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Genetic evaluation for piglet crushing behaviour in primiparous sows

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ABSTRACT

Stress in farrowing sows is associated with the number of piglets crushed or attacked. Sow's behaviour is variable and heritable, therefore genetic selection can be a viable approach for improving pig's welfare. In this report, we used first parity litter records of Yorkshire sows to test a genetic evaluation model for piglet crushing. The data were split into training and validation to check the prediction accuracy of piglet crushing EBVs for young sows. We found that the estimated heritability of piglet crushing was 0.07±0.03. The difference in the EBVs in the validation set was equivalent to 0.15 more piglets crushed in the top 10% group than in the bottom group of sows. These results indicate that the genetic selection may be used to reduce piglet crushing which will improve the welfare of pigs as well as production efficiency. More research on evaluation models and the genetics underlying sow stress and behaviour is warranted to improve the reliabilities of modeling and to identify robust genetic markers for animal breeding for the implementation.

KEY WORDS

Genetic evaluation, piglet crushing, sow stress, sow behaviour

INTRODUCTION

The pork industry has enjoyed healthy growth in recent years, but is facing ever-increasing competitive pressure to continuously enhance meat quality and increase production efficiency. In the meantime, evolving animal welfare standards have brought new challenges, such as phasing out of gestation crates. Although larger living areas are beneficial to animals in general, group housing also exposes pigs to social stress. It has been identified that social stress impacts immune response and productivity of growing pigs (Camerlink *et al*. 2012). The number of piglets produced per sow per year is one of the most important economic traits for pig breeders. However, stress response behaviours of farrowing sows has been found to be associated with the number of piglets crushed or attacked by farrowing sows (Lensink *et al*. 2009). Furthermore, sow stress affects other maternal behaviours (e.g. piglet neglect), which can also negatively impact piglet growth and health (Rutherford 2014; Ringgernberg 2012; Goumon 2018).

According to benchmark data from commercial farms in the US over several years (Stadler, 2017), approximately 17.5% of piglets die before weaning. Canadian Centre for Swine Improvement (CCSI) records show that the majority of piglet mortality is due to crushing or savaging by sows. Alarmingly, it has been found that group housing has led to significantly higher piglet mortality rates than conventional stalls, as well as lower farrowing rates and more gilt injuries (Jang *et al*. 2015). It is generally accepted that these adverse effects are caused by stress (Ringgenberg *et al*, 2012). Since animal behavioural and neuroendocrine responses to stress are highly heritable in pigs (Larzul *et al*. 2010) and highly variable, even more so than production traits (Foury *et al*. 2007), genetic selection can be a viable approach for improving animal welfare and adaptability to the environment (Knap and Rauw 2009). Until now, little has been done in the area of genetics to enhance welfare in the swine industry.

The objective of this study was to develop a genetic evaluation system for piglet loss due to crushing by sows as part of an ongoing research project to develop genomic tools to help reduce sow stress and improve piglet survival and overall performance.

MATERIALS AND METHODS

Animal ethics: The historical data used in this study originated from farms taking part in the national swine genetic evaluation program managed by CCSI. The participating farms operate in accordance with the recommended Code of Practice for the Care and Handling of Farm Animals – PIGS (Canadian Agri-Food Research Council) [NFACC, 2014].

Data: First parity litter records of 4,048 Yorkshire sows from three Ontario farms in the years from 2012 to 2020 were used in this study. Usually, crushing events tend to increase in the later parities due to leg problems and other injuries, which can increase the environment variance or decrease the heritability for crushing behaviour (Gäde *et al.,* 2007). Increasing the size of a litter is another reason for observing more crushing events in upper parities (Gäde *et al.,* 2007).

Outlier records were excluded on 25 sows with farrowing age of less than 300 days, 260 sows with farrowing age of more than 399 days, 374 sows with litter size less than 7 or greater than 18, 4 sows with more than 8 cross-fostering transfers, 73 sows with less than 5 piglets after transfer and 10 sows with more than 5 crushed piglets. The outlier limits were determined based on the distribution of the traits, biological expectations and standard breeding practices. The genetic age of the sows with a farrowing age of more than 399 is different from a normal first parity sow, or sows with litter size less than 7 or greater than 18 have extreme number of offspring in the litter and its crushing behaviour would be influenced by the extreme number of piglets and the associated biological status of its body. It was also assumed that sows with more than 5 crushed piglets should have crushed their piglets due to reasons other than genetics (e.g., extreme health problems) and were excluded from the analysis. Records of 14 sows with unknown dams were also excluded. Summary statistics for the remaining 3,228 litter records are shown in Table 1.

Distribution of crushing events: Overall, the majority of sows (Figure 1) did not crush any piglets (59%) and 26% had one piglet crushed. Thus, about 85% of the sows had only one or no crushed piglets, while 9% had two crushed piglets and 6% of the sows had three or more crushed piglets in their first parity litter.

Statistical analysis: Data was analyzed with the following final generalized linear mixed model:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Z_1a} + \mathbf{Z_2s} + \mathbf{Z_3hys} + \mathbf{e}$$

where **y** is the vector of number of crushed piglets by sows in parity one, which was assumed to follow a Poisson distribution [$\mathbf{P}(\mathbf{y}, \lambda)$] with expected mean and variance equal to λ, where λ is the expected number of crushed pigs/litter.

b is a vector of fixed environmental effect, which included an overall mean, regression on farrowing age (AGE) and farrowing age squared (AGE^2), regression on the square of number of piglets after transfers (PAT^2), and classification effects of herd of farrowing (h) and interaction of herd by year of farrowing (hy).

a is a vector of random additive animal genetic effects,

s is a vector of random effects of the sows' litter of birth,

hys is a vector of random effects of season of farrowing (calendar quarter) by herd by year,

e is a vector of unknown residual effects,

X is the known incidence matrix for the fixed effects, $\mathbf{Z_1}$, $\mathbf{Z_2}$, $\mathbf{Z_3}$ are known incidence matrices for the random effects **a**, **s** and **hys**, respectively. The elements of **a**, **s, hys** and **e** are assumed normally distributed with an expected mean of zero and variances $\sigma_a^2\mathbf{A}$, $\sigma_s^2\mathbf{I}$, $\sigma_{hys}^2\mathbf{I}$ and $\sigma_e^2\mathbf{I}$, respectively, where **A** and **I** are the numerator additive relationship and identity matrices, respectively. The ASReml package (Gilmour *et al.*, 2009) was used to analyze the data by fitting a generalized linear mixed model using a natural logarithm link function and the model equation defined above. The predicted values (expected number of crushing) were calculated as $\boldsymbol{\lambda}=\exp(\mathbf{Xb}+\mathbf{Z_1a}+\mathbf{Z_2s}+\mathbf{Z_3hys})$. The terms $\boldsymbol{\lambda}$, $\mathbf{Xb}$, $\mathbf{Z_1a}$, $\mathbf{Z_2s}$ and $\mathbf{Z_3hys}$ are as explained above.

Estimated Breeding Values (EBVs): The data was split into two subsets, one for estimating breeding values and one for validation. A total of 2,649 litter records of sows farrowing up to the end of 2019 was used for the calculation of EBVs. This left 579 litter records from 2020 for validation. To validate the crushing EBV accuracy, the parent average EBVs for crushing (paEBV) of sows farrowing in 2020 were used as a predictor and compared to the actual number of piglets crushed in each litter in 2020. Adjusted phenotypes from 2020 were calculated as the model residuals in a separate analysis using the same model as used for EBV calculation, except for the random animal genetic effect. Sows with records in 2020 were ranked based on paEBV. The average number of piglets crushed in the top 10% of paEBV was then compared to the average number of piglets crushed in the bottom 10% of paEBV.

Reliability of EBVs: Reliabilities of EBVs were calculated based on the standard error of predictions (SEP) from ASReml as follows:

$$\mathrm{Rel_i} = 1 - \frac{\mathrm{SEP_i^2}}{(1+\mathrm{F_i}) * \sigma_a^2}$$

Where $\mathrm{Rel_i}$ is the reliability of the EBV, $\mathrm{SEP_i}$ is the standard error of prediction and $\mathrm{F_i}$ is the inbreeding coefficient of individual I, and σ_a^2 is the estimated additive genetic variance.

RESULTS AND DISCUSSIONS

Significance and distribution of the effects: The effects of herd, herd by year and the quadratic effect of the litter size after transfer were highly significant ($p<0.001$). The linear effect of litter size after transfer was not significant and excluded from the model. The linear and quadratic effects of the farrowing age were not significant but were left in the model since they approached significance ($p<0.10$) in a test run with the full dataset (including the 2020 crushing phenotypes). The distributions of the random effects appeared to have normal distributions as assumed in the model. The solutions for effect of season by herd*year were small and accounted for less than one percent of the total variance and the effect of sow's birth litter explained 11%± 3% of the total variance.

Heritability of crushing piglets and potential for selection against piglet crushing: The estimated heritability of piglet crushing at first parity was 0.07± 0.03. This is in the range of other sow productivity traits for which breeders have been able to make substantial genetic progress. In particular, the heritability for the number of piglets born per litter is 0.11 (Rothschild and Bidanel, 1998) and breeding companies on the Canadian Swine Improvement Program have been able to genetically improve this trait by almost two pigs per litter in just the past 10 years (CCSI annual report, 2020), with similar progress in the 10 years before that. The results of this study suggest that it is feasible to decrease the frequency of crushing using genetic selection. Though genetics only explains a small proportion of the variation in crushing, the economic benefit of decreasing the average crushing behaviour in multiplier and commercial herds can be very significant. In this study, crushing was considered an indicator of sow behaviour and selection against crushing should improve the general behaviour of the sows and welfare of their piglets. In order to effectively reduce crushing incidents, other factors such as management, health and nutrition of the sows also need consideration (Gäde *et al.,* 2007). Health and nutrition of the sows were not available in the analyzed data set.

Reliability of EBVs were estimated for all animals using the procedure explained in material and methods. The average reliabilities for sires, dams, and the sows in the validation group were 21%, 24% and 10%, respectively.

Validation of the predictions: The difference in the EBVs of the top and bottom 10% of the sows for crushed piglets was 0.25 on the log scale in the 579 sows included in the validation group. On the observed scale (back-transformed), this is equivalent to 0.15 more piglets crushed in the high group than in the low group. The back-transformation assumed an average of 0.64 piglets crushed per litter in first parity, which is the average across herds in this study. The expected difference would be larger for herds with higher average crushing and lower for herds with lower average crushing. The difference in the raw phenotypes between the high and low groups in the validation sows was about 0.14 piglets (Table 2) which is close to the predicted (0.19), residual (0.15) and EBV (0.15) differences between high and low groups. This demonstrates the potential of using EBVs for distinguishing the top and bottom sows for crushing their piglets based on their calculated EBVs using the proposed model.

Implementation of selection against piglet crushing into the genetic improvement program: The estimated heritability and the difference between the top and bottom groups of sows in the validation set indicate the possibility of selection against piglet crushing in sows. The implementation of this trait into the selection program needs more investigation, in particular the potential negative effect of selection against crushing on other economically important traits. The phenotypic correlation for the number of crushed piglets with litter size was significant ($p<0.0001$) (also reported by Gäde *et al.,* 2007) and positive (0.12), which indicates the need for estimation of genetic correlations between piglet crushing and other economically important traits, which are part of the economic selection indexes implemented on nucleus herds. Gathering more detailed information about other related factors such as piglets' weight as mentioned by other researchers (Grandinson *et al.,* 2002) should increase the accuracy of the EBVs. Due to the complicated nature of piglet crushing trait, which is also related to different factors, such as maternal health and behaviour, a more detailed model in a multiple trait evaluation can potentially generate more accurate EBVs. Genetic progress of about 20% of a genetic standard deviation per year has been achieved in other traits related to a sow's litter. For example, the genetic standard deviation of litter size is 0.97 which means 0.97/5=0.19 piglet genetic progress/year. This rate of progress has been achieved in practice in Canada resulting in an extra pig per litter every 5 years for the past two decades (CCSI, 2020). Applying this to piglet crushing, with the estimated genetic standard deviation of 0.30 piglets per litter crushing by sows, the economic benefits of selection against piglet crushing after five years can be about $25.99 million, considering 1.2 million sows and bred gilts on farms in Canada (cpc-ccp, 2021) with an average of 2.2 litters per year and a net value of $32.82 per pig saved (Louis-Carl Bordeleau, personal communication, 2019). Since such genetic gain is long term and sustained in the breeding herd, accurate genetic selection will continuously drive down crushing deaths year after year and it will diminish as crushing deaths get closer to zero.

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Authors' contributions: MJ participated in the data acquisition, carried out the analysis, interpreted results and prepared the manuscript. ZK participated in the data acquisition, data analysis and revision of the manuscript. BD participated in the data acquisition and revision of the manuscript. FS participated in discussions, data analysis and revising the manuscript. BS participated in the data acquisition, data analysis and revision of the manuscript. RL coordinated the study, participated in data analysis and reviewed the manuscript. All authors read and approved the final manuscript.

REFERENCES

Camerlink, I., Bijma, P., Kemp, B. and Bolhuis, J.E., 2012. Relationship between growth rate and oral manipulation, social nosing, and aggression in finishing pigs. Applied Animal Behaviour Science, 142(1-2), pp.11-17.

Canadian Agri-Food Research Council. Recommended code of practice for the care and handling of farm animals - PIGS. 2014. https://www.nfacc.ca/pdfs/codes/pig_code_of_practice.pdf. Accessed 23 November, 2020.

CCSI, 2020. Canadian Centre for Swine Improvement Annual Report. [Accessed February 26, 2021]. http://www.ccsi.ca/meetings/annual/2020AnnualReport.pdf.

Canadian Pork Council, 2021, Hog Farm Data. [Accessed June 23, 2023]. https://www.cpc-ccp.com/file.aspx?id=bff3d735-e80f-4024-9151-fce2cb4d0ce5

Foury, A., Geverink, N.A., Gil, M., Gispert, M., Hortos, M., i Furnols, M.F., Carrion, D., Blott, S.C., Plastow, G.S. and Mormède, P., 2007. Stress neuroendocrine profiles in five pig breeding lines and the relationship with carcass composition. Animal, 1(7), pp.973-982.

Gäde, S., Bennewitz, J., Kirchner, K., Looft, H., Knap, P.W., Thaller, G. and Kalm, E., 2007. Genetic parameters for maternal behaviour traits in sows. Livestock Science, 114(1), pp.31-41.

Gilmour, A.R., Gogel, B.J., Cullis, B.R., and Thompson, R. 2009 ASReml User Guide Release 4.1

Grandinson, K., Lund, M.S., Rydhmer, L. and Strandberg, E., 2002. Genetic parameters for the piglet mortality traits crushing, stillbirth and total mortality, and their relation to birth weight. Acta Agriculturae Scandinavica, Section A-Animal Science, 52(4), pp.167-173.

Goumon, S., Leszkowová, I., Šimečková, M., & Illmann, G. (2018). Sow stress levels and behavior and piglet performances in farrowing crates and farrowing pens with temporary crating1. Journal of Animal Science, 96(11), 4571-4578. https://doi.org/10.1093/jas/sky324

Jang, J.C., Jung, S.W., Jin, S.S., Ohh, S.J., Kim, J.E. and Kim, Y.Y., 2015. The effects of gilts housed either in group with the electronic sow feeding system or conventional stall. Asian-Australasian journal of animal sciences, 28(10), p.1512.

Knap, P.W. and Rauw, W.M., 2009. Selection for high production in pigs. Resource allocation theory applied to farm animal production (ed. WM Rauw), pp.210-229.

Larzul, C., Foury, A., Terenina, E., Billon, Y. and Mormede, P., 2010, August. Genetic parameters for ACTH response in pig. In 9th World Congress on Genetics Applied to Livestock Production (ed. 507 German Society for Animal Science), com (Vol. 169).

Lensink, B.J., Leruste, H., Le Roux, T. and Bizeray-Filoche, D., 2009. Relationship between the behaviour of sows at 6 months old and the behaviour and performance at farrowing. Animal, 3(1), pp.128-134.

Ringgenberg, N., Bergeron, R., Meunier-Salaün, M.C. and Devillers, N., 2012. Impact of social stress during gestation and environmental enrichment during lactation on the maternal behavior of sows. Applied Animal Behaviour Science, 136(2-4), pp.126-135.

Rothschild, M.F. and Bidanel, J.P. (1998) Biology and genetics of reproduction. In: Rothschild, M.F. and Ruvinsky, A. (eds) The Genetics of the Pig. CAB International, Wallingford, UK, pp. 313–343.

Rutherford, Kenneth M. D. et al. "Prenatal stress produces anxiety prone female offspring and impaired maternal behaviour in the domestic pig." Physiology & Behavior 129 (2014): 255-264.

Stalder, K.J., 2017. Pork industry productivity analysis. National Pork Board Report [accessed February 21, 2019]. https://www.pork.org/wp-content/uploads/2018/09/2018-pork-industry-productivity-analysis.pdf.

Table 1: Descriptive statistics of first parity litter records included in the analysis (N=3,288)

Variable	Mean	Standard deviation	Minimum	Maximum
Farrowing age (months)	11.37	0.65	9.86	13.11
#Piglets born alive	12.56	2.95	6	22
#Piglets transferred[1]	0.50	2.67	-7	8
#Piglets after transfers	13.06	2.02	7	18
#Piglets crushed	0.64	0.96	0	5

[1]Transferred on to the sow (positive number) or transferred off of the sow (negative number)

Table 2: Raw and adjusted phenotypes in the top and bottom sows in the validation set having first parity litter in the year 2020, ranked based on the average of their parents' piglet crushing EBVs.

	Number of sows		Mean		Difference	Standard Deviation		Minimum		Maximum	
	B[a]	T[a]	B	T	T-B	B	T	B	T	B	T
EBV[b]	58	58	-0.19	0.06	0.25	0.01	0.05	-0.22	0.01	-0.17	0.19
Phenotype[c]	58	58	0.48	0.63	0.14	0.82	1.00	0.00	0.00	3.00	4.00
Residual[c]	58	58	-0.27	-0.11	0.16	1.25	1.40	-1.00	-1.00	4.72	4.40
Predicted phenotype	58	58	0.47	0.66	0.19	0.34	0.49	0.14	0.11	1.86	2.23

[a]B and T stand for Bottom and Top sows, respectively, ranked based on the average of their parents' piglet crushing EBVs.
[b]EBVs are in log-scale. After accounting for the population mean, the difference between the top and bottom group EBVs was 0.15 piglets on the original scale.
[c]Phenotype, residual and predicted phenotypic values are all on the original scale.

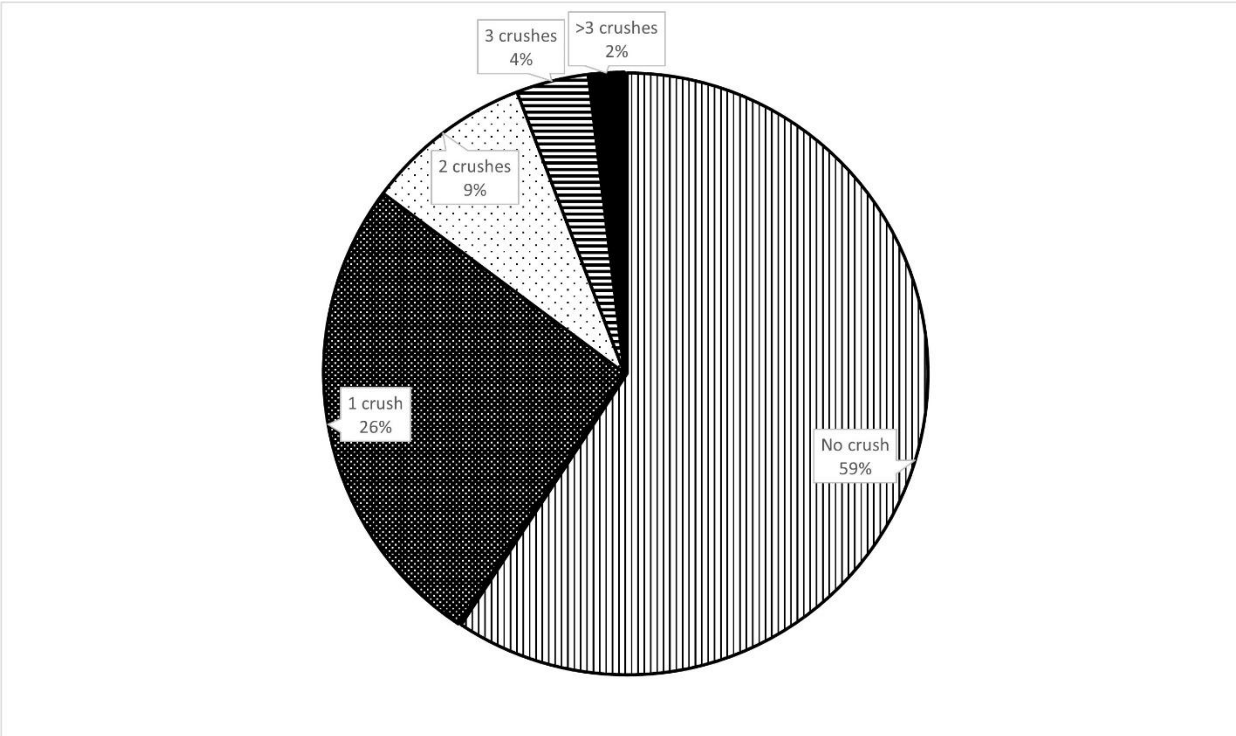

Figure 1: Percentages per classes of number of crushed piglets by first parity sows.