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The influence of feed delivery and feeding patterns during gestation on reproductive outcomes for sows

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Summary

Mid-parent breeding values and outcomes from 6126 mating (4998 farrowing) events and accompanying feed-related traits, derived from feeding events recorded during gestation, were used to investigate the associations between these factors with reproductive outcomes for commercial sows. Variability in genetic merit for piglet birth weight had undesirable consequences for premature sow removal (REM35). Sows in the highest quintile for missed feeding events (> 24 hours between meals) recorded over 90 days had both lower farrowing rate (97.2% vs 97.9 - 99.2%) and increased REM35 (12% vs 7 - 9.5%) compared to the rest. Results from the present study demonstrated that when feeding during gestation did not accommodate variation in litter size and body weight amongst sows, performance of the "average" sow with respect to litter size was favoured. While heritability of intake under restricted feed delivery was zero, variability in litter size alone created heritable variation (h^2 ~ 0.05) in actual feed requirement, and therefore the deviation in actual intake from requirement. Reproductive outcomes for commercial sows, and the retention of genetically superior sows for reproductive traits, might be better optimised if gestational feeding was better adapted to sow phenotypes.

Keywords: heritability, nutritional requirements, out-of-feed events, culling

Introduction

In commercial pig production, diets and feeding levels for gestating sows are typically based on requirements of the parity "average" sow, using assumed parameters for maintenance and maternal gain during gestation, along with expected litter size and piglet/conceptus weight. However, variation amongst sows occurs in nutritional requirements due to variation around these average values, due to both genetic and environmental effects. Feeding levels during gestation are also relatively restrictive, when compared to feed intakes observed in gestating sows allowed *ad-libitum* access to feed (van Barneveld *et al.* 2007). Therefore, sows cannot moderate their own intake upwards, even if required. Both over- and under-feeding of sows can contribute to poor outcomes in the farrowing house at the end of gestation (Kim 2010), but there are few reports of the full impact in a wider window around the farrowing period. Sows must have their nutritional needs during gestation met by diet, or their own body reserves, and/or the requirements of the developing litter, could become compromised. Changes in sow body composition and sow weight gain associated with litter size were previously illustrated by Bunter *et al.* (2010). We hypothesised that genetic variation amongst commercial sows combined with fixed feeding curves during gestation may have unintended consequences for sow performance, resulting in culling related to genetic merit combined with sub-optimal feeding level. In addition, we investigated whether feeding behaviours observed during gestation had any impact on outcomes.

Material and methods

Data

Data were obtained for all feeding events recorded at a single site, which housed large dynamic groups of commercial (predominantly F1) sows during gestation. Sows were fed with electronic sow feeders (ESFs: manufactured by Rivalea Australia Pty Ltd), capable of delivering individually specified feeding levels for group sizes of up to 300 sows. Two feed delivery curves were applied throughout gestation without seasonal adjustment. Gilts received allocations of 2.4 kg/day for days 1-35 of gestation, 2.0 kg/day for days 36-90 and 2.2 kg/day above 90 days of gestation; sows received corresponding allocations of 2.7, 2.2 and 2.4 kg/day. A small proportion of sows were allocated higher levels, based on body condition.

Groups of ~ 250 sows of variable parity and gestational age were initially constructed over a one week period in January 2015. Subsequently, new sows were introduced to gestation groups after mating. All sows had received prior training with ESFs and were conditioned to using the feeders. Daily feed allocations for individual sows were activated for each 24 hour period at midday every day. Each feeding event per sow was subsequently recorded to date, time of entry and exit from the feeder, diet (A vs B), and volume of feed delivered (kg). Sow visits to feeders which did not result in feed delivery were not recorded. Individual feeding event records (N > 1 million) were collapsed to become daily records per sow (N ~ 500K events), combining separate events recorded within a day. Days without a feeding event, spanned by adjacent days of intake (N = 21522), were allocated a zero feed delivery record.

Subsequently, daily event data were used to calculate a range of variables relating to feed intake and feeding behaviours recorded over N = 6126 mating events with outcomes known. These traits included averages of feed intake (ADI, kg/day), time spent in the feeder (AFT, minutes/day), the average number of feeding events per day (AFE) and the rate of feed consumption (AFR, g/minute), for sows with 90+ days recorded within a parity (N = 3926 records). An interval of 90 days allowed for multiple mating events and/or recording over the majority of the gestation period. In addition, the cumulative number of missed (MISS) or low intake (LOW, < 1 kg/day) feeding events per day was obtained for individual sows.

The required daily intake (RDI, kg/day) was calculated for sow i in parity j by accumulating MJ DE per day required to maintain assumed parity averages for weight at mating (WT_j) and the targeted maternal gain (MG_j), and obtain the expected average piglet birth weights (BWT_j) for (TB_{ij}) recorded at farrowing (equation 1), for a diet averaging 13.5 MJ DE/kg. The difference between actual and required intake (defined generally as AFI-RDI) was considered as an additional trait (DEVR).

$$RDI_{ij} = ((WT_j\text{^}0.75 \times 0.455) + MG_j + (TB_{ij} \times BWT_{ij}))/13.5 \qquad \text{for sow } i \text{ in parity } j \quad (1)$$

Mid-parent averages of breeding values, estimated based on purebred data, were available for 91.7% of the commercial sows for the traits: average daily gain (mpADG), back fat (mpBF), along with number born alive (mpNBA) and piglet birth weight (mpBW1, mpBW2) in the first and later parities.

The outcomes from each mating event were known for 3785 sows. Sows with unknown outcomes included sows with lost identity, which can be a significant problem in large dynamic groups. Sows were firstly identified as farrowed or not (FARR) from each mating event. Returns to service and negative pregnancy test combined with "not in pig" were the primary alternative outcomes. Other unsatisfactory outcomes included: 1) FFAIL: farrowing failure (abortion, NBA<=5, farrowing difficulty, excessive still births or mummies), 2) LFAIL: lactation failure (lactation length<14 days or number weaned <6), 3) DD: death (including destruction) and 4) REM35: premature culling, within 35 days of farrowing, or removed between days 100 and 120 days post-mating.

Analyses

The significance of mid-parent breeding values for production and reproductive traits on outcomes for FARR, FFAIL, LFAIL, DD and REM35 was evaluated using PROC GLIMMIX (SAS Institute, Cary NC). Each breeding value was fitted separately as a linear regression within models which accounted for mating year-month (MYM: 16 levels) and sow parity group (4 levels). The significance of feed-related traits on outcomes for sows was evaluated by fitting terms for MYM, sow age group (gilt vs sow), quintile ranking for the feed-related trait of interest (defined separately within gilt and sow groups) and their interaction terms, when significant at $P<0.05$. Sows with less than 90 days of feed intake data recorded were allocated to a "6th quintile". Sow was fitted as a random effect in the model to accommodate observations from multiple mating events per sow.

Sows were progeny of 267 sires and 2403 dams, and the pedigree was extended back by 4 generations for parameter estimation. Estimates of heritability were obtained for all traits using models which accounted for mating year-month (16 levels), parity group (4 levels), diet (2 levels) and shed-pen (12 levels), where significant ($P<0.05$). Sow identity and sow permanent environmental effects were fitted to accommodate repeated records. All parameter estimates were obtained under an animal model using ASREML (Gilmour *et al.* 2009).

Results and Discussion

In total, 3785 sows had 6126 mating events with known outcomes, including 4998 farrowing events (81.6% of records). Sows which did not have a farrowing outcome from a mating event were re-mated (creating a new mating event), culled or dead. FFAIL was established using 5403 records, because FFAIL included sows with pregnancy loss, due to abortion or not-in-pig sows. Outcomes for LFAIL were confined to sows with a farrowing date, while REM35 also included sows which were removed from the herd between 90-150 days post-mating, or within 35 days of farrowing. These outcomes either represent forced removals or variables contributing to culling decisions for individual sows.

Data characteristics and heritability estimates

Consistent with results presented by Vargovic *et al.* (2018), who used the same resource data, AFI had negligible heritability, while AFT, AFR and MISS recorded over 90 days had moderate to high heritabilities (Table 1). Therefore, sows can express heritable feeding behaviours under restricted feeding, when time limits are not imposed at feeding. In contrast to zero heritability for AFI, both the estimated daily feed requirement (RFI) and DEVR were lowly heritable traits (Table 1). This demonstrates that genetic variation which alters performance levels creates heritable phenotypes for nutritional requirements, and therefore heritable variation in whether sows will be over-or under-supplied with feed during gestation under fixed feeding curves. The magnitude of this heritability could represent, more generally, the nutritional limitation to optimising performance of all sows. This estimate might be conservative, given that other heritable traits also alter nutritional requirements. The heritability of an outcome from a single mating event was negligible, whereas significant sow effects (genetic or non-genetic) were present for sow removals, and to a lesser extent farrowing or lactation failures. With few records per sow and a single generation of data, partitioning between genetic and non-genetic effects was relatively inaccurate.

Table 1. Raw data characteristics (N, Mean(SD)), along with estimates of heritability (h^2±se), permanent environmental effects (pe^2±se) and phenotypic variance (σ^2_p)

Trait (units)		N	Mean (SD)	h^2	pe^2	σ^2_p
Feeding events (N/day)	AFE	3926	1.17 (0.105)	0.06±0.02	0.25±0.04	0.012
Intake (kg/day)	AFI	3926	2.27 (0.124)	0.01±0.01	0.14±0.03	0.002
Time eating (mins/day)	AFT	3926	14.8 (3.75)	0.33±0.05	0.37±0.05	13.1
Rate of intake (g/min)	AFR	3926	163 (4136)	0.41±0.06	0.28±0.05	1401
Missed days (N)	MISS	3926	4.38 (3.61)	0.17±0.04	0.21±0.04	11.5
Required FI (kg/day)	RFI	3676	2.47 (0.238)	0.04±0.02	0.05±0.04	0.006
AFI-RFI	DEVR[1]	3676	0.0 (0.117)	0.06±0.03	0.08±0.04	0.002
Total born (pigs/litter)	TB	4997	12.4 (2.81)	0.17±0.03	0.08±0.03	7.40
Farrowed (or not)	FARR[3]	6126	81.6 (38.8)	0.01±0.01	B[2]	1381
Farrowing failure	FFAIL[3]	5403	4.71 (21.4)	0.01±0.01	0.05±0.03	443
Lactation failure	LFAIL[3]	4998	10.1 (30.1)	0.00±0.01	0.04±0.02	890
Removals	REM35[3]	5785	9.68 (29.6)	0.04±0.02	0.28±0.03	819

[1]centred around 0; [2]B: boundary estimate; [3]×100

Influence of breeding values on sow reproductive outcomes

Mid-parent breeding values of commercial gilts were variable for growth (SD: 16.1 g/day), litter size traits (SD: 0.45-0.54 pigs/litter), back fat (SD: 0.40mm) and piglet birth weight (SD: 59g) traits (not shown). Using linear regression, mpNBA predicted daughter litter sizes with regression coefficients >0.70 across parity groups and a model R^2 of 8-10%, demonstrating that EBVs for litter size based on purebred performance were predictive (with low accuracy, as expected) of realised litter size for F1 sows in a commercial setting. With respect to outcomes for sows, mpBF approached significance ($P=0.07$) for FARR, as higher mpBF significantly ($P<0.0001$) reduced returns, which increases farrowing rate. Positive associations between fatness and farrowing outcomes have been observed previously (Bunter *et al.* 2010; Farmer *et al.* 2017). Sows with higher mpBWT1 or mpBWT2 had significantly ($P=0.01$) decreased LFAIL, but sows with higher mpBWT1 were also more likely ($P=0.04$) to be removed prematurely around the farrowing event (REM35). A high birthweight EBV (adjusted for litter size) is consistent with a sow partitioning more resources towards piglet development, potentially to their own detriment with respect to fatness and longevity (Bunter *et al.* 2010). These results demonstrated that genetic variability present in F1 sow populations contributed to phenotypic variability, while unidentified variation amongst individual sows in genetic merit for specific traits was also associated with outcomes (both beneficial and detrimental) for sow performance.

The impact of feed-related traits on sow reproductive outcomes

Least squares means for FARR, FFAIL, LFAIL and REM35 by quintile are shown in Table 2 for effects which were significantly ($P<0.05$) associated with these outcomes. Increasing quintile rank reflects increasing value of the explanatory variables. There were no factors identified which were significantly associated with sow deaths, which occurred at a low frequency per mating event.

Since records reflected outcomes for each mating event, sows not recorded for 90 days or more had low farrowing rates (ie culled due to returns, etc) and also elevated rates of FFAIL (abortions included) and REM35, as expected. In addition, for sows with the majority of their gestational intake recorded, as MISS increased from quintiles 1 to 5, FARR declined from 99.2 to 97.2%, REM35 increased from 7.0 to 12.0%, and there was a gradual increase ($P>0.05$) in FFAIL. Sows in quintile 5 had 10 periods, on average, of > 24 hours between feeding events, although many consumed close to their feed allocation. MISS is equivalent to out-of-feed events, which has detrimental effects for growth and is a known contributor to ulcers in growing pigs (Brumm *et al.* 2005). As sows ate more of their feed allocation (higher AFI), FARR tended to increase but FFAIL and REM35 did not differ. Sows spending the most time eating (high AFT), with a lower rate of feed consumption (AFR) and a tendency towards more feeding events per day (AFE), had lower FFAIL. Therefore, even under restricted feeding levels during gestation, the pattern of feed intake was associated with outcomes.

When expressing feed intake as a deviation from feed requirement (based on parity and litter size only), quintile 1 represented underfed sows and quintile 5 represented sows overfed, relative to litter size only and assumed average body weights by parity. For comparison, results for TB itself are presented. Quintile 1 for TB (<9-10 pigs per litter) had the highest FFAIL, LFAIL and REM35 relative to larger litters. The corresponding pattern for DEVR was consistent with the impact of TB for FFAIL and LFAIL, but demonstrated that both over and under-fed gilts had increased REM35. Overfed gilts and sows (quintile 5) had significantly higher FFAIL, but both over- and under-fed sows had higher rates of REM35. Sows least likely to be removed were those closest to average litter size for their parity.

We hypothesised that sows whose nutritional requirements were not met during gestation could have undesirable outcomes as a consequence. Other species can adapt their intakes (eg through increased time spent grazing) or are fed more (eg better pasture or supplementary feed for twinning ewes) to better meet their nutritional requirements based on output. This will not occur when combining fixed feed delivery with variable but unknown animal phenotypes. In general, low accuracy of predicting individual phenotypes (eg for litter size or body weight) from breeding values hinders the ability to address this issue during gestation for commercial sows. However, knowledge of individual sow weights and gestating litter size could assist in the development of more suitable feeding schedules for higher risk sows. Evidence for missed feeding events during gestation will also assist in predicting at risk sows. These steps could lead to better retention of sows with superior litter size potential.

Conclusions

Results from this study imply that variation in both genetic potential and phenotypes, combined with feed delivery and feeding patterns during gestation, contributes to unintended detrimental outcomes for commercial sows. This suggests that genetic improvement distributed to commercial herds might not be fully exploited, due to premature removal of sows with higher nutritional requirements. More research is required to optimise outcomes for commercial sows.

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Table 2. Least squares means for quintile group of significant (P<0.05) explanatory variables[1] for a successful farrowing outcome (FARR), a farrowing (FFAIL) or lactation (LFAIL) failure[2], or premature removal (REM35) around the farrowing event[2] for gilts (G) and sows (S)

			Quintile (defined separately within gilt and sow group)					Variable not recorded
Trait	Variable[1]	Age	1	2	3	4	5	
FARR	AFI	GS	97.1±0.7^{a}	98.3±0.3^{ab}	98.6±0.2^{b}	98.8±0.2^{b}	98.1±0.3^{a}	32.4±1.9^{c}
(N=6126)	MISS	GS	99.2±0.2^{a}	98.6±0.2^{ab}	98.3±0.3^{b}	97.9±0.3^{b}	97.2±0.2^{c}	32.4±1.9^{d}
FFAIL	TB	GS	18.6±1.7^{a}	1.6±0.4^{b}	1.8±0.5^{b}	1.1±0.4^{b}	2.5±0.6^{b}	29.1±2.9^{c}
(N=5403)	AFI	GS	3.6±0.7^{a}	4.1±0.8^{a}	1.7±0.5^{a}	3.2±0.7^{a}	3.3±0.7^{a}	12.7±1.3^{b}
	AFT	G	5.0±1.3^{a}	2.8±0.9^{ab}	3.5±1.0^{ab}	4.8±1.2^{a}	1.8±0.7^{b}	10.8±1.6^{c}
	AFT	S	2.9±0.8^{a}	4.2±1.0^{a}	3.0±0.9^{a}	1.9±0.7^{c}	1.9±0.6^{c}	14.6±1.8^{b}
	AFR	G	1.8±0.7^{a}	5.1±1.2^{b}	3.2±1.0^{b}	3.1±1.0^{b}	4.7±1.2^{b}	10.8±1.6^{c}
	AFR	S	1.9±0.6^{a}	1.7±0.6^{a}	3.3±0.8^{ab}	4.4±1.0^{b}	2.7±0.8^{ab}	14.6±1.8^{b}
	MISS	GS	2.6±0.6^{a}	3.0±0.6^{a}	3.2±0.7^{a}	3.2±0.7^{a}	3.8±0.8^{a}	12.7±1.3^{b}
	DEVR	G	1.1±0.5^{a}	1.0±0.5^{a}	1.1±0.5^{a}	1.9±0.7^{a}	9.9±1.8^{b}	12.0±1.6^{b}
	DEVR	S	1.8±1.6^{a}	1.5±0.6^{a}	0.6±0.4^{a}	0.8±0.4^{a}	6.1±1.2^{b}	16.5±1.8^{c}
REM35	TB	GS	11.0±1.3^{a}	5.0±0.7^{b}	5.1±0.9^{b}	5.6±0.8^{b}	4.5±0.8^{b}	55.2±2.2^{c}
(N=5804)	AFI	GS	11.6±1.4^{a}	9.6±1.3^{a}	7.8±1.1^{a}	7.0±1.1^{a}	9.6±1.3^{a}	19.8±1.4^{b}
	AFE	GS	10.8±1.3^{a}	8.4±1.2^{a}	9.6±1.3^{a}	8.4±1.2^{a}	8.3±1.2^{a}	19.8±1.4^{b}
	MISS	GS	7.0±1.1^{a}	8.3±1.1^{a}	9.1±1.3^{a}	9.5±1.3^{a}	12.0±1.5^{b}	19.8±1.4^{c}
	DEVR	GS	3.1±0.6^{ac}	2.3±0.5^{ac}	2.1±0.5^{a}	2.4±0.5^{ac}	4.8±0.8^{c}	31.3±1.4^{b}
LFAIL	TB	GS	12.5±1.3^{a}	8.8±0.9^{b}	8.2±1.1^{b}	9.8±1.1^{b}	8.8±1.0^{b}	NE
(N=4998)	DEVR	G	11.5±2.4^{a}	6.8±1.7^{a}	10.1±2.2^{a}	11.0±2.3^{a}	12.6±2.5^{a}	11.9±2.5^{a}
	DEVR	S	3.4±1.0^{a}	7.4±1.7^{ab}	8.6±1.9^{b}	6.7±1.6^{ab}	8.2±1.8^{ab}	11.0±2.2^{ab}

[1] TB: total born; AFI: average feed intake; AFE: average feeding events; AFT: average time spent feeding; AFR: average rate of feed intake; MISS: count of missed feeding events; DEVR: deviation of intake from requirement; NE: not estimable

[2] FARR: sow farrowed (1) or not (0); FFAIL=1 for abortion, low litter size, farrowing difficulty, excessive stillbirths or mummies (otherwise 0); REM35: sow removed from herd between within 35 days of farrowing, or between days 100 and 120 days post-mating (otherwise 0); LFAIL=1 for lactation length<14 days or small number weaned (otherwise 0)