RESEARCHREPORT
ANIMAL SCIENCE

Title: Managing gilt "litter of origin" to improve sow lifetime productivity" **– NPB #18-138**

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Industry Summary:

In an earlier, multi-year project funded by the NPB and carried out in collaboration with Holden Farms Inc., we reported effects of individual gilt birth weight (BWi) on survival and retention to around 170 days of age, on the pubertal response of gilts pre-selected for entry to the breeding herd, and on the reproductive performance and retention to fourth parity of gilt actually bred. An extreme low BWi (< 1.18 kg) negatively affected retention during development. Moreover, many of the gilt losses were involuntary and involved still-born pigs or pigs already crushed by day 4. The study also established a birth weight phenotype (BWP) for sows producing potential replacement gilts, based on three or more litter records in multiparous sows, and an extreme low BWP (litter average BW < 1.18 kg) had similar negative consequences for gilt retention to selection. From a practical perspective, it is important to recognize that the low BWP phenotype sow inevitably produces a high proportion of gilts with a BWi in the "risk" category for survival and retention. For those gilts that reached the pre-selection stage of development, there were no significant effects of BWi or sow BWP on the pubertal response to an aggressive program of boar-induced puberty stimulation. Overall, gilts bred showed excellent retention and productivity in the commercial sow herds, and paradoxically a high birth weight and breeding weight was a significant risk factor for retention in the breeding herd. Therefore, the early retention of low BWi gilts has a major impact on the efficiency of replacement gilt production. At the multiplication sow level, early culling strategies based on a low BWi would improve the efficiency of the replacement gilt program. Additionally, management strategies at commercial nucleus sow level, could improve the efficiency of genetic transfer from the nucleus herd to commercial sow production, as measured by the number of commercial replacement gilts produced per nucleus sow per year. The present "implementation" project had two primary objectives: 1) To establish the extreme low birth weight "risk" categories for gilt retention in primiparous nucleus sow litters and the repeatability of the low BWP as these sows reached second parity. 2) To explore "implementation" strategies (such as early culling of both sows and individual gilts falling into the extreme low BW category, and rearing of gilts in smaller sized litters) that would increase the number of replacement gilts per nucleus sow bred. Ultimately, it was hoped to demonstrate the effect of these implementation strategies on replacement gilt production and commercial sow performance.

The study was unfortunately terminated at about the half-way stage due to a PRRS-v outbreak in the nucleus-multiplication herd. However, by that stage sufficient data had been collected to provide validation for the implementation strategies proposed. In 262 primiparous nucleus sows studied, a BWi of 1.00 kg was established below which the risk of death or removal by day 4 increased

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substantially. On the basis of a litter average BW of < 1.0 kg, 15% of the sows had an extreme low BWP phenotype, and 68 % of the gilts in these low BWP litters had a BWi of <1.00kg, compared to 22% and 5% gilts in the litters of medium and high BWP sows. Gilt retention to 170 d of development was much lower (28%) in low BWi gilts compared to medium and high BWi gilts (about 50%) and this major difference in retention was already apparent at weaning (32% in low, compared to 70% in medium and high BWi gilts). These data confirm that culling of extreme low BWi gilts and low BWP sows, would remove one of the biggest obstacles to efficient replacement gilt production at the nucleus-multiplication sow level. A low BWP characterization based on the first two litters was initially suggested as being a sound strategy. However, the high repeatability of the low BWP in the majority of the 93 second parity sows for which a low gilt BWP had been established, suggests that culling of the lowest 10 to 15% of nucleus sows based on a single low BWP record would carry little risk of making a wrong culling decision.

In support of proposed intervention strategies to improve weaning weight, and hence retention rate, in lower BWi gilts born to medium and high BWP sows, significant effects of both a medium or high BWP (>1.0 to1.22 vs >1.22 kg) and the size of the litter at day 4 (12 to 14 vs 16 to 16) on weaning weight were established. Targeting litter size reduction to the lowest average BW litters in the nucleus sow population will, therefore, have the biggest impact in moving weaning weights above the threshold needed to improve subsequent retention in the replacement gilt flow.

Overall, therefore, the data collected in this “implementation” project, are consistent with the suggestion that interventions at production nucleus sow level, based on birth weight phenotype could significantly increase the efficiency of genetic transfer to the commercial sow level. These interventions can be based on measurements of litter birth weight in the litters of primiparous nucleus females and would include culling of sows with an extreme low BWP, culling of all female progeny with a BWi of less than 1.0 kg from the replacement gilt flow, and manipulations to marginally reduce litter size during lactation in sows falling into the medium BWP category. Because the overall retention rate of gilts not removed from the replacement gilt production flow would improve, this would compensate for the early removal of the small percentage of sows with an extreme low BWP. As with the evaluation and culling of AI boars based on their proven reproductive performance, the proposed nucleus sow culling strategies based on established BWP, seeks to achieve efficiencies overall pork production. For those production systems that are able to implement such strategies, the differences in reproductive phenotypes measured are largely independent of the assigned estimated breeding value (genetic index) of the boars and sows involved.

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Key Findings:

- Irrespective of their estimated breeding value, nucleus-multiplication sows express important and repeatable differences in litter birth weight phenotype that impact survival and retention of gilts in the system.
- By definition, litters of sows with an extreme low birth weight phenotype include a high proportion of low birthweight gilts.
- A low birth weight significantly reduces gilt retention, with most deaths and removals already occurring by weaning.
- Culling sows with an extreme low birth weight phenotype will increase the overall efficiency of genetic transfer from nucleus to production level.
- Intervention strategies during lactation can improve weaning weights and retention of potential replacement gilts.
- Monitoring and managing the number of replacement gilts bred as a measure of nucleus-multiplication performance will increase the overall efficiency of pork production systems.

Keywords: Production nucleus sows; Genetic transfer; Gilt retention

Scientific Abstract:

The overall goal of a nucleus-multiplication program is to optimize the transfer of the best dam-line genetics available in the industry to the commercial sow farm level. This ultimately will improve downstream commercial performance and is driven by both the quantity and quality of weaned gilts produced. Sow birth weight phenotype (BWP) is an important factor in the overall efficiency of replacement gilt management. Litters from sows with a repeatable low average BWP are largely composed of low individual birth weight (BWi) gilts, many of which are already lost or culled from the pool of potential replacement gilts before weaning. In the present study BWP was established in 262 first parity nucleus-multiplication sows producing replacement gilts in a large commercial operation and classified as low (L-BWP, < 1.0 kg, n = 24); medium (M-BWP, ≥1.0 to ≤ 1.22 kg, n =109) or high (H-BWP, > 1.22 kg, n = 129) on the basis of a BWi of 1.0 kg below which there was a high risk of early mortality (AUC = 0.93%; $P < 0.0001$) and the average BWi (1.22 kg) for the population. Potential replacement gilts born to these sows (n = 1588) received a unique identification tag that allowed the impact of BWi, BWP and their interactions on the efficiency of replacement gilt production to be evaluated. Nearly 68% of the gilts produced from sows with a low BWP were in the low BWi category. Negative effects of BWi on mortality until d 4 after birth, and cumulative losses to weaning, to d 70 of age, and to final pre-selection at 170 d of age, were confirmed ($P < 0.05$). Cumulative losses to weaning were affected ($P \leq 0.05$) by the interaction between BWP and individual weaning weight (WNWi; $P < 0.0001$). At weaning, the probability of mortality was lower for M-BWP compared to H-BWP classes until WNWi exceeded 4.8 kg; above a WNWi of 7.2 kg, cumulative losses increased ($P \leq 0.05$) in M-BWP compared to H-BWP gilts. Mortality until d 70 and d 170 after birth was affected ($P \leq 0.05$) by WNWi but not affected by BWP, nor by the WNWi x BWP interaction. A lower WNWi was associated with increased cumulative gilt losses ($P < 0.0001$). As a proportion of gilts tagged, fewer L-BWP gilts were retained in the herd compared to M-BWP or H-BWP gilts at weaning (L-BWP: 34.09 ± 14.1; M-BWP: 66.0 ± 12.6; H-BWP: 70.7 ± 11.7 %) and at 170 days of age L-BWP: 21.1 ± 7.5; M-BWP: 49.3 ± 9.3; H-BWP: 52.5 ± 9.3 %). A smaller lactating litter size by day 4 of lactation (12-14 vs 15-16 pigs suckling) increased weaning weight (12-14: 5.4 ± 0.1; 15-16: 5.1 ± 0.1 kg) and resulted in more pigs being retained at weaning (12-14: 83.3 ± 0.9; 15-16: 72.2 ± 0.1 %), d70 (12-14: 79.4 ± 0.8; 15-16: 64.4 ± 1.0 %) and d170 (12-14: 64.0 ± 0.9; 15-16: 53.9 ± 0.9 %). In the 93 nucleus sows that farrowed a second litter before the study was terminated, there was a positive relationship between parity 1 and parity 2 litter average birth weight ($y = 0.3695x + 0.9$, $R^2 = 0.14$, $P < 0.0002$). Results from the current study are consistent with previous reports that BWP is repeatable across successive parities. Overall, results show that sows with the L-BWP are largely composed of low individual birth weight gilts and confirm that low individual birth weight is a primary concern for early losses of potential replacement gilts before weaning. Strategically removing the 9% of sows with an extreme low birth weight phenotype will increase the overall efficiency of genetic transfer from nucleus to production level. On all remaining females, intervention strategies during lactation can improve weaning weights and retention of potential replacement gilts. Monitoring and managing the number of replacement gilts bred as a measure of nucleus-multiplication performance will increase the overall efficiency of pork production systems.

Introduction: The most effective way to introduce the present "implementation" project is to quote more or less directly from the discussion section of the paper that described the outcome of our earlier multi-year study of the effects of gilt birth weight on subsequent production efficiency (Patterson et al., 2020).

"The lifetime efficiency of nucleus-multiplication sows in producing quality weaned gilts is important, and these gilts will pass on the genetic superiority of their dams for important commercial traits. However, the number of replacement gilts that actually enter commercial production is also critical and affects the efficiency of the genetic transfer program. Therefore, the impact of commercial nucleus-multiplication sow birth weight phenotype (BWP) on gilt retention rates to pre-selection, and then the ongoing proportion of gilts actually selected and bred, are critical issues for the industry. However, BWP presently bears little relationship to the ascribed genetic index of nucleus-multiplication sows. At production nucleus level, a low BWP would be associated with a lower production of gilts from these litters as pure-line replacements, either because the gilts born fail to meet growth requirements, or because of potential negative developmental impacts of a low BWP on reproductive performance (Almeida et al., 2017). At production multiplier level, although sows with a low BWP may produce few productive replacement gilts in their entire lifetime, this association between BWP and the efficiency of genetic transfer through the production nucleus-multiplication system is essentially unrecognized. Ladinig et al. (2014) reported a transgenerational effect of birth weight in pigs; consequently, those gilts born to low BWP multiplication sows that do enter commercial production would also be expected to pass on the low BWP to their slaughter generation progeny. Removing the 10 to 15 % of nucleus-multiplication sows with an established low BWP, and management practices to further improve gilt retention rates in the remaining sows, would lead to more efficient genetic transfer from nucleus sow to terminal line production in the smaller population of multiplication sows remaining. Indeed, if culling was based on litter birth weight data of the first two litters farrowed, even purebred nucleus replacement gilts could be removed as potential pure-line replacements at the pre-selection 2 stage of development, at which time their birth dams would already have produced a second litter and a reliable and extreme low BWP would have been established.

From a genetic transfer perspective, the production of very few replacement gilts in the productive lifetime of some sows in the production nucleus-multiplication herd, represents a poor genetic investment. These sows only "earn" their genetic premium if their genetic potential is effectively passed on to the replacement gilts used for terminal line production. The disconnect between a high genetic merit for genetic traits included in the estimated breeding value of some nucleus/multiplication sows, and their poor reproductive performance in terms of replacement gilt production, emphasizes the need to measure and manage important phenotypic traits in contemporary sow populations. This is analogous to similar issues with investing in high-indexing artificial insemination boars with unproven fertility. Investing in high indexing boars that are determined to have relatively low fertility when used for artificial insemination, either in single-sire matings, or when used in pooled semen doses out of which the less fertile (uncompetitive) boars sire very few progeny, has been identified as a weakness in the management of many commercial boar studs (Dyck et al., 2018). Investing in high indexing nucleus-multiplication sows that are found to have a low litter BWP phenotype, and thus limited potential for supplying replacement gilts for commercial production, suggest another inefficiency in genetic transfer that could be avoided in well managed, in-house, breeding programs. In the larger production enterprises that manage both their own boar studs and production nucleus/multiplication sow farms, the opportunity to optimize genetic transfer to the level of terminal line production offers significant economic benefits. In both cases, the additional replacement costs of early culling of unproductive boars and sows are very largely offset by the enhanced performance of the boars and nucleus sows remaining in production. In terms of replacement gilt costs, a smaller but higher quality supply of potential replacement gilts into the gilt development program, would provide further economic benefits".

As an extension to the main study reported above, a two-year "implementation" project was proposed, that further explored the reality of using sow birth weight phenotype to improve gilt production efficiency at the commercial nucleus-multiplication level.

Supplementary comments to our NPB funders: Although it was disappointing that the entire implementation project proposed could not be completed, the continued NPB funding for Jenny Patterson's salary had unanticipated benefits. After submission of the Final Report from the previous multi-year project, a paper describing the results contained in that final report was submitted for peer-reviewed publication. Both of the peer reviewers were very complimentary about the scope and impact of the study completed and supported publication of the results. However, both reviewers suggested that a more insightful approach to the analysis would involve fitting birth weight phenotype as a continuous variable, rather than our initial approach which used three discrete birth weight categories. This substantial reanalysis was completed in a further collaboration between Jenny Patterson and Dr. Mari Bernardi from Brazil, and allowed effects of individual gilt birth weight, sow birth weight phenotype, and their interactions to be considered. The eventual analysis and presentation of the data in the published paper of Patterson et al. (2020) was therefore more insightful and extensive than that presented in the earlier Final Report submitted to the NPB. For the purpose of the present implementation study, the revised and more comprehensive approach to data analysis has been implemented.

Objectives:

The overall objective could be summarized as **"Measuring and managing litter birth weight to improve the efficiency of the production nucleus/multiplication program and sow lifetime productivity at commercial production level".**

This overall objective was to be achieved using a number of integrated strategies:

1. Early culling of pure-bred nucleus sows with a repeatable low average litter birth weight phenotype.
2. Voluntary culling (non-selection at birth) of individual gilts with a birth weight < 1 kg.
3. Implementation of "litter size reduction strategies" for lower birth weight gilts early in lactation.
4. Adjustment of pre-selection criteria applied to replacement gilts beyond the nursery stage, removing relatively low growth performance as a criterion for non-selection, resulting in increased retention of potential replacement gilts in the system.
5. Application of high quality management of gilts in the GDU to deliver gilts with greater than a 90% chance of being bred and retained in the breeding herd to parity 2.

The expected outcomes would be:

1. Improvements in genetic transfer efficiency from production nucleus to commercial sow level.
2. Improved efficiency of gilt production (replacement gilts bred per multiplication sow per year).
3. Improved retention of gilts in the breeding herd as a key factor affecting SLP.
4. Increased numbers (due to deceased pre-weaning losses) and quality (weaning weights) of commercial pigs produced driven by the transgenerational consequences of culling multiplication sows will a low litter birth weight phenotype.

Materials & Methods:

This study was performed in accordance with the guidelines of Pork Quality Assurance Plus and Holden Farms Inc. ethical guidelines, and with approval of the Faculty Animal Care and Use Committee - Livestock, University of Alberta (AUP00001767).

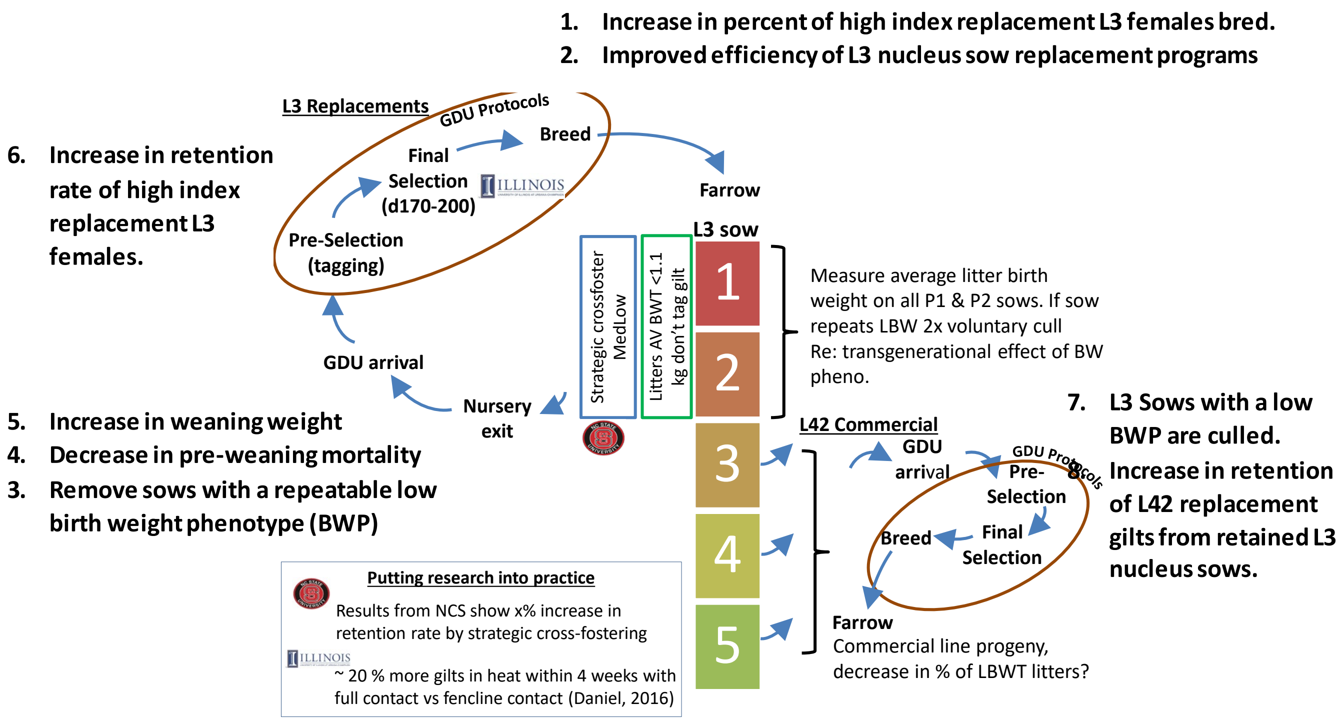

Figure 1. Strategic outline describing the implementation of a voluntary culling strategy at production nucleus level (Replacement of pure-bred Line 3 females) to remove sows with an extreme low birth weight phenotype after farrowing their second litter (Steps 1, 2 and 3). This already improves the efficiency of the L3 pure-bred replacement program (Overall outcome shown as Step 6). Removal of individual gilts born in other litters with a weight of < 1.0 kg, and implementation of a "reduced litter size" management strategy for remaining lower birth weight gilts, will also result in a decrease in pre-weaning mortality and heavier weaning weights (Steps 4 and 5). Implementation of an early culling strategy for low birth weight phenotype Line 3 sows by parity 2 removes the biggest risk factor for inefficient replacement gilt production at the multiplication level of the production nucleus/multiplication farm (Steps 7 and 8). Non-selection of individual Camborough gilts with < 1 kg birth weight could also be applied at the multiplication level to further improve the quality and retention rate of gilts entering the replacement gilt program. Because the program will largely remove low growth performance as a risk factor for gilt retention in the system, pre=selection protocols will need to be progressively adjusted to remove relatively low growth performance as a "non-selection" criterion, resulting in a higher retention of gilts in both the Line 3 and Camborough replacement flows.

Animals and Location

The primary study locations were the production nucleus-multiplication farm (n = 2,400) Line 03 (L03) sows (PIC, Hendersonville, USA) of Holden Farms Inc. (HFI) located near Northfield, Minnesota, USA. The study was conducted between October 2018 and November 2019.

In November 2019, the production nucleus-multiplication farm suffered a PRRS-v break. As a result the management and veterinary team closed the herd and the study was halted. Table 1 illustrates an overall summary of what was initially proposed and impact of ending the study early on data collection.

Table 1. Overall summary of data collected and modified time table[1]								
L3 sow P1 farrow dates	**Nos. sows per mth[2]**	**Nos. pigs weighed at birth**	**Nos. pigs weighed at weaning**	**Nos. P1 Tagged Gilts**	**Nos. P2 Tagged Gilts**	**P1 L3 gilts enter Triagra GDU[4]**	**P1 L3 gilts bred at Triagra**	**P1 Gilts Due to Farrow**
10/1/2018	**22**	**315**	**73**	**122**	**-**	**3/20/2019**	5/29/2019	9/21/2019
11/1/2018	**45**	**667**	**164**	**266**	**-**	**4/20/2019**	6/30/2019	10/21/2019
12/1/2018	**54**	**770**	**273**	**337**	**-**	**5/20/2019**	7/29/2019	11/21/2019
1/1/2019	**65**	**932**	**289**	**415**	**-**	**6/20/2019**	7/30/2019	12/21/2019
2/1/2019	**49**	**681**	**259**	**306**	**-**	**7/21/2019**	8/30/2019	1/23/2020
3/1/2019	**39**	**719**	**251**	**230**	**61**	**8/18/2019**	9/27/2019	2/19/2020
4/1/2019[3]	**13**	**650**	**132**	**83**	**88**	**9/18/2019**	10/28/2019	3/22/2020
5/1/2019[3]	**-**	**531**	**193**	**-**	**219**	10/18/2019	11/28/2019	4/21/2020
6/1/2019[3]	**-**	**492**	**139**	**-**	**216**	11/18/2019	12/18/2019	5/12/2020
7/1/2019[3]	**-**	**262**	**114**	**-**	**125**	12/18/2019	1/18/2020	6/12/2020
8/1/2019[3]	**-**	**292**	**32**	**-**	**106**	1/18/2020	2/18/2020	7/11/2020
Totals:	**274**	**6337**	**1925**	**1759**	**815**			
Nos. Gilts Added to Gilt Flow:				**2574**				

[1]Data that was not collected/analyzed due to the PRRS break.
[2]Numbers reflect total data collected, not the data that was ultimately analyzed.
[3]To manage workload at the Nucleus farm and to enable the farm team to focus on weighing litters at P2, no additional P1 gilts were added to the trial. The intention was that once the initial data were collected and analyzed, Phase 2 implementation would have started.
[4]The un-bolded data was not collected/analyzed due to the PPRS break.

Management of Multiplication Sows

Similar protocols as reported in Patterson et al. (2020) were implemented in the current trial. Parity 1 nucleus sows were initially allocated to the trial. Within 24 h after birth and before cross-fostering, sow identification, parity, date of birth, total number of piglets born, number of piglets born alive, number of stillborn, and the individual birth weight and sex of all pigs born were recorded. The same measurements were taken at the subsequent farrowing in Parity 2 (the ability to do this was hampered by management and the PRRS break). Cross-fostering between litters was kept to a minimum and completed within 24 h after birth. Individual weaning weights were recorded for the gilt progeny of the first parity sow included in the study.

Management of Gilts from Birth to Final Pre-Selection

Postnatal care involved drying each piglet at birth and adherence to a split-suckling protocol to ensure colostrum ingestion of all piglets after birth. Tail docking and iron injections were completed no later than 6 d after birth. Within 24 h after the birth all live potential replacement gilts were individually identified with an ear tag in both ears. From birth gilt performance was recorded in the genetic database PICtraq (PIC), and from entry into the sow herd the swine management software Porcitec (Agritec Software, Barcelona, Spain) was used.

Contrary to the previous study (Patterson et al., 2020), the farm managed the gilts as per standard operating procedures, and no limitations to culling were implemented. All females were reared using industry standard protocols, and fed a gilt developer diet *ad libitum.* A final pre-selection process at approximately 165 d of age identified gilts acceptable for entry to the final selection program in a GDU facility associated with the nucleus-multiplication farm.

Statistical Analyses

Prior to analyses, the raw data underwent rigorous data verification. All data were analyzed using the software Statistical Analysis System (SAS) version 9.4. Differences were considered significant at $P \leq 0.05$ and a tendency at probabilities between 0.05 and ≤ 0.10. Numerical data are expressed as LS means ± SEM, or as percentages.

Using the same approach as Patterson et al. (2020) and Magnabosco et al. (2015), individual gilt birth weight (BWi) was used as a continuous variable to determine the predicted probability for mortality 4 d after birth using logistic regression models in SAS (GLIMMIX procedure): Birth dam and season were used as random variables in the model. The predicted probabilities were used to obtain Receiver Operating Characteristic (ROC) curves (LOGISTIC procedure). The optimal cut-off value for predicting mortality within 4 d after birth for BWi was determined. Model accuracy was assessed by calculating the area under the ROC curve and interpreted as described by Greiner et al. (2000). The best cut-off point estimation for mortality based on gilt BWi was 1.00 kg (AUC = 0.93%; $P < 0.0001$). Overall, this weight was used to establish birth weight phenotype classifications in 262 nucleus-multiplication primiparous sows which subsequently produced 1,588 potential "pure-bred" nucleus replacement gilts for which effects of BWi and BWP on gilt retention to selection could be determined.

Litter average birth weight was determined on each litter born to a sow by averaging BWi for all pigs born within a single litter (male, female, born live and stillborn). To ensure the integrity of the BWP data, litter data in the experimental records recorded on-site were compared to data recorded in the sow farm database and in the few instances where these records differed by more than 15%, the data were not used in the determination of average litter birth weight and sow BWP. The litter average birth weights (n = 262: overall mean litter average birth weight = 1.22 kg) was then used to establish three sow BWPs with respect to the critical threshold of birth weight for increased mortality established (1.0 kg) and the overall population mean average birth weight of 1.22 kg, as follows: low BWP (L-BWP: < 1.0 kg; n = 24); medium BWP (M-BWP: ≥1.0 to ≤ 1.22 kg; n = 109), and high BWP (H-BWP: > 1.22 kg; n = 129).

Having applied the standardized selection/culling criteria described above, cumulative losses by death or health at 4 d after birth, until weaning, at 70 d of age, at pre-selection into the breeding herd at approximately 170 d of age were determined in 1588 gilts. Retention rates were analyzed using logistic regression models (GLIMMIX procedure). In these models, BWi, BWP and their interaction were considered as fixed effects to investigate whether gilts with different BWi would respond differently among BWP classifications. Random effects consisted of season and birth dam.

If the interaction between BWP and BWi was significant, the PLM procedure was used to obtain the overall comparison of slopes among BWPs, or to make specific comparisons at different levels of BWi. In models in which BWi was significant but with no interaction effect, the predicted probabilities concerning the effect of continuous BWi on variables with binary response were used to obtain ROC curves and optimal cut-off values, as described earlier. When neither an association with BWi, nor the BWi by BWP interaction, were significant, the model was run considering only the fixed effect of BWP and LSmeans were compared using the Tukey-Kramer test.

Results:

Overall

The overall phenotypic characteristics of the 262 primiparous multiplication sows assigned a BWP and their gilt offspring are shown in Table 2. The L-BWP sows represented the 9.1% of sows producing litters with the greatest risk of increased deaths in the immediate post-natal period. The average total litter sizes born in the litters used to establish the L- and M-BWPs were similar, but were higher than in H-BWP sows ($P < 0.001$); Nevertheless, the litter average birth weight was different between L-, M- and H-BWP sows ($P < 0.001$). In L-BWP sows a greater percentage of piglets had individual birth weights < 1.0 kg compared to M-BWP and H-BWP sows ($P < 0.001$). Despite differences in total born, the number of gilts born alive and gilts tagged did not differ ($P > 0.05$) among

BWP classifications. Figure 2 illustrates the reason for death or removal at 4 days of age and at weaning.

Table 2. Summary statistics of measured traits (LS means ± SEM) in sows with low, medium and high birth weight phenotypes

	Sow birth weight phenotype (BWP)			
	Low (≤ 1.00 kg)	Medium (>1.00 to ≤1.22 kg)	High (>1.22 kg)	P-value
Number of sows	24	109	129	
Proportion of total, %	9.1	41.6	49.2	
Average total born	16.5 ± 0.6[a]	15.7 ± 0.3[a]	14.0 ± 0.2[b]	<0.0001
Average litter birth weight, kg ± g	0.93 ± 20[a]	1.13 ± 9[b]	1.36 ± 8[c]	<0.0001
Nos. potential replacement gilts	144	679	765	
Pigs <1.00 kg, %	67.6 ± 0.6[a]	22.2 ± 0.3[b]	5.6 ± 0.1[c]	<0.0001
Gilts born alive per litter	6.8 ± 0.5	6.4 ± 0.3	6.4 ± 0.3	0.7413
Gilts tagged per litter[2]	6.3 ± 0.4	6.1 ± 0.2	6.1 ± 0.2	0.9401

[1]The average number of litters used to establish each sow BWP.
[2]Not all gilts born alive were tagged, reflecting additional death losses immediately after birth.
[,b,c]Within row, significant difference between phenotype classification ($P < 0.05$).

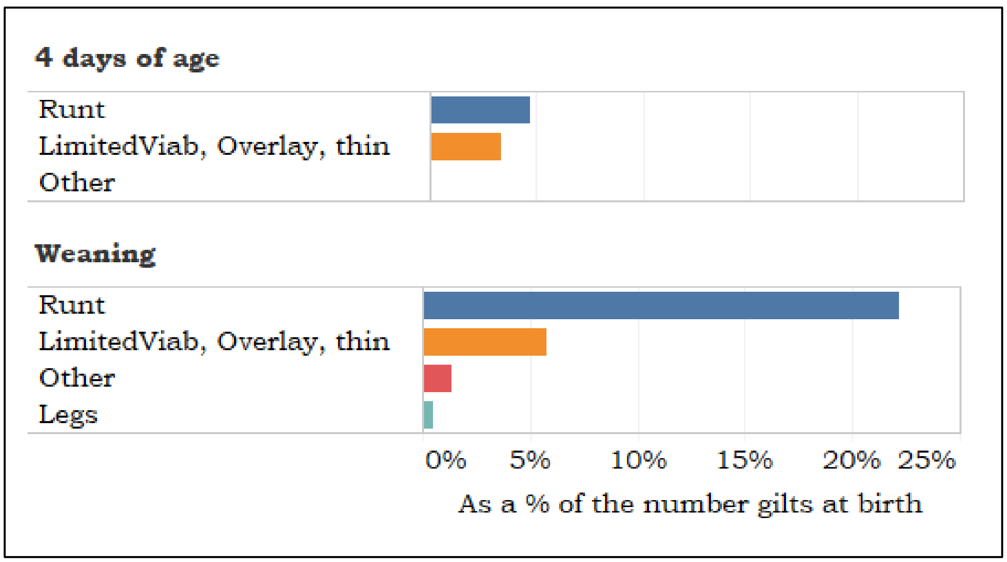

Figure 2. The reason for removal at 4 days of age and at weaning for all gilts, irrespective of BWP.

Selection Efficiency – Individual Birth Weight (kg)

Figure 3a illustrates the relationship between litter average birth weight and litter size in the 262 primiparous sows for which a BWP phenotype was established. Across all litter sizes with more than 10 pigs born, there was a negative relationship between total litter size born and the litter average birth weight of that litter ($y = -0.027x + 1.6$, $R^2 = 0.22$, $P < 0.0001$; Figure 3a). The population litter average birth weight was 1.22 kg. Figure 3b shows the relationship between litter size (as total number of pigs born) and litter average birth weight in 644 multiparous sows as reported in Patterson et al. (2020). As expected, the average birth weight of the population of gilt litters studied is lower than in the multiparous sows studied previously. In the multiparous sow population, 0.5% of litters had a BWP <1.0 kg compared to 9.1% in the primiparous sow population (Table 1).

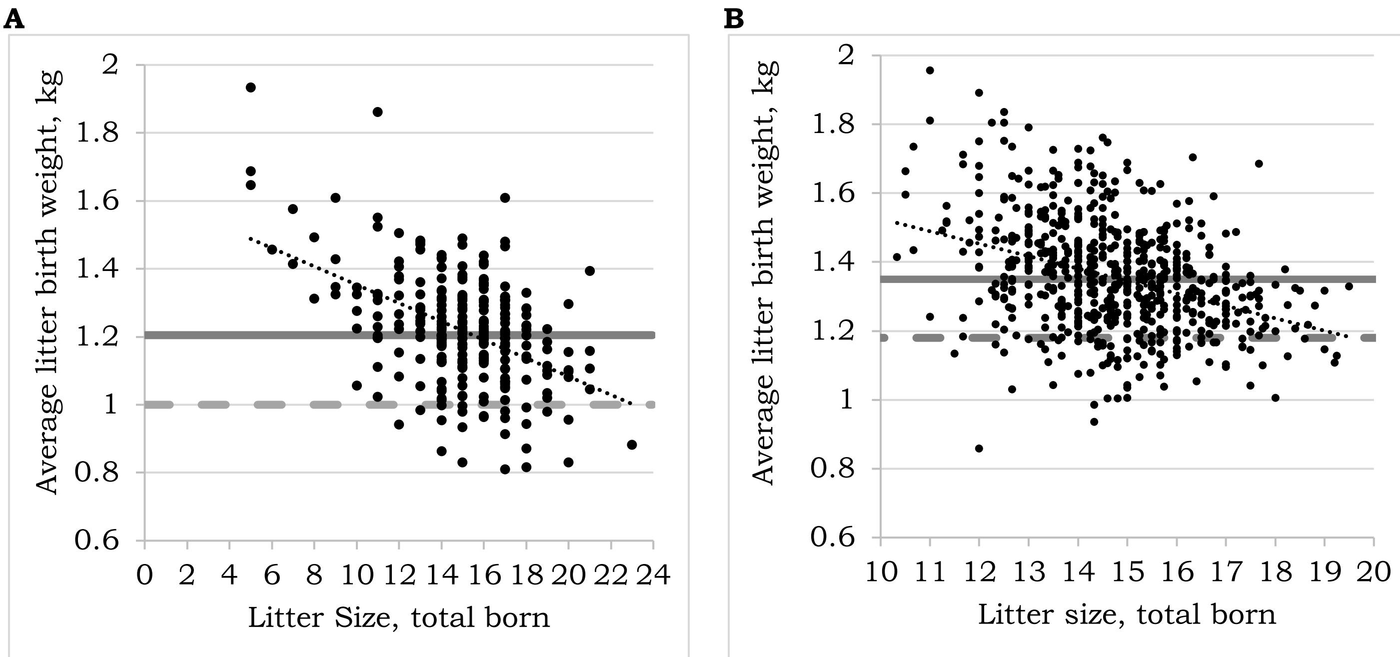

Figure 3. A) Relationship between litter size (as total number of pigs born) and litter average birth weight in 262 primiparous sows. The average litter birth weight over the population is 1.2 kg (solid black line). The dashed black line indicates the birth weight of 1.0 kg, below which sows were classified as having a low birthweight phenotype. B) Relationship between average litter size based on at least two litters (as total number of pigs born) and litter average birth weight in 644 multiparous sows as reported in Patterson et al. 2020. The average litter birth weight over the population is 1.35 kg (solid black line). The dashed black line indicates the birth weight of 1.18 kg, below which sows were classified as having a low birthweight phenotype.

Cumulative losses d 4 of age, to weaning, to d 70 of age, and to final pre-selection at approximately 150 d of age were affected ($P \leq 0.05$) by BWi (Figure 4) but not affected by BWP, nor by the BWi by BWP interaction. A lower BWi was associated with increased gilt losses and the best cut-off point estimation for survival at d 4 was 1.0 kg (AUC = 0.92%; $P < 0.0001$; Figure 4A). At weaning, a lower BWi was associated with increased gilt losses and the best cut-off point estimation for survival was 1.25 kg (AUC = 0.91%; $P < 0.0001$; Figure 4B). At d 70 of age a lower BWi was associated with increased gilt losses and the best cut-off point estimation for survival was 1.34 kg (AUC = 0.87%; $P < 0.0001$; Figure 4C). At d 170 of age a lower BWi was associated with increased gilt losses and the best cut-off point estimation for survival was 1.34 kg (AUC = 0.83%; $P < 0.0001$; Figure 4D).

Selection Efficiency – Individual Wean Weight (kg)

Cumulative losses to weaning were affected ($P \leq 0.05$) by the interaction between BWP and individual weaning weight (WNWi; Figure 5). At weaning (Figure 5A), the probability of mortality was lower for M-BWP compared to H-BWP classes until WNWi exceeded 4.8 kg; above a WNWi of 7.2 kg, cumulative losses increased ($P \leq 0.05$) in M-BWP compared to H-BWP gilts. Mortality until d 70 and d 170 after birth was affected ($P \leq 0.05$) by WNWi but not affected by BWP, nor by the WNWi by BWP interaction. A lower WNWi was associated with increased gilt losses and the best cut-off point estimation for survival at d 70 was 4.8 kg (AUC = 0.93%; $P < 0.0001$; Figure 5B) and at d170 was 5.2 kg (AUC = 0.85%; $P < 0.0001$; Figure 5C).

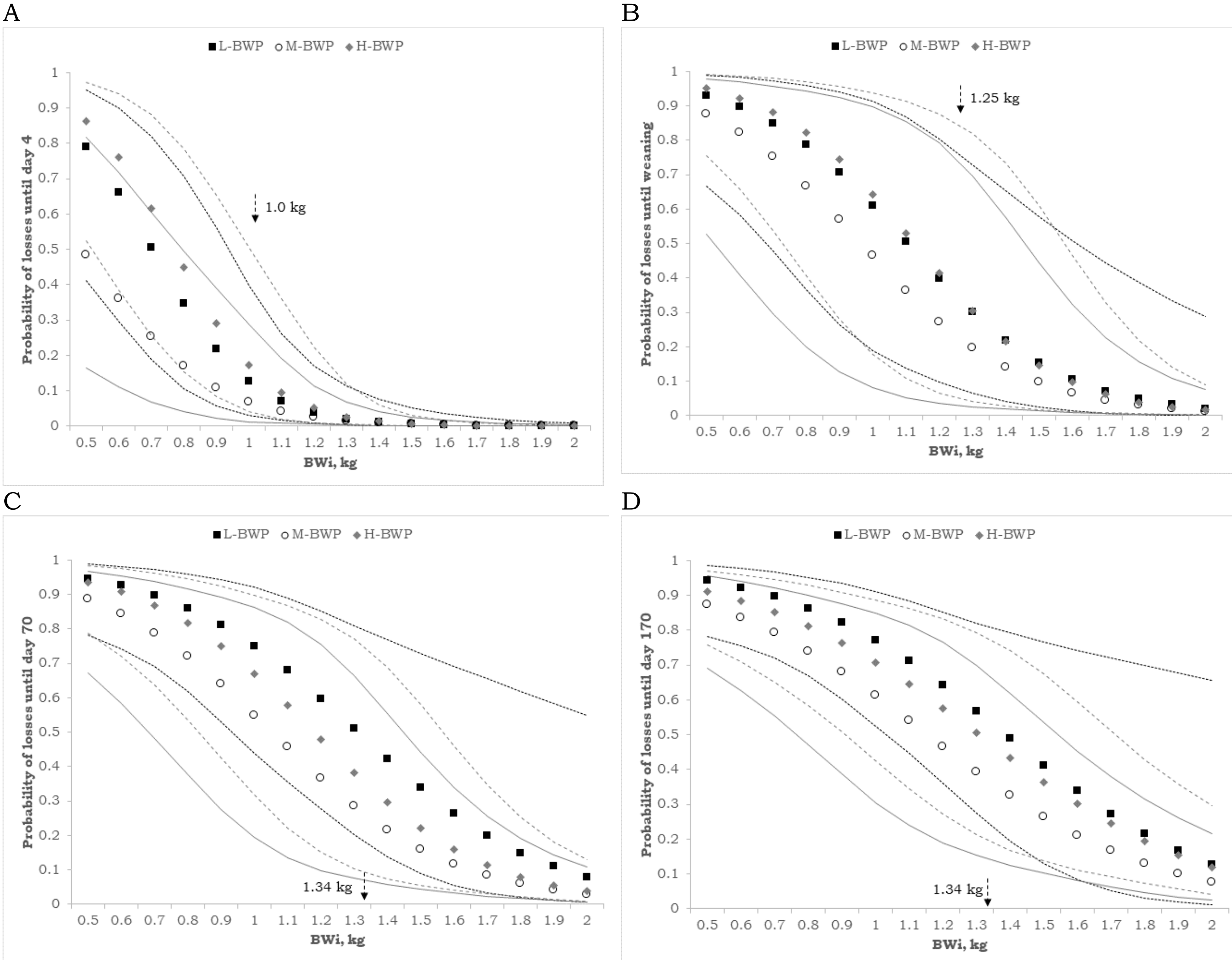

Figure 4. Predicted probabilities of mortality and losses until A) 4 days of age B) weaning C) 70 days of age D) final pre-selection by individual birth weight (BWi) and birth weight phenotype (BWP) estimated using logistic regression models. L-BWP: piglets with an individual birth weight < 1.0 kg; M-BWP: piglets with an individual birth weight ≥1.0 to ≤ 1.2 kg; H-BWP: piglets with an individual birth weight > 1.2 kg. The dashed arrow indicates the best cut-off point of BWi for survival until 4 days of age, at weaning, at 70 days of age and at 170 days of age. Gray dashed line, solid gray line, solid gray line and dotted black line indicate the 95% confidence limits for L-, M- and H-BWP, respectively.

Retention Rate from birth to 170 days of age

The litters of sows with the L-BWP are largely composed of low individual birth weight gilts, and the current results show that by 170 days of age 78.9 ± 7.5% of gilts born to L-BWP sows were removed from the herd compared to 50.0 ± 9.4% and 48.5 ± 9.4% of M-BWP and H-BWP, respectively ($P < 0.0001$) (Figure 6).

Results confirm that gilts born to L-BWP sows had lower retention rates by d4, weaning, d70 and d170 after birth. Most gilts either died or were culled by weaning.

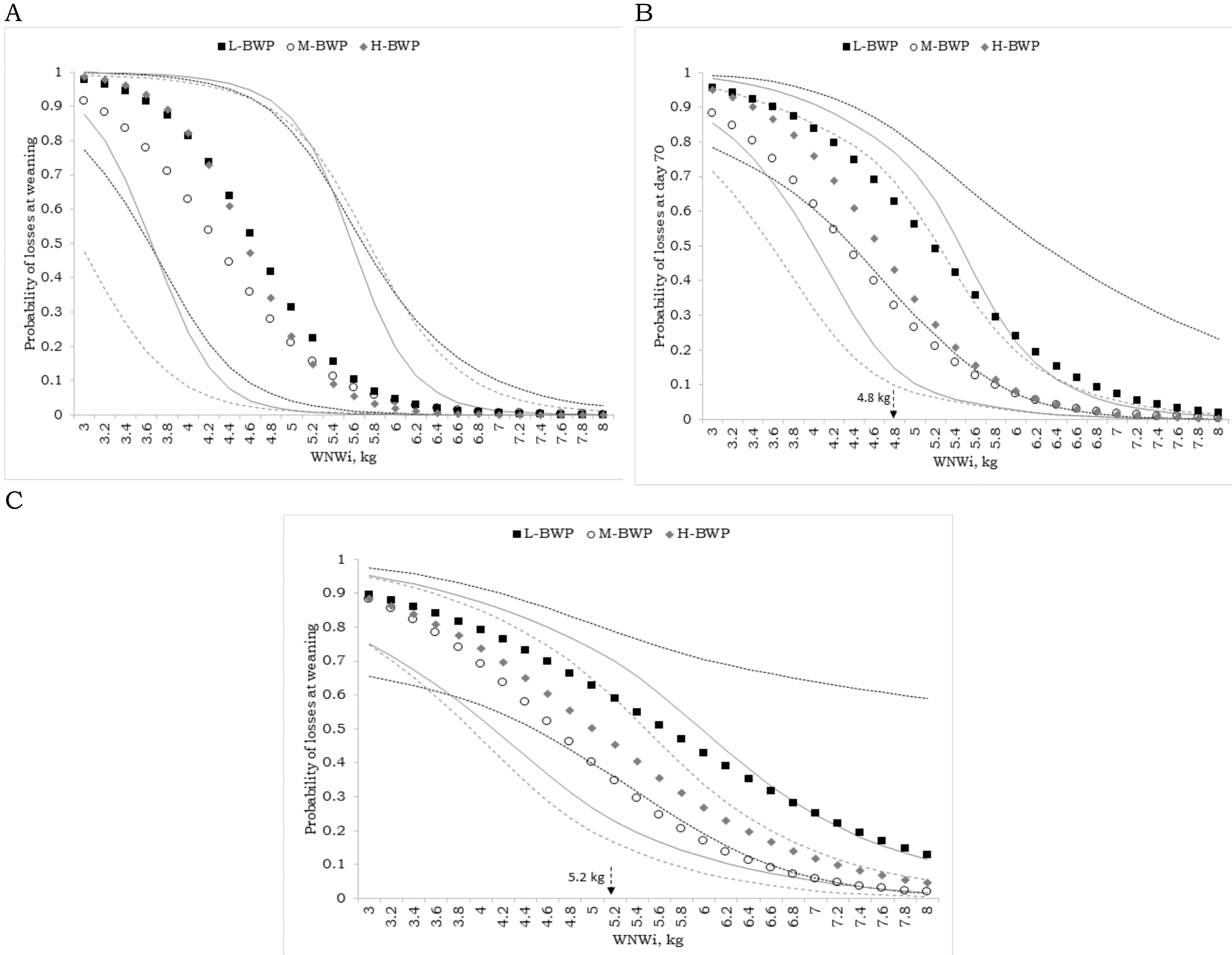

Figure 5. Predicted probabilities of mortality and losses until A) weaning, B) 70 days of age, and C) final pre-selection by individual weaning weight (WNWi) and birth weight phenotype (BWP) estimated using logistic regression models. L-BWP: piglets with an individual birth weight < 1.0 kg; M-BWP: piglets with an individual birth weight ≥1.0 to ≤ 1.22 kg; H-BWP: piglets with an individual birth weight > 1.22 kg. The dashed arrow indicates the best cut-off point of BWi for survival until 4 days of age, at weaning, at 70 days of age and at 170 days of age. Gray dashed line, solid gray line, solid gray line and dotted black line indicate the 95% confidence limits for L-, M- and H-BWP, respectively.

Effects of litter size in lactation supporting implementation of "litter size reduction strategies" for lower birth weight gilts early in lactation.

As illustrated above, only 34% of L-BWP gilts originally tagged at birth were retained after weaning. As a result, data from an insufficient number of L-BW were available to test the effect of lactation litter size on gilt retention in this phenotype. Additionally, from a practical implementation perspective, extreme low BWP sows and their litters are destined to be removed from the replacement gilt flows, and the implementation of "litter reduction strategies" would, therefore, focus litters from the M- and H-BWP sows.

The number of pigs at weaning, gilt weaning weight, and retention rate to weaning, 70 day of age and 170 days of age according to the BWP and the number of pigs present at 4 days after birth within these phenotypes are shown in Table 2. Significant effects of BWP (M-BWP: 5.1 ± 0.2, H-BWP: 5.4 ± 0.1 kg) and litter size at day 4 after birth (12-14: 5.4 ± 0.1, 15-16: 5.1 ± 0.1 kg) on weaning weight were detected ($P < 0.01$). Retention to weaning (12-14: 83.3 ± 0.9, 15-16: 72.2 ± 0.1 %), d70 (12-14: 79.4 ± 0.8, 15-16: 64.4 ± 1.0 %) and d170 (12-14: 64.0 ± 0.9, 15-16: 53.9 ± 0.9 %) days of age was positively affected by a lower lactating litter size at day 4 after birth. These results confirm that reducing the lactating litter size by day 4 of lactation increases weaning weight and results in more pigs being retained at weaning, and at 70 and 170 days after birth.

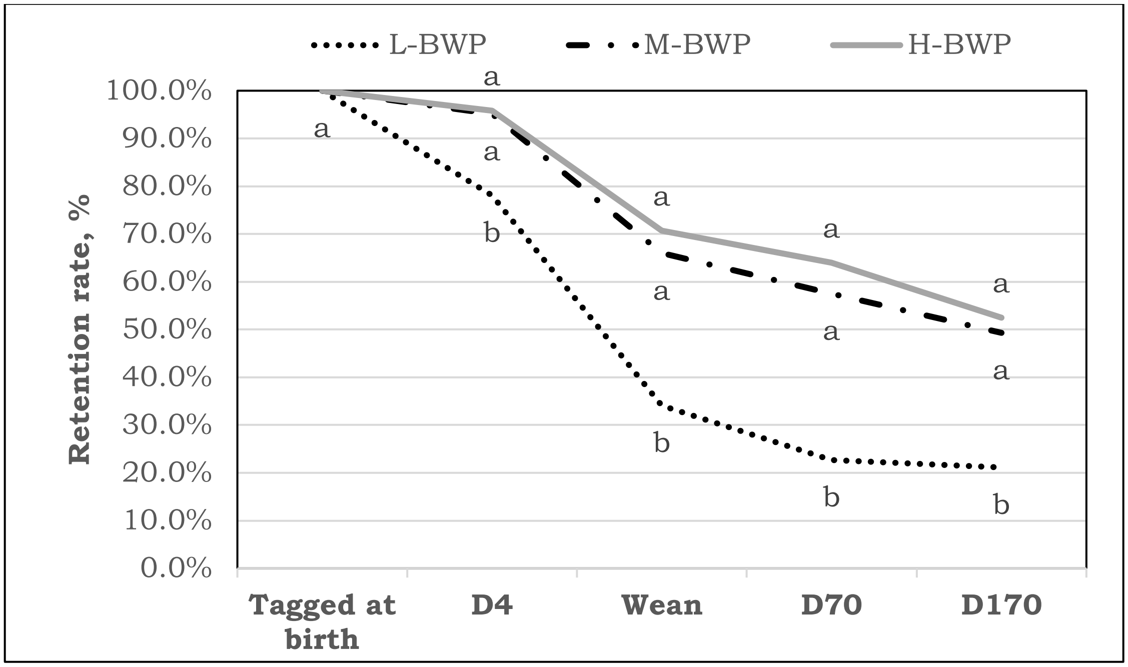

Figure 6. Retention rate to d 170 days of age for gilts classified according to the birth weight phenotype of their litter of origin. [a,b] Within time period, significant difference between phenotype classification ($P < 0.05$).

Table 3. Number of pigs at weaning, gilt weaning weight and retention rate to weaning, 70 day of age and 170 days of age according to the birth weight phenotype of their litter of origin and number of pigs lactating 4 days after birth

	Medium (>1.00 to ≤1.22 kg		High (>1.22 kg)		P-value		
Litter size at day 4 after birth[1]	12-14	15-16	12-14	15-16	BWP	NoD4	B*No
Number of gilts	119	209	315	300			
Average weaning weight, kg	5.2 ± 0.2[ab]	4.9 ± 0.1[b]	5.6 ± 0.2[a]	5.2 ± 0.1[b]	<.01	<.01	0.50
Number of pigs at weaning	12.6 ± 0.2[a]	13.0 ± 0.1[b]	13.9 ± 0.[c]	13.6 ± 0.1[d]	0.77	<.01	<.01
Retention to							
Weaning, %	77.8 ± 1.2	73.6 ± 1.2	87.7 ± 0.7	70.8 ± 1.6	0.34	0.03	0.16
70 days of age, %	73.0 ± 1.1	64.0 ± 1.1	84.6 ± 0.7	65.0 ± 1.1	0.14	<.01	0.20
170 days of age, %	60.3 ± 1.1	55.5 ± 1.0	67.6 ± 0.9	52.2 ± 1.0	0.65	0.04	0.26

[1]The average number of pigs lactating at day 4 of lactation.
[a,b,c,d] Within row, significant difference between phenotype classification ($P < 0.05$).

Repeatability of Birth Weight Phenotype

The relationship between average litter birth weight in parity 1 vs average litter birth weight in parity 2 in the same L3 sows for which data were available (n=93) is illustrated in Figure 7. There was a positive relationship between parity 1 and parity 2 litter average birth weight of that litter (y = 0.3695x + 0.9, $R^2 = 0.14$, $P < 0.0002$; Figure 3a). The average litter birth weight for Parity 2 over the population is 1.37 kg (solid black line). The dashed black line indicates the birth weight of 1.0 kg, below which primiparous sows were classified as having a low BWP.

These results are consistent with previous observations on the repeatability of litter birth weight phenotype across successive parities. This provides the opportunity to identify and cull sows expressing an extreme low birth weight phenotype at an early stage, thereby increasing the overall efficiency of replacement gilt production in the remaining sows in later parities.

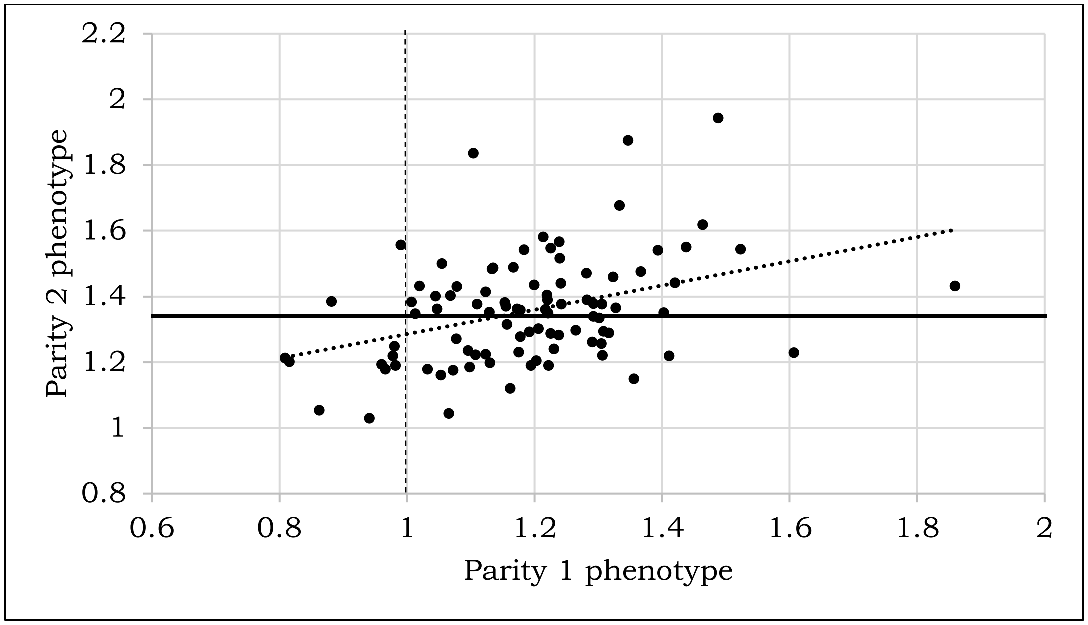

Figure 7. The relationship between average litter birth weight in parity 1 vs average litter birth weight in parity 2 in the same L3 sows (n=93). The average litter birth weight for Parity 2 over the population is 1.37 kg (solid black line). The dashed black line indicates the birth weight of 1.0 kg, below which sows were classified as having a low birthweight phenotype.

Discussion:

As has been observed previously, at the extreme low end of the birth weight range, all gilts in the litter fall below the "risk" threshold for survival and would have poor retention to the pre-selection stage of development at around 170 days. Strategic culling of the sows producing these litters therefore makes a proportionately high contribution to addressing the problem of low birthweight gilt offspring on gilt retention. As the extreme low BWP is a very repeatable trait, collection of even first parity litter birth weights will allow nucleus sows with the most extreme low birth weight phenotypes (averaging less than 1.0 kg) to be identified. These sows can then be strategically culled with little fear that they would have achieved a higher and more productive BWP in later parities.

As weaning weight has been shown to be another good predictor of subsequent gilt development, retention to breeding, and ultimately sow lifetime productivity (SLP), collection of the appropriate weaning weight data in the Implementation Project has allowed the relationship between original birth weight and the number of pigs in the litter at day 4 on weaning weight to be confirmed in the absence of any voluntary management interventions. The results available to-date (shown in Figure 4) confirms the likely value of the proposed strategy of intentionally reducing the number of pigs suckling in litters in the of the lower birth weight categories retained at nucleus-multiplication level, with the intention of breaking the relationship between a lower relative birth weight and weaning weight. The projected outcome of this marginal litter size reduction strategy, is an improvement in gilt retention to the pre-selection stage of production. Overall, increased gilt retention in litters from sows remaining in production in the nucleus-multiplication herd will offset the limited supply of replacement gilts from the culled low BWP sows, that were recorded as having only a 30% retention rate at weaning.

It was unfortunate that the PRRS-v outbreak in the nucleus-multiplication farm used in these studies prevented the collection of a more comprehensive set of data on the impacts of sow BWP on replacement git production at the production nucleus level and the downstream benefits for commercial replacement gilt production. However, the data available support the suggestions that sows with an extreme and repeatable low BWP will produce very few replacement gilts if left in production and disproportionally compromise genetic transfer from nucleus sow to commercial sow level of production. Early intervention strategies like the culling of the 10% or so of nucleus sows with the extreme low BWP, and manipulations to marginally reduce the size nucleus sow litters by day 4 after birth, can make proven contributions to the efficiency of the nucleus-multiplication herd in terms of the number of replacement gilts produced per sow bred.

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