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Benchmarking framework for predicting sow reproductive efficiency from parity, genotype, and cycle dynamics

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Improving reproductive efficiency remains a central objective in modern pig production, and robust benchmarking tools are essential for identifying the biological and management factors that influence litter size in commercial herds. This study analysed 1,013 reproductive records from a Czech commercial farm (2019–2022) to quantify how parity, genotype, gestation length, farrowing interval, weaning-to-conception interval, season, and year of conception contribute to variation in total piglets born (TNB) and piglets born alive (NBA). A Poisson mixed-effects modelling approach was applied to estimate incidence rate ratios (IRR) using Statistica 14 (TIBCO Software Inc.), allowing for the evaluation of the relative magnitude of each factor. Parity had the strongest biological influence. Sows were classified into 3 parity groups (1–2, 3–5, and 6–7). Parity group 1 produced smaller litters (TNB IRR: 0.944; NBA IRR: 0.971) compared with the reference group 3, while parity group 2 showed the highest prolificacy (TNB IRR: 1.047; NBA IRR: 1.049). Genotype also contributed significantly to the variation. The large White × Landrace genotype achieves higher TNB (IRR: 1.044) and NBA (IRR: 1.027) than the reference genotype, and pure Large White sows demonstrated similarly favourable results. A short weaning-to-conception interval (≤4 days) increased TNB (IRR: 1.025) and had a positive, although smaller, effect on NBA. By contrast, gestation length, farrowing interval, and season at conception had minimal influence under stable production conditions. Predicted litter values from the model were used to develop a practical benchmarking system classifying reproductive performance as optimal, expected, or suboptimal. This framework provides producers with a clear decision-support tool for sow retention, gilt replacement, and breeding planning, supporting more efficient and sustainable reproductive management in commercial swine herds.

Keywords: sow; reproduction; parity; litter size; predictive model; benchmarking.

Introduction

Reproductive efficiency is essential for profitable and sustainable swine production. One of the most important economic measures is the number of piglets weaned per sow each year (Klimas et al., 2020; Knox, 2025). This depends largely on litter size, both total number born (TNB) and number born alive (NBA), as well as how quickly sows can reproduce again (Bell et al., 2015; Koketsu et al., 2017). Even small improvements in these outcomes can have a substantial effect on the overall productivity and economic viability of commercial operations (Guan et al., 2022). Accurate and timely prediction of sow performance is therefore essential for making informed management decisions, such as strategic culling or tailored nutritional intervention (Piñeiro et al., 2019). However, predicting reproductive success remains challenging due to the complex interplay of biological, genetic, and management factors (Piñeiro et al., 2019).

Continuous efforts to identify and optimise the factors governing sow prolificacy remain a critical focus in animal science (Arango et al., 2005; Guan et al., 2022). A substantial body of research has identified several key factors influencing sow reproductive performance. Parity is consistently recognised as a major determinant, with a documented curvilinear relationship where litter size typically increases until the third to fifth parity before declining (Yang et al., 2019). Genetic composition also plays a crucial role, with cross-breeding strategies often employed to harness heterosis and improve litter traits (Bell et al., 2015). Beyond these intrinsic factors, management practices are equally critical. The weaning-to-conception interval (WCI) is also well-established as a key performance indicator; shorter intervals are strongly correlated with improved subsequent litter size and sow longevity (Yatabe et al., 2019). Studies have been conducted in regards with other variables, including gestation length, farrowing interval, age at first farrowing, and seasonal effects, with their impacts documented to varying degrees (Nowak et al., 2020a; Nowak et al., 2020b). Despite this extensive knowledge base, a noticeable gap remains between research findings and practical application on commercial farms. Many existing studies analyse these factors in isolation or under controlled research station conditions, which may not fully capture the integrated, non-linear dynamics present in a commercial farm environment (Piñeiro et al., 2019). While these studies effectively identify problems and associations, they often fall short of translating their findings into practical, predictive tools for daily herd management. There is a pressing need for integrated, multifactorial analyses that simultaneously evaluate management, genetic, and temporal variables within commercial herds to generate actionable insight (Piñeiro et al., 2019; Guan et al., 2022). Moreover, continuous genetic progress and evolving management practices necessitate contemporary, longitudinal data to establish current benchmarks (Sanz-Fernández et al., 2024). Finally, the development of predictive systems that allow farmers to track performance against empirically derived targets requires a foundational analysis of key, routinely recorded performance indicators from the real world (Piñeiro et al., 2019; Guan et al., 2022).

Therefore, the objective of this study was to develop and validate a practical benchmarking framework for predicting sow reproductive efficiency. We focused specifically on predictors that are routinely and reliably recorded in most commercial herd management software (parity, genotype, farrowing interval, gestation length, weaning-to-conception interval, season and year of conception) to ensure that the results would be widely applicable. Using a four-year dataset from a commercial herd, this research sought to (1) quantify the simultaneous effects of these factors on TNB and NBA; (2) identify the most influential predictors of reproductive performance; and (3) establish benchmark categories for herd-level evaluation and individual sow decision making. We hypothesised that an integrated analysis of a modern commercial dataset would reveal parity as a dominant biological driver and would identify a critical management threshold for WCI, enabling the creation of a highly accurate and practical benchmarking tool. By integrating multiple determinants of prolificacy into a unified analytical model, this study would contribute practical tools for performance monitoring and provide empirical insights into the biological and management drivers of sow reproductive success.

Materials and methods

The present research was designed using a dataset of 1,013 sows collected from the cloud-based digital herd management system of a commercial farm in the South Bohemia region of the Czech Republic (approximately 49°16′ N, 13°54′ E) between 2019 and 2022. The region experiences a temperate continental climate, which averages 8.4 °C and 650 mm of precipitation per year. The farm maintained a closed herd system with standard biosecurity, health monitoring, and vaccination procedures. Large White (LW), Landrace (L), and Large White × Landrace (LW × L) cross-bred sows made up most of the herd. Duroc boars were used as terminal sires to produce market pigs. Fresh semen dosages from artificial insemination studs recognised by the Czech Pig Breeders Association were frequently utilised. When the gilts reached 140 kg of body weight, or about eight months of age, they were added to the breeding herd. Any sow that displayed a standing reflex, characterised by immobility, was artificially inseminated. During breeding and early stages of gestation, sows were kept individually in gestation stalls. Sows were transferred from individual breeding units to a collective group-housing gestation facility once pregnancy was confirmed. On average, piglets were weaned between 26 and 30 days of age. Lactating sows were housed in environmentally controlled housing with mechanical ventilation and localised heating for piglets. Rations were prepared in accordance with the National Research Council (2012) and were delivered by an automated feeding system. Water was freely accessible through nipple drinkers.

Table 1
Descriptive statistics (mean ± SD) of sow reproductive traits for all-born piglets and live-born piglets

Parameters	All-born piglets (TNB)	Live-born piglets (NBA)
	Parity	
1–2	15.6 ± 3.4^{b}	14.3 ± 3.2^{b}
3–5	17.3 ± 3.5^{a}	15.5 ± 3.2^{a}
6–7	16.7 ± 3.6^{a}	14.5 ± 3.5^{b}
	Season at first conception (SFC)	
Dec–Feb	16.3 ± 3.6^{ns}	14.7 ± 3.4^{ns}
Mar–May	16.3 ± 3.5^{ns}	14.7 ± 3.1^{ns}
Jun–Aug	16.6 ± 3.6^{ns}	15.1 ± 3.2^{ns}
Sep–Nov	16.2 ± 3.7^{ns}	14.6 ± 3.5^{ns}
	Genotype	
LW	16.4 ± 3.8^{a}	15.0 ± 3.5^{a}
LW × L	16.6 ± 3.5^{a}	14.9 ± 3.2^{a}
L × LW	14.7 ± 3.4^{b}	13.6 ± 3.2^{b}
	Gestation length (GL)	
≤114	16.6 ± 3.6^{ns}	15.1 ± 3.4^{ns}
≥115	16.3 ± 3.6^{ns}	14.7 ± 3.3^{ns}
	Farrowing interval (FI)	
≤146	16.9 ± 3.4^{ns}	15.2 ± 3.2^{ns}
≥147	16.8 ± 3.7^{ns}	15.1 ± 3.3^{ns}
	Weaning-to-conception interval (WCI)	
≤4	17.1 ± 3.4^{a}	15.3 ± 3.1^{ns}
≥5	16.3 ± 3.9^{b}	14.7 ± 3.6^{ns}
	Year of conception (YC)	
2019	15.2 ± 3.6^{b}	13.9 ± 3.4^{b}
2020	15.7 ± 4.0^{b}	14.4 ± 3.6^{b}
2021	16.3 ± 3.7^{ab}	14.6 ± 3.3^{a}
2022	16.9 ± 3.1^{a}	15.3 ± 3.3^{a}

Note: within each parameter, mean in the same column with different letter superscript ($^{a,\ b}$) differ significant, while "ns" as a superscript indicates no significant differences, as determined by Tukey's HSD post hoc test at P < 0.05.

Each record contained data on sow genotype, parity, TNB, NBA, GL, FI, WCI, SFC, and YC. Parity was categorised into three groups (1–2, 3–5, and 6–7). Records with missing or implausible values were excluded. To remove data-entry errors and pathological cases, sows with GL < 110 days or > 118 days, or WCI > 35 days were eliminated from the dataset. After data cleaning, 1,013 full observations remained for analysis. Shapiro-Wilk tests were used to verify the normality of continuous variables. All analyses were performed in Statistica 14 (Tibco Software Inc.).

The modelling approach was designed to determine benchmark values for anticipated reproductive output under commercial production settings and to identify the most significant drivers of sow reproductive efficiency. The generalised linear mixed model (GLMM) with a Poisson distribution and log link function was fitted to the data using the Laplace approximation algorithm. The model's response variables were TNB and NBA. Parity, genotype, GL, FI, WCI, SFC, and YC were the fixed effects that were taken into consideration. To accommodate repeated measurements across parities within the same sow, sow identity was added as a random effect. Descriptive statistics are presented as mean ± standard deviation (SD) to reflect variability among individual observations, whereas Poisson regression and model-predicted mean were reported as mean ± standard error (SE) to indicate the precision of parameter estimation.

The model was specified as:

$$log(\mu ijklmno) = \beta_0 + PAR_i + GEN_j + GL_l + FI_m + WCI_n + YC_o + SFC_p + u_q + \varepsilon_{ijklmno}$$

where: ($\mu ijklmno$) is the expected count of piglets (TNB or NBA) per farrowing, β_0 is the overall intercept, PAR_i, GEN_j, GL_l, FI_m, WCI_n, SFC_p, and YC_o represent the fixed effects of the corresponding factors, u_p is the random effect of sow, and $\varepsilon_{ijklmno}$ is the random residual term.

P < 0.05 was used to assess the model's significance. Model comparison and model fit were evaluated using the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). To make benchmarking easier, estimated means (least square means) were calculated for key factors. Predicted mean values of TNB and NBA were extracted from the final model and stratified by parity group, genotype, and important reproductive cycle intervals in order to create benchmarking frameworks. When comparing individual sow or herd-level performance to model-predicted expectations under comparable circumstances, these values were used as reference performance markers.

The dataset used in this study originated from the performance record of a commercial producing farm. There was no intrusive procedure or experimental treatment. As a result, the study did not require ethical approval.

Results

Descriptive statistics of sow reproductive traits are presented in Table 1. Significant difference was observed in some individual parameters. Parity had considerable influence on prolificacy. A substantial increase in litter performance was observed in the parity 3-5 group (17.3 ± 3.5 all-born and 15.5 ± 3.2 live-born piglets) compared with the parity 1-2 group (15.6 ± 3.4 all-born and 14.3 ± 3.2 live-born piglets). Cross-bred Large White × Landrace (LW × L) sows produced the highest number of all-born piglets (16.6 ± 3.5), while Large White (LW) sows had the highest number of live-born piglets (15.0 ± 3.5). Conversely, Landrace × Large White (L × LW) sows had smaller litters for both traits (14.7 ± 3.4 all-born and 13.6 ± 3.2 live-born piglets), confirming a heterosis advantage associated with the LW × L cross. Reproductive management factors also influenced performance. A shorter weaning-to-conception interval (WCI ≤ 4 days) was significantly different for all-born piglets only (17.1 ± 3.4) when compared with WCI ≥ 5 days (16.3 ± 3.9). Farrowing interval, season at first conception, and gestation length were not significantly different for both all-born piglets and live-born piglets. The year of conception significantly influenced litter size, with 2022 having different parameters (16.9 ± 3.1 all-born and 15.3 ± 3.0 live-born) compared with 2019 (15.2 ± 3.6 all-born and 13.9 ± 3.4 live-born piglets).

The Poisson regression models (Table 2 and 3) identified parity, genotype, and weaning-to-conception interval as the most significant predictors of both all-born and live-born litter size. For all-born, sows in the parity 3–5 group showed significantly higher productivity (IRR = 1.047; P < 0.001) relative to the reference group (parity 6–7), whereas the parity 1–2 sows had reduced prolificacy (IRR = 0.944; P < 0.001). For live-born piglets, a similar pattern was seen: Parity 1–

2 once again showed decreased performance (IRR = 0.972; P = 0.027), while parity 3–5 showed improved output (IRR = 1.049; P < 0.001). Additionally, genotype LW and LW × L had a significant impact compared with the reference genotype (L × LW). For LW and LW × L, IRR ranged from 1.027 to 1.044 for both outcomes (P < 0.05).

Among management variables, a shorter weaning-to-conception interval (≤ 4 days) increased the likelihood of higher all-born litter size (IRR = 1.025; P = 0.013); the same trend was observed for live-born piglets, although the effect was marginal (IRR = 1.020; P = 0.061). By contrast, gestation length, farrowing interval, and season of first conception had no significant effect on either trait. Year of conception showed modest influences, with lower litter sizes in earlier years (notably 2019) relative to the 2022 reference. Overall, the regression analyses confirmed that parity, genotype, and WCI are the strongest and most consistent determinants of sow reproductive efficiency in commercial production settings.

Table 2
Poisson regression parameter estimates and rate ratio for factors influencing all-born piglets

Effect	Group level	Estimate β ± SE	Wald χ	Incidence Rate Ratio (IRR)	P-value
Parity	6–7 (Ref.)	2.805 ± 0.011	69926.68	16.536	<0.0001
	1–2	-0.058 ± 0.012	21.78	0.944	<0.0001
	3–5	0.046 ± 0.013	13.21	1.047	0.0003
SFC	Sep–Nov (Ref.)	2.794 ± 0.008	128253.20	16.350	<0.0001
	Dec–Feb	-0.002 ± 0.013	0.00	0.998	0.8623
	Mar–May	-0.002 ± 0.014	0.00	0.998	0.8976
	Jun–Aug	0.014 ± 0.013	1.20	1.015	0.2706
Genotype	L x LW (Ref.)	2.764 ± 0.011	59626.44	15.860	<0.0001
	LW	0.031 ± 0.015	3.94	1.031	0.0472
	LW x L	0.043 ± 0.012	11.87	1.044	0.0005
GL	≥115 (Ref.)	2.799 ± 0.008	109913.80	16.420	<0.0001
	≤114	0.010 ± 0.008	1.30	1.010	0.2553
FI	≥147 (Ref.)	2.826 ± 0.009	90265.26	16.870	<0.0001
	≤146	0.003 ± 0.009	0.09	1.003	0.8254
WCI	WCI ≥5 (Ref.)	2.816 ± 0.010	79580.20	16.700	<0.0001
	WCI ≤4	0.025 ± 0.010	6.20	1.025	0.0128
YC	2022 (Ref.)	2.775 ± 0.010	76440.05	16.040	<0.0001
	2019	-0.051 ± 0.024	4.45	0.951	0.0347
	2020	-0.018 ± 0.016	1.27	0.982	0.2594
	2021	0.015 ± 0.014	1.10	1.015	0.2941

Table 3
Poisson regression parameter estimates and rate ratio for factors influencing live-born piglets

Effect	Group level	Estimate β ± SE	Wald χ	Incidence Rate Ratio (IRR)	P-value
Parity	6–7 (Ref.)	2.692 ± 0.011	56397.10	14.764	<0.0001
	1–2	-0.028 ± 0.013	4.89	0.972	0.0270
	3–5	0.047 ± 0.013	12.39	1.049	0.0004
SFC	Sep–Nov (Ref.)	2.693 ± 0.008	107672.70	14.780	<0.0001
	Dec–Feb	-0.002 ± 0.014	0.00	0.998	0.8678
	Mar–May	-0.004 ± 0.015	0.10	0.996	0.8044
	Jun–Aug	0.022 ± 0.014	2.40	1.022	0.1182
Genotype	L x LW (Ref.)	2.674 ± 0.012	51345.05	14.500	<0.0001
	LW	0.035 ± 0.016	4.83	1.036	0.0279
	LW x L	0.027 ± 0.013	4.20	1.027	0.0405
GL	≥115 (Ref.)	2.700 ± 0.009	92831.81	14.880	<0.0001
	≤114	0.015 ± 0.009	2.67	1.015	0.1018
FI	≥147 (Ref.)	2.717 ± 0.010	74887.59	15.130	<0.0001
	≤146	0.004 ± 0.010	0.17	1.004	0.8171
WCI	WCI ≥5 (Ref.)	2.709 ± 0.011	66316.06	15.010	<0.0001
	WCI ≤4	0.020 ± 0.011	3.50	1.020	0.0614
YC	2022 (Ref.)	2.677 ± 0.011	64613.73	14.540	<0.0001
	2019	-0.048 ± 0.025	3.68	0.953	0.0552
	2020	-0.008 ± 0.017	0.23	0.992	0.6289
	2021	0.003 ± 0.015	0.04	1.003	0.8424

The model-predicted means for all-born and live-born piglets across variables included in the final Poisson regression model are shown in Table 4. Benchmark categories reflecting optimal, expected, or suboptimal reproductive performance were created using the predicted values. Parity 3–5 displayed the highest predicted litter size for both traits and was therefore classified as the optimal performance benchmark. Parity 1–2 was identified as suboptimal, while parity 6–7 represented an expected benchmark level. Among genotypes, Large White Landrace cross-bred sows constituted the optimal benchmark for total born, whereas Large White sows represented the optimal benchmark for live-born piglets. Short weaning-to-conception intervals (≤ 4 days) were associated with superior model-predicted performance and are thus considered optimal. By contrast, extended WCIs (≥ 5 days) served as a suboptimal benchmark due to their reduced predicted prolificacy. Other predictors, including gestation length, farrowing interval, and season at first conception, displayed lower model-predicted variation and were therefore categorised as expected performance benchmarks. Year of conception influenced predicted litter size, with 2022 serving as the optimal benchmark year due to the highest predicted output. Figure 1-3 represent the main factors that had the greatest impact on sow reproductive efficiency.

Discussion

The use of data-driven prediction techniques is becoming increasingly important in agriculture (Piñeiro et al., 2019; Su et al., 2025) and effort towards global food sustainability (Guilpart et al., 2022; Martini et al., 2022). In the swine sector, sow reproductive and biological cycles involve multiple interconnected factors, necessitating complex modelling approaches to enhance management and overall efficiency (Chitakasempornkul et al., 2019; Su et al., 2025). This study examined the relative importance of various reproductive factors on litter size and developed a performance benchmarking model for a commercial sow herd. By combining descriptive analyses with predictive modelling, it clarified how parity, genotype and other reproductive parameters collectively influence both total and live-born piglet numbers.

Table 4
Benchmarking Framework based on Poisson model-predicted means for all-born piglets and live-born piglets

Predictor	Group level	Predicted all-born (LSM ± SE)	Predicted live-born (LSM ± SE)	Benchmark
Parity	1–2	15.610 ± 0.011	14.340 ± 0.011	suboptimal
	3–5	17.310 ± 0.012	15.480 ± 0.013	optimal
	6–7	16.730 ± 0.027	14.480 ± 0.029	expected
SFC	Dec-Feb	16.320 ± 0.015	14.750 ± 0.016	expected
	Mar-May	16.320 ± 0.016	14.730 ± 0.017	expected
	Jun-Aug	16.590 ± 0.015	15.100 ± 0.016	expected
	Sep-Nov	16.180 ± 0.016	14.550 ± 0.017	expected
Genotype	LW	16.360 ± 0.018	15.020 ± 0.019	optimal (NBA)
	LW x L	16.560 ± 0.009	14.880 ± 0.010	optimal (TNB
	L x LW	14.740 ± 0.027	13.620 ± 0.028	suboptimal
GL	≤114	16.590 ± 0.014	15.090 ± 0.015	expected
	≥115	16.260 ± 0.009	14.660 ± 0.010	expected
FI	≤146	16.920 ± 0.015	15.200 ± 0.015	expected
	≥147	16.830 ± 0.012	15.070 ± 0.013	expected
WCI	≤4	17.130 ± 0.011	15.310 ± 0.012	optimal
	≥5	16.300 ± 0.017	14.720 ± 0.017	suboptimal
YC	2019	15.250 ± 0.031	13.860 ± 0.032	suboptimal
	2020	15.750 ± 0.019	14.420 ± 0.019	expected
	2021	16.280 ± 0.014	14.580 ± 0.015	expected
	2022	16.930 ± 0.012	15.340 ± 0.013	optimal

Parity emerged as one of the strongest predictors of the reproductive output in our study, confirming a non-linear pattern between parity and litter size. This finding aligns with the study by Koketsu & Iida (2020), who used farm-level data to predict breeding sow performance over a lifetime. Sows in parity 3–5 showed the highest predicted litter sizes, indicating peak productivity during this mid-parity stage. By contrast, gilts and early parity sows (parity 1–2) had lower reproductive success, while older sows (≥6 parity) displayed a declining trend compared with parity 3–5. Koketsu et al. (2017) also reported a similar trend when identifying key factors for improving sow reproduction in commercial breeding operations. The reduced output among younger parities likely stems from incomplete uterine development and less mature follicles (Patterson et al., 2010). These results highlight the importance of maintaining a herd structure with a larger proportion of mid-parity sows to optimise overall productivity (Koketsu et al., 2017). Genotype was another significant factor impacting litter size, with LW × L crosses and pure-bred LW performing better than L × LW. The 4.4% higher expected number for total piglets born in LW × L lines agrees with Thiengpimol et al. (2017), who documented the influence of Landrace and Large White genotype on sow reproductive traits in commercial herds. Similarly, Kantanamalakul et al. (2007) reported that heterozygous sows produce larger litters and piglets with greater birth weights compared with pure-bred Large White and Landrace sows. The interval between weaning and conception was also identified as a major driver of reproductive success (Tummaruk et al., 2010; Yatabe et al., 2019). Weaning-to-conception intervals at ≤4 days achieved significantly larger litters than those requiring ≥5 days. This supports the findings of Yatabe et al. (2019) on how weaning-to-first-mating interval influences lifetime performance and retention in parity 1 sows. A short WCI indicates faster physiological recovery and optimal hormonal profiles for fertilisation and embryo development. Therefore, reducing post-weaning stress and minimising body condition loss is essential for achieving shorter intervals and maximising subsequent litter performance (Koketsu et al., 2017; Arend et al., 2023). In the benchmarking framework, WCI ≤4 days represents the optimal reproductive performance, while ≥5 days signals decreased reproductive success.

Gestation length, season of conception, and farrowing intervals did not show a significant impact on reproductive performance in this study. This agrees with Kramarenko et al. (2024), who found no major effect of gestation length on reproduction among cross-bred sows on a large commercial farm. Gourley et al. (2020) also reported average gestation lengths of 115.8 and 115.5 days for LW × L crosses with no statistical difference, aligning with our results. While seasonal effects often influence reproduction in tropical environments due to heat stress, controlled housing and consistent environmental management in commercial farms can mitigate such impacts. This likely explains the insignificant patterns observed. These findings suggest that some traditionally monitored farm indicators may have limited benchmarking value when environmental variation is minimised.

The effect of year of conception reflects herd-level management changes that occurred between 2019 and 2022, including improvements in nutrition, biosecurity, gilt induction protocols, and farrowing management. The higher predicted litter sizes observed in 2022 indicate that management and genetic improvement over time had meaningful impacts on reproductive outcomes. Year effects in longitudinal datasets often encapsulate multiple subtle changes in herd conditions (Knox 2024), and the present data similarly highlight how continuous improvement programs contribute to better reproductive benchmarks.

One of the major contributions of this study is the establishment of predicted benchmarks for different reproductive categories. By translating predicted model means into practical performance categories (optimal, expected, and suboptimal), farms can more easily set targets, identify limitations, and prioritise interventions. These benchmarking-driven approaches are increasingly advocated in modern swine reproduction and management. This study is not without limitations, as the dataset represents a single commercial farm. Additionally, other variables such as body condition score and feed intake were not captured, yet could influence reproductive outcomes. However, even with these limitations, this research still serves as a benchmarking framework for sow reproductive efficiency. Future research addressing these limitations will improve the predictive accuracy and practical value of benchmarking frameworks.

Conclusion

This study introduces a practical benchmarking framework designed to help predict sow reproduction efficiency in real-world commercial farms by integrating factors such as parity, genotype, and reproductive cycle. The framework provides a clearer understanding of what drives litter size on modern farms. In our analysis, parity (especially 3–5), genotype (Large White × Landrace), and short weaning-to-conception intervals consistently showed the strongest influence on litter size. By contrast, other factors showed little effect under stable conditions. By translating model predictions into clear performance categories, this tool supports targeted management decisions to improve productivity. This framework offers a straightforward and data-driven approach to optimising reproductive outcomes in swine production.

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The authors declare no conflicts of interest.

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