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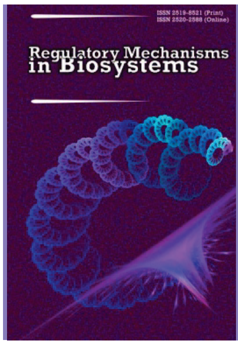
4 authors, including:

Alexander S Kramarenko
Mykolayiv National Agrarian University

Serhii Kramarenko
Mykolayiv National Agrarian University

Iryna M Liuta
Mykolayiv National Agrarian University



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Genetic and non-genetic factors influencing piglet stillbirth risk

A. S. Kramarenko, O. I. Karatieieva, I. M. Liuta, S. S. Kramarenko

Mykolayiv National Agrarian University, Mykolayiv, Ukraine

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Mykolayiv National Agrarian University, George Gongadze st., 9, Mykolayiv, 54008, Ukraine. Tel.: +38-050-991-53-14. E-mail: kssnail0108@gmail.com, karateeva1207@gmail.com, liutaim@mnau.edu.ua

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Piglet mortality is a major challenge in organic production and in recent years there has been increasing public concern about the level of animal losses before weaning. The main objective of this study was the analysis of the relative role of genetic and non-genetic risk factors for stillbirth in piglets of the world's widely represented breeds. A total of 2,817 litter records of productive parent sows were collected between 2010 and 2013. The following traits were estimated for each litter: the number of stillborn piglets per litter and the stillbirth rate, defined as the number of stillborn piglets divided by the total number of piglets born per litter. In addition, the proportion of litters with at least one stillborn piglet was determined also. The proportion of litters with at least one stillborn piglet for the study sample was 59.2%, indicating that the majority of sows exhibited the occurrence of at least one stillbirth. The mean number of stillborn piglets ranged from 0 to 15 head, with a mean of 1.40 ± 0.03 head, and the range of stillbirth rates per litter was 0 to 100%, with a mean of 12.91 ± 0.28%. The breed of the boar had a highly statistically significant impact on all piglet loss traits at birth employed in the analyses. The mean piglet losses estimates for the piglets born in the Large White boar litters were all found to be lower than those for the piglets born in the Duroc and Landrace boar litters. The year of farrowing also significantly influenced the observed traits, particularly for the number of stillborn piglets per litter and the stillbirth rate. The highest values were observed for litters born in February-March, while farrowing in May exhibited the lowest piglet losses at birth. Furthermore, the sows with the shortest gestation length (110 days) always had at least one stillborn piglet per litter. A significant increase in piglet mortality at birth was associated with an increase in total litter size, both at the level of individual sows and piglets per litter. The optimal average piglet birth weight value, at which piglet losses at birth were lowest, was 1700 g or more. Conversely, piglets with lower average piglet birth weight values exhibited a higher probability of dying at birth or immediately thereafter. As the variability in live birth weight of newborn piglets increased, there was a notable rise in the frequency of litters with at least one stillborn piglet. The lowest proportion of litters with at least one stillborn piglet values were observed in litters in which all newborn piglets had the same body weight at birth. The potential for research on stillbirth includes the analysis of its impact on the average daily growth rates and survival of piglets until weaning, as well as its effect on the development of performance, meat and carcass traits of fattening pigs.

Keywords: losses of piglets; breed of sow and boar; year and month of farrowing; gestation length; piglet birth weight.

Introduction

Piglet mortality constitutes a major challenge in organic production. The majority of piglet deaths are due to stillbirth, crushing, starvation, and infection (Kobek-Kjeldager et al., 2023). In recent years, with improved genetic selection and breeding management, the average litter size of modern hyperproductive sows has increased, but so has the stillbirth rate of piglets (Ma et al., 2024). Due to unfavourable genetic correlations with piglet losses, breeding objectives should include survival traits in addition to litter size. Imbalanced breeding programmes that do not take this into account have resulted in higher mortality rates. Against this background in recent years, there has been an increase in public concern about the level of animal losses before weaning (Peltoniemi et al., 2021; Hansen et al., 2023; Knap et al., 2023).

Stillbirths are a major cause of reduced piglet numbers, reaching rates of 3–8% and accounting for up to 25% of piglet losses between farrowing and weaning. Stillbirths are mainly caused by maternal, environmental and piglet factors, although they can be caused by infection. In view of the importance of knowing the risk factors for stillbirth and the impact of sows on herd efficiency, data on stillbirths in hyperproductive sows must be updated in order to define strategies for the reduction of such occurrences in production systems (Sens Junior et al., 2023).

According to Sprecher et al. (1974), stillbirths can be classified into two distinct types based on the time of death: Type I, or deaths, include fetuses that die before the end of gestation (antepartum or prepartum deaths), usually from infectious causes. Type II stillbirths are animals that die during parturition (intrapartum deaths). They are usually associated with non-infectious causes such as intrauterine asphyxia and dystocia. Of all stillborn piglets, 10% die shortly before farrowing, 75% die during farrowing and the remaining 15% die immediately after farrowing (Leenhouwers et al., 1999). In many cases, the different mortality groups (such as type II stillbirths or piglets that died immediately after birth) do not represent separate disease entities, but are different clinical manifestations of the same underlying condition, namely the degree of asphyxia during parturition. Fetal hypoxia has the strongest relationship with the survival of piglets at farrowing, and even transient hypoxia during birth can cause permanent brain damage and reduce the survival of piglets born alive (Edwards, 2002).

The risk factors for stillbirth in piglets that are not of an infectious nature have been studied for a long time. In most cases, they can be divided into several groups (Kirkden et al., 2013; Vanderhaeghe et al., 2013). Firstly, there are factors that are related to the characteristics of the sow. This group includes the farrowing number (i.e., parity), the sow body weight and condition, the litter size at birth, the gestation length, the farrowing duration, etc., as well as sow age. Secondly, these are factors related to newborn piglet characteristics. This includes the birth interval, the order in which the pigs are born, the body weight at birth and the intra-litter variation in body weight at birth, etc. Finally, the third group includes factors related to environmental and management effects, such as the pregnant sow's diet, the farrowing year and month/season, farrowing induction (for example, use of oxytocin), human intervention in the farrowing process (palpation), and stress (for example, air temperature, THI) (Raguvaran et al., 2017).

The breed of sow, boar and piglets was found to have a significant effect on the risk of piglet stillbirth among genetic factors. The differences between the breeds are manifested in differences in fertility, survival and the general condition of the newborn piglets. A study conducted by Canario et al. (2006) showed that piglets born to Meishan sows had a lower risk of stillbirth compared to other breeds. Meishan pigs are known for their high fertility and better ability of piglets for survival. This reduces the incidence of birth complications such as strangulation or prolonged farrowing time. Leenhouwers et al. (2003) reported that the genetics of the sows affected the probability of mortality at farrow, whereas the genetics of the piglets affected mortality before and immediately after farrow. The study by Pedersen et al. (2019) showed that the Pietrain boars used as terminal sires had a higher total number of piglets born per litter than the Duroc boars, showing that the Pietrain boars are more fertile than the Duroc boars. It is an indication that the Pietrain semen has a higher fertilisation capacity than semen from the Duroc boars.

Thus, piglet stillbirth is a multifactorial, complex trait related to risk factors. These risk factors may manifest and interact differently under different environmental conditions and for different genetic groups. In Ukrainian conditions, risk factors for stillbirth have only been studied for the autochthonous Ukrainian meat breed (Kramarenko et al., 2023) and partially for the Large White breed sows (Kramarenko & Kramarenko, 2021). On the other hand, no such studies have been carried out for the Duroc and Landrace breeds and their crosses with the Large White breed, which are represented in Ukrainian farms.

The main objective of this study was the analysis of the relative role of genetic and non-genetic risk factors for stillbirth in piglets of the most common breeds in Ukraine.

Materials and methods

The study was conducted in accordance with the "Procedure for Conducting Experiments on Animals by Scientific Institutions" (Order of the Ministry of Education and Science, Youth and Sports of Ukraine No. 249 dated 1 March 2012, Kyiv), the Law of Ukraine "On Protection of Animals from Cruelty" (No. 3447-IV dated 21 February 2006, Kyiv), and the "European Convention for the Protection of Vertebrate Animals Used in Experiments and for other Scientific Purposes" (Strasbourg, 1986). The research protocol of the current study was approved by the Ethics Committee of the Mykolaiyv National Agrarian University (approval number: 2013/2). In addition, the study was conducted in accordance with the ARRIVE guidelines.

A total of 2,817 litter records of productive parent sows of the PJSC 'Plemzavod 'Stenoi' of Zaporizhzhia region (Ukraine) were collected between 2010 and 2013. The study sample comprised purebred individuals of two distinct breeds: the Duroc (DR; n = 654) and the Landrace (LN; n = 584). The mean number of farrowings (± SE) for the Duroc and Landrace sows was 2.25 ± 0.06 and 2.51 ± 0.07, respectively with a range of one to 9 farrowings. The sows were inseminated with semen from three breeds of boar: the Duroc (DR; n = 38), Landrace (LN; n = 35) and Large White (LW; n = 39).

The following traits were estimated for each litter: the number of stillborn piglets per litter (NSB, head) and the stillbirth rate (SBR, %), defined as the number of stillborn piglets divided by the total number of piglets born per litter. In addition, the proportion of litters with at least one stillborn piglet (ISSL) was determined also. The ISSL score was either 0 (indicating that no stillborn piglets were identified per litter) or 1 (indicating that at least one stillborn piglet was identified per litter). The frequency of litters with one (NSB = 1), two to four (NSB = 2–4) or five or more stillborn piglets (NSB = 5+) was also calculated for sows for whom at least one stillborn piglet was observed per litter.

Additionally, the following quantitative traits were evaluated for each litter: the maternal sow's gestation length (GL, day), total number of piglets born per litter (TNB, head), the average piglet birth weight (APWB, g), which is calculated as the ratio of litter weight to the total number of piglets at birth per litter, and the difference between the maximum and the minimum piglet birth weight per litter (DWPB, g).

The analysis of piglet losses at birth also incorporated the year (2010 to 2013) and month of farrowing (January to December) of the sow.

The General Linear Model were,

$$Yijklmnopr = \mu + SBj + BBj + YoFk + MoFl + GLm + \\ + TNBn + APWBo + DWPBp + \varepsilon ijklmnopr,$$

were Yijklmnopr – is the observed value; μ – is the overall means; SBj – is the fixed effect of the ith breed of sow (i = DR, LN); BBj – is the fixed effect of the jth breed of boar (j = DR, LN, LW); YoFk – is the fixed effect of the kth year of farrowing (k = 2010, 2011, 2012, 2013); MoFl – is the fixed effect of the lth month of farrowing (l = January, February, March, …, December); GLm – is the fixed effect of the mth gestation length class (m = 110, 111, 112, …, 121 days); TNBn – is the fixed effect of the nth total number of piglets born per litter class (n = 3, 4, 6, …, 18+ head); APWBo – is the fixed effect of the oth piglet birth weight class (o = < 1400, 1401–1500, 1501–1600, …, 1901–2000 g); DWPBp – is the fixed effect of the pth difference between the maximum and the minimum weight of the piglets at birth in the litter class (0, 1–100, 101–200, 201–300, …, > 601 g); εijklmnopr – is random error.

The mean and statistical error estimates (x ± SE) were calculated for individual subgroups, formed based on the levels of the factors included in the model. Tukey's Honestly Significant Difference (HSD) test was employed to ascertain the statistical significance of the differences between the individual subgroup means, given the unequal sample sizes.

All statistical analyses were conducted with the use of Statistica 7 (Stat Soft Inc., USA, 2004), on the basis of generally accepted algorithms (Sokal & Rohlf, 1995).

Results

The ISSL mean value for the study sample was 59.16%, indicating that the majority of sows exhibited the occurrence of at least one stillbirth. The number of stillborn piglets ranged from 0 to 15 head, with a mean of 1.40 ± 0.03 head, and the range of stillbirth rates per litter was 0 to 100%, with a mean of 12.91 ± 0.28%.

Among the sows that had stillborn piglets, the distribution was as follows: 22.10% had one, 15.44% had two, 9.75% had three, 5.10% had four, and 6.77% had five or more stillborn piglets per litter.

The sow breed had no significant impact on either the NSB or ISSL values (Table 1). Conversely, the SBR value was significantly (P = 0.020) higher in litters born from the DR sows (13.71%) in comparison to those derived from the LN sows (12.23%).

Table 1
Descriptive statistics (x ± SE) for the piglet losses depending on the breed of sow and boar sire

Breed	NSB, head	ISSL	SBR, %
Breed of sow:			
DR (n = 1309)	1.39 ± 0.05	0.599 ± 0.014	13.71 ± 0.42
LN (n = 1508)	1.42 ± 0.04	0.582 ± 0.013	12.23 ± 0.36*
Breed of boar sire:			
DR (n = 827)	1.55 ± 0.06a	0.642 ± 0.017a	15.21 ± 0.56c
LN (n = 1353)	1.48 ± 0.05a	0.605 ± 0.013a	13.11 ± 0.39b
LW (n = 637)	1.05 ± 0.06b	0.491 ± 0.020b	9.52 ± 0.50a

Nones: n – number of litters; NSB – the number of stillborn piglets per litter; ISSL – the incidence of stillbirth at the sow level; SBR – the stillbirth rate per litter; different letters indicate significant (P < 0.05) differences between the means of the subgroups; * – P < 0.05.

Conversely, the breed of the boar had a highly statistically significant impact (P < 0.001) on all piglet loss traits at birth employed in the analyses (Table 1). The mean NSB, ISSL and SBR values for the piglets born in the LW boar litters were all found to be lower than those for the piglets born in the DR and LN boar litters.

The year of farrowing also significantly influenced the observed traits, particularly for the NSB and SBR (in both cases, P < 0.001). The highest values were observed across all traits for litters born in 2011, whereas the lowest values for the NSB, ISSL and SBR were identified in litters born to sows that farrowed in 2012 (Table 2). Finally, the litters born in 2010 and 2013 exhibited intermediate values with regard to these traits.

Table 2
Descriptive statistics (x ± SE) for the piglet losses depending on the year of farrowing of the sow

Year of farrowing	NSB, head	ISSL	SBR, %
2010 (n = 713)	1.48 ± 0.06bc	0.609 ± 0.018ab	14.06 ± 0.58bc
2011 (n = 778)	1.65 ± 0.07c	0.617 ± 0.017b	14.67 ± 0.58c
2012 (n = 848)	1.20 ± 0.05a	0.555 ± 0.017a	10.95 ± 0.45a
2013 (n = 478)	1.25 ± 0.07ab	0.579 ± 0.023ab	11.81 ± 0.62ab

Notes: see Table 1.

With respect to the farrowing month, a marginal influence (P < 0.05) was discerned solely for the NSB and SBR values (Table 3). The highest values were observed for litters born in February–March (1.60–1.62 head and 14.58–15.23%, respectively), while farrowing in May exhibited the lowest piglet losses at birth.

Table 3
Descriptive statistics (x ± SE) for piglet losses depending on the month of farrowing of the sow

Month of farrowing	NSB, head	ISSL	SBR, %
Jan (n = 236)	1.36 ± 0.11ab	0.585 ± 0.032	12.08 ± 0.93ab
Feb (n = 220)	1.62 ± 0.12b	0.655 ± 0.032	14.58 ± 1.01ab
Mar (n = 285)	1.60 ± 0.10b	0.653 ± 0.028	15.23 ± 0.93b
Apr (n = 274)	1.42 ± 0.11ab	0.599 ± 0.030	13.10 ± 0.92ab
May (n = 289)	1.16 ± 0.08a	0.571 ± 0.029	10.38 ± 0.69a
Jun (n = 325)	1.33 ± 0.10ab	0.538 ± 0.028	12.20 ± 0.84ab
Jul (n = 277)	1.23 ± 0.09ab	0.549 ± 0.030	11.97 ± 0.88ab
Aug (n = 217)	1.43 ± 0.12ab	0.562 ± 0.034	12.59 ± 0.98ab
Sep (n = 200)	1.46 ± 0.13ab	0.570 ± 0.035	13.14 ± 1.09ab
Oct (n = 189)	1.44 ± 0.12ab	0.630 ± 0.035	13.43 ± 1.02ab
Nov (n = 148)	1.34 ± 0.14ab	0.561 ± 0.041	12.75 ± 1.21ab
Dec (n = 157)	1.59 ± 0.15ab	0.637 ± 0.039	14.80 ± 1.24ab

Notes: see Table 1.

The observed differences between winter and spring farrowings were associated with a lower frequency of litters with no stillborn pigs, but a higher frequency of litters with five or more stillborn pigs born in February–March. In contrast, the opposite was observed for farrowings in May (Fig. 1).

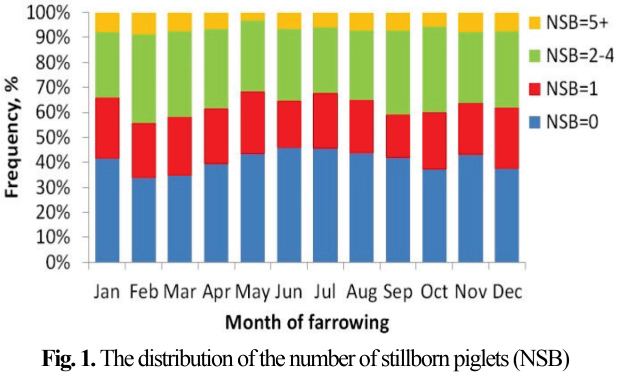

Fig. 1. The distribution of the number of stillborn piglets (NSB) per litter depending on the sow's month of farrowing (N = 2,817)

The findings revealed a significant (in all cases: P < 0.001) decline in the calculated estimates of qualitative and quantitative traits of piglet losses at birth with an increase in the duration of the sow's gestation length (Table 4). Furthermore, all sows with the shortest gestation duration (110 days) had at least one stillborn piglet per litter. The mean estimates of the number and proportion of such piglets per litter were found to be 3.53 head and 31.64%, respectively. The data indicated that the optimal level of piglet mortality at birth was observed in sows with a gestation length of 114 days or more.

A significant (in all cases: P < 0.001) increase in piglet losses at birth was associated with an increase in total litter size, both at the level of individual sows (ISSL) and piglets per litter (NSB and SBR, Table 5). The observed decrease in the proportion of litters without stillborn piglets (NSB = 0) and the concurrent increase in the proportion of litters with five or more stillborn piglets (NSB = 5+) with increasing litter size were the primary factors responsible for this outcome (Fig. 2).

Table 4
Descriptive statistics (x ± SE) for piglet losses depending on the gestation length of the sow

Gestation length, day	NSB, head	ISSL	SBR, %
110 (n = 15)	3.53 ± 0.50d	1.000 ± 0.000ab	31.64 ± 3.70c
111 (n = 18)	1.89 ± 0.41abcd	0.722 ± 0.109ab	19.23 ± 3.81abc
112 (n = 74)	1.89 ± 0.26bcd	0.649 ± 0.056ab	16.17 ± 1.92abc
113 (n = 202)	1.81 ± 0.14cd	0.649 ± 0.034a	16.58 ± 1.22bc
114 (n = 375)	1.50 ± 0.09abc	0.653 ± 0.025a	14.30 ± 0.78ab
115 (n = 483)	1.30 ± 0.07ab	0.582 ± 0.022ab	12.10 ± 0.63a
116 (n = 597)	1.36 ± 0.07abc	0.581 ± 0.020ab	12.36 ± 0.58ab
117 (n = 509)	1.41 ± 0.08abc	0.583 ± 0.022ab	12.66 ± 0.64ab
118 (n = 309)	1.25 ± 0.09ab	0.537 ± 0.028ab	11.46 ± 0.82a
119 (n = 170)	1.07 ± 0.12a	0.471 ± 0.038b	10.0 ± 1.04a
120 (n = 53)	1.15 ± 0.17abc	0.585 ± 0.068ab	11.57 ± 1.70ab
121 (n = 12)	1.00 ± 0.25abc	0.667 ± 0.142ab	9.91 ± 2.35ab

Notes: see Table 1.

As litter size increases from 14 piglets or more, the incidence of stillbirths among newborn piglets rises to nearly one in four to five births. The incidence of stillbirths was consistently observed in the litters comprising 17 or more newborn piglets (Table 5).

Table 5
Descriptive statistics (x ± SE) for piglet losses depending on the total number of piglets born per litter (TNB)

TNB, head	NSB, head	ISSL	SBR, %
3 (n = 25)	0.20 ± 0.08abc	0.200 ± 0.082abcd	6.67 ± 2.72abc
4 (n = 37)	0.22 ± 0.08ab	0.189 ± 0.065ab	5.41 ± 1.97ab
5 (n = 64)	0.55 ± 0.10ab	0.391±0.061abcdg	10.94 ± 2.04abce
6 (n = 115)	0.52 ± 0.08ab	0.357 ± 0.045abg	8.70 ± 1.26abe
7 (n = 179)	0.53 ± 0.07a	0.341 ± 0.036ag	7.58 ± 0.95a
8 (n = 289)	0.74 ± 0.06a	0.457 ± 0.029abcg	9.26 ± 0.74abe
9 (n = 371)	1.01 ± 0.07ab	0.536 ± 0.026bcd	11.17 ± 0.73abe
10 (n = 510)	1.15 ± 0.06bc	0.565 ± 0.022cd	11.55 ± 0.60abe
11 (n = 454)	1.43 ± 0.08c	0.623 ± 0.023df	13.04 ± 0.69bcef
12 (n = 319)	1.97 ± 0.10d	0.771 ± 0.024e	16.41 ± 0.83cdf
13 (n = 203)	2.20 ± 0.13d	0.778 ± 0.029ef	16.90 ± 1.00cdf
14 (n = 132)	2.89 ± 0.20e	0.826 ± 0.033e	20.62 ± 1.43d
15 (n = 61)	3.38 ± 0.30ef	0.852 ± 0.046ef	22.51 ± 2.00d
16 (n = 36)	4.03 ± 0.39ef	0.944 ± 0.039ef	25.17 ± 2.45d
17 (n = 11)	5.45 ± 0.76f	1.000 ± 0.000efg	32.09 ± 4.44def
18+ (n = 11)	5.27 ± 0.89f	1.000 ± 0.000efg	27.99 ± 4.64df

Notes: see Table 1.

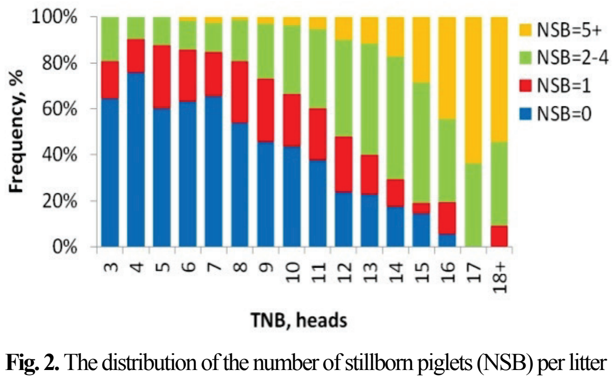

Fig. 2. The distribution of the number of stillborn piglets (NSB) per litter depending on the total number of piglets born per litter (TNB) (n = 2,817)

The optimal AWPB value, at which piglet losses at birth were lowest, was 1700 g or more. Conversely, piglets with lower AWPB values exhibited a higher probability of dying at birth or immediately thereafter (Table 6). It was established that the degree of variation in piglet body weight within a litter has a significant influence on the mortality rate of piglets at birth also. As the variability in live birth weight of newborn piglets increased, there was a notable rise in the frequency of litters with at least one stillborn piglet (P = 0.012). The lowest ISSL values were observed in litters in which all newborn piglets the same body weight had at birth (Table 7).

Table 6
Descriptive statistics (x ± SE) for piglet losses depending on the average piglet birth weight (AWPB)

AWPB, g	NSB, head	ISSL	SBR, %
< 1400 (n = 16)	1.81± 0.51ab	0.563 ± 0.128ab	14.47 ± 4.13ab
1401–1500 (n = 27)	1.41 ± 0.41ab	0.407 ± 0.096ab	12.60 ± 3.69ab
1501–1600 (n = 113)	1.58 ± 0.18ab	0.646 ± 0.045ab	13.30 ± 1.31ab
1601–1700 (n = 383)	1.77 ± 0.09b	0.695 ± 0.024b	15.89 ± 0.79b
1701–1800 (n = 1085)	1.34 ± 0.05a	0.581 ± 0.015a	12.10 ± 0.43a
1801–1900 (n = 568)	1.34 ± 0.07a	0.590 ± 0.021a	12.64 ± 0.59a
1901–2000 (n = 645)	1.30 ± 0.07a	0.538 ± 0.020a	12.63 ± 0.60a

Notes: see Table 1.

Table 7
Descriptive statistics (x ± SE) for piglet losses depending on the difference between the maximum and the minimum weight of the piglets at birth per litter (DWPB)

DWPB, g	NSB, head	ISSL	SBR, %
0 (n = 488)	1.34 ± 0.09	0.518 ± 0.022b	13.23 ± 0.67
1–100 (n = 363)	1.32 ± 0.09	0.583 ± 0.026ab	13.13 ± 0.77
101–200 (n = 943)	1.38 ± 0.05	0.596 ± 0.016a	12.68 ± 0.48
201–300 (n = 530)	1.35 ± 0.07	0.596 ± 0.021a	11.93 ± 0.64
301–400 (n = 265)	1.58 ± 0.11	0.623 ± 0.030a	13.84 ± 0.90
401–500 (n = 111)	1.66 ± 0.17	0.658 ± 0.047a	13.70 ± 1.39
501–600 (n = 60)	1.83 ± 0.25	0.717 ± 0.063a	15.00 ± 1.90
> 601 (n = 78)	1.53 ± 0.19	0.585 ± 0.055ab	13.24 ± 1.64

Notes: see Table 1.

Discussion

The results of the analysis of different aspects of stillbirth rates exhibit a considerable degree of variation between various pig breeds (and crosses) globally. For example, estimates of the proportion of litters with at least one stillborn piglet have ranged from 30.4% for the Yorkshire (YR), LN and their crosses in Canada (MacDonald et al., 1963) to 60.2% for the LN × YR sows in Vietnam (Nam & Sukon, 2021). Conversely, it is possible that this estimate may have differed considerably between herds. For instance, in the case of crossbred LN × YR sows in Vietnam, 47.9% of litters were found to have at least one stillborn piglet, with a range for individual herds of 37.5% to 60.8% (Nam & Sukon, 2020). Furthermore, Lucia Jr. et al. (2002) demonstrated that on two commercial farms, the incidence of litters with at least one stillborn piglet was found to be 39.0% and 25.0%, respectively. In our previous researches, which focused on sows of the LW and Ukrainian Meat breeds, the corresponding estimates were 63.3% (Kramarenko & Kramarenko, 2021) and 56.9% (Kramarenko et al., 2023). In the present study, the ISSL value of 59.2% was observed for the DR and LN sows. It can be seen that the estimates obtained for Ukrainian pig populations are situated at the upper end of the aforementioned range.

The mean number of stillborn piglets per litter (NSB) ranged from 0.7 for the YR sows in Sweden (Rydhmer et al., 2008) up to 1.9 for the crossbreeding LN × YR sows in Denmark (Rangstrup-Christensen et al., 2018). Notwithstanding the relatively low estimate of 0.2 for the LN sows provided by Imboonta et al. (2007), an average of 0.4 piglets per litter were born alive also but died within the first 24 hours of life. Furthermore, considerable variation was observed in the estimate of the NSB values per litter between the sampled farms. To illustrate, a study of nine Danish farms utilising the LN × YR sows estimated the number of stillborn piglets per litter at an average of 1.1 head, with a range observed between 0.7 and 1.9 head across the different farms (Rangstrup-Christensen et al., 2018). The mean number of stillborn piglets of the LN × YR sows in five herds (Denmark) was found to range from 1.0 to 2.3 head per litter (Schild et al., 2019).

The estimated stillbirth rate per litter (SBR) varies considerably between studies. For example, the SBR value for the LN × YR sows in Thailand was reported to be 4% (Roongsitthichai & Olanratmanee, 2021), while the SBR value for the LW sows in the USA was 17.6% (Arango et al., 2006). The mean SBR value in 22 pig herds comprising different breeds (Belgium) was 8.5%, with a range from 1.8% to 15.0% (Vanderhaeghe et al., 2010). Nevertheless, the evaluation of this trait may vary considerably between different farrowings. For instance, in France, the SBR values ranged from 0% to 91.6% in individual LW sow farrowings (Rosendo et al., 2007).

The estimates obtained in the present study for the NSB (1.4 ± 0.03 head) and SBR (12.91 ± 0.28%) are in agreement with the findings of previous research in the field, particularly with regard to different breeds that have been studied in a variety of countries worldwide.

In a study conducted by Pedersen et al. (2019), the mortality rate of piglets born to crossbred LN × YR sows mated to purebred the Pietran and DR boars was analysed. The results demonstrated that the piglet losses at birth and in the first five days after farrowing were significantly lower ($P < 0.001$) among the progeny of the DR boars compared with the progeny of the Pietrain boars. Scofield and Penny (1969) demonstrated that the proportion of stillborn piglets per litter of sows mated to the LN boars was significantly ($P < 0.01$) lower (6.9%) than among sows mated to LW boars (11.4%). Significant inter-individual differences were observed with regard to the SBR values among individual boars within a specific breed. However, it is possible that these discrepancies could be attributed to the specific circumstances of the year in which the study was conducted (Randall & Penny, 1970).

The study by Nevrkla et al. (2021) revealed a significant impact of the breed of terminal boar on the incidence of stillbirths. The lowest average NSB value was observed in litters derived from the DR × Pietrain boars (1.1 head) while the highest was noted in litters derived from purebred Pietrain boars (2.8 head per litter). In contrast, Damgaard et al. (2003) demonstrated that the breed of boar (YR, LN, Hampshire or DR) did not exert an influence on the estimated stillbirth rate of the Yorkshire sows that were mated to them.

It was previously demonstrated that, with regard to the Erhualian pig breed, the year of farrowing did not have a statistically significant impact on the NSB value for the LW sows and their crosses from China, but it was found to have a statistically significant effect on the SBR value (Chu, 2005). Additionally, Vazquez et al. (1994) demonstrated that farrowing year had a significant ($P < 0.001$) effect on the proportion of stillborn piglets per litter of Iberian sows in Spain.

In a study conducted by Lewis & Hermesch (2013), a comparison was made between three breeds of sows (LW, LN and DR) in Australia. The results indicated a decline in the proportion of litters with no stillborn pigs during the period between 1996 and 2010, despite fluctuations in the data. The annual fluctuations in the NSB values exhibited by the DR sows may potentially be attributable to the limited sample size. Moreover, the nature and magnitude of the annual fluctuations displayed distinctive patterns contingent on the order of farrowing of the sow. A study of 91 herds in Spain conducted between 2007 and 2016 revealed a statistically significant linear trend for temporal variability in the number of stillborn piglets per litter ($P = 0.01$) (Koketsu et al., 2021).

The effect of the month or season of farrowing on the number and proportion of stillborn piglets per litter has been the subject of numerous studies. However, these studies have often yielded conflicting results. The majority of studies have indicated that there is an increase in the incidence of stillbirths during the spring and summer months of the year. For instance, the Iberian sows that farrowed during the winter months were demonstrated to have the lowest proportion of stillborn piglets (Vazquez et al., 1994). Conversely, the NSB values was found to be significantly higher ($P < 0.05$) in the LW sows (French West Indies) that farrowed during the hot season of the year compared to the warm season. A near-significant correlation was identified between the SBR values and ambient temperature at farrowing ($r = 0.25$; $P = 0.06$) (Renaudeau et al., 2003). The influence of the farrowing season on the NSB values of crossbred LN × YR sows (Denmark) has been demonstrated to exhibit a peak during the summer time (May to August). This was due to the fact that during the summer of 2014, when the study was conducted, the mean air temperature was 1.6 °C above the long-term average (Rangstrup-Christensen et al., 2018).

However, it is also known that there is an increase in the number and proportion of stillborn piglets per litter during farrowing in the colder months of the year. Accordingly, the results of a three-year study conducted by Scofield and Penny (1969) revealed a significantly higher proportion of stillborn piglets during winter farrowing (10.8%) compared to farowing during the summer months (7.9%), which aligns with the findings of our study. Furthermore, the data indicated a significant elevation in stillbirth rate (P < 0.01) on three of the farms during the winter months in comparison with the summer period. In contrast, the other two farms demonstrated a lack of association between farrowing season and the likelihood of stillbirth. However, the months during which the incidence of stillbirth was greatest differed between the various farms and between the years covered by the study (Randall & Penny, 1970).

Furthermore, Chu (2005) demonstrated that for the indigenous Erhualian pig breed, the LW sows and their crosses (China), the farrowing season had a significant impact on the number of stillborn piglets per litter. A higher incidence of stillbirth was observed in sows that farrowed in the winter, in comparison to animals that farrowed in the autumn. It is a possibility that the exposure of sows to low temperatures during the winter months may have resulted in an extended farrowing duration, thereby increasing the risk of stillbirth. This phenomenon bears resemblance to the impact observed in sows subjected to heat stress during the summer season. Conversely, the number of stillborn piglets farrowed by sows during the summer months was found to be affected by humidity levels when the temperature exceeded a specified threshold (Suriyasomboon et al., 2006). Tani et al. (2016) examined the impact of farrowing season on the stillbirth rate among the crossbred LN × LW sows in Japan. Their findings revealed that the ISSL values were not statistically different between animals farrowed in the warm wet season (June-September) and the cold season (December–March). Furthermore, no significant differences were identified with regard to the mean NSB values. While temporal variation was observed to exert some influence on stillbirth rates among the LN sows and crossbred YR × LN (Denmark) sows, no pronounced seasonal effect was discerned (Chu et al., 2022). It is likely that a significant lack of green forages in the diet is responsible for the increased stillbirth rate in sows farrowing in late winter (February) or early spring (March) (Yang et al., 2023).

A trend towards a gradual increase in sow litter size at birth has been observed in recent years. In this case, litter size correlates significantly positively with increasing farrowing time and gestation length (Ju et al., 2021). On the other hand, better piglet development at farrowing and thus lower postnatal mortality is favoured by a gestation period of at least the average estimate (most commonly 114–115 days). In addition, the number of stillborn piglets per litter at birth increased with decreasing gestation length, and the average body weight of piglets at birth tended to decrease with increasing litter size (Ogawa et al., 2019). Nam & Sukon (2020) also showed that a gestation length of less than 114 days was an important risk factor for stillbirth in crossbred LN × YR sows under Vietnamese conditions. Sows gestating for less than 114 days were 1.80-fold (P < 0.001) more likely to have at least one stillborn piglet in the litter. This may be due to lung underdevelopment in piglets born prematurely (before 114 days gestation). The earliest studies, conducted by McPhee & Zeller (1934) and Asdell (1941), demonstrated that an increase in the litter size at birth was associated with an elevated risk of stillbirths. In general, there was an increase in both the mean number and proportion of stillborn piglets per litter as the total number of piglets born per litter increased. It is noteworthy that an increase in the magnitude of piglet losses in very small litters has also been documented. Perry (1956) demonstrated that the lowest proportion of stillborn piglets was observed in the LW sows giving birth to 10–12 piglets. And this proportion exhibited an increase with an increase or decrease in total litter size.

In Japan, it was observed that the proportion of crossbred LN × LW sows giving birth to dead piglets was 41.6–42.3% higher among sows with 16 piglets or more per litter compared to individuals giving birth to only 8 piglets per litter (Tani et al., 2016). This pattern was established for not only the number and proportion of stillborn piglets per litter, but also the proportion of the litter that had at least one stillborn piglet (Randall & Penny, 1970). Despite the fact that the SBR value rises in line with the increasing total number of piglets born, the number of live piglets prior to weaning still rises gradually in line with the increasing number of piglets born (Glastonbury, 1976).

An increase in the total number of piglets at birth is associated with a reduction in body weight at birth, which is indicative of reduced viability (see below). This is accompanied by a lengthened farrowing duration, which in turn increases the risk of complications associated with the last-born piglets (Friend & Cunningham, 1966). It has been demonstrated that between 80% and 85% of all stillbirths occur during the final third of the farrowing period (Christianson, 1992).

The frequency of fetal deaths prior to farrowing was found to be largely consistent across litter sizes in the YR sows and their crosses with the Lacombe (Canada) pigs. However, mortality rates at farrowing exhibited a notable increase with an increase in litter size, reaching 3.3% for litters with 14 or fewer piglets and 11.1% for litters with 15 or more piglets (Dyck & Swierstra, 1987).

The upper limit of litter size beyond which there will be a significant increase in the rate of stillbirths merits special attention. In a study conducted by Nam and Sukon (2021) on crossbred LN × YR sows (Vietnam), the SBR value was found to be similar in the litters with 5–10 and 11–13 piglets at birth (3.6 and 1, 7%, respectively), but significantly higher in the litters with 14–21 piglets (6.7%). According to Ngo et al. (2024), the higher percentage of stillbirths was found in crossbreed LN × YR sows with large litter sizes (≥ 17 piglets, 10.9%) compared to those with small (≤ 13 piglets, 6.1%) and medium (14–16 piglets, 2.8%) litter sizes (P < 0.001). Adi et al. (2024) pointed out that the incidence of stillbirth in litters with TNB ≥ 16 was also higher than that in litters with TNB ≤ 9 and 10–12 head (P < 0.05). Therefore, the findings presented here align with those previously reported.

Previously, it was shown that in crossbred LW × LN sows (France), the body weight of stillborn piglets was lower than that of live-born piglets (1.2 and 1.4 kg, respectively). However, no significant effect of individual piglet body weight or its variability within a litter on the number or proportion of stillborn individuals per litter was demonstrated (Le Cozler et al., 2001). However in another study, the same authors (Le Cozler et al., 2002) found that an increased probability of stillbirth was associated with a low estimate of mean piglet body weight per litter and with a low body weight of the sow at farrowing. In a study of sows representing a complex cross between the LW, LN and Pietrain breed (France), the probability of stillbirths was only 7.0% for piglets weighing 1.0 kg or more. In crossbred LN × YR sows (Thailand) the proportion of stillborn piglets per litter was higher and piglet birth weight lower in litters that had TNB ≥ 16 than those with TNB = 8–12 piglets (P < 0.05) (Adi et al., 2022). It is characteristic that the coefficient of variation of birth weight within the litter increased with litter size (Knap et al., 2023).

It has been shown that in hyperprolific sows, piglet mortality at 24 h after birth was negatively (P < 0.01) influenced by the birth weight of the piglets. On the other hand, piglet birth weight had a positive association (P < 0.01) with individual colostrum intake per piglet. Piglets ingesting more colostrum had lower (P < 0.01) mortality from 24h after birth until weaning (Schoos et al., 2023).

For piglets born with a live weight of 0.8 kg and 0.6 kg, the corresponding estimates of SBR were 11.0% and 24.0%. In addition, the proportion of individuals that died within the first 24 h after birth was 12 % and 33 % for piglets in these weight groups, respectively (Quiniou et al., 2002). In crossbred LN × LW sows (Brazil) low-birth-weight piglets were 2.3 and 3.1 times more likely than their medium-birth-weight and high-birth-weight counterparts, respectively, to be stillborn (Sens Junior et al., 2023). On the other hand, Leenhouwers et al. (1999) showed that individuals born to crossbred YR × LW sows with a live birth weight of 1.9–2.1 kg were also characterised by an increased probability of stillbirth. However, in general the overall trend showed an inverse relationship between mean piglet weight at birth and the probability of stillbirth. The risk of stillbirth increases rapidly when the body weight of the piglet falls below the average for the litter. Although this pattern may be breed dependent. For example, the LW piglets that weighed 500 g less than the litter average were 7.8 times more likely to be stillborn than those born to the Meishan sows (Canario et al., 2006). The reasons for the association between low piglet body weight and increased risk of stillbirth may be as follows: lighter fetuses suffer from nutritional deficiencies due to poor placental function during farrowing, have a higher risk of umbilical cord rupture and suffer more from hypoxia during farrowing (Pedersen et al., 2011). On the other hand, very heavy piglets experience difficulties during farrowing due to their large size in relation to the width of the maternal pelvis, which can lead to a delay in farrowing, resulting in hypoxia and stillbirth. Therefore, selection for high litter uniformity in terms of birth weight is a promising method to improve piglet survival at birth (Vanderhaeghe et al., 2013).

Conclusion

The boar breed was identified as a significant factor contributing to the increased risk of stillbirths per litter among the genetic factors considered in the study. The uneven use of boars from different breeds across the study years appeared to influence the temporal variability of this parameter. It is likely that a significant lack of green forages in the diet is responsible for the increased stillbirth rate in sows farrowing in late winter (February) or early spring (March). An increase in the total litter size of sows leads to two outcomes for the newborn piglets: firstly, a reduction in the average body birth weight, and secondly, an increase in intra-litter variability of birth weights. Both of these factors significantly raise the risk of stillbirths. Additionally, the probability of piglet mortality at farrowing rises due to a shortened gestation length, which may not provide sufficient time for proper fetal development.

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