The amount of kilogram lysine needed per kilogram lean gain was

Table 2 *Initial models used in the analysis of pig daily feed intake (DFI), daily gain (DG), feed conversion ratio (FCR), lysine/kg lean gain, daily lean meat gain (DLMG), serum, meat and carcass quality*

	DFI	DG	FCR	Lysine/kg lean gain	DLMG	Serum	Meat quality	Carcass quality
Fixed effects								
Sire	x	x	x	x	x	x	x	x
Dam breed	x	x	x	x	x	x	x	x
Feeding phase	x	x	x					
Sex					x	x	x	x
Measuring device							x[2]	
Cold carcass weight[1]				x				x
Round	x	x	x	x	x			x
Sire × dam breed				x	x	x	x	x
Sire × dam breed × feeding phase	x	x	x					
Random effects								
Pen	x	x	x	x	x	x	x	x
Slaughter date							x	

For final models, interaction terms with *P*-values above 0.1 were excluded.
[1]Continuous variable.
[2]For pH only.

significantly higher for offspring of breed B compared to breed A ($P < 0.001$), but did not differ significantly between offspring of different sires.

Metabolic parameters
Serum urea concentrations were increased in offspring of sire 1, sire 3 and sire 6 compared to sire 2 ($P < 0.001$, Table 3, Supplementary Tables S4 and S5), and tended to be affected by dam breed (higher for breed B) ($P = 0.075$). Sire or dam breed did not affect serum creatinine levels.

Carcass quality
None of the CQ parameters was affected by a sire × dam breed interaction (Table 4, Supplementary Tables S4 and S5). Sire had a significant effect on all carcass traits. Sire 2 pigs had the highest dressing percentage compared to sire 4 pigs ($P = 0.009$). In addition, offspring of sire 2 had the highest carcass leanness ($P < 0.001$) due to having the highest muscle thickness ($P < 0.001$) and the lowest fat thickness ($P < 0.001$). The lowest lean meat percentage was observed with sire 1, sire 4, sire 5 and sire 6 ($P < 0.001$), the lowest muscle thickness with sire 4 ($P < 0.001$), and the highest fat thickness with sire 1 and sire 3 ($P < 0.001$). The relative weight of the ham was highest with sire 2, intermediate with sire 3, and lowest with sire 1 and 4 ($P < 0.001$). Compared to all other sires, sire 2 led to the highest relative weight of the loin ($P < 0.001$) and shoulder ($P < 0.001$). Sire 2 pigs also had the lowest relative weight of the belly compared to sire 1, sire 3 and sire 4 pigs ($P < 0.001$).

Dam breed influenced multiple carcass parameters (Table 4, Supplementary Table S4). Compared to breed B, offspring of breed A showed a higher lean meat percentage ($P < 0.001$), and a higher relative weight of the loin ($P = 0.023$) and shoulder ($P = 0.013$). In addition, a significantly lower fat thickness ($P < 0.001$) and lower relative weight of the belly ($P < 0.001$) was observed in offspring of breed A. Dressing percentage, muscle thickness and relative weight of the ham did not differ between dam breeds.

Meat quality
None of the meat quality parameters was affected by sire × dam breed interactions (Table 5, Supplementary Tables S4 and S5). Pork of sire 3 pigs was significantly less red than pork from offspring of sire 1 and sire 2 ($P < 0.001$), and less yellow than offspring of sire 2 ($P = 0.023$). Compared to sire 4 pigs, a significant lower IMF percentage was observed for sire 2 pigs ($P = 0.020$). Intramuscular fat correlated negatively with lean meat percentage, with a correlation coefficient of $r = -0.42$ ($P < 0.001$) and $r = -0.48$ ($P < 0.001$) for barrows and gilts, respectively. Intramuscular fat correlated positively with fat thickness, with a correlation coefficient of $r = 0.40$ ($P < 0.001$) and $r = 0.42$ ($P < 0.001$), respectively. Intramuscular fat and muscle thickness did not correlate significantly. The pH measured at 45 min *post-mortem* (pH_{45}), pH_u, drip loss and shear force did not vary among sires. Breed A dams tended to induce less red pork ($P = 0.085$), and resulted in a significant higher drip loss ($P = 0.001$) and lower shear force ($P = 0.004$). In contrast, pH_{45}, pH_u, yellowness, cooking loss and IMF percentage were not affected by dam breed. For lightness of the meat, sire and dam breed tended to interact ($P = 0.093$) (Table 5, Supplementary Tables S4 and S5). In dams of breed B, sire 1 induced significantly darker meat compared to sire 5, while no differences between individual sires were observed for dams of breed A.

Discussion

Effect of dam breed
Dam breed affected diverse growth performance and carcass or meat quality parameters. Offspring of breed A tended to

Table 3 *Effect of pig sire (S) and dam breed (D) on growth performance (20 to 110 kg) (A), and urea and creatinine levels (B) in their offspring (means)*

A

		Sire							*P*-value[1]		
		1	2	3	4	5	6[2]				
	Dam	P_0Q_0[3]	P_-Q_{++}	$P_{++}Q_-$	P_+Q_{++}	$P_{++}Q_+$	$P_{++}Q_+$	SEM[3]	Sire	Dam breed	S × D
Number of pens (*n*) (A|B)		5|6	6|6	6|6	6|6	3|3	3|3				
DFI[3] (kg)[4]	A	1.90	1.83	1.96	1.95	2.08	1.77	0.02	<0.001	0.650	0.087
	B	2.02	1.89	1.93	1.98	2.07	1.89	0.02			
DG[3] (kg)[4]	A	0.84	0.76	0.86	0.86	0.91	0.80	0.01	<0.001	0.849	(0.241)[5]
	B	0.83	0.74	0.78	0.79	0.83	0.78	0.01			
DLMG[3] (kg)[6]	A	0.40	0.39	0.42	0.41	0.45	0.40	0.00	0.031	<0.001	(0.603)[5]
	B	0.37	0.36	0.39	0.38	0.38	0.38	0.01			
FCR[3] (kg/kg)[4]	A	2.27	2.41	2.28	2.28	2.29	2.22	0.02	0.002	0.063	(0.974)[5]
	B	2.45	2.56	2.48	2.52	2.51	2.41	0.02			
Lysine lean gain (g/kg)[4]	A	41.81	43.68	42.13	45.37	40.93	42.05	0.59	0.176	<0.001	(0.539)[5]
	B	51.72	47.44	49.90	47.06	45.78	43.60	0.90			

B

		Sire						*P*-value		
		1	2	3	4	6[2]				
	Dam	P_0Q_0[3]	P_-Q_{++}	$P_{++}Q_-$	P_+Q_{++}	$P_{++}Q_+$	SEM[3]	Sire (S)	Dam breed (D)	S × D
Number of animals (*n*) (A|B)		11|17	18|17	18|17	17|17	17|17				
Urea (mg/dl)	A	21.7	17.3	23.9	19.8	22.7	0.57	<0.001	0.075	(0.638)[5]
	B	26.0	19.9	21.8	22.3	25.1	0.61			
Creatinine (mg/dl)	A	1.7	1.5	1.6	1.4	1.7	0.03	0.163	0.121	(0.201)[5]
	B	1.4	1.4	1.6	1.5	1.5	0.03			

[1]Performance parameters (DFI, DG and FCR) were analyzed using a longitudinal model that included feeding phase as a fixed factor.
[2]In the second round, sire 5 was replaced by sire 6.
[3]P = growth performance; Q = carcass quality; − = poor; 0 = average; + = moderate; ++ = good; DFI = daily feed intake,; DG = daily gain; FCR = feed conversion ratio; DLMG = daily lean meat gain, SEM = SEM of all sires within one dam breed.
[4]Measured at pen level.
[5]Interaction was not included in statistical model if $P > 0.1$, *P*-values of the excluded interactions in initial models are shown in brackets.
[6]Measured at animal level ($n \times 6$).

have a better FCR and had a significantly better lean meat percentage and lower fat thickness compared to breed B, while pork of breed A had lower shear force values, but also less water holding capacity. In line with our results, dam breed was shown to affect average DG, carcass and meat characteristics, further illustrating that dam breed effects in pigs extend beyond reproductive traits (Bereskin *et al.*, 1976; Oliver *et al.*, 1994) because of the 50% contribution of genes from the dam to the fattening pig.

Effect of sire

Sires were chosen based on their EBV for DG, FCR and CQ, based on offspring performance. According to these breeding values, sire 2 used in this study should theoretically perform worst in terms of DG and FCR and best for CQ. This was confirmed by our results: offspring of sire 2 had the lowest DG, the highest FCR, but the highest lean meat percentage. The higher FCR of sire 2 pigs can be explained by their reduced DFI, slower growth and reduced (but not significantly different) DLMG, resulting in higher maintenance requirements. As a result, a lower IMF content, a lower fat thickness and a higher muscle thickness was observed, leading overall to a higher lean meat percentage (Patience *et al.*, 2015). The lower serum urea levels indicate that nitrogen was used more efficiently, which seems logical given the high lean meat percentage (van Milgen and Dourmad, 2015).

As expected, cold carcass weight did not differ among the selected sires. However, offspring of sire 2 were characterized by the highest relative weight of the ham, loin and shoulder, but the lowest relative weight of the belly. This agrees with the findings of Tanghe *et al.* (2015) who showed that the relative weight of the ham, loin and shoulder is negatively correlated with the relative weight of the belly and positively correlated with each other. Moreover, lean meat percentage was reported to be positively correlated

Table 4 *Effect of pig sire (S) and dam breed (D) on carcass quality of their offspring (means)*

		Sire							*P*-value		
	Dam	1 P_0Q_0[2]	2 P_-Q_{++}	3 $P_{++}Q_-$	4 P_+Q_{++}	5 $P_{++}Q_+$	6[1] $P_{++}Q_+$	SEM[2]	Sire	Dam breed	S × D
Number of animals (*n*) (A∣B)		28∣34	36∣34	36∣35	35∣35	18∣17	17∣17				
Slaughter weight (kg)	A	114.3	113.6	115.0	115.3	114.5	115.1	0.73	0.009	0.464	(0.162)[3]
	B	114.4	112.4	115.1	114.2	116.1	116.3	0.73			
Cold carcass weight (kg)	A	90.4	90.5	90.7	89.9	89.9	91.3	0.60	0.737	0.924	(0.658)[3]
	B	90.0	88.9	91.5	89.8	92.1	92.0	0.60			
Dressing percentage (%)	A	79.1	79.7	78.9	78.0	78.5	79.3	0.10	0.009	0.453	(0.187)[3]
	B	76.4	79.1	79.5	78.6	75.2	79.1	0.65			
Lean meat (%)	A	63.9	65.3	63.0	63.0	63.5	64.4	0.21	<0.001	<0.001	(0.240)[3]
	B	60.6	64.5	62.9	61.9	62.3	62.4	0.25			
Fat thickness (mm)	A	7.6	7.0	9.0	8.3	8.5	7.3	0.19	<0.001	<0.001	(0.162)[3]
	B	11.2	8.2	9.6	9.5	10.0	9.4	0.24			
Muscle thickness (mm)	A	63.0	67.1	66.8	61.9	65.0	63.4	0.37	<0.001	0.510	(0.626)[3]
	B	63.4	68.5	65.9	62.2	66.6	63.2	0.41			
Relative weight ham (%)	A	23.3	23.7	23.5	23.1	23.3	23.4	0.05	<0.001	0.626	(0.489)[3]
	B	23.0	23.9	23.5	23.2	23.4	23.2	0.05			
Relative weight loin (%)	A	27.4	28.4	27.4	27.0	27.5	27.6	0.07	<0.001	0.023	(0.543)[3]
	B	26.6	28.3	27.4	26.9	27.4	26.9	0.09			
Relative weight shoulder (%)	A	15.8	16.0	15.7	15.7	15.8	15.8	0.01	<0.001	0.013	(0.191)[3]
	B	15.6	15.9	15.8	15.7	15.8	15.7	0.02			
Relative weight belly (%)	A	15.0	14.8	15.3	15.2	15.2	14.9	0.04	<0.001	<0.001	(0.218)[3]
	B	15.8	15.0	15.3	15.5	15.4	15.4	0.05			

[1]In the second round, sire 5 was replaced by sire 6.
[2]P = growth performance; Q = carcass quality; − = poor; 0 = average; + = moderate; ++ = good; SEM = SEM of all sires within one dam breed.
[3]Interaction was not included in statistical model if $P > 0.1$, *P*-values of the excluded interactions in initial models are shown in brackets.

Table 5 *Effect of pig sire (S) and dam breed (D) on meat quality of their offspring (means)*

		Sire						*P*-value		
	Dam	1 P_0Q_0[1]	2 P_-Q_{++}	3 $P_{++}Q_-$	4 P_+Q_{++}	5 $P_{++}Q_+$	SEM[1]	Sire	Dam breed	S × D
Number of animals (*n*) (A∣B)		18∣16	18∣16	18∣18	18∣18	17∣18				
pH_{45}[1]	A	6.3	6.3	6.3	6.2	6.3	0.02	0.245	0.564	(0.142)[2]
	B	6.4	6.2	6.4	6.3	6.2	0.03			
pH_u[1]	A	5.5	5.5	5.5	5.5	5.4	0.01	0.636	0.469	(0.916)[2]
	B	5.5	5.5	5.5	5.5	5.5	0.01			
L (lightness)	A	57.3	55.6	58.5	57.8	57.4	0.29	0.138	0.112	0.093
	B	54.0	55.4	55.9	56.1	58.1	0.40			
a (redness)	A	8.0	8.0	6.4	6.9	7.6	0.14	<0.001	0.085	(0.505)[2]
	B	8.3	9.2	7.2	7.5	7.3	0.15			
b (yellowness)	A	16.7	16.6	15.8	16.3	16.6	0.10	0.023	0.713	(0.569)[2]
	B	16.3	17.0	15.9	16.2	16.2	0.11			
Drip loss (%)	A	8.2	7.3	7.2	8.1	8.3	0.18	0.326	0.001	(0.209)[2]
	B	7.2	7.4	6.1	6.4	6.7	0.19			
Cooking loss (%)	A	0.33	0.33	0.34	0.34	0.32	0.00	0.104	0.178	(0.373)[2]
	B	0.33	0.33	0.5	0.34	0.35	0.00			
Shear force (*n*)	A	35.1	38.0	37.9	39.5	34.2	0.51	0.269	0.004	(0.139)[2]
	B	39.4	37.9	42.6	39.5	39.5	0.57			
IMF[1] (%)	A	1.4	1.5	1.5	1.7	1.4	0.03	0.020	0.751	(0.121)[2]
	B	1.5	1.2	1.4	1.7	1.6	0.04			

[1]P = growth performance; Q = carcass quality; − = poor; 0 = average; + = moderate; ++ = good; pH_{45} = pH 45 min *postmortem*; pH_u = ultimate pH; IMF = intramuscular fat; SEM = SEM of all sires within one dam breed.
[2]Interaction was not included in statistical model if $P > 0.1$, *P*-values of the excluded interactions in initial models are shown in brackets.

with the relative weight of the ham, loin and shoulder, but negatively correlated with the relative weight of the belly (Tanghe *et al.*, 2015), which is in line with our observations.

In contrast to sire 2, sire 3 had the best EBV for DG and FCR, but the worst for CQ. Indeed, offspring of sire 3 had the highest fat thickness and the highest relative weight of the belly. This agrees with the negative correlation between lean meat percentage and relative weight of the belly as described by Tanghe *et al.* (2015). The predicted effect on FCR and DG for sire 3 pigs was less clear. Other sires could as well show a less pronounced ranking than predicted, however, no big outliers were present and most sires performed as expected.

Interaction between sire and dam breed

Trends to significant interactions between sire and dam breed were observed for average DFI between 20 and 110 kg, and pork lightness. However, in our experimental setup, no significant sire × dam breed interactions were reported. In general, offspring of all sires behaved similarly in dam breed A compared to breed B and EBVs remained valid over the two commercial dam breeds used in this study (Figure 1). Analogous with our results, high correlations between test station and on-farm performance for growth rate and/or back fat were reported (Van Diepen and Kennedy, 1989; Bidanel and Ducos, 1996). In addition, in a

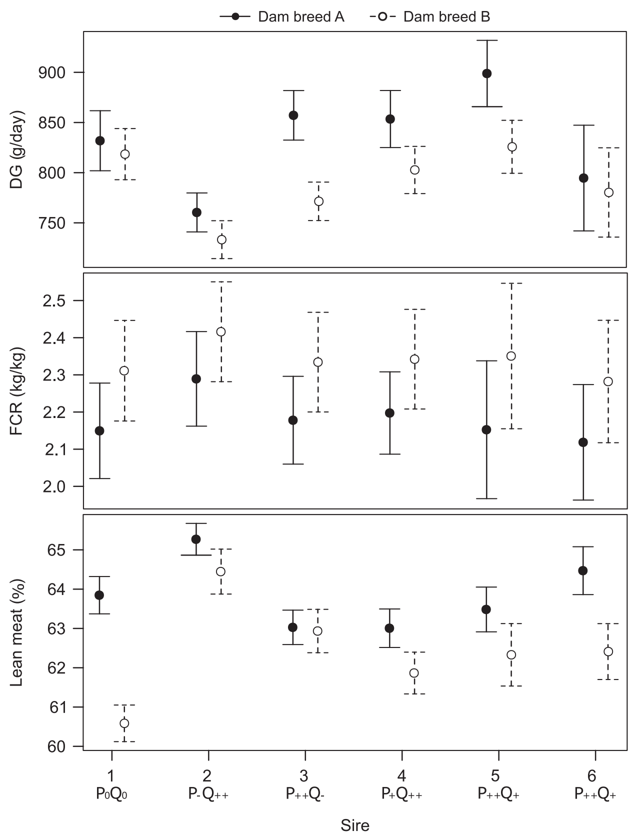

Figure 1 Average daily gain (DG), feed conversion ratio (FCR) and lean meat percentage for the different pig sire by dam breed crossings. Sire codes for growth performance (P, based on DG and FCR) and carcass quality (Q), varying from poor (−), average (0), moderate (+) to good (++) are indicated. Bars represent SEM.

study comparing the performance of sires between conventional and organic production systems, no major shift of the ranking order was observed (Brandt *et al.*, 2009). These results further support that EBVs can be a useful and reliable tool across different environments.

Because selection for leanness of Piétrain sires has resulted in reduced feed intake capacity (Lean *et al.*, 1972; Labroue *et al.*, 1999), differences in growth performance and CQ traits of their offspring might be limited (but still economically important) and similar when crossed with different dam breeds. As the maximum deviation between the EBV for DG of the selected sires was about 150 g/day, a difference of 75 g/day in DG was chosen to be relevant, since the sire is only responsible for half of the additive genetic value of the piglets. Next, in the European SEUROP-classification system of meat quality, different classes (S to P) are given per decrease in lean meat percentage of 5% (S, E, U, R, O, P for respectively >60%, 55% to 60%, 50% to 55%, 45% to 50%, 40% to 45% and <40%). Therefore, a difference in lean meat percentage of 3% was selected as economically relevant. For FCR, the maximal deviation between the EBVs was about 260 g/kg, or 0.13 g/g explained by the sire. A difference of 0.1 in FCR was therefore considered as economical relevant. In our experiment setup with 354 experimental animals studied, an acceptable power could be reached for a difference of 75 g in DG, 3% in lean meat percentage, and 0.3 in FCR. No acceptable power for a difference of 0.1 in FCR could be calculated. Considering FCR, our experimental setup can be regarded as underpowered. An increased number of animals would have allowed a higher power for smaller, but still economical relevant differences. However, numerically there is no indication for an interaction between sire and dam breed: in both dam breeds, sire 2 scores worst and sire 6 scores best in terms of FCR.

For diverging breeds, sire breed × dam breed interactions have been reported. For instance, among Yorkshire, Spotted, Landrace and Duroc breeds, sire breed × dam breed interactions have been described for DG (McLaren *et al.*, 1987a), for weight of ham, loin and loin muscle area (McLaren *et al.*, 1987b), and for age and weight at puberty (Hutchens *et al.*, 1982). In addition, among Minnesota no 1, Piétrain and Yorkshire breeds, sire breed × dam breed interactions were observed for carcass length, loin eye area, biceps brachii, biceps femoris, ham and loin percentage, and for loin, shoulder, ham, boned ham, semitendinosus, semimembranosus, femur and humerus weight (McKay *et al.*, 1984a). Further, sire breed × dam breed interactions have been reported for large intestine length and for kidney, heart, spleen and leaf fat weight (McKay *et al.*, 1984b). While specific crossings between different breeds can be beneficial for certain traits, our study could not confirm that within a set of Piétrain sires, terminal boars would rank differently depending on the commercial dam breed.

In conclusion, the present study confirmed the existence of (large) differences in performance between offspring of different Piétrain sires and different dam breeds, which may have a major impact on farm profitability. However, the results obtained with our experimental setup indicate that the main effects of the sire and the dam breed seem to be of greater importance than their interaction. The current breeding value estimation of Piétrain sires thus remains representative among different dam breeds, further illustrating the importance of EBVs for more sustainable pig husbandry.

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Declaration of interest

The authors declare that there is no conflicts of interest.

Ethics statement

This study was approved by the Ethics Commission of Flanders Research Institute for Agriculture, Fisheries and Food (ILVO; EC-2015-249).

Software and data repository resources

None of the data were deposited in an official repository.

Supplementary material

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References

Bereskin B, Davey RJ and Peters WH 1976. Genetic, sex and diet effects on pig growth and feed use. Journal of Animal Science 43, 977–984.

Bidanel JP and Ducos A 1996. Genetic correlations between test station and on-farm performance traits in Large White and French Landrace pig breeds. Livestock Production Science 45, 55–62.

Bligh EG and Dyer WJ 1959. A rapid method of total lipid extraction and purification. Canadian Journal of Biochemistry and Physiology 37, 911–917.

Boccard R, Buchter L, Casteels E, Cosentino E, Dransfield E, Hood DE, Joseph RL, MacDougall DB, Rhodes DN, Schön I, Tinbergen BJ and Touraille C 1981. Procedures for measuring meat quality characteristics in beef production experiments. Report of a working group in the commission of the European communities' (CEC) beef production research programme. Livestock Production Science 8, 385–397.

Brandt H, Werner DN, Baulain U, Brade W and Weissmann F 2009. Genotype–environment interactions for growth and carcass traits in different pig breeds kept under conventional and organic production systems. Animal 4, 535–544.

Department Agriculture and Fisheries 2016. Spermacentra varkens – Jaarrapport 2016. Flemish Government, Brussels, Belgium.

Gonyou HW and Stricklin WR 1998. Effects of floor area allowance and group size on the productivity of growing/finishing pigs. Journal of Animal Science 76, 1326–1330.

Henderson CR 1973. Sire evaluation and genetic trends. Journal of Animal Science 1973, 10–41.

Honikel KO 1987. How to measure the water-holding capacity of meat? Recommendation of standardized methods. In Evaluation and control of meat quality in pigs (ed. PV Tarrant, G Eikelenboom and G Monin), pp. 129–142. Springer, Dordrecht, The Netherlands.

Hutchens LK, Hintz RL and Johnson RK 1982. Breed comparisons for age and weight at puberty in gilts. Journal of Animal Science 55, 6.

Knap PW and Su G 2008. Genotype by environment interaction for litter size in pigs as quantified by reaction norms analysis. Animal 2, 1742–1747.

Labroue F, Guéblez R, Meunier-Salaün M-C and Sellier P 1999. Feed intake behaviour of group-housed Piétrain and Large White growing pigs. Annales de Zootechnie 48, 247–261.

Lean IJ, Curran MK, Duckworth JE and Holmes W 1972. Studies on Belgian Pietrain pigs 1. A comparison of Pietrain, Landrace and Pietrain Landrace crosses in growth, carcass characteristics and meat quality. Animal Science 15, 1–9.

McKay RM, Rempel WE, Cornelius SG and Allen CE 1984a. Differences in carcass traits of three breeds of swine and crosses at five stages of development. Canadian Journal of Animal Science 64, 293–304.

McKay RM, Rempel WE, Cornelius SG and Allen CE 1984b. Visceral characteristics of three breeds of swine and their corsses. Canadian Journal of Animal Science 64, 9–19.

McLaren DG, Buchanan DS and Johnson RK 1987a. Growth performance for four breeds of swine: crossbred females and purebred and crossbred boars. Journal of Animal Science 64, 99–108.

McLaren DG, Buchanan DS and Johnson RK 1987b. Individual heterosis and breed effects for postweaning performance and carcass traits in four breeds of swine. Journal of Animal Science 64, 83–98.

Merks JWM 1989. Genotype × environment interactions in pig breeding programmes. VI. Genetic relations between performances in central test, on-farm test and commercial fattening. Livestock Production Science 22, 325–339.

Millet S and Aluwe M 2014. Compensatory growth response and carcass quality after a period of lysine restriction in lean meat type barrows. Archives of Animal Nutrition 68, 16–28.

Oliver MA, Gou P, Gispert M, Diestre A, Arnau J, Noguera JL and Blasco A 1994. Comparison of five types of pig crosses. II. Fresh meat quality and sensory characteristics of dry cured ham. Livestock Production Science 40, 179–185.

Patience JF, Rossoni-Serão MC and Gutiérrez NA 2015. A review of feed efficiency in swine: biology and application. Journal of Animal Science and Biotechnology 6, 33.

R Core Team 2017. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Street BR and Gonyou HW 2008. Effects of housing finishing pigs in two group sizes and at two floor space allocations on production, health, behavior, and physiological variables 1. Journal of Animal Science 86, 982–991.

Susenbeth A and Keitel K 1988. Partition of whole body protein in different body fractions and some constants in body composition in pigs. Livestock Production Science 20, 37–52.

Tanghe S, Millet S, Hellebuyck S, Van Meensel J, Buys N, De Smet S and Janssens S 2015. Effect of sex and sire on lean meat percentage and weight of primal cuts of pork using Autofom data. In Proceedings of the 66th Annual Meeting of the European Federation of Animal Science, 31 August to 4 September 2015, Warsaw, Poland, 166 pp.

Van Diepen TA and Kennedy BW 1989. Genetic correlations between test station and on-farm performance for growth rate and backfat in pigs. Journal of Animal Science 67, 1425–1431.

van Milgen J and Dourmad J-Y 2015. Concept and application of ideal protein for pigs. Journal of Animal Science and Biotechnology 6, 15.

Wallenbeck A, Rydhmer L and Lundeheim N 2009. GxE interactions for growth and carcass leanness: re-ranking of boars in organic and conventional pig production. Livestock Science 123, 154–160.

Wood JD, Nute GR, Richardson RI, Whittington FM, Southwood O, Plastow G, Mansbridge R, da Costa N and Chang KC 2004. Effects of breed, diet and muscle on fat deposition and eating quality in pigs. Meat Science 67, 651–667.

Zhou X, Beltranena E and Zijlstra RT 2016. Effect of feeding wheat- or barley-based diets with low or and high nutrient density on nutrient digestibility and growth performance in weaned pigs. Animal Feed Science and Technology 218, 93–99.