Letters in Animal Biology

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Journal homepage: www.liabjournal.com

Determining sow and piglet characteristics associated with stillbirth and pre-weaning piglet survival in F1 Large White × Landrace pigs in South Africa

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Article info

Received: 18 June 2026
Received in revised form: 03 August 2026
Accepted: 05 August 2026
Published online: 24 September 2026

Keywords

Litter size
Sow mothering ability
Colostral immunoglobulins
Piglet mortality
Within-litter variation

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Reviewed by:
Consent to publish the name of the reviewers could not be obtained

Abstract

Pre-weaning mortality remains a persistent constraint in commercial pig production systems worldwide, affecting herd efficiency and economic returns. The aim of the study was to determine sow and piglet characteristics associated with stillbirth and pre-weaning piglet survival in the F1 Large White × Landrace pigs in South Africa. Secondary data were extracted from the farm database and the study included records from 360 sow litters with 5845 piglets. The sow characteristics analysed included parity, litter size, length of gestation, farrowing weight, litter weight variation, average litter weight and sow mothering ability. Piglet characteristics included birth weight, suckling period, sex, fostering status and colostrum immunoglobulin (IgG) concentration. Two separate multivariate logistic regression models were fitted: (1) predictors of stillbirth, (2) predictors of survival to weaning. Sows were categorized into quartiles for each of the independent variables to quantify the relationship to stillbirth rate or survival to weaning. A general linear model for a binomial response was fitted to analyze the difference in stillbirth and pre-weaning survival between the quartiles of each respective variable and Fisher's LSD was used to separate significantly different means ($p < 0.05$). The study revealed that parity, average litter weight, litter size, gestation length, and farrowing weight were significantly ($p < 0.05$) associated with the prevalence of stillbirths. Parity, litter size, length of gestation, farrowing weight, litter weight variation, average litter weight, sow mothering ability, fostering status, and colostrum immunoglobulin (IgG), were significantly associated with pre-weaning piglet survival ($p < 0.05$). Stillbirth was highest in sows with low farrowing weight (< 222.25 kg; 8.88%), intermediate gestation length (114–115 days; 4.47%), and small litters (≤ 14 piglets; 5.65%). Piglet survival was highest in larger litters (> 17 piglets; 92.18%), higher-parity sows (≥ 4; 80%), and heavier piglets (> 1.4 kg; 81.35%). The logistic regression models confirmed litter size, gestation length, and farrowing weight as key predictors ($p < 0.05$). These findings suggest that optimizing piglet survival requires a multifactorial approach that combines sow and piglet characteristics, and management practices to enhance production efficiency and reduce piglet mortality.

1. Introduction

The pig farming industry plays a significant economic and nutritional role worldwide, especially in developing nations (Tong et al. 2023). In South Africa, pig production is small, but it plays a critical role in the livestock sector, and it consists of a dual production system that includes commercial and smallholder farmers, contributing to agricultural gross domestic product (GDP) and the creation of employment (Mathobela et al. 2024; Hlongwane, 2026). The industry faces challenges, including restricted access to markets, credit, and government backing (Adesehinwa et al. 2024), feed shortages (Devillers et al. 2011), diseases (Leite et al. 2021), piglet mortality, among others (Buthelezi et al. 2024a, 2024b; Matukane et al. 2024). These challenges prevent the industry from making an optimal contribution to the country's social development. Among these challenges, the pig industry is increasingly concerned about issues related to piglet pre-weaning mortality (Muns et al. 2016; Buthelezi et al. 2024a, 2024b), because a significant percentage of piglet deaths occurs during the pre-weaning phase (Nuntapaitoon and Tummaruk 2015).

Piglet survival from birth to weaning is important for the global pig industry and it remains a challenge (Osei-Amponsah and Kaumbata 2025). The first few days following birth and weaning are the most difficult times for piglets' survival (Leite et al. 2021). The average piglet mortality rate from birth to weaning is 16–20%, with stillbirth, crushing, and malnutrition being the leading causes, where the stillborn and mummified fetuses account for 9.8% of all born piglets in herds (Buthelezi et al. 2024a, 2024b; Mpalala 2022). Piglets experience significant stressors before weaning, including relocation of the litter, changes in diet, care, and surroundings (Campbell et al. 2013). Through genetic improvement, the litter size has increased over the years (Zak et al. 2017); however, increased litter size has also been linked with poor survival (Oliviero et al. 2010; Kitkha et al. 2017; Buthelezi et al. 2024a, 2024b). As a result, more than 25 % of all pigs born do not make it to weaning, although producers in the modern pig industry anticipate that each sow will wean up to 30 pigs a year (Langendijk and Plush 2019). This poses a welfare issue and an economic burden to the industry (Gourley et al. 2020). Piglet factors, including birth weight (BWB), birth order, and sex, sow factors, including breed, parity, nutritional status, farrowing duration, sow mothering ability, and litter size (LS), and environmental factors (ambient temperature and stocking density), negatively affect piglet pre-weaning mortality (Zotti et al. 2017; Knol et al. 2022; Mabunda et al. 2025).

The economic loss is enormous due to the increased rearing costs per animal lost, even if fewer animals die after weaning than during the pre-weaning period (Vanderhaeghe et al. 2010). However, the challenges mentioned above associated with increased stillbirth and pre-weaning mortality rates highlight the importance of investigating the characteristics influencing the survival of piglets during the pre-weaning phase. There is limited information on the characteristics associated with piglet survival from birth to weaning of F1 Large White × Landrace crossbreed, leaving a gap in understanding the traits influencing the survival of these pigs. The study aimed to determine sow and piglet characteristics associated with increased stillbirth and pre-weaning piglet survival in the F1 Large White × Landrace pigs in South Africa. This study contributes to the local, continental and global priorities by creating knowledge that will optimise the efficiency of pig production, strengthen food security and enhance the sustainability of the pork industry in South Africa. By improving piglet survival, the study supports the development of a resilient and effective livestock system that will enhance economic growth and sustainable agricultural development while advancing the Sustainable Development Goals (SDGs), including poverty reduction (SDG 1), food security (SDG 2), and responsible consumption and production (SDG 12).

2. Materials and Methods

2.1 Study area and data extraction

Data were extracted from the Topigs Norsvin South Africa farm database for the period 2022–2024 and included records on total piglets born, number born alive, number of stillbirths, piglet birth weight, and the number of piglets that died and were weaned from F1 Large White × Landrace sows (5845 piglets from 360 sow litters). The farm is in the City of Tshwane Local Municipality, Gauteng Province, South Africa, in a subtropical highland climate characterised by dry winters, at latitude 25°48′36″ South and longitude 28°44′32″ East. The area experiences approximately 100.9 rainy days annually (27.6%) and has an average annual temperature of 22.1 °C, with minimum and maximum temperatures of 13.7 °C and 26.2 °C, respectively.

2.2 Animal management

During gestation, sows were housed in individual crates (1.2 m^2) in a traditional open-housing system. To lessen the effects of the high ambient temperature, each crate had its own water sprinkler and fans. Sows were fed a commercial gestation diet containing 19.7% crude protein, 14.0 MJ/kg metabolizable energy, 5.8% fat, 3.8% fiber, and 0.09% lysine, formulated to meet their nutritional requirements during gestation. Following a standardized feeding schedule, feed was given twice daily, yielding an average of 2.5 kg per sow daily. Water was supplied *ad libitum* through drinking nipples.

2.3 Farrowing management

Before being transferred to individual farrowing stalls, sows were kept in separate stalls from day 0 to day 113 of gestation. About a week before the anticipated farrowing date (day 113 of gestation), pregnant sows were weighed, backfat thickness was determined, and were transferred to the farrowing house. The animals were housed in separate 1.2 m^2 farrowing boxes in the middle of the pens, with 4.2 m space between them. The sows' pens had concrete in the middle, and the piglets' quarters had steel slats on either side of the farrowing container.

Daily observations were made for signs of parturition around farrowing. Birth intervention was carried out only when dystocia was clearly diagnosed, and sows were not interfered with during parturition as much as possible. Dystocia was diagnosed when more than 30 minutes had passed since the birth of the last piglet, the sow displayed repeated straining accompanied by leg paddling, or the sow excreted small amounts of foetal fluid with noticeable tail switching for more than 30 minutes without giving birth to a piglet.

After parturition started, each farrowing was tracked to determine the piglets' birth order, weight, and time, as well as whether they were mummified fetuses, stillborn piglets, or born alive. Piglets were considered born alive if they moved or breathed as soon as they were born. Stillborn piglets were defined as completely developed animals that did not have a detectable heartbeat at birth. Fetuses that were mummified were noted but not included in the total number of births. Each newborn was given an ear tag for the purpose of identification.

2.4 Piglet management

Piglets were weighed, had their tails docked and teeth clipped, and received an intramuscular injection of 1 mL (200 mg) of an iron supplement on the day of birth. Twenty-four hours after the first pig in the litter was born, each live piglet was weighed again. Piglets were orally administered a 20 mg/kg body weight dose to control neonatal coccidiosis at 3 days of age. During the first week following farrowing, each pen had a creep area for piglets (0.60 m) that was set up on one side of the floor and covered by a plastic plate and heating bulb. During the night or when the surrounding temperature dropped below 30 °C, the heating lamp was activated. The creep area temperature was maintained between 30 °C and 36 °C.

The sows were fed a commercial lactation diet twice a day throughout lactation, with the volume of feed offered increasing each day until, after a week of lactation, *ad libitum* feed was achieved. The diet was formulated to meet or exceed the nutritional requirements of lactating sows and contained 18.1% crude protein, 10 MJ/kg metabolizable energy, and 1.2% lysine. Daily health checks were conducted on the animals, and professional staff addressed any illnesses. Unless cross-fostering was needed, the piglets stayed with their dams. Piglet deaths from birth to weaning were recorded for each sow, along with the day of death, dead weight, and pig's identity. Factors such as weight gain, health status, cross-fostering status, and colostrum quality were assessed indirectly using Brix percentage measured with a Digital Brix Refractometer within the first 24 h after farrowing. The Brix values serve as an indirect estimate of colostral immunoglobulin G concentration and were obtained from the farm database and used in the analysis.

2.5 Sow and piglet characteristics

Sow mothering ability was assessed indirectly using farm-recorded sow-associated causes of pre-weaning piglet mortality. The database included incidences of piglet crushing, starvation, and sow-inflicted injuries. These outcomes were used as indicators of the sow's ability to successfully care for and rear her litter, as they are commonly associated with maternal performance traits such as attentiveness to piglets, nursing capacity, piglet acceptance, and care during posture changes. Sows were therefore evaluated based on the occurrence of these mortality events recorded during lactation. The study did not include direct behavioural observations or a standardized maternal behaviour scoring system; consequently, sow mothering ability was inferred from recorded piglet survival outcomes rather than measured through behavioural assessments.

The stillbirth and pre-weaning survival rates were calculated as follows:

Stillbirth rate (%) = (No. of stillbirths / Total births) × 100

Piglet survival Rate (%) = (No. piglets surviving to weaning / Total live birth) × 100

2.6 Statistical Analyses

The sow and piglet characteristics that were analysed included parity, litter size, length of gestation, farrowing weight, litter weight variation, average litter weight, sow mothering ability, birth weight, suckling period, sex, fostering status and colostrum immunoglobulin G (IgG) concentration. The chi-square test was used to determine sow and piglet categorical variables associated with the death of piglets at days 7 to 21 of lactation. Using the Student's t-test, continuous variables that represent the characteristics of sow and piglets (such as, litter size, length of gestation, farrowing weight, birth weight, and colostrum immunoglobulin) were compared between piglets that die and those that survive during lactation. Pearson's product-moment correlation was used to examine the relationship between the potential indicators associated with piglet survival. Two separate multivariate logistic regression models were fitted to identify the sow and piglet characteristics associated with (1) stillbirth and (2) pre-weaning piglet survival. All selected variables were entered simultaneously into each model based on their biological relevance and availability in the dataset. Model fit was assessed using the Hosmer-Lemeshow goodness of fit test. Regression coefficients (B), standard errors (SE), Wald chi-square statistics, odds ratios, 95% confidence intervals (CI) and p-values were reported. Statistical significance was declared at $p < 0.05$. A general linear model for a binomial response was fitted to analyze the difference in stillbirth and pre-weaning survival between the quartiles of each respective variable and Fisher's LSD was used to separate significant means ($p < 0.05$).

3. Results

3.1 Descriptive characteristics

Descriptive statistics (means, standard deviations, medians, and ranges) of sow and piglet characteristics are presented in Table 1. A total of 360 litters were analyzed with a mean litter size of 16.60 ± 3.56. Litter weight variation averaged 21.20 ± 5.87%, which indicates high variability within litters. The average length of gestation was 114.62 ± 1.39 days with a median of 115 days and a variation of 22 days, which demonstrates uniformity in the gestational length of sows. Farrowing weight averaged 236.33 ± 13.90 kg, with the highest variability of 60 kg. Conversely, piglet characteristics such as birth weight had a mean of 1.34 kg and an SD of 0.35 kg with a range of 2.54 kg. Colostral Immunoglobulin concentration (IgG) within the first 24 hours was 12.9 ± 1.31%, and the suckling period showed a mean of 20.6 ± 3.24 days with a median of 21 days, and a range of 35 days was observed, indicating considerable variation in suckling duration among piglets.

3.2 Pre-weaning mortality

Categorical variables influencing piglet pre-weaning mortality from day 7 to day 21 are presented in Table 2. The mortality rate increased ($p < 0.05$) with the number of parities, with the highest observed at parity 5 (18.22%). Sow mothering ability-related factors such as crushing, sow aggression (biting), and starvation were strongly associated with piglet mortality ($\chi^2 = 13.80$, $p < 0.05$), with a considerable mortality rate (20.52 %). Moreover, piglet characteristics, sex (male vs female) ($\chi^2 = 2.24$), were not significantly associated ($p > 0.05$) with piglet mortality and fostering status had an impact on pre-weaning mortality ($\chi^2 = 5.30$, $p < 0.05$).

The comparison between surviving and dying piglets for sows' continuous variables, including litter size, gestational length, farrowing weight, Colostrum immunoglobulin and average litter weight, is illustrated in Table 3. All the variables analyzed between the two groups were significantly different ($p < 0.05$). Surviving piglets exhibited greater mean values for litter size (14.81 ± 0.24), gestational length (114.88 ± 0.15), farrowing weight (230.20 ± 4.55), birth weight (1.45 ± 0.32), colostral immunoglobulin (23.63 ± 3.15) and average litter weight (18.66 ± 3.81) compared to dying piglets, which had corresponding mean values of 12.93 ± 0.30, 113.75 ± 0.22, 218.72 ± 5.23, 0.92 ± 0.24, 18.21 ± 2.84, and 14.27 ± 3.12, respectively.

3.3 Correlation between sow and piglet characteristics

Pearson's correlations for determining the potential indicators, such as total born, born alive, birth weight, colostral immunoglobulin, gestational length, suckling period and farrowing weight associated with piglet survival are presented in Table 4. Born alive had a positive, very strong correlation with total born ($r = 0.89$, $p<0.05$). Colostrum immunoglobulin G showed a strong positive correlation with total born and born alive piglets ($r = 0.93$, $p < 0.05$), indicating an association between litter size and colostrum immunoglobulin G. However, it had a weak negative and insignificant association with the length of gestation ($r = -0.26$, $p > 0.05$) and farrowing weight ($r = -0.17$, $p > 0.05$).

Table 1. Descriptive analysis of discrete variables (360 sow litter records and 5845 piglets)

Variables	N	Mean ± SD	Median	Max	Min	Range
Litter size	360	16.60 ± 3.56	17	27	5	22
Litter weight variation (%)	360	21.20 ± 5.87	21.08	41.96	3.64	38.32
Length of gestation (days)	360	114.62 ± 1.39	115	120	108	12
Farrowing weight (kg)	360	236.33 ± 13.90	238	262	202	60
Total Born alive	360	15.24 ± 3.32	15	24	5	19
Total Born dead / Stillbirths	360	1.37 ± 1.61	1	9	0	9
Birth weight (kg)	5485	1.34 ± 0.35	1.34	2.88	0.34	2.54
Colostral immunoglobulin IgG (%)	360	12.9 ± 1.31	12.70	16.50	11.30	5.20
Suckling period (days)	360	20.61 ± 3.24	21	35	20	15

Table 2. Contribution of categorical variables to piglet pre-weaning mortality and associated statistical significance (360 sow litter records and 5845 piglets)

Variables	Contribution to mortality rate	Chi-square (χ^2)	P value
Parity 1	7.80	2.80	>0.05
Parity 2	9.88	3.30	>0.05
Parity 3	10.96	3.60	>0.05
Parity 4	14.84	4.40	>0.05
Parity 5	18.22	6.90	<0.05
Sow mothering ability (crushing, bitten by the sow, starvation)	20.52	13.80	<0.000
Sex	6.06	2.24	>0.05
Fostering status	11.72	5.30	<0.05

Gestational length showed a significant negative very weak correlation with total born ($r = -0.13$, $p < 0.05$) and born alive ($r = -0.12$, $p < 0.05$) and an insignificant positive very weak correlation with body weight ($r = 0.01$, $p > 0.05$). The suckling period demonstrated very weak positive correlations with total born ($r = 0.11$, $p < 0.05$) and born alive ($r = 0.17$, $p < 0.05$). Birth weight had a very weak positive correlation with litter size ($r = 0.06$, $p < 0.05$) and born alive ($r = 0.07$, $p < 0.05$).

0.91; CI = 0.86-0.98) were significantly ($p < 0.05$) associated with increased stillbirth rate. The positive or negative sign of the coefficient (B) shows the direction between an independent variable (X) and the dependent variable, while the odds ratio indicates the magnitude of change in odds for a one-unit change in the independent variable. Average litter size, birth weight, and parity 2 were not significantly ($p > 0.05$) associated with the risk of stillbirths, whereas parity 3, 4, and 5 were significantly associated with the stillbirth rate ($p < 0.05$), with the highest Hosmer and Lemeshow Chi-square goodness-of-fit test ($X^2 = 19.38$).

3.5 Quartile analysis and stillbirths

Quartiles of sow and piglet characteristics associated with stillbirth rate were analyzed using a general linear model, and they are presented in Table 6. Farrowing weight had a significant ($p < 0.05$) impact on stillbirth rate. The highest ($p < 0.05$) stillbirth rate (8.88%) was observed in the sows classified in the first quartile (< 222.25 kg). Sow gestation length had a significant ($p < 0.05$) effect on stillbirth rates among piglets. The sows that farrowed on day 116 of gestation (fourth quartile) exhibited the lowest ($p < 0.05$) stillbirth rate (1.8%), whereas the sows with gestation length of 114-115 days (second and third quartiles) showed the highest stillbirth rate (4.47%). Sows that gave birth to 14 piglets or fewer classified in the first quartile (5.65%) of litter size ($p < 0.05$) had the highest stillbirth rate compared to sows that gave birth to 19 piglets or more in the fourth quartile (2%). A high ($p < 0.05$) stillbirth rate was observed in sows categorized in the second parity quartile (parity 1 to 3) (5.16%), which declined as the parity number increased, with parity 3 to 4 having the lowest ($p < 0.05$) stillbirth rates. The sows with the highest average litter weight (> 1.5 kg), categorized as the fourth quartile, exhibited the highest ($p < 0.05$) stillbirth rate, and those classified in the three lower quartiles had the lower ($p < 0.05$) stillbirth

Table 3. Comparison between sow continuous variables between surviving and dying piglets (means ± SE), (360 sow litter records)

Variables	Surviving	Dying	P value
Litter size	14.81±0.24	12.93±0.30	<0.001
Gestational length (days)	114.88±0.15	113.75±0.22	<0.001
Farrowing weight (kg)	230.20±4.55	218.72±5.23	<0.001
Birth weight (kg)	1.45±0.32	0.92±0.24	<0.001
Colostral immunoglobulin G (%)	23.63±3.15	18.21±2.84	<0.001
Average litter weight (kg)	18.66±3.81	14.27±3.12	<0.001

3.4 Factors associated with stillbirths

The multivariate logistic model for sow and piglet characteristics, including parity, average litter weight, litter size, birth weight, length of gestation, and farrowing weight, is presented in Table 5. The logistic regression models showed that litter size (Wald $X^2 = 11.35$; odds ratio = 0.86; CI = 0.78-0.94), length of gestation (Wald $X^2 = 4.74$; odds ratio = 1.44; CI = 1.04-2.00) and farrowing weight (Wald $X^2 = 9.22$; odds ratio =

Table 4. Pearson's correlations amongst potential indicators for piglet survival during the pre-weaning period (360 sow litter records and 5845 piglets)

Variables	Total births	Live born	Birth weight (kg)	Colostral IgG	Gestational length	Suckling period	Farrowing weight
Total born	-	-	-				
Born alive	0.89***	0.07**					
Birth weight (kg)	0.06***						
Colostral Immunoglobulin G (%)	0.93***	0.93***	-0.02^{NS}	-			
Gestational length (days)	-0.13***	-0.12***	0.01^{NS}	-0.26^{NS}	-		
Suckling period (days)	0.11***	0.17***	-0.02^{NS}	-0.21^{NS}	-0.16***		
Farrowing weight (kg)	0.27^{NS}	0.93***	0.15^{NS}	-0.17^{NS}	-0.21^{NS}	0.14**	-
Suckling period (days)	360	20.61 ± 3.24	21	35	20	15	

Table 5. Multivariate logistic regression predicting variables related to increased stillbirth rates (360 sow litter records)

Variables	B	SE	Wald χ^2	P value	Odds	CI (95%)
Parity 2	0.16	0.34	19.38	0.64	1.17	0.61-2.29
Parity 3	-0.80	0.38		0.04	0.45	0.21-0.96
Parity 4	-1.01	0.40		0.01	0.36	0.17-0.80
Parity 5	-1.25	0.43		0.00	0.29	0.12-0.66
Average litter weight (kg)	0.37	0.72	0.26	0.61	1.44	0.35-5.95
Litter size	-0.16	0.05	11.35	0.00	0.86	0.78-0.94
Birth weight (kg)	0.24	0.37	0.42	0.52	1.27	0.61-2.65
Length of gestation (days)	0.36	0.37	4.74	0.03	1.44	1.04-2.00
Farrowing weight (kg)	-0.09	0.03	9.22	0.00	0.91	0.86-0.98

SE: Standard error; CI: Confidence interval; B: Regression coefficient

rates (3.1%, 3.7%, 3.2%, respectively). Piglet birth weight was not significantly ($p > 0.05$) associated with stillbirth rate, with the middle quartile (1.4 - 1.96 kg) having the highest stillbirth rate (4%).

3.6 Factors associated with pre-weaning piglet survival

Table 7 shows a multivariate logistic regression model predicting sow and piglet characteristics associated with the survival of piglets up to weaning. The model revealed that litter size (Wald X^2 = 17.63; Odds ratio = 0.66; CI = 0.55-0.80), parity 3 (Wald X^2 = 7.41; Odds ratio = 0.30; CI = 0.11-0.79), cross fostering (Wald X^2 = 1.56; Odds ratio = 0.69; CI =0.39-1.23), length of gestation (Wald X^2 = 4.19; Odds ratio = 1.10; CI = 1.00-1.21), farrowing weight (Wald x^2 = 7.11; Odds ratio = 0.99; CI = 0.91-0.99), average litter weight (Wald X^2 = 11.59; Odds ratio = 24.82; CI = 2.91-157.66) and litter weight variation (Wald X^2 = 9.25; Odds ratio = 0.71; CI = 0.67-0.75) were significantly ($p < 0.05$) associated with pre-weaning piglet survival. In contrast, parity 2, 4, and 5 were not significantly associated with piglet survival ($B < 0$; $p > 0.05$), indicating decreased odds of survival with a low Chi-square statistic (Wald X^2 = 7.41). Sex of piglets displayed a positive effect on piglet survival with increased odds (B = 0.19; odds ratio = 1.17; CI = 0.72-1.91); however, this relationship was not statistically significant ($p > 0.05$). Birth weight and colostral immunoglobulin (IgG) were also not significantly ($p > 0.05$) associated with piglet survival. Although the suckling period was insignificantly ($p > 0.05$) associated with increased odds of survival ($B > 0$; Odds ratio = 1.03; CI = 0.98-1.07), it had the lowest Chi-square statistic (Wald X^2).

3.7 Quartile analysis and pre-weaning piglet survival

Results for quartiles of sow and piglet characteristics associated with pre-weaning piglet survival are shown in Table 8. Litter size categorized in the upper two quartiles (17 - 19 and >17) had the highest ($p < 0.05$) pre-weaning piglet survival rate (85.85% and 92.18%, respectively) compared with the other two quartiles. More interestingly, litters categorized with the lowest total born quartile (<14 piglets) had the lowest pre-weaning piglet survival rate (51.21%) compared with the other upper three quartiles. Sows categorized as parity 4 upwards had the highest ($p < 0.05$) pre-weaning piglet survival (80%), whereas sows that gave birth from parity 1 to 3 had the lowest ($p < 0.05$) pre-weaning piglet survival (66.17%). As the average litter weight category increased from the first quartile (< 1.196 kg) to the third quartile (1.196 - 1.34 kg), the pre-weaning piglet survival rate decreased from 92.89% to 70.67%. Birth weight classified in the first quartile (< 0.97 kg) had the lowest pre-weaning piglet survival (71.40%), whereas heavier piglets classified in the fourth quartile (> 1.4 kg) yielded the highest weaning rate (81.35%). Pre-weaning survival rate was high (81.68%) in gestational length categorized in the first quartile (115 days), whereas sows

Table 6. Quartiles for sow and piglet characteristics associated with stillbirth rate (360 sow litter records)

Variables	1st Quartile	2nd quartile	3rd Quartile	4th Quartile	P-value	SEM
Parity	<1	1 to 3	3 to 4	>4		
Stillbirth %	4.84^{ab}	5.16^{a}	3.22^{bc}	2.23^{c}	0.00	0.47
Average litter weight (kg)	<1.20	1.20 to 1.34	1.34 to 1.5	>1.5		
Stillbirth %	3.14^{b}	3.76^{a}	3.22^{b}	4.83^{a}	0.00	0.48
Litter size	<14	14 to 17	17 to 19	>19		
Stillbirth %	5.65^{a}	4.37^{ab}	3.90^{b}	2.00^{c}	0.00	0.47
Birth weight (kg)	<0.97	0.97-1.4	1.4-1.96	>1.96		
Stillbirth %	3.52^{a}	3.65^{a}	4.00^{a}	3.88^{a}	0.22	0.49
Length of Gestation (days)	<114	114 to 115	115 to 116	>116		
Stillbirth %	3.75^{b}	4.47^{a}	4.47^{a}	1.80^{b}	0.00	0.49
Farrowing weight (kg)	<222.25	225.25 to 238	238 to 248	>248		
Stillbirth %	8.88^{a}	7.78^{a}	2.22^{b}	2.50^{b}	0.00	0.42

a-c Means within a row with different superscripts differ (p<0.05); SEM: Standard Error of the Mean

Table 7. Multivariate logistic regression predicting sow and piglet characteristics associated with pre-weaning survival (360 sow litter records and 5845 piglets)

Variables	B	SE	Wald χ^2	P value	Odds	CI (95%)
Litter size	-0.41	0.09	17.63	0.00	0.66	0.55-0.80
Parity 2	-0.21	0.39	7.41	0.60	0.81	0.31-1.76
Parity 3	-1.21	0.50		0.02	0.30	0.11-0.79
Parity 4	-0.58	0.49		0.23	0.56	0.23-1.45
Parity 5	-0.88	0.55		0.11	0.41	0.14-1.22
Birth weight (kg)	-0.63	0.40	2.61	0.11	0.53	0.25-1.14
Average litter weight (kg)	3.21	0.94	11.59	0.00	2,482	3.91-157.66
Cross- fostering	-0.87	0.26	1.56	0.00	0.69	0.39-1.23
Sex Male	0.19	0.25	0.39	0.53	1.17	0.72-1.91
Length of gestation (days)	0.09	0.05	4.19	0.04	1.10	1.00-1.21
Suckling period (days)	0.03	0.02	1.36	0.24	1.03	0.98- 1.07
Farrowing weight (kg)	-0.05	0.01	7.11	0.01	0.99	0.91-0.99
Colostral immunoglobulin G (%)	-0.09	0.17	6.25	0.62	0.92	0.65-1.29
Litter weight variation (kg)	-0.34	0.03	9.25	0.03	0.71	0.67-0.75

classified in the fourth quartile (> 116 days) had the lowest weaning rate (73.23%). Sows that suckled their piglets in the upper two quartiles (21 to 22 days and > 22 days) had a considerable weaning rate (78.75% and 77.50%) compared to piglets in the lower two quartiles (< 20 days and 20 to 21 days), which had a pre-weaning survival rate of 71.24% and 76.19%, respectively. Litter weight variation classified in the upper two quartiles (5-20% and 21-35%) had the greatest rate of survival (94.93% and 92.22%, respectively) compared to the fourth quartile (56-90%) which had the lowest survival rate (75.85%). As farrowing weight increased, a descending trend in weaning rate (79.38%, 77.03%, 75.95%, 70.83%) was observed from the first quartile (225 kg) up to the fourth quartile (249 kg). Colostral immunoglobulin G (IgG) was highly associated with pre-weaning piglet survival ($p<0.05$). Pre-weaning survival rate was the highest (from 88%) in the first two upper quartiles of colostrum quality (< 12.1% and 12.1 - 12.5%), which declined to 85.53% from the fourth quartile (> 13.7%).

4. Discussion

Sow parity primarily affects the development of piglets during the post-partum period (Nweze 2021; Zotti et al. 2017). Stillbirth is a very complex issue, and not much is known about the risk factors associated with its occurrence in pig production. Several authors observed a

Table 8. Quartiles for sow and piglet characteristics associated with survival rate (360 sow litter records and 5845 piglets)

Variables	1st Quartile	2nd quartile	3rd Quartile	4th Quartile	P-value	SEM
Parity	<1	1 to 3	3 to 4	>4		
Survival%	72.12[ab]	66.17[b]	86.14[a]	80[ab]	0.00	0.43
Litter size	<14	14 to 17	17 to 19	>19		
Survival%	51.21[c]	68.04[b]	85.85[a]	92.18[a]	0.00	0.40
Average litter weight (kg)	<1.19	1.19 to 1.34	1.34 to 1.5	>1.5		
Survival%	92.89[a]	83.67[b]	70.67[b]	60.64[c]	0.00	0.41
Birth weight (kg)	<0.97	0.97 to 1.2	1.2 to 1.4	>1.4		
Survival%	71.40[a]	77.91[a]	76.42[a]	81.35[a]	0.32	0.43
Suckling period (days)	<20	20 to 21	21 to 22	>22		
Survival	71.24[a]	76.19[a]	78.75[a]	77.50[a]	0.55	0.40
Litter weight variation (%)	<5 -20	21-35	35-55	>56 -90		
Survival	94.93[a]	91.22[b]	84.77[c]	75.85[d]	0.00	0.41
Length of gestation (days)	<114	114 to 115	115 to 116	>116		
Survival	81.68[a]	77.24[ab]	75.37[b]	73.23[ab]	0.00	0.42
Farrowing weight (kg)	<225	225 to 239	239 to 249	>249		
Survival%	79.38[a]	77.03[b]	75.95[b]	70.83[c]	0.00	0.42
Immunoglobulin G (%)	<12.1	12.1 to 12.5	12.5 to 13.7	>13.7		
Survival	88.92[a]	88.21[a]	87.94[b]	85.53[c]	0.00	0.37

[a-d] *Means within a row with different superscripts differ ($p<0.05$); SEM: Standard Error of the Mean*

directly proportional relationship between parity and the number of stillbirths (Framstad and Nielsen 2018; Langendijk and Plush 2019; Rangstrup-Christensen et al. 2017). The findings that primiparous and younger multiparous sows (parities 1 - 3) exhibited the highest stillbirth rates (4.84 - 5.16%) could be explained by several physiological and developmental factors. Primiparous or young sows have narrower birth canals and less farrowing experience (Peltoniemi et al. 2019; Mota-Rojas et al. 2020), which could result in higher stillbirth rates. More importantly, the literature (Zotti et al. 2017; Hagan and Etim 2019) indicates that highly prolific primiparous sows are more susceptible to different types of dysfunctions. These include longer farrowing duration due to giving birth for the first time (Patterson and Foxcroft 2019) and weak or ineffective contractions due to inexperience, or poor alignment of the pelvic bones (Peltoniemi et al. 2019). Compared with mature multiparous sows (three or more parities), these factors contribute to an increased rate of stillbirths. Primiparous sows are still undergoing body growth and development, and therefore, nutrients are shared between their own growth and fetal development (Leite et al. 2011; Buthelezi et al. 2024b; Corrales-Hernández et al. 2025). This competition for nutrients can result in reduced placental efficiency and compromised fetal nourishment, leading to lower piglet viability and an increased risk of stillbirth. Additionally, primiparous sows generally have smaller uterine capacity and less developed uterine blood flow (Buthelezi et al. 2024a), which may limit oxygen and nutrient supply to the fetuses during late gestation. These findings are in contrast with those reported by Wientjes et al. (2012), who revealed that the 5th parity sows had a higher number of stillbirth piglets than younger sows. The reason for this could be that the piglets farrowed by older sows have a high within-litter variation, thus reducing their chances of survival (Zindove et al. 2021).

The present study revealed that parity is significantly associated with piglet pre-weaning survival, with the highest pre-weaning mortality rate (18.22%) within the first 7-21 days observed in sows in fifth parity. These findings could be attributed to the fact that old sows have an extended length of farrowing due to large amounts of fat (Klimas et al. 2020), high within-litter variation (Kramarenko et al. 2020), a low number of functional teats (Obermier et al. 2023) and minimal contraction of muscles in the uterus (Walls et al. 2022) compared to primiparous, younger and multiparous sows. This, in turn, influences the pre-and postnatal piglet survival rate. These observations were in line with earlier findings in Large White × Landrace piglets (Buthelezi et al. 2024a, 2024b). This contradicts findings by Zotti et al. (2017), who reported that the piglets from older sows had higher rates of survival, which may be due to better growth rate associated with greater milk production by older sows compared to younger parity sows. Moreover, it was also observed that the primiparous sows and multiparous sows in parities 1 – 3 had the lowest pre-weaning survival rate (66.17 – 72.12%). These findings are consistent with findings by Nweze (2021), who reported that piglets from second parity sows had less chance of survival in contrast to other parities. Furthermore, it was also observed that higher multiparous sows (3 and above) yielded higher pre-weaning survival (80 – 86.14 %) compared to primiparous and young multiparous sows. The reason for this could be that primiparous and young multiparous sows have low energy reserves for milk production because they were still growing and utilized most of their nutrients for their own biological activities, rather than milk production (Hagan and Etim 2019; Leite et al. 2021; Corrales-Hernández et al. 2025), which may reduce piglet survival as a result of starvation. In addition, the lack of experience in primiparous sows might be the cause of reduced pre-weaning piglet survival (Faccin et al. 2022). Supporting this, Li et al. (2023) reported that primiparous sows exhibit poor lateral nursing ability compared to multiparous sows in Large White pigs, which results in reduced access to colostrum, increases the risk of crushing and less provision of warmth to the piglets, leading to low rates of survival.

Highly prolific sows typically produce an average of 16 or more live-born piglets per litter (Nuntapaitoon et al. 2019). An increase in litter size is associated with an increase in the total litter weight (Kitkha et al. 2017). A large number of piglets increases the length of farrowing and the risk of hypoxia, resulting in stillbirths and reduced piglet survival (Rutherford et al. 2021). The association between high stillbirth rates and litter size is widely recognized by several authors (Rangstrup-Christensen et al. 2017; Gourley et al. 2020; Van den Bosch et al. 2022). In the current study, the stillbirth rate (5.65 %) for sows that produced 14 piglets or fewer was higher than the stillbirth rate of sows that gave birth to 19 piglets or more (2%). The observed association between small litter size and increased stillbirth may reflect underlying sow health, reproductive efficiency, or gestational complications rather than a direct causal effect of litter size (Faccin et al. 2022). Hypoxia, which occurs in both small and large litters, could be another possible explanation for this result. A prolonged parturition duration, a long farrowing interval, or impaired or irregular uterine contractions can lead to oxygen deprivation in piglets, thereby increasing stillbirth rates (Peltoniemi et al. 2019; Mabunda et al. 2025). Prolonged and frequent contractions during farrowing can impair the flow of blood in the uterus, which further reduces the amount of oxygen received by the foetus (Mabunda et al. 2025). This leads to foetal hypoxia and metabolic acidosis, which can have an impact on cardiac and respiratory function and eventually cause pre-partum deaths (Chaiyapatmaetee et al. 2025). Similarly, sows that gave birth to a moderate litter size (14 to 17) had a high stillbirth rate (4.37%) compared to sows that gave birth to 17 to 19 piglets (3.90%). The biological explanation for this could be that a small litter size does not always guarantee that all piglets are healthy; some may be physically weak or have low birth weights, making them prone to dying during parturition (Tucker et al. 2021). These findings are in contrast with the stillbirth rate reported by Rangstrup-Christensen et al (2017) in a litter size of 16 piglets (1.1%). Furthermore, the genetic selection for larger litter size results in an increase in litter weight variation and multiple low birth weight piglets, which are highly associated with reduced pre-weaning survival (Nweze 2021). Although smaller litters (14 piglets or fewer) were associated with lower survival in this study (51.21 %) than those that farrowed 19 piglets or more (85.85%), the mechanism remains unclear. This finding contradicts much of the literature and this difference may reflect the influence of on-farm management practices including cross-fostering, parity distribution, selective management of weak piglets, and other unmeasured management or environmental factors. Larger litters are associated with increased competition among littermates for access to teats and colostrum, which may reduce the survival of lightweight piglets (Schoos et al. 2021). Additionally, animal management such as closer supervision (Tucker et al. 2021), assisting with colostrum intake (Nuntapaitoon et al. 2019) and split suckling (Vandaele et al. 2020) can also compromise the survival of piglets from large litters since they are known to be more vulnerable than the small litter piglets (Gourley et al. 2020). These findings are in contrast with what was reported by several authors who found that piglets from small litter sizes had higher rates of survival compared to larger litter size piglets (Buthelezi et al. 2024a; Gourley et al. 2020; Mabunda et al. 2025). This could be explained by the fact that sows farrowing larger litters experience longer farrowing duration, which negatively affects the health of the sow and vitality of the piglets, thus reducing the survival rate of piglets (Peltoniemi et al. 2019). This suggests that the survival of piglets was associated with other factors besides litter size, making it a multifactorial trait.

In the current study, maternal-related causes of piglet mortality (crushing, piglets being bitten by the sow, and starvation) were highly associated with piglet pre-weaning mortality (20.52 %) within 7-21 days post-partum. This could be attributed to the role played by the sow during lactation in providing protection and nutrition. Poor maternal ability can result in piglet crushing due to poor responsiveness during posture changes, insufficient milk intake leading to starvation and abnormal maternal aggression, such as biting of piglets (Muns et al. 2016). Supporting this, Hagan and Etim (2019) observed increased piglet pre-weaning mortality in crossbred sows as they were not able to feed their piglets properly. Pre-weaning survival of piglets is dependent on the mothering ability of the sow, hence, there is a high prevalence of mortality if sows are unable to effectively nurse the young ones (Hagan and Etim 2019). Similar trends were reported by Wientjes et al (2012), who conducted a study of large organic litters and found that the major causes of death were crushing (40.2%). Conversely, sows that were more cautious when lying down, moving and standing, facilitated communication with the piglets (grunting, sniffing, nudging) or spent a lot of time doing nest preparation before farrowing had a decreased mortality rate due to less crushing (Ocepek and Andersen 2017). Effective sow-piglet communication allows piglets to respond to their mother's posture adjustments, scent cues, and vocalizations in a biologically relevant manner (Ocepek and Andersen 2018). To facilitate adequate milk intake and the acquisition of energy, sow grunts are released before nursing to encourage piglets to gather at the udder and coordinate suckling behaviour (Ocepek et al. 2017). This reduces mortality caused by starvation and crushing and further enhances the survival of piglets.

Energy intake and metabolic activity are critical factors linking sow productivity to body condition (Muro et al. 2023). The interaction between body condition and stillbirth rate was reported by several authors (Tian et al. 2018; Gourley et al. 2020; Thongkhuy et al. 2020), wherein both the heavier and lighter body weight sows have been associated with an increased risk of stillbirths. In the present study, the lighter sows weighing 222.25 kg or less had the highest stillbirth rate (8.88%) compared to their heavier counterparts. These observations can be explained by the fact that lighter sows have low energy reserves, which reduce oxygen and nutrient supply to the foetus and prolong farrowing due to fatigue (Rangstrup-Christensen et al. 2017), consequently resulting in increased stillbirths. These findings are in line with observations for the lighter sows by several researchers (Vanderhaeghe et al. 2010; Tian et al. 2018; Thongkhuy et al. 2020). Additionally, lighter sows were also associated with a high pre-weaning piglet mortality rate in the current study, with sows weighing < 225 kg having a survival rate of 79.38% only. This is in line with findings by Lyderik et al. (2023) and Superchi et al. (2019), who reported that underweight sows are associated with low piglet post-natal survivability. This is mainly due to the fact that underweight sows give birth to piglets with low birth weight, resulting in compromised weight gain compared to their heavier counterparts, thus a high rate of mortality (Adi et al. 2025). Furthermore, in the current study, the heaviest sows at farrowing (>249 kg) had the lowest pre-weaning survival rate (70.83%) compared to the sows of other body weight classes (first – third quartile). Biologically, over-conditioned sows may reduce the survival of piglets before and post-partum. Excessive body weight may alter the functioning of the placenta and the allocation of nutrients, resulting in impaired growth and development of the foetus, and reduced piglet survival (Langendijk et al. 2023). After birth, over-conditioned sows have reduced *ad libitum* feed intake, which may reduce the production of milk during lactation (Knap et al. 2023), thus reducing the availability of nutrients and the survivability of piglets. Additionally, the piglets are at a greater risk of being crushed by the heavy sows (Tucker et al. 2021). Over-conditioned sows are also at greater risk of farrowing and lactation-related disorders, such as constipation, mastitis, and impaired udder development. Hormonal imbalances may also play a role (Knox 2019). This is consistent with findings by Zhou et al. (2018), who reported that Large White × Landrace sows that had excessive backfat thickness gave birth to lighter piglets, which did not make it to weaning. The compromised pre-weaning survival of such piglets could be attributed to immune, metabolic, respiratory and gastrointestinal dysfunctions. Intrauterine growth restriction (IUGR) piglets make up 76% of deaths that occur during the pre-weaning phase (Muro et al. 2023).

Sow gestation usually lasts three months, three weeks and three days with very little variation (1%) in gestational length (Imboonta et al. 2007). The length of gestation is a characteristic that is highly genetically transmissible ($h^2 = 0.39$) and is affected by the litter and the genes of the dam (Knol et al. 2022). In the present study, gestational length was negatively correlated with total born (r = -0.13) and, to a lesser extent, born alive (r = -0.12). These findings are consistent with an earlier report (Bumpenkul and Imboonta 2021), which also observed the negative genetic correlations between gestation length and born alive and total born in Landrace, Large White and Duroc sows. This relationship may be explained by the complex interconnectedness between fetal litter size, uterine capacity, and endocrine regulation of parturition. Larger litters tend to produce higher levels of fetal cortisol at the onset of farrowing (Corrales-Hernández et al. 2025), which may stimulate the maternal endocrine system, particularly prostaglandin release, leading to the earlier initiation of farrowing. As a result, sows with large litters often experience shorter gestational periods (Bumpenkul and Imboonta 2021), which reduces piglet survival due to low birth weights and high competition among littermates (Zindove et al. 2021). It is well noted that selection for sows with increased litter sizes might reduce the length of gestation, resulting in piglets with lighter weight at farrowing (Imboonta et al. 2007; Bumpenkul and Imboonta 2021). Moreover, in this study, it was also observed that sows that gave birth on day 115 of gestation with the smallest litter size (<14) had the highest rate of survival (81.68%) compared to those that gave birth from day 116 onwards, which had the lowest pre-weaning survival rate (73.23 %). In contrast, genetic selection and breeding for longer gestation enhance the pre-weaning survival rate, with more stillbirths as a trade-off (Imboonta et al. 2007). In the present study, it was observed that sows that farrowed between day 114 and 115 had the highest stillbirth rate (4.47%) compared to those that gave birth from day 116 (1.80%). These findings suggest that intermediate gestation lengths may be associated with an increased risk of stillbirth, whereas slightly longer gestation periods appear to enhance piglet survival. Biologically, this may be explained by the fact that shorter gestation periods can result in incomplete fetal development (Campos et al. 2012; Baek et al. 2021; Walls et al. 2022), particularly of vital organs such as the lungs and cardiovascular system, thereby reducing neonatal viability. Piglets born prematurely are also more likely to have lower energy reserves, making them less capable of withstanding the stress of parturition and the immediate postnatal environment (Vanden Hole et al. 2019). On the contrary, a slightly extended gestation period allows for improved fetal growth, greater maturation of physiological systems, and increased birth weight (Lyderik et al. 2023), all of which contribute positively to piglet survival. Additionally, uterine capacity and placental efficiency may play a role, as longer gestation could enhance nutrient transfer to the fetus, supporting better development (Tan et al. 2022). This relationship highlights the importance of optimal gestation duration in improving reproductive performance and reducing piglet mortality in pig production systems. Furthermore, the observed variations could be attributed to the fact that a small litter size on days 114 to 115 results in heavier piglets (Gourley et al. 2020). It is well noted that some heavier fetuses/piglets will have difficulty passing the birth canal, leading to oxygen deprivation and thus an increased stillbirth rate (Rutherford et al. 2021).

This study revealed that piglets with a birth weight of 0.97 kg or less had the lowest pre-weaning survival rate (71.40%), whereas heavier piglets showed a higher survival rate (81.35%). Overall, piglets weighing less than 1 kg exhibited reduced pre-weaning survival, while those with greater birth weights had increased odds of survival (Zotti et al. 2017). Lighter piglets at birth might fail to survive until weaning and die during the postpartum period due to reduced competitiveness at the udder (Devillers et al. 2011), hypothermia (Villanueva-García et al. 2021), inadequate colostrum intake, and whereas larger piglets have an increased risk of mortality due to dystocia (Hagan and Etim 2019). Birth weight uniformity also plays a critical role in piglet survival (Buthelezi et al. 2024b). Piglets that had a litter weight variation of 5-20% had the greatest piglet survival rate (94.9%) compared to piglets that had a weight variation ranging from 56% to 90%, with the lowest rate of survival (75.8%). This could be ascribed to the fact that the variation of piglet weight during parturition also depends on the site of implantation because of the high variation in the supply of nutrients and blood flow along the length of the uterus, because of the differences in density and vascular structure (Wang et al. 2017). A high variation within litter is associated with low birth weight piglets at birth (Buthelezi et al. 2024a), which results in insufficient ingestion of colostrum due to increased teat disputes with the heavier piglets, and the high body weight piglets might outperform the small weight piglets, which compromises their survival (Mabunda et al. 2025). The findings of this study are consistent with the results of Riddersholm et al. (2021), who reported an elevated pre-weaning mortality risk in piglets born from litters with high within-litter variation. There is an indirect effect of litter weight variation and piglet mortality, which suppresses survival opportunities for lighter and later-born piglets. In addition, the type of breed is significantly associated with the weight of the litter at birth, whereby the piglets sired by Large White boars were heavier than their counterparts (Hagan and Etim 2019). Moreover, other studies demonstrated that the weight of piglets also has an impact on the survival of piglets and the efficiency of cross-fostering during the pre-weaning period (Baxter et al. 2013; Alexopoulos et al. 2018; Pajžlar and Skok 2019). Heavy fostered piglets, which are highly vigorous, tend to perform better than biological piglets regarding survival, but fostering low birth weight piglets yields lower survival rates (Muns et al. 2014). However, other authors argued that fostering small weight piglets with other low weight piglets is more efficient in improving piglet survival and weight due to reduced teat fights, so they had sufficient colostrum intake (Heim et al. 2012; Huting et al. 2017; Alexopoulos et al. 2018). This is further supported by Alexopoulos et al. (2018), who showed that grouping small piglets with other small piglets resulted in 100% survival of fostered piglets, and the phenomenon decreases if lighter and heavier piglets are mixed.

Cross-fostering is commonly practiced to minimize variability among birth weights, match the number of piglets to the number of teats and standardize the number of piglets between litters (Alexopoulos et al. 2018). The study revealed that fostering status was significantly associated with pre-weaning mortality (16.08 %), and similar trends were reported by Marandu et al. (2015), who found that fostered piglets had a lower likelihood of survival before weaning. The underlying biological mechanisms may involve a decrease in physiological adaptation and impaired passive immune protection, which may be the cause of the lower survival rate in fostered piglets (Pajžlar and Skok 2019). Impaired nursing behaviour can lead to piglets consuming less milk when they are transferred to another sow, resulting in reduced absorption of energy, immunoglobulins and hormones that promote growth (Calderón Díaz et al. 2018). Fostering may elevate physiological stress by increasing cortisol levels (Byrd et al. 2022) and a decrease in the availability of calories may compromise thermoregulation, thereby increasing the risk of hypothermia (Gundersen et al. 2022). Therefore, these mechanisms can compromise thermoregulation, immune function, and the utilization of food, which further increases vulnerability to illness, hypothermia, and mortality and reduces the rate of pre-weaning piglet survival. This could be due to being transferred to a sow with poor maternal abilities (Vande Pol et al. 2021) and the fostered piglets not being able to adjust to their new littermates (Nielsen et al. 2022), which can negatively affect their performance. Supporting this, when the number of piglets surpasses the rearing ability of the sow, there is an increased risk of mortality (Alexopoulos et al. 2018). It is also noted that when the establishment of teat order is not done during early lactation, the growth and survival of piglets will be reduced remarkably (Skok and Škorjanc 2014). Litters containing 100% biological piglets had fewer teat disputes compared to those that had fostered piglets on day one post-partum and the fostered within 20 hours post-partum (Alexopoulos et al. 2018).

Adequate colostrum intake is important for supporting the survival of piglets during the pre-weaning period (Schoos et al. 2021). Piglets are born with an immature adaptive immune system, and the placental barrier prevents the transfer of maternal antibodies during gestation; therefore, they rely on innate immunity and the acquisition of passive immunity from the sow after birth through colostrum and milk (Hasan et al. 2016). Immunoglobulins are actively transported to the colostrum from the sow's blood within 24 hours after birth (Schoos et al. 2021). In the present study, high survival rates were observed in piglets born to sows with lower to medium colostrum Brix percentages (12.1% and 12.1 - 12.5%) with survival rates of 88.92% and 88.21%, respectively, compared to the higher Brix percentage classes (≥12.5%). The observed higher pre-weaning survival rates in piglets from sows with low to moderate colostrum Brix values (<12.5%) can be explained by a combination of biological and management-related factors. This unexpected finding should be interpreted with caution, as it may reflect the influence of confounding factors rather than the direct effect of colostrum quality. Although Brix percentage is commonly used as an indirect indicator of colostral immunoglobulin concentration (Langendijk 2025), it does not fully capture the dynamics of colostrum availability and intake. Sows with lower to moderate Brix percentages might have produced large volumes of colostrum, resulting in the consumption of adequate colostrum during the first few hours of birth. The survival of piglets depends on both passive immunity and nutrient intake, therefore, sufficient colostrum intake may counteract the lower immunoglobulin concentration (Hasan et al. 2016). Colostrum intake was not directly measured in the present study, limiting interpretation. In addition, heavier piglets with stronger suckling behaviour might have accessed the teats earlier than the weak piglets, making them more successful at acquiring adequate colostrum at birth (Oliviero et al. 2010), which might have contributed to the high rate of survival irrespective of the colostrum Brix percentage (Baxter et al. 2013). Management interventions such as cross-fostering and ensuring early access to the teats might have enhanced the efficiency of colostrum intake and reduced piglet mortality (Muro et al. 2023), resulting in high rates of pre-weaning survival. These findings are in contrast to those reported by Hasan et al. (2016), who observed that deceased piglets had lower IgG concentrations than surviving piglets, suggesting an association between passive immunity and piglet survival. The higher survival rate could be attributed to the fact that the increased passive immunological transfer enhanced the resistance to diseases throughout the neonatal stage. Additionally, piglet survival and vitality are elevated by the bioactive chemicals derived from colostrum, which promote the growth of the intestine, the use of nutrition and thermoregulation (Declerck et al. 2016).

A limitation of this study is that several established risk factors for piglet mortality, including back-fat thickness, body condition score, milk production, birth order, time of first suckling and environmental factors such as ambient temperature and humidity, were not available in the secondary dataset and therefore could not be included in the analysis. Future studies should incorporate these variables to provide a more comprehensive assessment of factors associated with stillbirths and pre-weaning piglet survival. Second, the analyses were performed using a multivariate logistic regression models without accounting for the hierarchical structure of piglets nested within litters. Although the model identified significant associations between predictor variables and the outcomes of interest, future studies should consider mixed-effects logistic regression models to account for within-litter clustering.

5. Conclusions

Pre-weaning piglet survival is influenced by a combination of various sow and piglet characteristics. The study revealed that sow and piglet characteristics, including parity, litter size, length of gestation, sow mothering ability, farrowing weight, colostrum quality, and fostering status, were associated with stillbirths and pre-weaning survival rates. Recognition and understanding of the sow and piglet characteristics associated with the pre-weaning survival of F1 Large White × Landrace pigs will help farmers enhance their farm productivity and reduce mortality rates during the pre-weaning phase. Moreover, the identified characteristics associated with neonatal deaths will be useful in guiding breeding programs aimed at improving maternal and piglet performance. As a result, the proposed management protocols are not merely technical adjustments, but are necessary steps towards achieving a more sustainable and equitable food system as envisaged by the SDGs 2030 vision.

Declarations

Funding: This work was funded by the Tshwane University of Technology Postgraduate Scholarship and the National Research Foundation

Conflict of interest: The author declare no conflicts of interest

Acknowledgements: The researchers appreciate Topigs Norsvin Farm for providing secondary data from its database for this study and the concerned staff for assisting with data collection and recording

Data Availability: The data supporting this study is given within the manuscript

Ethics approval: The study was approved by the Tshwane University of Technology Animal Research Ethics Committee (AREC202504006)

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Citation

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