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Can a super sow be a robust sow? Consequences of litter investment in purebred and crossbred sows of different parities[1]

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ABSTRACT: The aim of this project was to study the consequences of litter investment on physical characteristics in primiparous and multiparous sows in 3 Norwegian breeds (Norsvin Duroc [*n* = 12], Norsvin Landrace [*n* = 12], and crossbreeds [Norsvin Landrace and Swedish Yorkshire {*n* = 15}]). We predicted that the maternal sow line (Norsvin Landrace) would invest more in their litter in term of higher weight at birth, resulting in a higher litter weight of weaned piglets but with the consequence of greater loss in body condition and a higher prevalence of shoulder lesions. It was predicted that this should be more pronounced in primiparous sows than in multiparous sows. As predicted, the maternal pure line (Norsvin Landrace) had higher litter investment in terms of litter weight at birth ($P = 0.003$) and litter weight at weaning ($P = 0.050$) as well as higher total litter investment (litter weight at weaning plus weight of dead piglets [stillborn and mummified piglets and weight of piglets that died after farrowing but before weaning]; $P = 0.050$) and suffered larger losses of body condition ($P = 0.016$) and had a higher prevalence of shoulder lesions ($P = 0.008$) during lactation than other breeds. Moreover, only in Norsvin Landrace was development of shoulder lesions related to inadequate feed consumption ($P = 0.006$). This has become a major welfare concern of modern pig breeding. Although primiparous and multiparous sows had similar litter sizes, primiparous sows had lower litter investment in terms of litter weight at birth ($P = 0.032$) and litter weight at weaning ($P = 0.007$) as well as total litter investment ($P = 0.008$). Primiparous sows suffered greater losses in body condition ($P = 0.012$) and developed more shoulder lesions ($P = 0.026$) due to lower total feed consumption ($P < 0.001$) during lactation than multiparous sows. Especially in the highly productive maternal line (Norsvin Landrace), development of shoulder lesions during the lactation period was more pronounced in primiparous sows than in multiparous sows ($P < 0.001$). The selection program has shifted the balance to greater investments in earlier life, when sows still need resources for their own growth and development. This has resulted in a larger number of weaned piglets but at a higher sow welfare cost in terms of higher losses in body condition and a higher prevalence of shoulder lesions. Our results pinpoint the importance of improving the balance between economic traits and traits that improve welfare and longevity of the sows.

Key words: litter investment, pig breed, sow physical condition, welfare

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INTRODUCTION

Modern breeding programs have resulted in larger litters, lower mortality, and heavier piglets. From an evolutionary point of view, there is a trade-off between current and future litters and between number and fitness of piglets (Lessells, 1991). Genetic selection has produced a shift from an even distribution of

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reproductive resources over the sow's lifetime toward a larger maternal investment and reproductive cost early in life (Rauw et al., 1998; Andersen et al., 2011). This is likely to reduce the residual reproductive value of the sow, and longevity will thus be compromised. Indeed, in Norway, 30% of the sows are culled after their first litter (Thingnes et al., 2015).

Maternal sow lines are likely to invest more in their litters than breeds not selected for these traits. Sows with larger litters and higher milk production are not capable of maintaining adequate body reserves due to insufficient feed intake (Wallenbeck et al., 2008). For primiparous sows that still need energy for their own growth (Moustsen et al., 2011), such litter investment has larger consequences in terms of greater body condition losses (Schenkel et al., 2010). In addition to poorer body condition at weaning (Drake et al., 2008), these highly productive sows show a larger prevalence of developing shoulder lesions during the lactation period (Fredriksen et al., 2015).

The aim of this project was to study the consequences of litter investment on physical characteristics in primiparous and multiparous sows in 3 Norwegian breeds (Norsvin Duroc, Norsvin Landrace, and Norsvin Landrace crossed with Swedish Yorkshire). We predicted that the pure maternal sow line (Norsvin Landrace) would invest more in their litter in terms of higher weight at birth, resulting in a higher weight of weaned piglets but with the consequence of greater loss in body condition and a higher prevalence of shoulder lesions. Finally, this should be more pronounced in primiparous sows than in multiparous sows.

MATERIAL AND METHODS

The present experiment was conducted in accordance with the laws and regulations controlling experiments and procedures on live animals in Norway and was approved by the Norwegian Animal Research Authority, following the Norwegian Regulation on Animal Experimentation Act of 1996 (Nara, 2015).

Experimental Design

The sows were randomly chosen from 2 herds, one delivering Norsvin Duroc (**ND**) sows and the other producing both Norsvin Landrace (**NL**) and Norsvin Landrace × Swedish Yorkshire (**NL×Y**) sows. The selection criteria were that the sows should be healthy, with different parities, and that all sows within 1 batch should have similar dates for expected farrowing. The experiment took place at the Pig Research Unit at the Norwegian University of Life Sciences (Ås, Norway). During 3 farrowing batches, a total of 39 sows from 2 pure breeds—ND (a sire line) sows (n = 12) and NL (a dam line) sows (n = 12)—and a crossbreed—NL×Y sows (n = 15)—were evaluated for their physical condition, litter investment, and piglet mortality. Sows in breed groups (ND, NL, and NL×Y) had their first (n = 6, n = 6, and n = 9, respectively), second (n = 5, n = 0, and n = 1, respectively), third (n = 0, n = 4, and n = 0, respectively), fourth (n = 1, n = 0, and n = 3, respectively), fifth (n = 0, n = 1, and n = 2, respectively), and sixth litters (n = 0, n = 1, and n = 0, respectively).

Breed Description

The NL has been subjected to selection pressure for almost 60 yr. From 1959 and up to 1990, the breeding goal was mainly focused on production traits such as feed conversion ratio and litter size, whereas during the subsequent period (1990–2008), traits such as maternal, health, and meat quality were introduced. By 2012, the breeding goal included 25 traits, such as production (growth and feed efficiency), carcass quality, meat quality, reproduction, and robustness but with the main emphasis on litter size (total born and born alive) and indirect measures of maternal ability (piglet survival, litter weight at 21 d, total number of teats, and reduction in inverted teats). Production traits for rapid growth, larger litter size, and lower mortality of piglets represent 57% of overall weight in the selection index, whereas respective weight for shoulder lesion (**SL**) and BCS are 1 and 4% (Norsvin, 2012). In contrast, the terminal sire line ND is mainly subjected only to selection for traits such as growth, carcass quality, meat quality, and robustness (Norsvin, 2014). The Yorkshire breed from Sweden is used for crossing with NL to increase robustness, because the Yorkshire is not under such high selection pressure on production, litter size, and maternal traits as NL sows. Crossbred NL×Y sows are, therefore, likely to produce an intermediate level of maternal investment compared with NL and ND sows.

Housing, Management, and Feeding Strategy

Housing and management routines are described in detail in Ocepek et al. (2016) and included the standard feeding strategy used at the Norwegian University of Life Sciences (Animal Research Centre; Ås, Norway). Sows were moved to the farrowing unit 1 wk prior to the expected farrowing date of the first sow in each batch. From 3 d prior to parturition, the amount of feed was gradually decreased to 1 kg (9.9 MJ NE/kg and 8.3 g lysine/kg; Felleskjøpet, Oslo, Norway), automatically fed 2 times per day, with access to hay (approximately50 g) on a daily basis. After parturition, the amount of feed was subsequently adjusted according to voluntary feed intake, which was visually assessed by staff. In the case that less than 5% of the feed remained in the feeding trough, there was a gradual increase of feed (0.5 kg/d) until reaching maximum ad libitum feed consumption. If more than 10% of the provided feed remained in the feeding trough through 2 subsequent feeds, the provided amount of feed was decreased (0.5 kg) in the following days until reaching the situation where only 5% of the feed remained. Leftovers in the feeding trough were weighed and regularly removed, to ensure that the trough was empty. Within 1 d postpartum, oral iron (Pluss Jernstarter, 1.5 mL; Felleskjøpet) was individually given to each piglet, and subsequently, iron was given on a daily basis in peat (Pluss Smågristorv, 1 L per litter; Felleskjøpet). From 2 wk after parturition, piglets were given access to creep feed (Kvikk, 10.6 MJ NE/kg and 13.6 g lysine/kg; Felleskjøpet) from a piglet feeder.

Litter Investment – Litter Size and Weight

Farrowing was monitored, and all the live-born piglets (**LBP**) were counted and individually marked. Few piglets were cross-fostered and none of the fostered piglets died immediately after they were placed with the foster mother. The piglets were individually weighed on d 1 postpartum and at weaning (Day 35). The number of piglets in the litter was defined as number of the sow's own LBP plus the number of piglets fostered on minus the number of piglets fostered off. Litter weight at birth was defined as the litter weight of LBP at birth, and litter weight at weaning was defined as the weight of all weaned piglets in the litter. Total litter investment (**TLI**) was calculated as the litter weight at weaning plus the weight of stillborn and mummified piglets and the weight of piglets that died after farrowing but before weaning.

Postmortem Examination of Dead Piglets

All dead piglets were weighed, and a postmortem examination was performed at the Norwegian Veterinary Institute, Pathology Section (Oslo, Norway), to reveal causes such as prenatal mortality (mummified and stillborn), stillborn (based on whether the lung tissue would float in water), and postnatal mortality (piglets that died after the farrowing and before weaning).

Sow Assessment – Physical Condition

Sows were individually moved from the gestation unit to the farrowing unit. At that time, prefarrowing physical condition (body condition [**BC**], movement disorder [**MD**], and **SL**) of the sows were assessed.

The BC was scored according to a scale as used in the breeding goal, from 1 to 5 (1 = very thin, with hips and backbone very prominent without fat covering hips and backbone; 2 = thin; hip bones and backbone are easily felt without any pressure on the palms; 3 = normal–good; it takes firm palm pressure to feel the hip bones and backbone; 4 = fat; impossible to feel the bones at all, even when pressed with palm; and 5 = very fat; so fat that it is impossible to feel the hip bones and backbone even by pushing down with a single finger), and half scores in between were used (1.5, 2.5, 3.5, and 4.5), according to instruction given by Animalia (2014). To facilitate subsequent calculations, BCS were transformed into values from 1 to 9.

Movement disorders (difficulties during walking) were scored using a scale from 1 to 3 (1 = normal, without visible movement problems; 2 = marked MD; walks slowly or limps in a stiff way; and 3 = severe movement problems; can hardly get up from a lying position or walk; Andersen and Bøe, 1999).

Presence of SL was assessed using 5 categories (0 = healthy skin; no reddening or swelling; intact shoulder region; 1 = initial stage; mild lesions of the skin, including reddening or swelling or minor nonbleeding patches/wounds [diameter < 2 cm]; 2 = moderate skin lesions; the wound includes the entire skin thickness and causes bleeding; crusts are common [2–3 cm diameter] and the amount of granulation tissue is very moderate; 3 = serious lesions; these lesions include subcutaneous tissue but not bone; swelling around the wound and production of granulation tissue are common [3–5 cm diameter]; and 4 = very serious lesions; serious injury involving the scapula bone; the tissue around the lesion is thickened and often adherent to the underlying bone; granulation tissue is common; the wound has commonly a diameter of 5 cm or more; Animalia, 2014).

All physical traits were recorded again at weaning (BC, MD, and SL), when the sows were individually moved back to the gestation unit. Previous work has demonstrated a positive correlation between BC losses and BW losses during lactation (Thingnes et al., 2012). Therefore, in the present study, BC losses were calculated as BCS before farrowing minus BCS at weaning. Two sows that increased BC during lactation were defined as sows without losses. Shoulder lesion development was defined as SL score at weaning minus SL score before farrowing.

Statistical Analysis

Descriptive statistics were presented as least squares means and SE for normally distributed data, whereas data for litter size, physical condition traits, and causes of piglets' mortality were presented as arithmetic means and SE. Statistical analyses were performed in SAS 9.4 program (SAS Inst. Inc., Cary,

Table 1. Litter size (mean [SE]) in relation to breed and parity

	Breed[1]			Parity	
Production variable	NL	NL×Y	ND	Primiparous	Multiparous
Live-born piglets, no.	15.1 (1.1)[a]	14.5 (0.9)[a]	9.9 (1.2)[b]	12.1 (0.7)[a]	12.3 (1.2)[a]
Piglets in the litter after fostering, no.	14.6 (0.6)[a]	13.6 (0.5)[a]	9.2 (0.9)[b]	12.8 (0.6)[a]	12.2 (0.9)[a]
Weaned piglets, no.	12.7 (0.7)[a]	11.9 (0.7)[a]	7.6 (0.8)[b]	11.0 (0.7)[a]	10.6 (0.9)[a]

[a,b]Means with different superscripts are significantly different ($P < 0.05$).

[1]NL = Norsvin Landrace; NL×Y = Norsvin Landrace × Swedish Yorkshire; ND = Norsvin Duroc.

NC). If a statistically significant interaction was obtained, the significant differences between individual means were assessed by calculation of the LSD.

Differences in total feed consumption (during the lactation period) were analyzed using a GLM procedure including the fixed effects of breed (ND, NL, and NL×Y) and parity (primiparous sows [parity = 1] and multiparous sows [parity > 1]) as class variables. Point biserial correlation between total feed consumption and parity (primiparous sows [parity = 1] and multiparous sows [parity > 1]) confirmed a significant positive correlation ($r = 0.807$). Therefore, according to Graham (2003), feed consumption was regressed against parity. The residual values of feed consumption were computed, which eliminated the correlation ($r = -2.33 \times e^{-7}$). These were used as the predictor variable in the models of litter investment (litter weight at birth, litter weight at weaning, and TLI) and physical condition (BC losses, BC at weaning, and SL development and SL at weaning).

The variables of litter size (number of LBP, number of piglets in the litter, and number of weaned piglets) were analyzed using the GENMOD procedure (Poisson distribution) including the fixed effects of breed (ND, NL, and NL×Y) and parity (primiparous sows [parity = 1] and multiparous sows [parity > 1]) as class variables and the interaction between breed and parity.

Differences in litter weight at birth were analyzed using a GLM procedure including the fixed effects of breed (ND, NL, and NL×Y) and parity (primiparous sows [parity = 1] and multiparous sows [parity > 1]) as class variables and litter size (number of piglets in the litter) and residual feed consumption as continuous variables. The interaction between breed and parity and the interaction between breed and residual feed consumption were included in the model.

Other variables of litter weight investment (litter weight at weaning and TLI) were analyzed using a GLM procedure including the fixed effects of breed (ND, NL, and NL×Y) and parity (primiparous sows [parity = 1] and multiparous sows [parity > 1]) as class variables and litter size (number of piglets in the litter) and residual feed consumption as continuous variables. The interaction between breed and parity and the interaction between breed and residual feed consumption were included in the model.

The differences in sow BC assessed before farrowing were analyzed using a GENMOD procedure (multinomial distribution) including the fixed effects of breed (ND, NL, and NL×Y) and parity (primiparous sows [parity = 1] and multiparous sows [parity > 1]) as class variables and litter size (number of LBP) and total litter weight at birth as continuous variables. The interaction between breed and parity and the interaction between breed and total litter weight at birth were included in the model.

The differences in sow BC (BC losses and BC at weaning) were analyzed using a GENMOD procedure (multinomial distribution) including the fixed effects of breed (ND, NL, and NL×Y) and parity (primiparous sows [parity = 1] and multiparous sows [parity > 1]) as class variables and litter size (number of piglets in the litter), TLI, and residual feed consumption as continuous variables. The interaction between breed and parity, the interaction between breed and TLI, and the interaction between breed and residual feed consumption were included in the model.

The differences in SL scores (SL development and SL score at weaning) were analyzed using a GENMOD procedure (multinomial distribution) including the fixed effects of breed (ND, NL, and NL×Y) and parity (primiparous sows [parity = 1] and multiparous sows [parity > 1]) as class variables and litter size (number of piglets in the litter), TLI, residual feed consumption, SL before farrowing, and BC at weaning as continuous variables. The interaction between breed and parity, the interaction between breed and TLI, and the interaction between breed and residual feed consumption were included in the model.

The variables of mortality (prenatal, stillborn, and postnatal) were analyzed using the GENMOD procedure (Poisson distribution) including the fixed effects of breed (ND, NL, and NL×Y) and parity (primiparous sows [parity = 1] and multiparous sows [parity > 1]) as class variables, TLI as a continuous variable, and the interaction between breed and parity. In the model of postnatal mortality, additionally, SL development, BC losses, the interaction between breed and SL development, and the interaction between breed and BC losses

Table 2. Influence of fixed effects on litter investment

	Breed		Parity		Breed × parity		Litter size[1]		RFC[2]		Breed × RFC	
Production variable	$F_{2, 27}$	*P*-value	$F_{1, 27}$	*P*-value	$F_{2, 27}$	*P*-value	$F_{1, 27}$	*P*-value	$F_{1, 27}$	*P*-value	$F_{2, 27}$	*P*-value
Litter weight at birth, kg	7.5	0.003	5.1	0.032	3.4	0.050	44.3	<0.001	7.1	0.013	10.9	<0.001
Litter weight at weaning, kg	3.5	0.050	8.6	0.007	9.4	<0.001	30.3	<0.001	7.8	0.010	6.0	0.007
Total litter investment, kg	3.4	0.050	8.2	0.008	8.3	0.002	38.1	<0.001	7.8	0.010	4.9	0.016

[1]Litter size is the number of piglets in the litter.

[2]RFC = residual feed consumption.

were included. Statistical significance was accepted at $P \leq 0.05$, with a strong tendency noted at $P \leq 0.06$.

RESULTS

Feed Consumption

The NL breed had significantly higher total feed consumption than the ND breed (198.2 ± 10.7 vs. 165.8 ± 10.7 kg) but significantly lower total feed consumption than NL×Y crossbreeds (239.5 ± 9.9 kg; $F_{2, 34} = 12.9$, $P < 0.001$). Primiparous sows had lower total feed consumption than multiparous sows (159.2 ± 8.3 vs. 243.1 ± 9.9 kg; $F_{1, 34} = 48.5$, $P < 0.001$).

Litter Investment

Litter Size. The NL breed had higher number of LBP than the ND breed, without significant differences from NL×Y crossbreeds ($\chi^2_{2, 38} = 17.4$, $P < 0.001$; Table 1). There was no significant effect of parity on number of LBP ($\chi^2_{1, 38} = 0.2$, $P = 0.686$; Table 1). A significant interaction showed that primiparous sows had higher LBP in comparison with multiparous sows only in the ND breed ($\chi^2_{2, 38} = 7.6$, $P = 0.022$). The number of piglets in the litter as well as the number of weaned piglets was higher in the NL breed than in the ND breed, without any differences from the NL×Y breed ($\chi^2_{2, 38} = 18.0$, $P < 0.001$ and $\chi^2_{2, 38} = 18.7$, $P <$ 0.001, respectively; Table 1). There was no significant effect of parity or interaction between breed and parity on the number of piglets in the litter ($\chi^2_{1, 38} = 0.6$, $P =$ 0.440 and $\chi^2_{2, 38} = 2.8$, $P = 0.242$, respectively) or on the number of weaned piglets ($\chi^2_{1, 38} = 0.3$, $P = 0.607$ and $\chi^2_{2, 38} = 1.4$, $P = 0.486$, respectively).

Litter Weight. Norsvin Landrace sows had significantly higher litter investment (litter weight at birth, litter weight at weaning, and TLI) in comparison with the 2 other breeds (Tables 2 and 3). Primiparous sows had lower litter investment (litter weight at birth, litter weight at weaning, and TLI) than multiparous sows (Tables 2 and 3). In the NL breed, primiparous sows had significantly lower litter investment (litter weight at birth, litter weight at weaning, and TLI) than multiparous sows (Table 2; Fig. 1a–1c). Litter investment (litter weight at birth, litter weight at weaning, and TLI) increased with the number of piglets in the litter (Fig. 2) and with residual feed consumption (Table 2). There was a significant interaction between residual feed consumption and breed, showing a positive relationship between litter investment (litter weight at birth, litter weight at weaning, and TLI) and residual feed consumption, but only in the NL sows (Table 2).

Sow Physical Condition

Body Condition. The sow's BC before farrowing was not significantly associated with breed ($\chi^2_{2, 38} =$ 0.3, $P = 0.871$), parity ($\chi^2_{1, 38} = 0.1$, $P = 0.812$), number of LBP ($\chi^2_{1, 38} = 0.4$, $P = 0.658$), total litter weight at birth ($\chi^2_{1, 38} = 1.0$, $P = 0.321$), the interaction between breed and parity ($\chi^2_{2, 38} = 0.8$, $P = 0.658$), or the interaction between breed and total litter weight at birth ($\chi^2_{2, 38} = 0.2$, $P = 0.909$). Eight sows were thin, 26 of the sows were categorized as normal, and 5 of the sows were classified as fat, without any sow being

Table 3. Litter weight (least squares means [SE]) in relation to breed and parity

	Breed[1]			Parity	
Production variable	NL	NL×Y	ND	Primiparous	Multiparous
Litter weight at birth, kg	24.1 (1.0)[a]	19.4 (1.1)[b]	17.7 (1.3)[b]	19.1 (0.8)[a]	21.9 (1.0)[b]
Litter weight at weaning, kg	132.0 (6.1)[a]	123.0 (10.6)[b]	99.1 (9.3)[c]	106.4 (5.0)[a]	129.6 (7.1)[b]
Total litter investment,[2] kg	135.9 (5.6)[a]	125.6 (9.8)[b]	104.8 (8.6)[c]	111.7 (4.6)[a]	132.5 (6.5)[b]

[a–c]Means with different superscripts are significantly different ($P < 0.05$).

[1]NL = Norsvin Landrace; NL×Y = Norsvin Landrace × Swedish Yorkshire; ND = Norsvin Duroc.

[2]Total litter investment was calculated as litter weight at weaning plus weight of piglets born dead and weight of piglets that died after farrowing but before weaning.

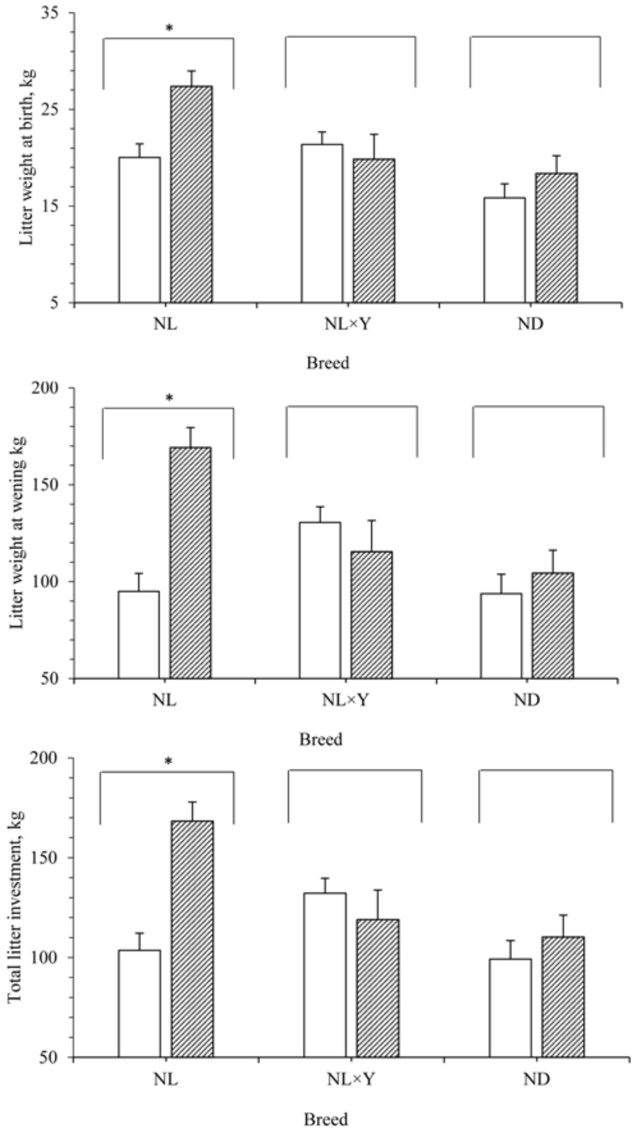

Figure 1. (a) Litter weight at birth in relation to the interaction between breed (Norsvin Landrace [NL], Norsvin Landrace × Swedish Yorkshire [NL×Y], and Norsvin Duroc [ND]) and parity (primiparous sows [□] and multiparous sows [▨]; $F_{2, 27} = 3.4$, $P < 0.050$). *$P < 0.05$. (b) Litter weight at weaning in relation to the interaction between breed (NL, NL×Y, and ND) and parity (primiparous sows [□] and multiparous sows [▨]; $F_{2, 27} = 9.4$, $P < 0.001$). *$P < 0.05$. (c) Total litter investment in relation to the interaction between breed (NL, NL×Y, and ND) and parity (primiparous sows [□] and multiparous sows [▨]; $F_{2, 27} = 8.3$, $P = 0.002$). *$P < 0.05$.

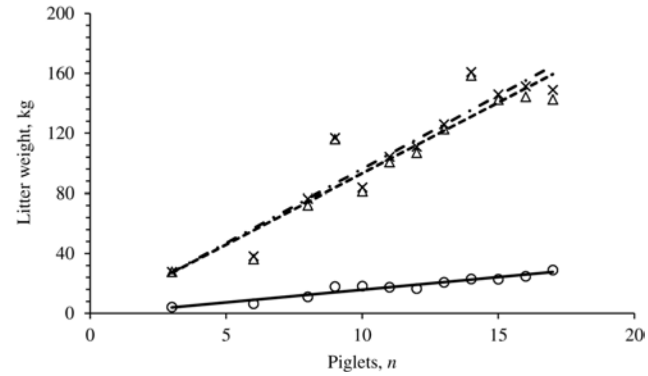

Figure 2. Relation between litter weight (litter weight at birth [○ —— ; $F_{1, 27} = 44.3$, $P < 663$ 0.001], litter weight at weaning (△- - -; $F_{1, 27} = 30.3$, $P < 0.001$], and total litter investment [× - · -; $F_{1, 27} = 38.1$, $P < 0.001$]) and number of piglets in the litter.

very thin or very fat. During lactation, sows showed an average BC loss of 1.7 ± 0.2 points. Losses in BC were significantly greater in NL sows than in NL×Y sows, whereas there was a strong tendency to also differ from the ND breed (Tables 4 and 5). Primiparous sows had higher BC losses than multiparous sows (Tables 4 and 5). Larger TLI resulted in higher BC losses of the sow (Table 5). Interaction between breed and TLI showed than in the NL sows, larger TLI resulted in higher BC losses ($P = 0.003$), whereas in the ND sows, there was a strong positive tendency between TLI and BC losses ($P = 0.052$), and there was no effect in NL×Y sows ($P = 0.086$; Table 5; Fig. 3). Sows with lower residual feed consumption had higher BC losses (Table 5). Norsvin Landrace sows had significantly lower BC score at weaning in comparison with the 2 other breeds (Tables 4 and 5). At weaning, primiparous sows had a lower BC score than multiparous sows (Tables 4 and 5).

Movement Disorders. Before farrowing, 36 sows had no MD (score 1), whereas 3 were slower and limping (score 2) and none of the sows had severe movement problems (score 3). At weaning, 35 sows did not have MD and only 4 of the sows were slower and limped.

Table 4. Physical condition (mean [SE]) in relation to breed and parity

	Breed[1]			Parity	
Physical condition	NL	NL×Y	ND	Primiparous	Multiparous
BC[2] before farrowing	4.9 (0.4)[a]	5.4 (0.2)[a]	5.7 (0.3)[a]	5.2 (0.2)[a]	5.4 (0.3)[a]
BC losses	−2.2 (0.3)[a]	−1.4 (0.4)[b]	−1.5 (0.4)[b]	−2.0 (0.2)[a]	−1.3 (0.4)[b]
BC at weaning	2.8 (0.2)[a]	3.9 (0.3)[b]	4.2 (0.3)[c]	3.2 (0.2)[a]	4.2 (0.3)[b]
SL[3] before farrowing	0.3 (0.1)	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	0.2 (0.1)
SL development	1.0 (0.3)[a]	0.7 (0.2)[b]	0.3 (0.2)[b]	0.9 (0.2)[a]	0.4 (0.1)[b]
SL at weaning	1.3 (0.3)[a]	0.9 (0.2)[b]	0.3 (0.2)[b]	1.0 (0.2)[a]	06. (0.2)[b]

[a–c]Means with different superscripts are significantly different ($P < 0.05$).

[1]NL = Norsvin Landrace; NL×Y = Norsvin Landrace × Swedish Yorkshire; ND = Norsvin Duroc.

[2]BC = body condition (1–9 scoring scale).

[3]SL = shoulder lesions (0–4 scoring scale).

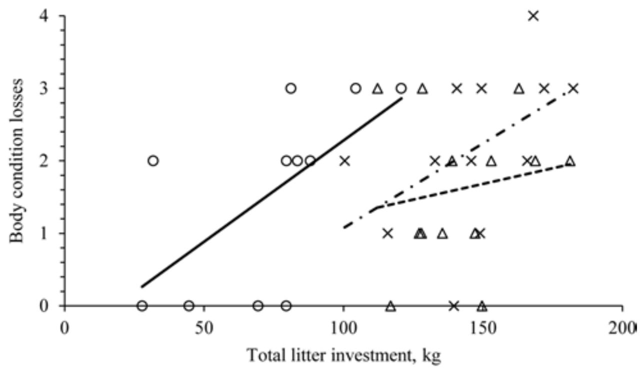

Figure 3. Body condition losses in relation to the interaction between total litter investment and breed (Norsvin Duroc [○ ——], Norsvin Landrace [× - · -], and Norsvin Landrace × Swedish Yorkshire [△- - -]; $\chi^2_{2,\,38} = 8.7$, $P = 0.013$).

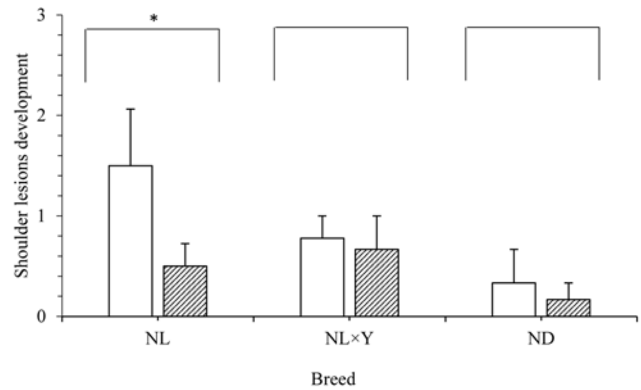

Figure 4. Shoulder lesion development in relation to the interaction between breed (Norsvin Landrace [NL], Norsvin Landrace × Swedish Yorkshire [NL×Y], and Norsvin Duroc [ND]) and parity (primiparous sows [□] and multiparous sows [▨]; $\chi^2_{2,\,38} = 13.5$, $P < 0.001$). $^*P < 0.05$.

Therefore, for MD, there was not enough variation in the data to conduct any meaningful statistical analysis.

Shoulder Lesions. Before farrowing, 33 of the sows had healthy skin without SL, and the remaining 6 sows were classified with initial shoulder injuries. There was not enough variation in the data to conduct any statistical analysis on SL before farrowing. Because SL development and SL at weaning are highly correlated ($r = 0.981$) and provide similar results, and the fact that SL development was not affected by SL before farrowing ($\chi^2_{1,\,38} = 0.0$, $P = 0.876$) whereas there was a positive relationship between SL before farrowing and SL at weaning ($\chi^2_{1,\,38} = 6.8$, $P = 0.009$), only SL development was used in further analyses. During lactation, sows developed SL with an average increase in score of 0.7 ± 0.1. Norsvin Landrace sows had significantly higher SL development than the other 2 breeds (Tables 4 and 5). There was greater SL development in primiparous sows than in multiparous sows (Tables 4 and 5). A significant interaction between breed and parity showed that NL primiparous sows had significantly higher SL development than NL multiparous sows, whereas this was not the case for the ND and the NL×Y breeds (Table 5; Fig. 4). Larger TLI resulted in higher development of SL (Table 5). Interaction between breed and TLI showed that in the NL sows, the higher the TLI, the higher the SL development ($P = 0.003$), whereas in the NL×Y sows, there was a strong tendency ($P = 0.058$), and there was no effect in the ND sows ($P = 0.186$; Table 5; Fig. 5). Sows with lower residual feed consumption were the ones with greater development of SL (Table 5). Interaction between breed and residual feed consumption showed that lower residual feed consumption significantly influenced development of SL in NL sows ($P = 0.013$; Table 5), but this was not the case in the NL×Y sows ($P = 0.757$) or the ND sows ($P = 0.268$). Shoulder lesion development was not affected by BC at weaning ($\chi^2_{1,\,38} = 1.8$, $P = 0.175$).

Piglet Mortality

Prenatal Mortality. Mean prenatal mortality was 7.9 ± 1.6%. Crossbred NL×Y sows had significantly lower stillborn and prenatal mortality than the other 2 breeds (Tables 6 and 7). There was no significant difference between parities in stillborn and in prenatal mortality (Tables 6 and 7). With increasing TLI, the proportion of prenatal mortality significantly decreased;

Table 5. Influence of fixed effects on sow physical condition

Physical condition	Breed		Parity		Breed × parity		Litter size[1]		TLI[2]		Breed × TLI		RFC[3]		Breed × RFC	
	$\chi^2_{2,\,38}$	*P*-value	$\chi^2_{1,\,38}$	*P*-value	$\chi^2_{2,\,38}$	*P*-value	$\chi^2_{1,\,38}$	*P*-value	$\chi^2_{1,\,38}$	*P*-value	$\chi^2_{2,\,38}$	*P*-value	$\chi^2_{1,\,38}$	*P*-value	$\chi^2_{2,\,38}$	*P*-value
BC[4] losses	8.3	0.016	6.3	0.012	4.0	ns[5]	0.0	ns	7.5	0.006	8.7	0.013	6.6	0.010	0.6	ns
BC at weaning	2.0	ns	5.0	0.026	1.5	ns	3.2	ns	0.1	ns	1.7	ns	0.0	ns	0.9	ns
SL[6] development	9.7	0.008	13.2	<0.001	13.5	<0.001	3.2	ns	17.1	<0.001	11.2	0.004	10.1	0.002	10.2	0.006
SL at weaning	8.6	0.014	11.4	<0.001	13.1	<0.001	1.0	ns	14.6	<0.001	10.2	0.006	8.1	0.005	8.3	0.016

[1]Litter size = number of piglets in the litter.

[2]TLI = total litter investment.

[3]RFC = residual feed consumption.

[4]BC = body condition (1–9 scoring scale).

[5]ns = not significant.

[6]SL = shoulder lesions (0–4 scoring scale).

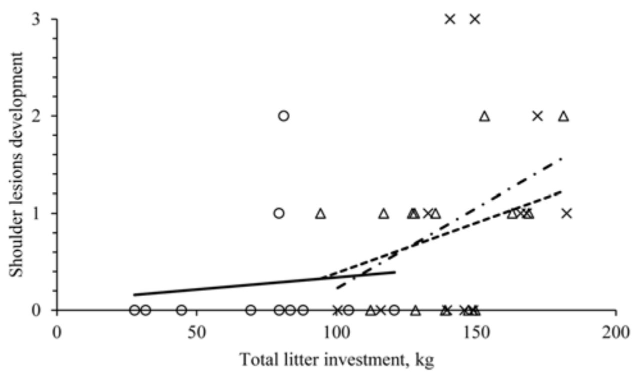

Figure 5. Shoulder lesion development in relation to the interaction between total litter investment and breed (Norsvin Duroc [○ ——], Norsvin Landrace [× - · -], and Norsvin Landrace × Swedish Yorkshire [△- - -]; $\chi^2_{2, 38} = 17.1$, $P = 0.004$).

likewise, with increasing TLI, the proportion of stillborn piglets significantly decreased (Table 7; Fig. 6).

Postnatal Mortality. Mean postnatal mortality was 13.4 ± 2.3%. Norsvin Duroc sows, in comparison with the 2 other breeds, had significantly higher postnatal mortality (Tables 6 and 7). Primiparous sows had higher postnatal mortality in comparison with multiparous sows (Tables 6 and 7). A significant interaction between breed and parity showed that primiparous sows had higher postnatal mortality in comparison with multiparous sows only in the NL and the ND breeds (Table 7; Fig. 7). A negative relationship was found between postnatal mortality and SL development ($\chi^2_{1, 38}$ = 40.3, $P < 0.001$). There was a significant breed × SL development interaction ($\chi^2_{2, 38}$ = 40.3, $P < 0.001$), in that the relationship between postnatal mortality and SL development was present only for NL ($P < 0.001$) and ND sows ($P < 0.001$) but not for the NL×Y sows (P = 0.166). Higher BC losses were associated with lower postnatal mortality ($\chi^2_{1, 38}$ = 63.6, $P < 0.001$), without significant breed × BC loss interaction ($\chi^2_{2, 38}$ = 5.1, $P = 0.077$). There was a negative relationship between postnatal mortality and TLI (Table 7; Fig. 6).

DISCUSION

As predicted, the maternal purebred line (NL) had higher litter investment in terms of litter weight at birth and litter weight at weaning as well as higher weight of dead piglets (stillborn and mummified piglets and weight of piglets that died after farrowing but before weaning) than the other 2 breeds. Even though the NL sows had increased feed intake per kilogram litter investment, they suffered larger losses of BC and had a higher prevalence of SL during lactation than the other breeds, as predicted. Shoulder lesions in lactating sows have become one of the main challenges for highly productive (i.e., high milk producing) sows producing large litters (Lundeheim et al., 2014; Fredriksen et al., 2015). More than 50% of the sows with SL are the ones with poor BC (Fredriksen et al., 2015) and the 2 traits are moderately genetically correlated at weaning (Lundgren et al., 2012). Moreover, the present study documented that sows with lower feed consumption are at higher risk of developing SL and suffer greater BC losses during lactation. Improving feed consumption during lactation, to improve sow physical condition, may be just as important as to select for BC and reduced SL per se, because feed consumption is a prerequisite for maintenance of BC and to avoid development of SL. Because voluntary feed consumption is a heritable trait (Gilbert et al., 2012; Bergsma et al., 2013), it might be possible to introduce this trait in sows as a new selection criterion in the breeding goal, to compensate for the large losses that sows suffer during lactation.

This study showed that crossbred sows lost less BC and developed less severe SL compared with the purebred NL line. Besides the fact that crossbred sows invest less in their litter than the purebred maternal line, as predicted, they have greater feed consumption ability. Our results showed that crossing breeds is likely to improve feed consumption and thus physical condition. However, as long as production traits for rapid growth, larger litter size, and mortality of piglets exceeded 50% weighting in the selection index in the pure maternal line and noneconomic traits such as SL and BC at weaning constitute 5% of the selection index (Norsvin, 2012), the welfare of the highly productive sows will not improve. In fact, the present results showed that all attempts made to improve physical condition in the NL line, such as implementing new traits (BCS at weaning and SL status) into the breeding goal as well as improving fat to protein ratio in lactation diet, were only short-term solutions without any actual effect. More importantly, our data indicate that NL sows continue to lose more and

Table 6. Causes of piglet mortality (mean [SE]) in relation to breed and parity

	Breed[1]			Parity	
Mortality	NL	NL×Y	ND	Primiparous	Multiparous
Prenatal mortality (% of total born)	8.5 (2.0)[a]	5.7 (2.2)[b]	10.0 (3.9)[a]	7.0 (1.8)[a]	9.0 (2.7)[a]
Stillborn, %	8.0 (1.8)[a]	4.7 (1.9)[b]	10.0 (3.9)[a]	7.0 (1.8)[a]	7.7 (2.6)[a]
Postnatal mortality (% of live born)	12.3 (4.2)[a]	12.3 (3.6)[a]	15.9 (4.7)[b]	14.3 (3.5)[a]	12.3 (3.2)[b]

[a,b]Means with different superscripts are significantly different ($P < 0.05$).

[1]NL = Norsvin Landrace; NL×Y = Norsvin Landrace × Swedish Yorkshire; ND = Norsvin Duroc.

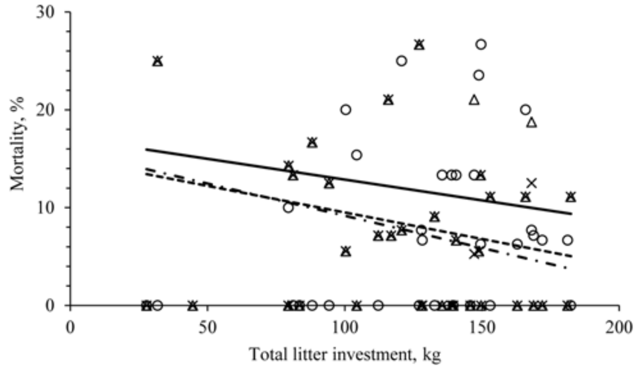

Figure 6. Relation between mortality (prenatal mortality [△- - -; $\chi^2_{1,38} = 6.9$, $P < 0.009$], stillborn [×- · -; $\chi^2_{1,38} = 11.2$, $P = 0.001$], and postnatal mortality [○——; $\chi^2_{1,38} = 25.0$, $P < 0.001$]) and total litter investment.

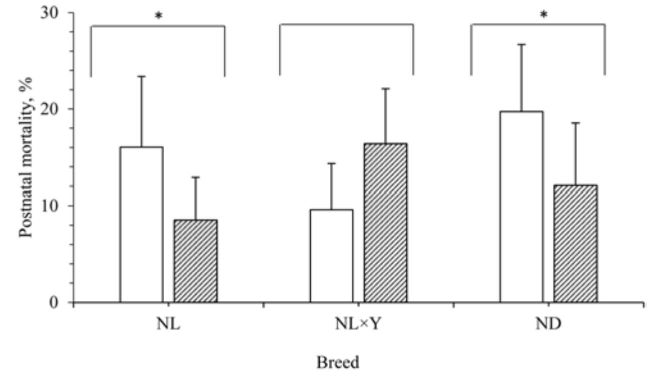

Figure 7. Postnatal mortality in relation to the interaction between breed (Norsvin Landrace [NL], Norsvin Landrace × Swedish Yorkshire [NL×Y], and Norsvin Duroc [ND]) and parity (primiparous sows [□] and multiparous sows [▨]; $\chi^2_{2,38} = 37.4$, $P < 0.001$). *$P < 0.05$.

more BC during lactation and become even more susceptible to SL. As Bergsma (2011) already predicted, the lack of emphasis on sows' physical condition has resulted in large BW loses during lactation, and shoulder ulceration has become a welfare concern. Compared with the nonselected (for maternal traits) paternal Duroc line, our data showed that the NL line had 30% more LBP and weaned around 40% more piglets while having 30% lower postnatal mortality. Given the fact that the NL maternal line is already highly productive, improvement of their physical condition is of great importance. One approach would be to balance the breeding goal by increasing weights on sows' physical condition traits (BCS and SL status) while decreasing weights on litter investment traits. The future breeding goal should, therefore, become even broader; new traits such as improved voluntary feed intake, or feed efficiency, or even increased milk yield during lactation, etc., could easily be implemented (Bergsma, 2011). However, this would most likely increase selection costs and some traits might even cause negative side effects. The question is whether we want to select for a super sow or for a robust sow, which is a high-efficiency sow at low cost for the farmer. How, then, can we define a robust sow? In our view, a robust sow is a sow that distributes her resources over several parities; for instance, one that gives birth to 12 piglets of similar weight and weans 12 heavier piglets in 5 consecutive parities while maintaining normal BC and without developing SL or leg problems. This sow not only has better welfare but she also demands less management effort from the farmer, thereby improving the total economic output.

Contrary to our prediction, primiparous and multiparous sows had similar litter sizes and primiparous sows had higher postnatal mortality than multiparous sows. In old studies, it was reported that litter size increased until the sow fulfilled her fifth parity (Dagorn and Aumaitre, 1979; Kroes and Van Male, 1979). Due to more efficient selection and better gilt management over recent decades, modern sows are giving birth to larger litters in their first parity. Therefore, given also the routine practice of cross-fostering to standardize initial litter size, it is no surprise that there is hardly any variation in number of weaned piglets between sows of different parities from Norwegian commercial herds (Norsvin, 2014). Higher maternal investment in early litters may lead to a substantial drop in maternal investment in later litters, and therefore, longevity of the sows may be compromised (Andersen et al., 2011).

As predicted and in accordance with previous studies, primiparous sows suffered greater losses in BC due to lower feed consumption during lactation, even though the litter weight was lower than that of multiparous sows (Stalder et al., 2004; Schenkel et al., 2010; Thingnes et al., 2012). In the first reproductive cycle, sows are still showing substantial maternal growth (McGlone et al., 2004; Moustsen et al., 2011) and at this stage, they are not capable of consuming enough feed to fulfill the energy requirements needed during lactation (Thingnes

Table 7. Influence of fixed effects on causes of piglet mortality

	Breed		Parity		Breed × parity		TLI[1]	
Mortality	$\chi^2_{2,38}$	*P*-value	$\chi^2_{1,38}$	*P*-value	$\chi^2_{2,38}$	*P*-value	$\chi^2_{1,38}$	*P*-value
Prenatal mortality	6.5	0.039	1.2	ns[2]	1.0	ns	7.4	0.007
Stillborn	12.5	0.002	0.5	ns	4.8	ns	10.4	0.001
Postnatal mortality	15.6	<0.001	22.5	<0.001	37.4	<0.001	25.0	<0.001

[1]TLI = total litter investment.

[2]ns = not significant.

et al., 2012), which may affect their physical condition. A sow's physical condition at weaning is important for her future reproductive ability. Sows with poor BC may have estrus problems, with longer weaning-to-services intervals, and this has become the main reason for culling young sows (Rauw, 2009; Prunier et al., 2010). More than 40% of primiparous sows may be culled due to reproduction problems (Engblom et al., 2007), and a more recent study documented that 30% of the sows were already replaced before or after the first litter is weaned (Thingnes et al., 2015). This implies great replacement costs for the farmer and a sow welfare concern.

As predicted, primiparous sows developed more SL than sows of higher parity. Because primiparous sows were not capable of consuming enough feed to cover litter investment and suffered greater losses of BC, it is not surprising that primiparous sows were more susceptible to SL development in our study. Previously, it has been discussed that multiparous sows were more susceptible to SL at weaning than primiparous sows, as shoulder ulcers can relapse during subsequent lactations (e.g., Herskin et al., 2010; Lundgren et al., 2012). However, our results show that primiparous sows suffered greater SL development than multiparous sows only in the NL breed and not the other breeds. This has become of great concern, because the breeding program of the maternal NL line is, in fact, promoting SL development from early on. Even if the superficial lesions diminish between litters, the tissue underneath can still be damaged. This pinpoints the importance of improving physical condition in young sows and thus longevity.

In nature, sows have an opportunity to balance between reproductive resource invested in present and future litters as well as between number and fitness of offspring (Lessells, 1991). Modern selection programs have shifted the balance toward greater investments earlier in life, when sows still need resources for their own growth and development. This has resulted in a larger number of weaned piglets but at a higher welfare cost in terms of higher losses in BC and high prevalence of painful SL (e.g., Herskin et al., 2010).

Conclusions

The highly productive dam line Norsvin Landrace had a higher litter investment and suffered greatest losses in body condition and developed more shoulder lesions. This is a major welfare cost of modern pig breeding. Primiparous sows were more exposed to these problems than multiparous sows. Our results pinpoint the importance of improving the balance between economic traits and traits that improve welfare and longevity of the sows.

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