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THE EFFECTS OF PEN DESIGN FOR FARROWING AND BOAR BREED ON REPRODUCTIVE TRAITS OF SOWS

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ABSTRACT: Modern pig production increasingly requires compliance with welfare-oriented housing standards, prompting farms to modernize farrowing systems while maintaining productive performance. This study aimed to evaluate the effects of farrowing pen design during the suckling period and boar line on the reproductive performance of sows, piglet growth, and survival under industrial conditions aligned with contemporary animal welfare requirements. The experiment was conducted using a 2 × 2 factorial design involving 192 sows (Large White × Landrace) of second to fourth parity and 2,443 piglets obtained through terminal crossbreeding with Maxter and PIC 337 boars. Animals were fed complete diets and housed under controlled microclimate conditions. Reproductive traits, piglet survival, and sow backfat thickness were assessed using standardized methods and subjected to statistical analysis. Sows housed in fixed traditional farrowing pens exhibited superior reproductive performance compared with those kept in improved welfare-oriented pens. The boar line significantly affected the total number of piglets born and the number born alive, with the highest total number of piglets born (14.1 piglets) recorded in sows inseminated with PIC 337 semen. Farrowing pen design had a significant effect on litter size, litter uniformity, stillbirth rate, litter weight at weaning, sow backfat thickness, and piglet weaning weight. The highest average daily gain and piglet live weight at weaning were observed in Group 1, whereas the lowest values were recorded in Group 4. Piglet survival to weaning was the highest in Group 3 (97.3%). A combined effect of farrowing pen design and boar line was identified for milk performance (defined as total milk output estimated from litter weight gain), litter uniformity index (reflecting within-litter variation in piglet body weight), and piglet survival. The practical significance of these findings lies in providing science-based recommendations for selecting farrowing pen configurations and boar lines that support welfare-compliant and efficient pig production systems in Ukraine. The study demonstrates a performance–welfare trade-off, whereby traditional pens improved piglet growth parameters, while welfare-oriented improved pens enhanced sow mobility. This balance should be considered when implementing welfare-compliant farrowing systems.

Keywords: Breeding systems, Fertility, Performance, Pig, Welfare.

INTRODUCTION

Modern pig production increasingly emphasizes the implementation of welfare-oriented housing systems that comply with international standards for the humane treatment of animals (Nevrkla et al., 2024; Vandresen et al., 2024). According to current scientific protocols, farrowing pen design must meet not only technological and sanitary-hygienic requirements but also the biological needs of animals at different physiological states (Dourmad et al., 2022). Properly organized pen designs reduce stress, minimize injuries to sows and piglets, and facilitate effective control of feeding, microclimate and sanitary conditions, thereby positively influencing productive performance and overall pork production efficiency (Leonard et al., 2020; Pacheco et al., 2024). The most critical periods in sow production are gestation, farrowing, lactation and weaning, during which animals are particularly sensitive to external stimuli and changes in housing and feeding conditions (Robbins et al., 2021; Do et al., 2023; Seddon and Moustsen, 2023). The use of specialized farrowing pen design protects piglets from crushing, ensures convenient access to the udder, provides designated areas for rest and activity, and allows farrowing operators to monitor and manage animals effectively while minimizing interference with natural behavioral patterns (Jang and Oh, 2022).

In many pig-producing regions, farms face economic constraints, limited access to modern equipment, and the need to balance production efficiency with rising welfare requirements (EFSA AHAW Panel, 2022; Vandresen et al., 2024).

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These challenges encourage for the development of cost-effective technological solutions, including the reconstruction of existing facilities and the gradual modernization of farrowing pen designs. Such approaches enable producers to optimize housing conditions, maintain or enhance animal welfare, and adapt to contemporary industry standards without compromising economic viability. Consequently, pork producers increasingly prioritize engineering flexibility, practical innovation, and strategic decision-making to meet both welfare expectations and economic demands (Lykhach et al., 2025).

In addition to technological and economic considerations, ethical aspects play an increasingly important role in the design and improvement of sow housing systems, particularly in the context of the European animal welfare movement and the adoption of advanced production technologies (Mahfuz et al., 2022; Turner et al., 2024). Growing attention to humane treatment promotes the implementation of housing designs that allow sows to partially express natural behavioral, including standing, lying down, changing body position, and interacting with piglets and the surrounding environment (Choi et al., 2020). Practical experience indicates that even under limited financial resources, farms can achieve substantial welfare improvements through rational pen redesign and the replacement or modification of individual structural elements (Ludwiczak et al., 2021; Malak-Rawlikowska et al., 2024).

At the same time, the use of adaptive farrowing pens – such as convertible structures that allow spatial adjustment according to piglet age and sow condition - represents a promising direction in housing system development. combining functional efficiency with animal welfare requirements and facilitating the expression of natural behaviors (Nevrkla et al., 2024; Mackinnon, 2024; Klassen et al., 2025). Such systems contribute to reduced injury risk, improved hygiene, simplified management, and, consequently, increased piglet survival and improved reproductive performance of sows (Glencorse et al., 2019). As a result, pig producers not only achieve better animal health and higher production efficacy, but also gain increased consumer trust, as public awareness of the ethical origin of animal products continues to grow.

Accordingly, even under current challenging economic conditions, investment in the reconstruction and functional improvement of farrowing pens represents strategic decision that enables national pig farms to remain competitive in both domestic and foreign markets, while supporting alignment with European integration goals and the sustainable development of the sector (Sossidou et al., 2025). At the same time, increasing attention is being paid to compliance with European regulatory standards in pig production, particularly the implementation of Council Directive 2008/120/EU, which restricts the long-term use of fixed farrowing crates (Council Directive 2008/120/EU). This regulatory framework presents both a challenge and an incentive for scientific research aimed at identifying optimal, adaptable housing solutions suitable for commercial farm conditions. The present study not only identifies farrowing pen design features that positively influence sow reproductive performance but also provides practical recommendations for the reconstruction and improvement of existing housing systems.

In view of the above, the motivation for this experiment was to ensure stable pork production under conditions of economic uncertainty, enhance the reproductive traits of sows and harmonize housing systems with European animal welfare. Therefore, this research is both timely and of direct practical relevance.

MATERIALS AND METHODS

Experimental design

The practical experiment was conducted on a commercial pig farm belonging to Viktoria Private Lease Enterprise (PLE) located in the Bashtanskiy district, Mykolaiv region, Ukraine. A total of 192 litters from suckling sows housed in the farrowing unit, comprising 2443 suckling piglets, were included in the study. The maternal genotype consisted of Large White × Landrace crossbred sows breeds, while the paternal genotypes were boars of the Maxter terminal line (France Hybrides, France) and the PIC 337 terminal line (PIC, United Kingdom). Artificial insemination of sows in the experimental groups was performed using the standard vaginal insemination technique, in accordance with the farm's approved reproductive protocol. Disposable insemination catheters manufactured by MS Schippers (Netherlands) were used to ensure a high level of biosecurity and ease of application. Freshly diluted semen obtained from boars housed at the farm's artificial insemination station was used, thereby minimizing ejaculate quality loss and improving fertilization efficiency. All insemination procedures were conducted in compliance with established technological, veterinary, and sanitary standards and were synchronized with the optimal estrus period of the sows.

The experiment was carried out in the reproduction and farrowing units, and the housing and management conditions were organized in accordance with the Departmental Norms of Technological Design: Pig Enterprises (Complexes, Farms, Small Farms-2005) and the recommendations of genetic companies, with due consideration of animal welfare principles.

According to the experimental scheme (Table 1), four experimental groups of sows were formed based on the principle of analogues (Ladyka and Khmelnychiy, 2023). A total of 192 clinically healthy sows of similar parity (second to fourth farrowing), live weight, body condition, and expected farrowing date were selected. Group formation followed the principle of analogues to ensure uniformity before allocation. After matching, sows were randomly assigned to one of four experimental groups using simple randomization within analogue blocks based on individual animal identification numbers. All groups were balanced for parity, body condition, and previous reproductive performance, and no significant differences were detected among groups prior to the start of the experiment.

During the non-productive (idle) and gestation periods, sows from all four groups were housed in group pens (Figure 1) manufactured by AgroDana LLC (Ukraine). Five days prior to the expected farrowing date, sows were transferred to the farrowing unit and allocated to housing to housing treatments as follows: sows in Groups 1 and 2 were housed in traditional fixed farrowing pens with a total area of 4.32 m² throughout the suckling period (Figure 2), whereas sows in Groups 3 and 4 were housed in improved farrowing pens with an increased total area of 7.20 m², allowing free movement from day 7 postpartum until weaning (Figure 3). All farrowing pens were manufactured by AgroDana LLC (Ukraine). Two types of farrowing pen designs were evaluated in the experiment, differing in construction, available space, and degree of sow mobility. Traditional pens (groups 1 and 2; total area 4.32 m²) were equipped with a standard fixed farrowing crate that restricted sow movement throughout the entire lactation period. The crate prevented the sow from turning around and limited forward and backward movement. A piglet creep area with a heated floor and protective anti-crushing rails was positioned along one side of the crate. This housing system represents the conventional farrowing design commonly used in intensive pig production. Improved pens (groups 3 and 4; total area 7.20 m²) were designed as partially free farrowing systems. During the first seven days postpartum, sows were temporarily restrained in a fixation crate to reduce the risk of piglet crushing during the critical neonatal period. After day 7, the crate was opened, allowing the sow free movement within the pen. The increased pen area enabled the sow to turn around, freely change body position, and interact with the surrounding environment. Improved pens were additionally equipped with an enlarged piglet creep area, anti-crushing rails, and a fully slatted plastic floor.

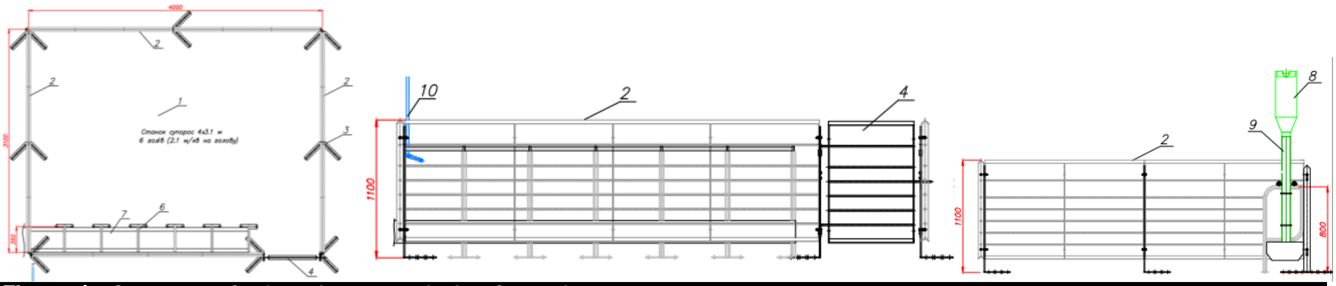

Figure 1 - Group pen for keeping sows during farrowing.
1 = Pen (top view); 2 = Side of the pen; 3 = Rack of fasteners to the concrete slatted floor; 4 = Pen`s door; 6 = Delimiter; 7 = Group feeder; 8 = Individual feeding dispenser; 9 = Dispenser outlet pipe; 10 = Nipple drinker.

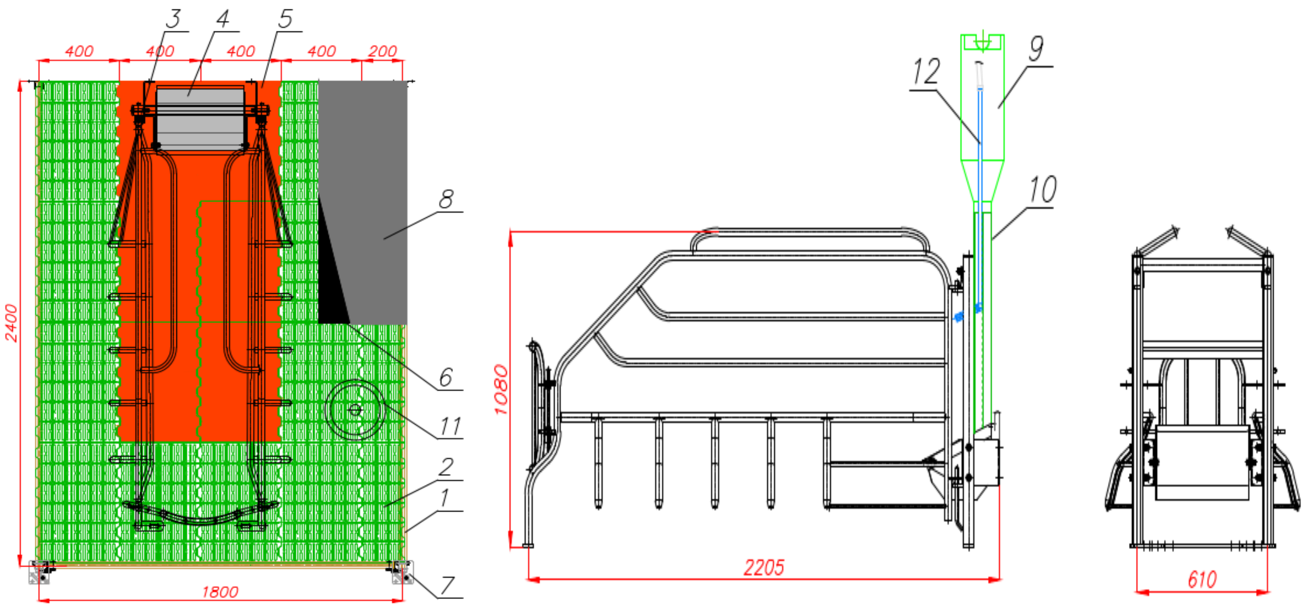

Figure 2 - Pen for keeping lactation sows and suckling piglets (traditional).
1 = Fence of the pen of polyvinyl chloride; 2 = Slatted plastic floor (50% open); 3 = Fixing pen; 4 = Sow feeder; 5 = Plastic floor (100% solid); 6 = heating carpet; 7 = Mounting rack; 8 = Piglet rest and heating space; 9 = Feeding dispenser; 10 = Dispenser lowering pipe; 11 = Suckling piglet feeder; 12 = Mounting and drinking bowl for the sow.

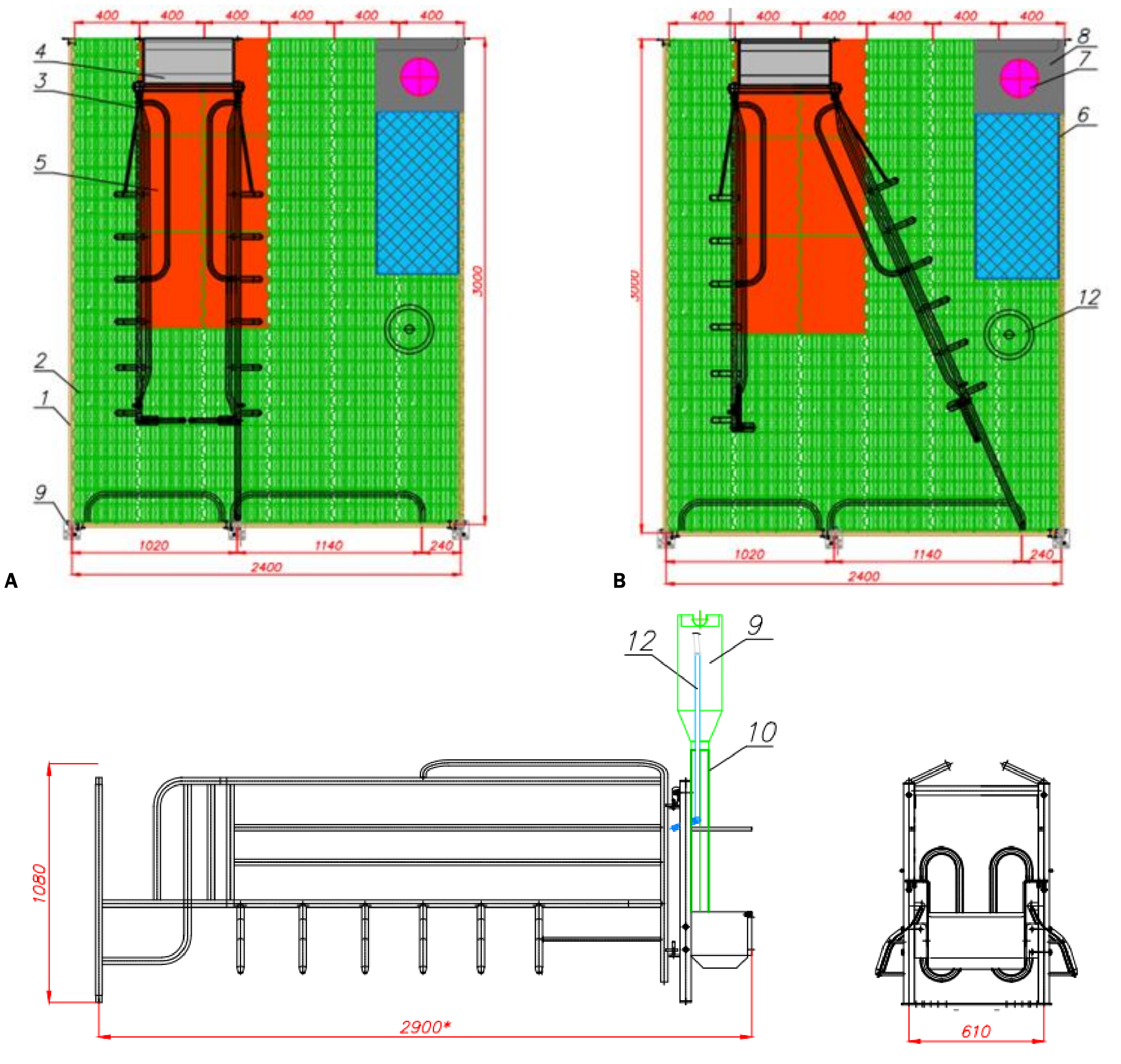

Figure 3 - Pen for free keeping of sows from 7 days after farrowing to weaning (improved).
A: Location of the fixing pen until 7 days after farrowing; B: Free keeping of sows after 7 days from the date of farrowing; 1 = Fence of the pen of polyvinyl chloride; 2 = Slatted plastic floor (50% open); 3 = Fixing pen; 4 = Sow feeder; 5 = Plastic floor (100% solid); 6 = Heating carpet; 7 = mounting rack; 8 = Piglet rest and heating space; 9 = Feeding dispenser; 10 = Dispenser lowering pipe; 11 = Suckling piglet feeder; 12 = mounting and drinking bowl for the sow.

Feeding

Sows were fed specialized complete compound diets formulated according to their physiological state, with separate rations for gestating and lactating sows. All feeds were produced at the farm's feed mill and formulated in accordance with internationally recognized nutritional standards for swine (NRC, 2012). To ensure adequate balancing of protein, minerals, and vitamins in the basal diet, protein-mineral-vitamin supplements and premixes manufactured by Cehavae Korm LLC (Ukraine) were incorporated into the feed. This approach ensured high nutritional value and compliance with the nutrient requirements of animals at different stages of the reproductive cycle. Feeding management was adjusted according to physiological status. During the non-productive (idle) and gestation periods, sows were fed restrictively at 2.8–3.1 kg per head per day. During the 28-day lactation period, sows received feed ad libitum, except on the day of farrowing, when feed allowance was limited to 1.0 kg per head. Suckling piglets were offered a commercial pelleted prestarter feed from day 7 postpartum via automated self-feeders. The ingredient composition and calculated nutritional values of all experimental diets are presented in Table 1. Water was supplied to sows through nipple drinkers to ensure continuous access and hygienic conditions. Suckling piglets were provided water via cup drinkers, positioned 7 cm above the floor, allowing easy access even for the smallest piglets.

Table 1 – Feed ingredients and nutritional value of diets for sows and piglets

Ingredients, %	Gestating sows	Lactating sows	Piglets Prestarter
Wheat	34.0	43.5	-
Barley	45.0	30.0	-
Sunflower meal	14.5	10.0	-
Soybean meal	3.0	11.5	-
Premix*	3.5	5.0	-
Complete pelleted feed**	-	-	100.0
Total	100.0	100.0	100.0
Nutritional value			
Metabolizable energy, MJ	12.20	12.40	13.60
Crude protein, g/kg	144.91	165.61	190.0
Crude fat, g/kg	16.62	16.09	58.0
Fiber, g/kg	57.68	50.82	27.0
Calcium, g/kg	7.67	9.88	7.40
Total phosphorus, g/kg	4.71	5.35	6.00
Digestible phosphorus, g/kg	3.02	3.67	5.50
Sodium, g/kg	2.14	2.50	2.50
Lysine, g/kg	6.30	9.33	15.60
Digestible lysine, g/kg	4.95	7.88	14.00
Methionine, g/kg	2.62	3.49	6.30
Digestible methionine, g/kg	2.18	3.06	5.90
Methionine+cystine, g/kg	5.42	6.49	9.20
Digestible methionine+cystine, g/kg	4.29	5.37	8.10
Threonine, g/kg	4.93	6.79	10.40
Digestible threonine, g/kg	3.50	5.30	8.80
Tryptophan, g/kg	1.73	1.98	3.50
Digestible tryptophan, g/kg	1.31	1.55	3.10
Vitamin A, IU/g	13149	13000	15000
Vitamin D3, IU/g	2023	2000	2500
Vitamin E, mg/kg	101.15	100.00	100.00

* - Cehavit Sow Gestation, Cehavit Sow Lactation; ** - Prestarter Cehavit Pig Lux C12.

Microclimate conditions

To ensure optimal microclimate conditions in piglet nests, a combined local heating system was used, including infrared incandescent lamps, electric heating mats, and brooders. This approach enabled the creation of comfortable thermal conditions for newborn piglets, thereby reducing stress and mobility and improving piglet survival. Ambient air temperature in the sow area was maintained at 20–22°C, while temperatures in piglet nests were maintained at 37–34°C during the first week postpartum and gradually reduced to 26–28°C by weaning. Relative humidity was kept within the range of 60–70%, and air velocity did not exceed 0.2 m/s to prevent draughts.

Ventilation in the pig housing was provided by a combined system of exhaust fans and aerodynamic air inlets operating under negative pressure (Deschenko et al., 2024). This system ensured effective removal of contaminated air and a continuous supply of fresh air, maintaining microclimatic parameters in accordance with technological requirements. Ventilation rates ranged from 5–10 m³/kg live weight per hour during the cold season and increased to 80–100 m³/kg live weight per hour during warm periods, ensuring efficient dilution and removal of ammonia, moisture, and dust. Manure removal was achieved using a periodically operated vacuum self-flowing system. Manure was collected in channels located beneath the slatted floor, allowing effective separation of animals from waste and contributing to reduced ammonia concentration and humidity levels in the housing. Veterinary preventive and therapeutic procedures were carried out identically for all experimental groups in accordance with the farm's approved veterinary health program. All procedures complied with biosafety requirements and included vaccination, deworming, and routine health monitoring. Housing and management conditions for experimental animals complied with the Departmental Norms of Technological Design: «Pig Enterprises (Complexes, Farms, and Small Farms)" (2005) and the recommendations of genetic companies.

Performance parameters

Reproductive performance of sows in the experimental groups (Table 2) was evaluated using the following indicators: total number of piglets born (TNB, head), number of piglets born alive (NBA, head), proportion of stillborn piglets (PSB, %), litter weight at birth (LWB, kg) and at weaning (28 days; LWW, kg), average piglet weight at birth (AWPB, kg) and at weaning (28 days; APWW, kg), number of piglets at weaning (NW28d, head), average daily gain of suckling piglets (ADG, g), and piglet survival rate (%). All measurements were performed according to generally accepted methodologies

(Ladyka and Khmelnychiy, 2023). To obtain an integrated assessment of sow reproductive performance, a composite reproductive index was calculated based on a limited number of key parameters (Ladyka and Khmelnychiy, 2023):

$$I = B + 2W + 35G \quad (1)$$

Where *I* is the reproductive performance index; *B* is the number of piglets at birth (head); *W* is the number of piglets at 28 days of age (head) *G* is the average daily weight gain of piglets until weaning (kg).

Sow body condition was assessed by measuring backfat thickness at the P2 anatomical point, located 65 mm lateral to the dorsal midline at the level of the head of the last rib. Measurements were taken twice: immediately before farrowing and on the day of piglet weaning, allowing assessment of changes in sow energy reserves during lactation. Backfat thickness was measured using a Renco ultrasonic scanner, which provides a rapid, non-invasive, and reliable estimation of subcutaneous fat depth. These data enabled an objective evaluation of sow condition and facilitated adjustments to feeding or housing management when necessary to maintain optimal physiological status throughout the reproductive cycle (Ladyka and Khmelnychiy, 2023).

Table 2 – The scheme of the experiment researching reproductive traits of sows

Group			
1 *n* = 48	2 *n* = 48	3 *n* = 48	4 *n* = 48
Breeding			
♀(LW[a] × L[b]) × ♂Maxter[c]	♀(LW × L) × ♂*PIC* 337[d]	♀(LW × L) × ♂Maxter	♀(LW × L) × ♂*PIC* 337
Housing idle and gestation sows of group pens			
keeping on the farrowing unit			
Traditional pen of fixation of the sow during the suckling period		Improved pen for free-range sows from 7 days after farrowing until weaning	

a – Large White breed; b – Landrace breed; c – terminal line of boars «Maxter»; d – terminal line of boars PIC 337.

Statistical analysis

Experimental data were processed using standard biometrical methods (Kramarenko et al., 2019) and analyzed using Statistica 12.0 (StatSoft Inc., 2014; www.statsoft.com) and Microsoft Excel 2019. Performances that met the assumptions of parametric analysis were evaluated using two-way analysis of variance (ANOVA). The fixed effects included: A: type of farrowing pen (traditional vs. improved), B: boar line (Maxter vs. PIC 337), and A × B: the interaction between pen design and boar line. When significant main or interaction effects were detected identified, pairwise comparisons among group means were performed using Tukey's multiple comparison test implemented in Statistica. Quantitative data are presented as means ± standard error (M ± SE). Categorical variables, including piglet survival, were analyzed using Pearson's chi-square (χ^2) test. Statistical significance was accepted at $P < 0.05$, with $P < 0.01$ and $P < 0.001$ considered highly significant.

Ethical regulation

All experimental procedures complied with European legislation governing the protection and welfare of farm animals, including Council Directive 95/58/EC on the protection of animals kept for farming purposes (as amended by Regulation No. 806/2003) and Council Directive 91/630/EEC on minimum standards for the protection of pigs. The study was also conducted in accordance with Ukrainian legislation on animal welfare during farming practices (Law of Ukraine "On Veterinary Medicine", 2021; Order of the Ministry for Development of Economy, 2021). The experimental protocol was reviewed and approved by the Bioethics Commission of the National University of Life and Environmental Sciences of Ukraine (June 26, 2025; Protocol No. 039).

RESULTS

Table 3 presents the results of the two-way analysis of variance assessing the effects of farrowing pen type, boar line, and their interaction on sow reproductive performance at farrowing.

A significant effect of boar line was observed for the total number of piglets born (TNB; $F = 19.95$; $P < 0.001$). For the number of piglets born alive (NBA), significant effects were identified for both boar line ($F = 12.46$; $P < 0.001$) and farrowing pen type ($F = 12.46$; $P < 0.001$). The highest TNB values (14.1 piglets) were recorded in sows from Groups 2 and 4 inseminated with semen from PIC 337 boars, irrespective of pen type. In contrast, sows inseminated with Maxter boar semen (Groups 1 and 3) produced 0.5–1.1 fewer piglets (Figure 4).

The highest NBA values were observed in groups 1, 2 and 4, whereas sows in group 3 exhibited significantly lower values by 0.9–1.1 piglets. A similar pattern was noted for litter weight at birth (LWB), with Group 3 sows (improved pens × Maxter boars) exhibiting the lowest values. Sows in the remaining groups exceeded these values by 0.7–1.1 kg.

The proportion of stillborn piglets (PSB) was significantly influenced by pen type (F = 4.11; P = 0.044). The lowest PSB (5.1%) was observed in Group 1, while the highest value (8.4%) occurred in Group 4 (P < 0.05). Group 2 and 3 showed intermediate values. No significant effects of pen type or boar line were detected for average piglet weight at birth (AWPB). Although piglets in Groups 2 and 4 exhibited slightly lower AWPB values, these differences were not statistically significant (Figure 5).

Litter uniformity was significantly affected by both pen type (F = 17.50; P < 0.001) and boar line (F = 4.82; P = 0.029). The highest uniformity index was recorded in Group 2 (71.9 points), while the lowest was observed in Group 3 (61.1 points) (Figure 6). Although improved pens enhance piglet safety by reducing crushing risk, unrestricted sow movement on fully slatted floors may increase injury risk and negatively affect piglet growth uniformity, emphasizing the need for careful management and technological optimization.

Table 4 summarizes the effects of pen type, boar line, and their interaction on reproductive traits at weaning and piglet growth performance. For most traits, pen type exerted a significant influence, whereas for NW28d only a tendency was observed. Significant interaction effects were detected for milk performance and piglet survival to weaning.

The highest litter uniformity index and milk performance values were observed in Group 2 (44.1 points and 73.8 kg, respectively), while the lowest values were recorded in Groups 3 and 4. Sows in Group 1 showed intermediate values but differed significantly from the other groups, particularly in milk performance (Figure 7).

A similar pattern was observed for the number of piglets at weaning (NW28d), with a significant difference between Groups 2 and 3, while Groups 1 and 4 occupied intermediate positions. Litter weight at weaning (LWW) was strongly influenced by pen type (F = 20.34; P < 0.001), with sows housed in traditional pens (Groups 1 and 2) outperforming those housed in improved pens, regardless of boar line.

The highest average piglet weight at weaning (APWW) was recorded in Group 1 (7.34 kg), while the lowest value was observed in Group 4 (6.81 kg). Piglets from Groups 2 and 3 showed intermediate values. A similar trend was observed for average daily gain (ADG), with the highest gains recorded in Groups 1 and 2 and the lowest in Groups 3 and 4 (Figure 8).

Piglet survival to weaning was highest in Group 3 (97.3%), whereas significantly lower survival rates were observed in the remaining groups (Figure 9). Analysis of piglet mortality at the sow level revealed significant differences among all groups (χ^2 = 29.05; P < 0.001). The probability of at least one piglet death before weaning was 6.36 times higher in Groups 1, 2, and 4 compared with Group 3 (P < 0.001).

Table 5 presents the effects of pen type, boar line, and their interaction on sow backfat thickness. Backfat thickness before farrowing was significantly influenced by pen type (F = 24.81; P < 0.001), with sows housed in traditional pens (Groups 1 and 2) exhibiting higher values than those in improved pens. At weaning, backfat thickness remained significantly affected by pen type (F = 33.18; P < 0.001) and, to a lesser extent, by boar line (F = 4.05; P = 0.046).

The highest backfat thickness at weaning was observed in Group 1 (14.1 mm), while the lowest values (12.4–12.6 mm) were recorded in sows housed in improved pens. Significant differences were also detected between Groups 1 and 2 (P < 0.05). The greatest backfat losses during lactation were observed in Groups 2, 3, and 4 (4.92–5.27 mm), significantly exceeding losses in Group 1 (Figure 10). Although backfat loss remained within acceptable physiological limits across all groups, sows housed in improved pens exhibited greater energy depletion, likely due to increased physical activity associated with free movement.

Table 3 - Variability indicators (M ± SE) and results of two-factor analysis of variance (F; P) of the influence of the type of pens (farrowing) (A), breed of boars (B) and their combined effect (A×B) on the reproductive traits of sows during farrowing

Parameter	Group				Factor		
	1	2	3	4	Type of pen (farrowing) (A)	Boar`s breed (B)	A × B
TNB, head	13.6^{b}±0.18	14.1^{a}±0.22	13.0^{c}±0.14	14.1^{a}±0.18	2.95 (ns)	19.95 (< 0.001)	2.22 (ns)
NBA, head	12.9±0.16	13.1±0.16	12.0±0.14	12.9±0.15	12.46 (< 0.001)	12.46 (< 0.001)	3.49 (0.063)
PSB, head	5.1^{b}±0.87	6.8^{ab}±0.97	7.2^{ab}±0.83	8.4^{a}±1.00	4.11 (0.044)	2.33 (ns)	0.07 (ns)
LWB, kg	18.7^{a}±0.29	18.6^{a}±0.22	17.6^{b}±0.25	18.3^{a}±0.20	7.10 (0.008)	1.72 (ns)	2.92 (ns)
AWPB, kg	1.45±0.016	1.42±0.015	1.46±0.014	1.43±0.015	0.41 (ns)	4.56 (ns)	0.01 (ns)
Litter uniformity, points	66.5^{b}±1.42	71.9^{a}±1.76	62.1^{c}±1.61	63.4^{bc}±1.29	17.50 (< 0.001)	4.82 (0.029)	1.77 (ns)

n = number of records; M ± SE = estimate of the arithmetic means and statistical error; F = estimate of the Fisher-Snedecor test; P = significant level; ns = P > 0.05. Significance differences between the means of individual groups (P < 0.05) based on Fisher's LSD multiple comparison test are indicated by different letters; TNB = total number of piglets at born; NBA = number born alive; PSB = proportion of stillborn piglets; LWB = litter weight at birth; AWPB = a live weight of piglet at birth.

Table 4 - Variability indicators (M ± SE) and results of two-factor analysis of variance (F; P) of the influence of the type of pens (farrowing) (A), breed of boars (B) and their combined effect (A×B) on the reproductive traits of sows at weaning and the growth of piglets

Parameter	Group				Factor		
	1	2	3	4	Type of pen (farrowing) (A)	Boar`s breed (B)	A × B
Index, points	43.5^{ab}±0.39	44.1^{a}±0.41	42.0^{c}±0.41	42.7^{bc}±0.35	13.94 (< 0.001)	3.15 (ns)	0.03 (ns)
Milk performance, kg	70.7^{b}±0.79	73.8^{a}±1.01	67.6^{c}±1.03	65.5^{c}±0.78	39.14 (< 0.001)	0.31 (ns)	8.26 (0.004)
NW28d, head	11.9^{ab}±0.14	12.1^{a}±0.12	11.7^{b}±0.13	11.8^{ab}±0.12	3.56 (0.060)	1.51 (ns)	0.33 (ns)
LWW, kg	87.0^{a}±0.99	87.6^{a}±1.68	82.3^{b}±1.61	80.2^{b}±0.91	20.34 (< 0.001)	0.28 (ns)	1.04 (ns)
APWW, kg	7.34^{a}±0.074	7.24^{ab}±0.115	7.03^{bc}±0.113	6.81^{c}±0.057	15.83 (< 0.001)	3.05 (ns)	0.36 (ns)
ADG, g	196.4^{a}±2.49	193.9^{ab}±3.80	185.5^{bc}±3.82	179.3^{c}±1.81	16.75 (< 0.001)	1.97 (ns)	0.37 (ns)
Piglet survival, %	92.6^{b}±0.81	92.6^{b}±0.78	97.3^{a}±0.60	91.9^{b}±0.76	7.46 (0.007)	13.05 (< 0.001)	13.29 (< 0.001)

n = number of records; M ± SE = estimate of the arithmetic means and statistical error; F = estimate of the Fisher-Snedecor test; P = significant level; ns= P > 0.05. Significance differences between the means of individual groups (P < 0.05) based on Fisher's LSD multiple comparison test are indicated by different letters; NW28d = number of piglets at weaning (28 days); LWW = litter weight at weaning (28 days); APWW = a live weight of piglet at weaning (28 days); ADG =average daily gain.

Table 5 - Variability indicators (M ± SE) and results of two-factor analysis of variance (F; P) of the influence of the type of pens (farrowing) (A), breed of boars (B) and their combined effect (A×B) on the thickness of the fat of sows

Parameter	Group				Factor		
	1	2	3	4	Type of pen (farrowing) (A)	Boar`s breed (B)	A × B
Fat thickness before farrowing, mm	18.3^{a}±0.19	18.8^{a}±0.20	17.6^{b}±0.22	17.3^{b}±0.26	24.81 (< 0.001)	0.06 (ns)	2.76 (ns)
Fat thickness at weaning, mm	14.1^{a}±0.17	13.5^{b}±0.19	12.6^{c}±0.30	12.4^{c}±0.23	33.18 (< 0.001)	4.05 (0.046)	0.84 (ns)
Fat thickness losses per lactation, mm	4.19^{b}±0.212	5.27^{a}±0.214	4.98^{a}±0.243	4.92^{a}±0.254	0.89 (ns)	4.86 (0.029)	6.13 (0.014)

n = number of records; M ± SE = estimate of the arithmetic means and statistical error; F = estimate of the Fisher-Snedecor test; P = significant level; ns = P > 0.05. Significance differences between the means of individual groups (P < 0.05) based on Fisher's LSD multiple comparison test are indicated by different letters.

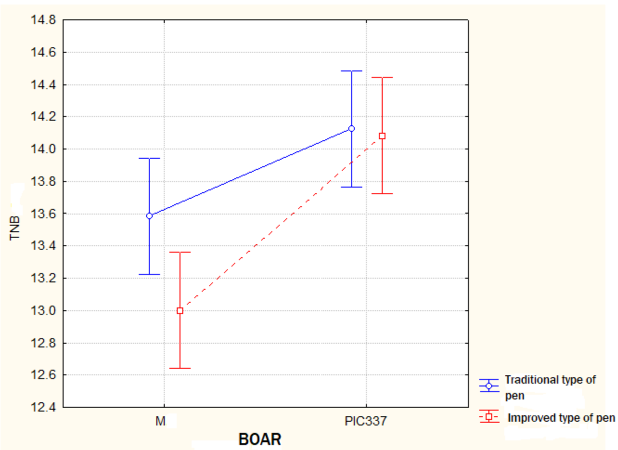

Figure 4 - Estimates of arithmetic means (± 95% CI) of the total number of piglets at birth (TNB) depending on the type of pen (farrowing) and breed of boar

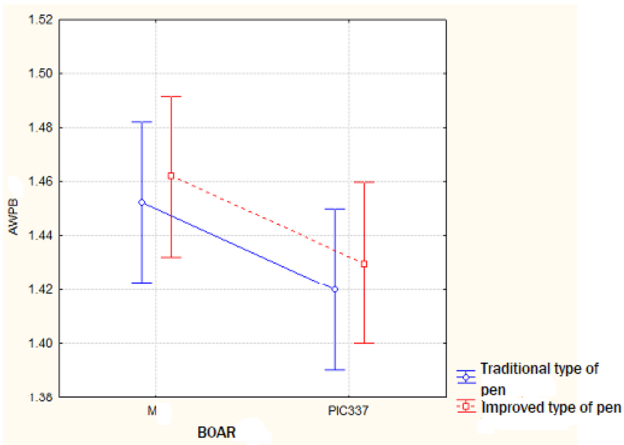

Figure 5 - Estimates of arithmetic mean (± 95% CI) a live weight of piglet at birth (AWPB) depending on the type of pen (farrowing) and breed of boar

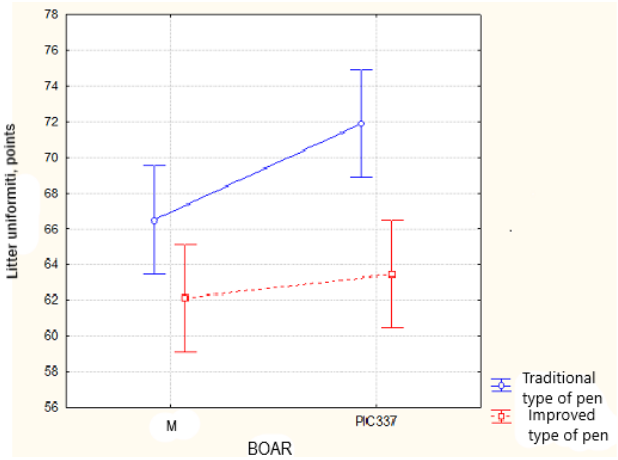

Figure 6 - Estimates of arithmetic mean (± 95% CI) a litter uniformity depending on the type of pen (farrowing) and breed of boar

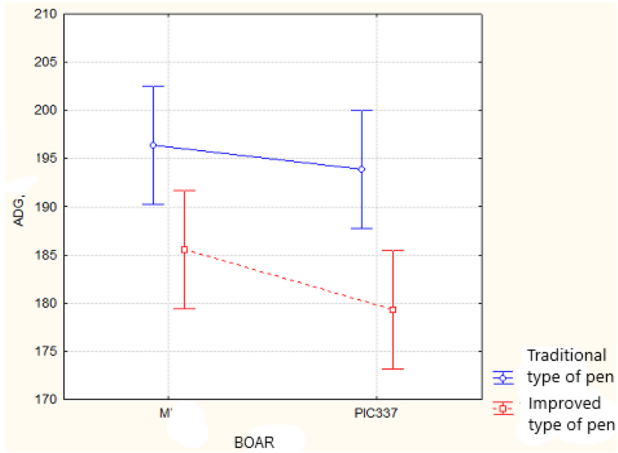

Figure 8 - Estimates of arithmetic mean (± 95% CI) an average daily gain of piglets depending on the type of pen (farrowing) and breed of boar

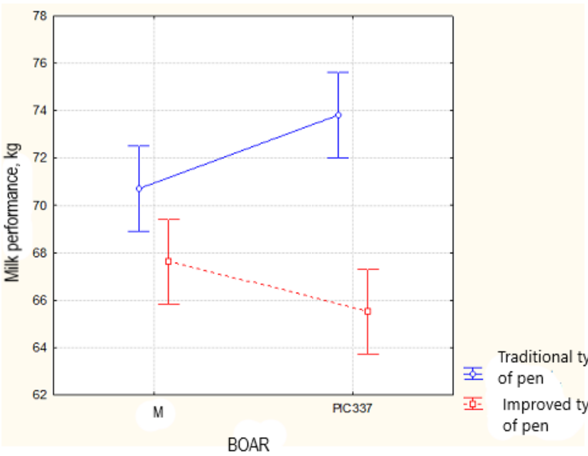

Figure 7 - Estimates of arithmetic mean (± 95% CI) a milk performance depending on the type of pen (farrowing) and breed of boar

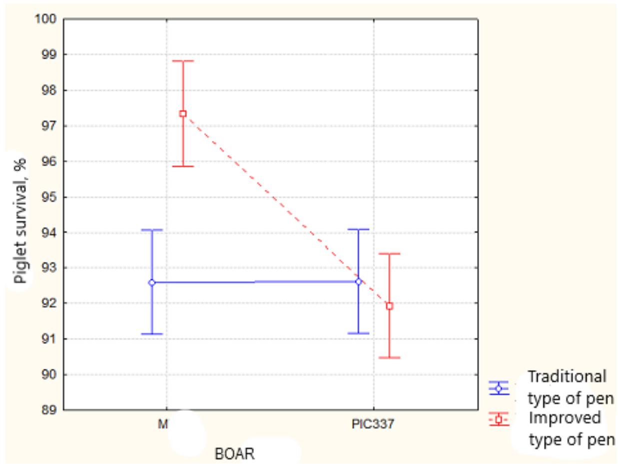

Figure 9 - Estimates of arithmetic mean (± 95% CI) a piglet survival depending on the type of pen (farrowing) and breed of boar

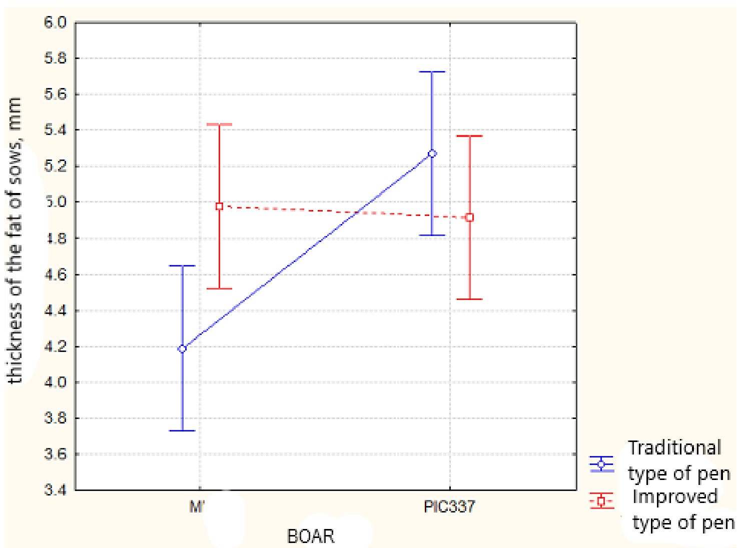

Figure 10 - Estimates of arithmetic mean (± 95% CI) a loss of backfat thickness in sows during the lactation period depending on the type of pen (farrowing) and breed of boar

DISCUSSION

In modern pig breeding, which aims to improve a reproductive efficiency and piglet survival, it is essential to consider a complex set of factors that shape sow reproductive performance and piglet viability. The results of the present study are consistent with findings recorded by Ukrainian and international researchers who emphasize the interaction between the genetic characteristics of boars and sow housing conditions in determining reproductive traits (King et al., 2020; Shvachka et al., 2022). The present research demonstrated that the total number of piglets born is significantly influenced by boar breed, highlighting the important genetic contribution of the paternal component. These findings are consistent with findings reported by Knap et al. (2023).

In particular, Sá et al. (2025) reported that trait transformation significantly affects the assessment of sperm trait repeatability, indicating that boar breed has a substantial influence on both quantitative and qualitative traits of offspring, including litter size, litter weight, and piglet uniformity.

At the same time, the present experiments showed that litter size was significantly affected not only by boar breed, but also by the type of farrowing pens in which sows and suckling piglets were housed. This confirms the need for a comprehensive approach to pig housing and insemination management. Similar results were reported by Pacheco et al. (2024), who demonstrated that farrowing pen design influences piglet performance, taking into account seasonal effects and parity number. These findings underscore the importance of appropriate housing management in pig production systems.

Regarding technological factors, particularly pen design, there is consensus among researchers that the design features of individual and group farrowing pens determine not only sow comfort but also piglet survival and the proportion of piglets weaned. Baxter and Edwards (2020), in «Optimizing sow and piglet welfare during farrowing and lactation», reported that improved pen designs reduce piglet injuries, enhance thermoregulation, and improve access to teats, thereby increasing piglet survival to weaning, and improving overall welfare.

Roy et al. (2022) also indicated that pen type, especially the degree of movement restriction, as well as the availability of environmental enrichment, affects stress levels in sows. These stress responses may influence milk production, farrowing behavior, and litter uniformity. Furthermore, Kinane et al. (2022) demonstrated that free-lactation pens improve sow welfare by increasing locomotor activity and reducing tear-stain scores, with lower stress levels compared to conventional farrowing crates.

The present experiments further showed that total litter weight at birth was influenced by the combined effects of boar breed and pen type, suggesting an interaction between genotype and housing conditions. Wiechers et al. (2022) reported that unrestricted sows spent more time nursing piglets, resulting in higher litter weights compared with sows housed in fixed systems. This can be considered a valuable technological strategy for improving piglet growth and weight uniformity at weaning.

In contrast, no significant effects of boar breed or pen type were observed for piglet fertility, likely due to greater individual variability in the expression of sow reproductive potential. Alexopoulos et al. (2018) noted that optimal reproductive outcomes are achieved through a specific combination of boar genotype and sow housing conditions. This observation aligns with the present findings on the combined effects of boar breed and pen design on litter weight at birth, milk performance, and piglet survival. At the same time, Kremez et al. (2022) suggested that large litter size is less sensitive to environmental factors than traits such as total number born or litter uniformity.

Both boar breed and farrowing pen design significantly influence litter uniformity, emphasizing the importance of uniform intrauterine development for providing newborn piglets with an equal start. Milk performance and piglet survival to weaning were affected by the combined action of genetic and technological factors, highlighting the need to consider both when optimizing farrowing management. Total litter weight at weaning was primarily influenced by pen type, irrespective of boar breed, underscoring the dominant role of housing conditions in piglet survival and growth. Conversely, piglet live weight at weaning was significantly affected by boar breed, confirming its decisive role in the realization of growth potential. Earnhardt-San et al. (2023) demonstrated genetic relationships between sow milk performance and the number of piglets weaned and emphasized the importance of incorporating these traits into breeding programs to enhance piglet survival and sustainable pork production. Accordingly, genetic selection programs should consider sow milk yield and the number of functional teats at farrowing to improve both productivity and animal welfare. In addition, the backfat thickness in sows before farrowing was significantly influenced by pen type, suggesting that this parameter may serve as an indicator of adaptive responses to housing conditions. Similar findings were reported by Farmer and Edwards (2021), who demonstrated that appropriate sow body condition and targeted feeding strategies enhance piglet survival and support effective litter size management.

The results indicate a complex interaction between genetic factors (boar breed) and technological factors (pen design) that jointly shape reproductive traits, growth performance, and productivity in pigs. The rational integration of these factors represents a key strategy for improving modern pig production systems and emphasizes the necessity for an integrated approach to reproductive planning that combines genetic selection with optimized housing conditions.

CONCLUSION

This study clearly demonstrates a trade-off between sow productivity and welfare when transitioning from traditional fixed farrowing pens to welfare-improved loose-housing systems. Sows housed in traditional fixed pens consistently showed superior reproductive performance, whereas improved pens allowed greater freedom of movement and enhanced welfare outcomes.

Boars breed of boars was a determining factor influencing reproductive output. Sows inseminated with PIC 337 boars achieved the highest total number of piglets born (TNB = 14.1), regardless of housing system, whereas sows inseminated with Maxter boars produced 0.5–1.1 fewer piglets. Pen design exerted a strong and statistically significant effect on litter uniformity, stillbirth proportion, litter weight at weaning (LWW), milk performance, and the composite reproductive index. Traditional pens resulted in lower stillbirth rates (5.1%) compared with improved pens (8.4%) and yielded higher values for number born alive, litter weight at birth, litter uniformity, and milk yield. The lowest overall performance was observed in Group III (improved pen + Maxter boar).

Litter weight at weaning and average piglet live weight at weaning (APWW) were significantly higher in traditional pens, independent of boar line. The highest APWW (7.34 kg) was recorded in Group 1, whereas the lowest value (6.81 kg) occurred in Group 4. Similarly, piglet daily gain and weaning weight followed similar trends.

Piglet survival to weaning reached its highest level in Group 3 (97.3%), indicating that despite lower maternal productivity, provide measurable welfare benefits that enhance piglet safety. The probability of losing at least one piglet before weaning was 6.36 times higher in Groups 1, 2, and 4 compared with Group 3 ($\chi^2 = 29.05$; $P < 0.001$), confirming the welfare advantage of partially loose-housing systems. Backfat thickness before farrowing and at weaning was significantly influenced by both pen type and boar line. Sows housed in traditional pens (Group 1) maintained the highest backfat levels (14.1 mm) and experienced lower mobilization during lactation, whereas sows in improved pens exhibited thinner backfat and greater body reserve depletion.

The combined effects of pen design and boar breed were particularly pronounced for milk performance, litter uniformity, and piglet survival, confirming the importance of integrating genetic and housing decisions in farrowing management.

Suggestion

Further research should focus on elucidating the behavioral mechanisms of sows and piglets in loose-housing systems and on evaluating the cost-effectiveness economic feasibility and cost-effectiveness of implementing improved farrowing technologies under commercial production conditions.

DECLARATIONS

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Data availability

The data generated and/or analyzed in this study can be obtained from the corresponding author upon reasonable request.

Authors' contribution

H.Sergiy made the primary contribution to the study. He was responsible for organizing and conducting the experimental work on the farm, coordinating data collection, validating the obtained results, and preparing the initial version of the manuscript. His role included ensuring accurate implementation of the experimental protocol and performing the first-stage interpretation of the results. L.Vadym acted as the scientific supervisor of the project. He coordinated the overall study design, developed the methodological framework, oversaw the statistical analysis and interpretation of the outcomes, and provided essential scientific guidance throughout all stages of the research. He also contributed substantially to refining the manuscript and ensuring its scientific integrity. L.Anna contributed to the conceptual development of the study, assisted in the organization and monitoring of experimental procedures, structured the manuscript, and performed major critical revisions and editions required for the final version. B.Yevhen, I.Olena, and M.Roman participated in data collection, data arrangement, and calculations, supported the implementation of the experimental work, and contributed to preparation of supplementary materials. All authors reviewed the manuscript, approved its final version, and agreed to its publication.

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Competing interests

The authors have not declared any competing interests.

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