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Risk factors associated with stillbirth of piglets in Ukrainian Meat breed sows

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Abstract. Stillbirth often causes significant piglet losses shortly before or during the farrowing process. This issue leads to a high level of stillbirths, causing substantial losses in the swine industry and requiring immediate attention. The purpose of this study is to evaluate farrowing order, the total number of piglets born, the year and season of farrowing, the breed of the boar, and the average piglet weight in the litter at birth as risk factors for stillbirths in sows of the Ukrainian Meat breed. Experimental data obtained from 262 sows of the Ukrainian Meat breed in the main herd of LLC "Tavriyski Svyni" (Skadovsk district, Kherson region, Ukraine) were used for the study. The proportion of litters containing at least one stillborn piglet, the number and proportion of stillborn piglets in the litter were investigated over 11 years. At least one stillborn piglet was observed in 56.9% of litters, with an average number and proportion of stillborn piglets in the litter of 1.2 and 10.5%, respectively. The results indicate a highly significant impact of the farrowing year on the proportion of litters

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containing at least one stillborn piglet, the number, and proportion of stillborn piglets in the litter (in all cases: *P*<0.001). There was a decrease in estimates of stillbirths during 2007-2013, with a gradual increase until 2017. The farrowing season had a certain (*P*<0.05) influence on estimates of stillbirth rates, since the proportion of stillbirth piglets in litters born in summer was 9.5%, and in litters born in autumn – 12.0%. The proportion of stillborn piglets in litters sired by Duroc boars (15.0%) was significantly higher (*P*<0.001) than in litters sired by Ukrainian Meat breed, Large White, or Landrace boars (10.1-10.0%). From the first to the 10th farrowing, stillbirth rates gradually increased (in all cases: *P*<0.001). The number and proportion of stillborn piglets in the litter tended to increase among sows with larger litter sizes at birth (in both cases: *P*<0.001). Binary logistic regression results suggested that the probability of having at least one stillborn piglet in the litter was significantly associated with the average live weight of piglets at birth

Keywords: stillbirths; farrowing order; litter size; year and season of farrowing; boar breed; Ukrainian Meat breed sows

INTRODUCTION

The death of piglets just before or during the farrowing process is a common phenomenon, resulting in high stillbirth rates causing significant losses to the pig industry. Accordingly, the analysis of the risk factors for the occurrence of stillbirths can help optimise the reproductive efficiency of sows by increasing the number of live piglets per sow per year. Stillborns are piglets that are found dead at farrowing but are fully formed and normally developed. There are three classes of stillborn piglets. The first class includes animals that died shortly before farrowing (*prepartum stillbirth*), the second class – animals that died directly during farrowing (*intrapartum stillbirth*) and, finally, the third – animals that died immediately after farrowing (*postpartum stillbirth*), most often, during the first 24 hours of life. Stillborn piglets typically account for 30-40% of all piglet mortality from birth to weaning, as described by S. Menčik *et al.* (2020). The appearance of at least one stillborn piglet in a litter increased the risk of piglet mortality by 1.28 times compared to litters where stillborn piglets were not observed, as noted by L. Rangstrup-Christensen *et al.* (2018).

Non-infectious risk factors for stillbirths have been studied for a long time and are typically classified into several groups, as described by R. Raguvaran *et al.* (2017). First, these are factors related to the characteristics of the sow. This group includes the parity number (age of the sow), the live weight and condition of the sow, the litter size at birth, the duration of pregnancy, the duration of farrowing, and more. Secondly, these are factors related to the characteristics of a newborn piglet. These are the interval between births, the birth order of each piglet, live weight at birth, and the variability in live piglet weights within a litter., etc. Finally, the third group consists of factors related to environmental and management influences, such as the diet of pregnant sows, the year and season of farrowing, induction of farrowing (e.g., the use of oxytocin and other drugs), human intervention during the farrowing process (e.g., palpation), stress (including temperature), and others.

Although the genetic heritability of stillborn piglets is low, with estimates ranging from 0.02 to 0.05, the influence of breed/genetics, both of the sow and the boar, plays a substantial role in shaping this reproductive trait in pigs. Recent studies, such as that conducted by V.L. Sens Junior *et al.* (2023), has expanded the understanding of risk factors for stillborn piglets by including variables such as piglet measurements, ponderal index, the total weight of the litter at birth, the thickness of the sow's backfat before farrowing, haematological parameters of piglet umbilical cord blood at birth, and polymorphism in the *RNF4-SacII* gene, among others. K. Gourley *et al.* (2020) showed that numerous factors of various natures affect the stillbirth of piglets, and these factors are closely related to each other. Accordingly, knowing the relative importance of risk factors may be important for pig specialists when dealing with stillbirth. Identifying specific factors associated with stillborn piglets is key to achieving this ultimate goal (Raguvaran *et al.*, 2017).

The problem of stillbirth of piglets is given little attention by Ukrainian researchers. Often, this aspect is considered as an element when assessing key fertility indicators of sows, primarily focusing on evaluating the total number of piglets born, prolificacy (the number of live piglets in a litter), and the overall number of piglets at weaning. Special emphasis is placed on factorial dependence (genotypic or technological factors) of these traits, without explicitly addressing piglet mortality levels at birth and from birth to weaning. There are a few exceptions where these issues have been covered for widely recognised pig breeds globally, such as the Large White breed (LW) (Kramarenko & Kramarenko, 2021) and their crosses with the Landrace breed (Luhovyi, 2023). However, research specific to local Ukrainian pig breeds, particularly the Ukrainian Meat breed, is currently lacking. Therefore, the purpose of this study is to identify the risk factors associated with stillborn piglets in Ukrainian Meat breed sows.

MATERIALS AND METHODS

The primary materials for analysing the risk factors of piglet stillbirth were obtained from 262 purebred Ukrainian Meat breed sows (UMB) maintained at the LLC "Tavriyski Svyni" farm (Skadovsk district, Kherson region, Ukraine). The average number of farrowings was 4.2±2.5 (*Mean*±*SD*) on a scale from 1 to 10. In total, data from 1533 farrowings were included in the analysis. For each farrowing, the following traits were evaluated: the number of stillborn piglets (NSB) and the stillbirth rate (SBR) in the litter. In addition, the incidence of stillbirths at the sow level (ISSL), defined as litters with at least one stillborn piglet, was determined.

Mean±*SE* estimates were calculated for specific subgroups formed based on relevant risk factor gradations included in the analysis. The distribution of litter characteristics in terms of both the number and proportion of stillborn piglets deviated significantly from normal (Kolmogorov-Smirnov *d*-test: $P<0.01$). Therefore, the non-parametric Kruskal-Wallis test (H_{KW}) was used to test the null hypothesis of no significant differences among specific subgroups. The chi-square goodness-of-fit test was employed for comparisons of qualitative data.

The independent variables used in the analysis included: the year of farrowing with 11 gradations (2007-2017), the season of farrowing with 4 gradations (winter, spring, summer, and autumn), the breed of the boar (UMB, LW, Landrace, Duroc), the farrowing order (parity) with 10 gradations (P1-P10), and the total number of piglets at birth with 15 gradations (3-17 piglets per litter). Furthermore, one quantitative trait, the average live weight of piglets in the litter at birth (AWPB), calculated as the ratio of the litter weight to the total number of piglets at birth, was used.

The likelihood of a linear trend was assessed using the Spearman's rank correlation coefficient (*Rs*). A binary logistic regression algorithm was applied to build a predictive model for the presence of at least one stillborn piglet in the litter:

$$P(SB) = [\exp(a + b \times AWPB]/[1+\exp(a + b \times AWPB)], \quad (1)$$

where $P(SB)$ – probability of having at least one stillborn piglet in the litter; AWPB – average live weight of the piglet in the litter at birth; a and b – regression coefficients. The predictive value of the model (1) was evaluated as the proportion of correct predictions, separately for '1' (presence of at least one stillborn piglet in the litter) and '0' (absence of any stillborn piglets in the litter), and for the overall model (1).

All statistical processing was performed using STATISTICA v. 7 software (Stat Soft Inc.). The maintenance of experimental animals and all manipulations with them were conducted in accordance with the provisions of the "Procedure for conducting scientific research, experiments on animals by scientific institutions" (Law of Ukraine No. 249, 2012) and the "European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes" (European convention..., 1986).

RESULTS AND DISCUSSION

General characteristics of the stillbirth rate. The average number of piglets in the litter at birth over the study period (2007-2017) was 10.9±0.07 (with a range from 3 to 17 piglets). The number of stillborn piglets in the litter ranged from 0 to 13 (with an average of 1.2±0.04), and the proportion of stillborn piglets varied from 0 to 100% (with an average of 10.5±0.3%). Of the 1,533 litters analysed, 872 (56.9%) had at least one stillborn piglet. Of these, one stillborn piglet was observed in 24.7% of farrowings, two – in 16.8% of farrowings, three – in 7.0% of farrowings four – in 4.2%, five or more – in 4.1% of farrowings. In previous studies on Large White pigs and crossbred Large White × Landrace sows, similar estimates were obtained, approximately 63.3% (Kramarenko & Kramarenko, 2021) and 56.8% (Luhovyi, 2023), respectively. Overall, it can be acknowledged that this trait, which characterises the level of stillbirth in pig herds in Ukraine, had high values, which requires further work aimed at improving their reproductive performance.

Estimates of the average number of stillborn piglets in the litter varied significantly when examining different farms. For instance, a study of nine farms with crossbred Landrace × Yorkshire sows (Denmark) allowed the estimation of this trait at 1.1 piglets, with a range of 0.7 to 1.9 piglets for different farms (Rangstrup-Christensen *et al.*, 2018). The average number of stillborn piglets in litters of crossbred Landrace × Yorkshire sows in five herds (Denmark) ranged from 1.0 to 2.3 piglets per litter (Schild *et al.*, 2019). The proportion of stillborn piglets in the litter was most often in the range of 4% to 10% (Roongsitthichai & Olanratmanee, 2021), although cases are known where this estimate reached 19% or more (Langendijk & Plush, 2019). Thus, the obtained estimates of the average number and proportion of stillborn piglets in the litters of UMB sows in the studied herd (1.2 piglets and 10.5%, respectively) fall within the values previously noted for highly productive pig herds from different countries worldwide.

Year of farrowing. The year of farrowing significantly influenced the proportion of litters that had at least one stillborn piglet (Pearson's chi-square goodness-of-fit test: $\chi^2=55.9$; $df=10$; $P<0.001$). In this regard, for farrowings in 2017, this proportion was the lowest (29.4%), while for farrowings in 2013, it reached the maximum value (72.3%). On the other hand, for farrowings in 2012-2014 and 2016, an increase in the proportion of litters with 2-4 stillborn piglets was noted (Fig. 1).

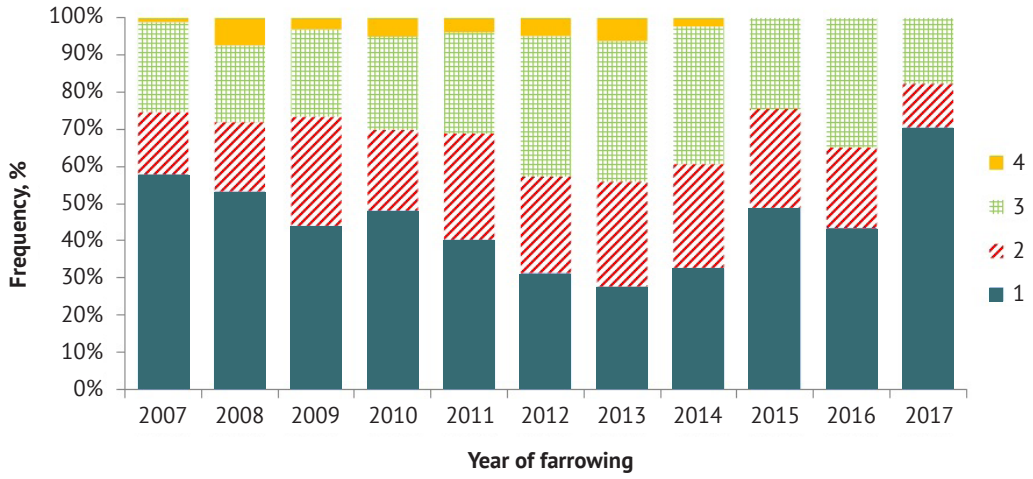

Figure 1. *Distribution by number of stillborn piglets (NSB) per UMB sow litter depending on the year of farrowing*
Note: *1 – NSB=0; 2 – NSB=1; 3 – NSB=2-4; 4 – NSB=5+*
Source*: compiled by the authors*

The average number of stillborn piglets in the litter ranged from 0.5 (farrowing 2017) to 1.6 heads (farrowing 2012-2013). The proportion of stillborn piglets in the litter ranged from 4.6% (farrowing 2017) to 14.8% (farrowing 2013). Overall, the year of farrowing significantly affected both the number and proportion of stillborn piglets in the litter (non-parametric Kruskal-Wallis test: in both cases, $P<0.001$) (Table 1).

Table 1. *Indicators of variability in the number (NSB) and proportion (SBR) of stillborn piglets in the litters of UMB sows depending on the year of farrowing*

Year of farrowing	*n*	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
2007	95	0 – 9	0.9±0.14	0 – 60.0	7.6±1.2
2008	150	0 – 10	1.2±0.16	0 – 76.9	9.4±1.2
2009	200	0 – 9	1.1±0.10	0 – 60.0	9.6±0.8
2010	262	0 – 13	1.2±0.11	0 – 92.9	9.8±0.8
2011	261	0 – 8	1.2±0.09	0 – 57.1	10.3±0.7
2012	185	0 – 9	1.6±0.12	0 – 90.0	13.6±1.0
2013	177	0 – 8	1.6±0.13	0 – 100.0	14.8±1.2
2014	89	0 – 6	1.3±0.14	0 – 42.9	11.2±1.1
2015	45	0 – 4	0.9±0.17	0 – 33.3	7.9±1.4
2016	23	0 – 4	1.2±0.28	0 – 28.6	8.9±2.0
2017	17	0 – 2	0.5±0.19	0 – 28.6	4.6±2.0
$H_{KW}(10; 1503); P$	-	-	54.69; $P<0.001$	-	56.38; $P<0.001$

Note: *H_{KW} – non-parametric Kruskal-Wallis test; P – level of significance*
Source*: compiled by the authors*

Previously, in a study of 91 herds in Spain over the period 2007-2016, a significant ($P<0.01$) linear trend for the temporal variability of the number of stillborn piglets in the litter was also found (Koketsu *et al.*, 2021).

Farrowing season. The farrowing season likely influenced the proportion of litters with at least one stillborn piglet (Pearson's chi-square goodness-of-fit test: $\chi^2=10.19$; $df=3$; $P=0.017$). This difference was primarily due to a significant increase in the proportion of such litters in the autumn months (63.3%) compared to farrowings in other seasons (52.4-57.0%) (Fig. 2).

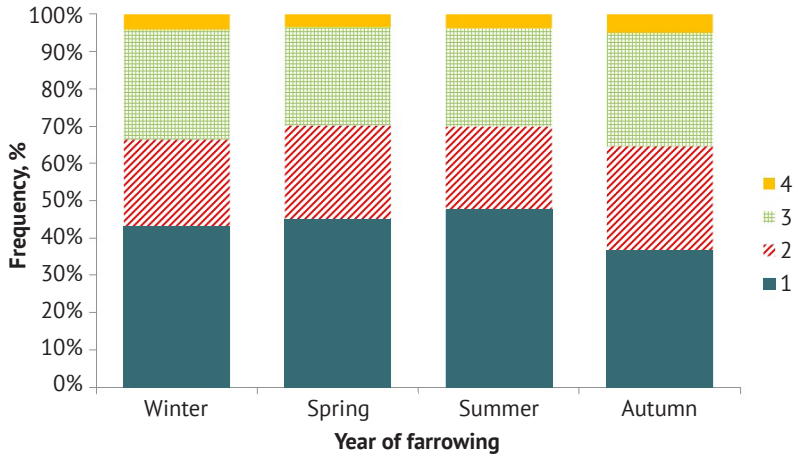

***Figure 2**. The distribution of the number of stillborn piglets (NSB) per litter of UMB sows depending on the farrowing season*

***Note:** 1 – NSB=0; 2 – NSB=1; 3 – NSB=2-4; 4 – NSB=5+*
***Source**: compiled by the authors*

The average number of stillborn piglets in the litter was highest for autumn (1.4 piglets) and winter (1.3 piglets) farrowings. However, for sows farrowing in spring and summer, this number was the lowest, 1.1 piglets. The proportion of stillborn piglets in the litter was highest for spring farrowings (12.0%) and lowest (9.5%) for farrowings that occurred during the summer months.

Overall, the farrowing season considerably influenced both the number and proportion of stillborn piglets in the litter (non-parametric Kruskal-Wallis test: in both cases $P<0.05$) (Table 2).

***Table 2.** Variability indicators of the number (NSB) and proportion (SBR) of stillborn piglets in the litter of UMB sows depending on the farrowing season*

Farrowing season	*n*	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
Winter	384	0 – 13	1.3±0.08	0 – 92.9	10.4±0.6
Spring	375	0 – 9	1.1±0.08	0 – 90.0	10.1±0.7
Summer	398	0 – 9	1.1±0.08	0 – 80.0	9.5±0.6
Autumn	376	0 – 10	1.4±0.09	0 – 100.0	12.0±0.7
$H_{KW}(3; 1533)$; *P*	-	-	9.00; *P*=0.029	-	10.57; *P*=0.014

***Note:** H_{KW} – non-parametric Kruskal-Wallis test; P – level of significance*
***Source**: compiled by the authors*

Numerical studies analysing the influence of the sow's farrowing season on the number and proportion of stillborn piglets in the litter often yield conflicting results. Most often, an increased stillbirth rate was observed for farrowing in the spring and summer seasons. The authors demonstrated the influence of the farrowing season on the number of stillborn piglets in the litter of crossbred sows (Landrace × Yorkshire, Denmark), with the highest values recorded for sows farrowing during the summer months (May to August). This was explained by the fact that during the summer of 2014, when the study was conducted, the average air temperature was 1.6°C higher than the long-term average (Rangstrup-Christensen *et al.*, 2018).

Some influence of temporal fluctuations on the stillbirth rate was also noted for Landrace sows and crossbred Yorkshire × Landrace sows (Denmark) but without a clear seasonal effect (Chu *et al.*, 2022).

The seasonality in the increased number and proportion of stillborn piglets in the litter may be related to the age of the sows. For Iberian × Duroc crossbred sows in Spain, a significant influence of the farrowing season and the combination of "farrowing order" × "farrowing season" on the number of stillborn and mummified piglets in the litter at birth was established. The lowest values were noted for primiparous sows in the spring months and sows in the 2-4 farrowings category in the summer months. The effect of farrowing number on stillbirth rates was most pronounced for summer farrowing. The curve of monthly estimates of the proportion of stillborn piglets in the litter demonstrated significant seasonal fluctuations, with a maximum (for

multiparous sows in the 2-4 farrowings category) in August-September and a minimum in March-May. In addition, the combined effect of the duration of the photoperiod, especially among sows in the 2-4 farrowings category, was noted (Piñán *et al.*, 2021).

Breed of the boar. A significant influence of the boar breed on the proportion of litters with at least one stillborn piglet was established (Pearson's chi-square goodness-of-fit test: χ^2=13.61; *df*=3; *P*=0.004). The highest proportion of such litters was recorded for UMB sows inseminated with Duroc boar sperm (77.5%). Primarily, this increase was due to the high proportion (46.5%) of litters with 2-4 stillborn piglets (Fig. 3). When using sperm from UMB, LW, and Landrace boars, the proportion of litters with at least one stillborn piglet was the lowest (55.2-58.9%).

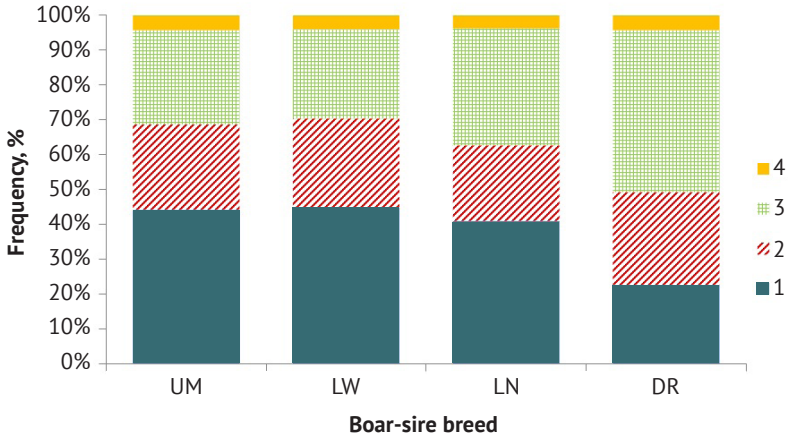

Figure 3. *Distribution by the number of stillborn piglets (NSB) per litter of sows depending on the boar breed*
Note: *1 – NSB=0; 2 – NSB=1; 3 – NSB=2-4; 4 – NSB=5+. UMB - Ukrainian Meat breed; LW – Large White breed; LN – Landrace; DR – Duroc*
Source*: compiled by the authors*

The boar breed also significantly influenced both the number and proportion of stillborn piglets in the litter (non-parametric Kruskal-Wallis test: in both cases *P*<0.001). These differences were primarily related to a substantial increase in the number (1.8 piglets) and proportion (15.0%) of stillborn piglets in litters from sows inseminated with Duroc boar sperm (Table 3).

Table 3. *Indicators of variability in the number (NSB) and proportion (SBR) of stillborn piglets in the litters of UMB sows depending on the breed of boar*

Boar breed	*n*	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
UWS	611	0 – 13	1.2±0.07	0 – 92.9	10.3±0.5
LW	651	0 – 9	1.1±0.06	0 – 100.0	10.1±0.5
Landrace	185	0 – 10	1.3±0.12	0 – 76.9	10.9±0.9
Duroc	71	0 – 7	1.8±0.19	0 – 100.0	15.0±1.5
H_{KW}(3; 1518); *P*	-	-	18.24; *P*<0.001	-	16.40; *P*<0.001

Note: *H_{KW} – non-parametric Kruskal-Wallis test; P – level of significance*
Source*: compiled by the authors*

The paper by M. Pedersen *et al.* (2019) presents the results of analysing the piglet mortality rate of crossbred sows (Landrace × Yorkshire) inseminated with purebred boars of the Pietrain and Duroc breeds. Piglet mortality at birth and within the first five days after farrowing was significantly lower (*P*<0.0001) among the offspring of Duroc boars compared to Pietrain boars. P. Nevrkla *et al.* (2021) established a significant influence of the breed/crossbreed origin of the terminal boar on the number of stillborn piglets. The lowest average number of such piglets was observed in litters from Duroc × Pietrain boars (1.1 piglets), while the highest was in litters from purebred Pietrain boars (2.8 piglets per litter). In addition, the farrowing order of the sow also had an impact on the stillbirth rate.

Farrowing order. With an increase in the farrowing order (i.e., the age of the sow), the proportion of litters with at least one stillborn piglet linearly increased,

ranging from 34.6% (sows with 2nd farrowing) to 83.3% (sows with 10th farrowing). These likely differences between animals of different ages (Pearson's chi-square goodness-of-fit test: χ^2=123.35; *df*=9; *P*<0.001) are primarily due to an increase with age in the proportion of litters with 2-4 stillborn piglets (Pearson's chi-square goodness-of-fit test: χ^2=73.01; *df*=3; *P*=0.004) and the proportion of litters with 5 or more stillborn piglets in the litter (Pearson's chi-square goodness-of-fit test: χ^2=36.23; *df*=3; *P*=0.004) (Fig. 4).

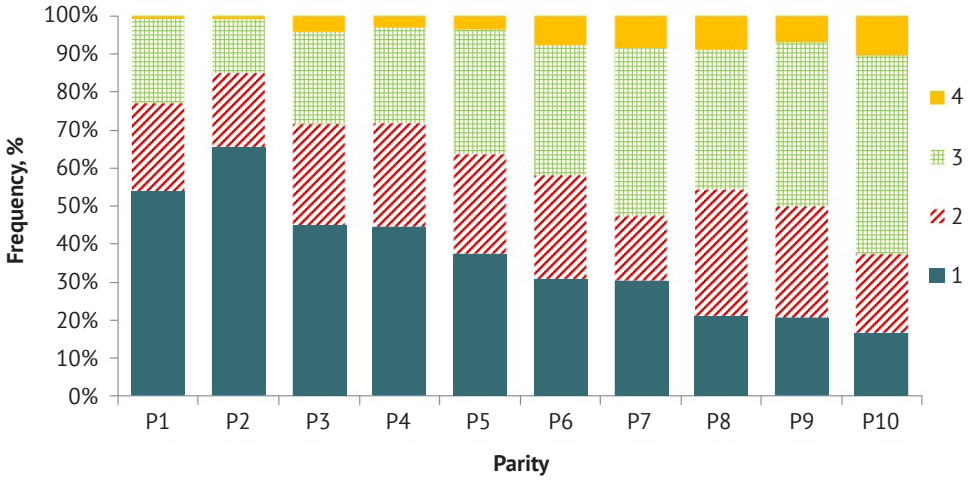

Figure 4. *Distribution by number of stillborn piglets (NSB) per UMB sow litter depending on farrowing order*
Note: *1 – NSB=0; 2 – NSB=1; 3 – NSB=2-4; 4 – NSB=5+*
Source*: compiled by the authors*

Similarly, with the age of the sow, the average number and proportion of stillborn piglets in the litter increased (non-parametric Kruskal-Wallis test: in both cases *P*<0.001) (Table 4). The lowest number and proportion of stillborn piglets were observed for sows with 2nd farrowing (0.6 piglets and 5.1%, respectively). In animals with 3-6 farrowing, the number and proportion of stillborn piglets ranged from 1.1 to 1.6 piglets and 9.8% to 12.6%, respectively. In the oldest sows (7th farrowing and above), these figures increased to 1.8-2.3 piglets and 15.1-21.4% of stillborn piglets per litter, respectively. Thus, the observed dependence had a clear linear trend (Spearman's rank correlation coefficient: in both cases *P*<0.001).

Table 4. *Indicators of variability in the number (NSB) and proportion (SBR) of stillborn piglets in the litters of UMB sows depending on the farrowing order*

Farrowing number	*n*	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
P1	262	0 – 6	0.8±0.07	0 – 57.1	8.4±0.7
P2	239	0 – 6	0.6±0.06	0 – 42.9	5.1±0.5
P3	212	0 – 10	1.2±0.12	0 – 80.0	9.8±0.9
P4	195	0 – 8	1.1±0.10	0 – 57.1	9.3±0.8
P5	168	0 – 8	1.3±0.12	0 – 50.0	10.6±0.9
P6	143	0 – 10	1.6±0.15	0 – 76.9	12.6±1.1
P7	118	0 – 9	2.0±0.18	0 – 90.0	15.9±1.4
P8	90	0 – 13	1.8±0.21	0 – 92.9	15.1±1.6
P9	58	0 – 8	1.8±0.23	0 – 80.0	16.0±1.9
P10	48	0 – 7	2.3±0.28	0 – 100.0	21.4±3.0
H_{KW} (9; 1533); *P*	-	-	157.41; *P*<0.001	-	135.00; *P*<0.001
Rs (*n* = 1533); *P*	-	-	0.295; *P*<0.001	-	0.260; *P*<0.001

Note: *H_{KW} – non-parametric Kruskal-Wallis test; Rs – Spearman's rank correlation coefficient; P – level of significance*
Source*: compiled by the authors*

Previously, R. Klimas *et al.* (2020) already established that the stillbirth rate increases with the farrowing order (i.e., the age of the sow). In most cases, this relationship is non-linear, with the number (proportion) of stillborn piglets in the litter slightly decreasing in sows with the 2nd farrowing compared to primiparous sows but then almost linearly increasing, which is consistent with the results obtained for UMB sows (Table 4). On the other hand, such an increase may not be proportional among sows of different genetic groups (Kobek-Kjeldager *et al.,* 2023). Overall, both the results of this study and the literature data (Leonard *et al.*, 2020) indicate that older sows have a 2-3 times higher risk of giving birth to a stillborn piglet than younger animals.

Litter size at birth. The total number of piglets at birth significantly influenced (Pearson's chi-square goodness-of-fit test: χ^2=204.75; *df*=14; *P*<0.001) the proportion of litters with at least one stillborn piglet. This was primarily due to the likely increase in the proportion of farrowings with 2-4 (Pearson's chi-square goodness-of-fit test: χ^2=183.16; *df*=14; *P*<0.001) and five or more (Pearson's chi-square goodness-of-fit test: χ^2=125.56; *df*=14; *P*<0.001) stillborn piglets with an increase in the litter size (Fig. 5).

In summary, for litters with 3-8 piglets at birth, the proportion of those that had at least one stillborn piglet varied between 23.7% and 33.0%. However, starting from litters with 9 or more piglets at birth, this proportion increased almost linearly. Finally, in litters with 17 piglets, there was always at least one stillborn piglet present, with most cases (87.2%) having 2 or more stillborn piglets (Fig. 5).

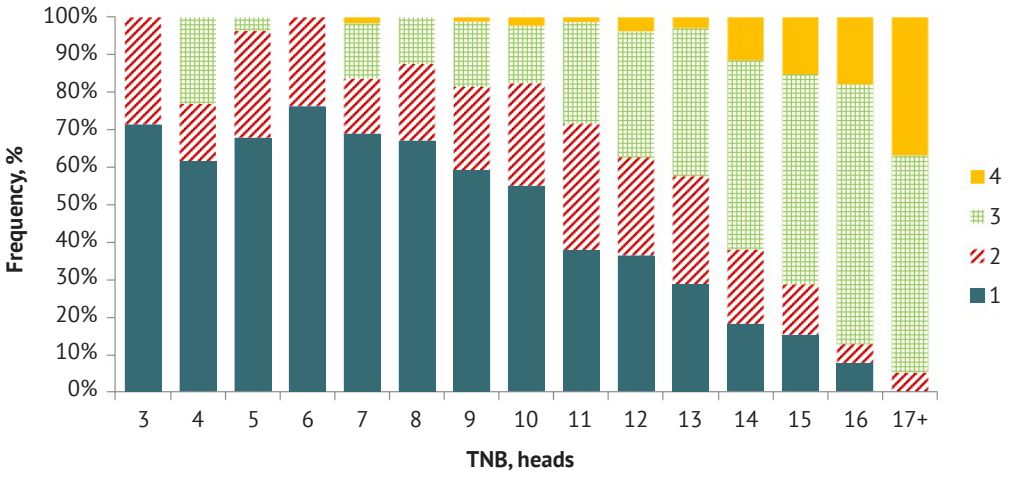

Figure 5. *Distribution by the number of stillborn piglets (NSB) in UMB sow litters based on the total number of piglets at birth (TNB)*

Note: *1 – NSB=0; 2 – NSB=1; 3 – NSB=2-4; 4 – NSB=5+*

Source*: compiled by the authors*

The average number and proportion of stillborn piglets in the litter for sows whose litter size ranged from 3-8 piglets at birth varied between 0.2-0.6 piglets and 3.9-15.4%, respectively (Table 5). For litters containing 9-13 piglets at birth, these values ranged from 0.8-1.5 piglets and 7.8-11.2%, respectively. For litters containing 14 or more piglets at birth, these values reached 2.4-4.4 piglets and 17.1-26.0%, respectively. Therefore, litter size significantly influenced the number and proportion of stillborn piglets in the litter (non-parametric Kruskal-Wallis test: in both cases *P*<0.001), and this relationship had an almost linear form (Spearman's rank correlation coefficient: in both cases *P*<0.001).

Table 5. *Indicators of variability in the number (NSB) and proportion (SBR) of stillborn piglets in the litters of UMB sows depending on the total number of piglets at birth (TNB)*

TNB, heads	*n*	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
3	14	0 – 1	0.3±0.13	0 – 33.3	9.5±4.2
4	13	0 – 2	0.6±0.24	0 – 50.0	15.4±6.0
5	28	0 – 2	0.4±0.11	0 – 40.0	7.1±2.1
6	38	0 – 1	0.2±0.07	0 – 16.7	3.9±1.2
7	61	0 – 7	0.6±0.15	0 – 100.0	8.4±2.2
8	88	0 – 4	0.5±0.09	0 – 50.0	6.1±1.1

Table 5, Continued

TNB, heads	n	NSB, heads		SBR, %	
		min – max	*Mean ± SE*	*min – max*	*Mean ± SE*
9	167	0 – 7	0.7±0.08	0 – 77.8	7.8±0.9
10	256	0 – 9	0.8±0.08	0 – 90.0	7.9±0.8
11	222	0 – 6	1.1±0.08	0 – 54.5	10.0±0.7
12	238	0 – 7	1.3±0.09	0 – 58.3	10.5±0.7
13	170	0 – 10	1.5±0.11	0 – 76.9	11.2±0.9
14	121	0 – 13	2.4±0.19	0 – 92.9	17.1±1.4
15	59	0 – 9	2.7±0.25	0 – 60.0	18.0±1.7
16	39	0 – 10	3.2±0.31	0 – 62.5	19.9±2.0
17	19	1 – 9	4.4±0.54	5.9 – 52.9	26.0±3.2
H_{KW}(9; 1533); *P*	-	-	331.80; *P*<0.001	-	176.94; *P*<0.001
Rs (n = 1533); *P*	-	-	0.440; P<0.001	-	0.305; P<0.001

Note: *H_{KW} – non-parametric Kruskal-Wallis test; Rs – Spearman's rank correlation coefficient; P – level of significance*
Source*: compiled by the authors*

The paper by M. Pedersen *et al.* (2019) previously demonstrated that as litter size at birth increased, the mortality of piglets in the first five days after farrowing (including stillborn piglets) also increased. In litters with 14 piglets, the mortality rate was 12-15%, while in litters with 24 piglets at birth, the mortality estimate was almost twice as high (24-27%). M. van den Bosch *et al.* (2022) showed that each additional piglet in the litter led to a reduction in the average birth weight of piglets by 17.6 grams, an increase in farrowing duration by an average of 11 minutes, and, consequently, an increase in the proportion of stillborn piglets in the litter by 0.5%.

The question of the threshold of litter size above which stillbirth rates would increase rapidly is noteworthy. In this study, this threshold separated litters with 13 or fewer piglets from those with 14 or more piglets at birth (Table 5). In the paper by N. Nam & P. Sukon (2021) on crossbred Landrace × Yorkshire (Vietnamese) sows, the proportion of stillborn piglets in litters containing 5-10 and 11-13 piglets at birth did not differ (3.6 and 1.7%, respectively), but these litters had a significantly lower proportion of stillborn piglets compared to litters with 14-21 piglets (6.7%). Thus, the results obtained for UMB sows fully coincide with the earlier findings.

Average live weight of a piglet at birth. The average live weight of a piglet at birth ranged from 0.600 to 2.440 kg (with an average of 1.362±0.008 kg). This characteristic proved to be a significant factor in predicting the presence or absence of at least one stillborn piglet in the litter (logistic binary regression: χ^2=204.75; *df*=1380; *P*<0.001). The resulting model was:

$$P(SB)=[\exp(4.2856 - 2.9087\times AWPB)]/[1+ \exp(4.2856 - 2.9087\times AWPB)], \quad (2)$$

where *P*(SB) – probability that there would be at least one stillborn piglet in the litter;

AWPB – average live weight of the piglet in the litter at birth (Table 6).

Table 6. *Indicators of the binary logistic regression model for the presence of stillborn piglets in UMB sow litters depending on the average live piglet birth weight (AWPB)*

Indicator	Assessment
Intercept (a)	4.2856
AWPB	-2.9087
χ^2; *P*	236.57; *P*<0.001
Forecast accuracy, %:	
absence of a stillborn piglet in the litter	49.0
presence of at least one stillborn piglet in the litter	79.9
total	66.8

Note: *χ^2 – Pearson's chi-square goodness-of-fit test; P – level of significance*
Source*: compiled by the authors*

The average predictive value of this model was 66.8%, and it performed well in predicting the presence of at least one stillborn piglet in the litter (79.9%), but relatively less well in predicting the absence (49.0%). As expected, litters with lower live piglet birth weights (0.5-1.0 kg) had a very high risk (77% or higher) of having at least one stillborn piglet. Conversely, litters with live piglet birth weights of 1.8 kg or higher had a low risk (25% or less) of stillborn piglets (Fig. 6). The 50% probability of giving birth to such a piglet in the litter corresponded to an average live birth weight of 1.5 kg.

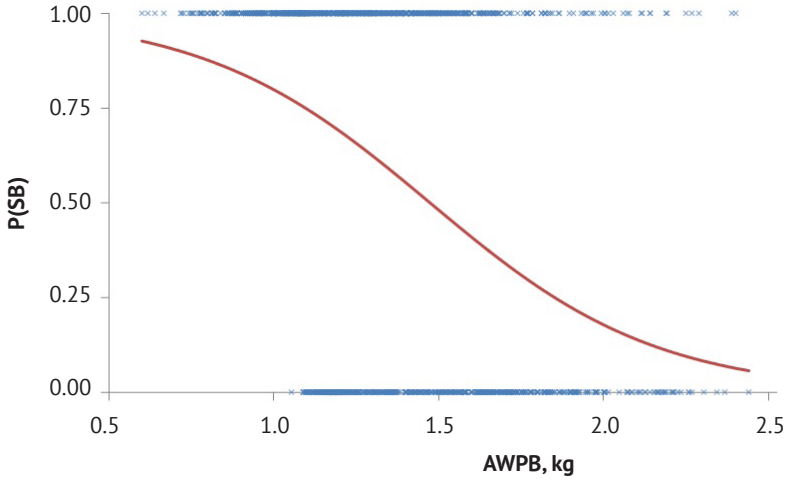

Figure 6. *Logistic regression of the presence/absence of at least one stillborn piglet in the litter based on the average live piglet birth weight (AWPB)*
Note: *for the Y-axis: 0 – no stillborn piglets in the litter; 1 – at least one stillborn piglet in the litter*
Source*: compiled by the authors*

It has been previously shown that the birth weight of piglets is one of the factors associated with the risk of stillbirth. For instance, 43.3% of live-born piglets had a birth weight below 1 kg, while among stillborn piglets, this percentage was 60.9% (Udomchanya *et al.*, 2019). Besides live birth weight, stillborn piglets were found to have significantly lower body mass index and ponderal index, indicating that they were disproportionately long and thin. Therefore, these indices proved to be better indicators of stillbirth risk than live piglet birth weight alone (Lanh & Nam, 2022).

The reasons explaining the link between low piglet body weight and increased stillbirth risk may include the following: lighter fetuses suffer from nutrient deficiency due to improper placental functioning during gestation period, they have a higher chance of broken umbilical cord, and they are more susceptible to hypoxia during farrowing (Udomchanya *et al.,* 2019). On the other hand, very heavy piglets at birth may experience difficulties during farrowing due to their large size relative to the maternal pelvis, leading to prolonged farrowing, hypoxia, and stillbirth. Thus, selection for high uniformity in litter birth weights shows great promise as a method for improving piglet survival at birth.

CONCLUSIONS

The obtained values for the average number and proportion of stillborn piglets in the litters of Ukrainian Meat breed sows (UMB) from the studied herd (1.2 piglets and 10.5%, respectively) correspond to the previously noted estimates for high-productivity pig herds in various countries worldwide. It was statistically demonstrated that the year of farrowing significantly influenced (in all cases: $P<0.001$) the proportion of litters containing at least one stillborn piglet, including the number and proportion of stillborn piglets in the litter. Notably, there was a substantial decrease in stillbirth estimates from 2007 to 2013, followed by a gradual increase until 2017. The season of farrowing also possibly ($P<0.05$) had an impact on stillbirth rates, with litters from sows farrowing in summer having a stillbirth rate of 9.5%, while those farrowing in autumn had a rate of 12.0%.

The proportion of stillborn piglets depended on the breed of boar. The breed of the boar used for breeding also influenced the proportion of stillborn piglets. It was significantly higher ($P<0.001$) in litters sired by Duroc boars (15.0%) compared to litters sired by boars of other breeds (10.1-10.0%). It was found that older sows had a 2-3 times higher risk of giving birth to stillborn piglets compared to younger animals. Among sows with larger litter sizes at birth (more than 14 piglets), both the number and proportion of stillborn piglets in the litter significantly increased ($P<0.001$). The results of binary logistic regression indicated that litters with low piglet weights (0.5-1.0 kg) had a very high risk (77% and higher) of containing at least one stillborn piglet. Future research prospects include analysing the combined influence of identified risk factors for piglet

stillbirth in Ukrainian Meat breed sows (UMB) and other local breeds in Ukraine.

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CONFLICT OF INTEREST

None.

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Фактори ризику мертвонародження поросят у свиноматок української м'ясної породи

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Анотація. Часто відбувається велика загибель поросят безпосередньо перед або під час процесу опоросу. Ця проблема призводить до високого рівня мертвонародження, що наносить серйозні збитки галузі свинарства і потребує негайного вирішення. Головною метою дослідження стало оцінювання номеру опоросу свиноматки, загальної кількості поросят при народженні, року та сезону опоросу, породи кнура-плідника та середньої маси поросяти у гнізді при народженні як факторів ризику мертвонародження поросят у свиноматок української м'ясної породи. Для дослідження було використано експериментальні дані, отримані від 262 свиноматок української м'ясної породи основного стада ТОВ «Таврійські свині» (Скадовський район, Херсонська область, Україна). Частку гнізд, що містили хоча б одне мертвонароджене порося, кількість та частку мертвонароджених поросят у гнізді було досліджено протягом 11 років. Хоча б одне мертвонароджене порося було відмічено в 56,9 % гнізд, середня кількість та частка мертвонароджених поросят у гнізді становила 1,2 гол. та 10,5 %, відповідно. Отримані результати свідчать про високо вірогідний вплив року опоросу на частку гнізд, що містили хоча б одне мертвонароджене порося, кількість та частку мертвонароджених поросят у гнізді (у всіх випадках: $P<0,001$). Відмічено суттєве зниження оцінок рівня мертвонародження протягом 2007-2013 рр. із їх поступовим

зростанням до 2017 р. Сезон опоросу мав певний (P<0,05) вплив на оцінки рівня мертвонародження, оскільки частка мертвонароджених поросят у гніздах, що народилися влітку, становила 9,5 %, а у гніздах, що народилися восени – 12,0 %. Частка мертвонароджених поросят у гніздах, отриманих від свиноматок, яких було запліднено спермою кнурів-плідників породи дюрок (15,0 %) була вірогідно вищою (P<0,001), ніж в гніздах, отриманих від свиноматок, яких було запліднено спермою кнурів-плідників української м'ясної, великої білої або породи ландрас (10,1-10,0 %). Від першого до 10-го опоросу оцінки рівня мертвонародження поступово зростали (у всіх випадках: P<0,001). Кількість та частка мертвонароджених поросят у гнізді мали тенденцію до зростання серед свиноматок із великим розміром гнізда при народженні (в обох випадках: P<0,001). Результати бінарної логістичної регресії свідчили про те, що ймовірність присутності хоча б одного мертвонародженого поросяти у гнізді, була вірогідно пов'язана із середньою живою масою поросяти при народженні

Ключові слова: мертвонародження; номер опоросу; розмір гнізда; рік та сезон опоросу; порода кнура-плідника; свиноматки української м'ясної породи