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Reproduction

Preweaning piglet survival on commercial farms

Santos Sanz-Fernández,[†] Cipriano Díaz-Gaona,[†] José C. Casas-Rosal,[‡] Nuria Alòs,[||] Llibertat Tusell,[||] Raquel Quintanilla,[||] and Vicente Rodríguez-Estévez[†,1]

[†]Department of Animal Production, UIC Zoonoses and Emerging Diseases (ENZOEM), Faculty of Veterinary Medicine, International Agrifood Campus of Excellence (ceiA3), University of Córdoba, Campus de Rabanales, 14071 Córdoba, Spain
[‡]Department of Mathematics, Universidad de Córdoba, 14071 Córdoba, Spain
[||]Animal Breeding and Genetics Program, Institute of Agrifood Research and Technology (IRTA), 08140 Caldes de Montbui, Spain
[1]Corresponding author: pa2roesv@uco.es

Abstract

Preweaning piglet mortality (**PWM**), a trait highly related to litter size, is one of the main concerns associated with productive efficiency and animal welfare in commercial pig farms. The objectives of this work were to study piglet survival at the farm level, to establish a survival rate (**SR**) as a target indicator to be improved, and to model it based on other reproductive parameters. Analyzed data corresponded to 580 Spanish commercial farms with a total inventory of 809,768 sows. These farms showed a mean SR of 85.70% piglets born alive (**BA**), which decreased to 81.81% when total piglets born (**TB**) were considered. The SR was strongly associated with prolificacy ($P < 0.01$), the parities with the highest prolificacy being those that had the lowest SR. Thus, the highest correlations were for the SR of piglets BA in the third and fourth parities ($r = -0.460$ and $r = -0.452$, respectively, $P < 0.01$), and for the SR of piglets TB in the fourth parity ($r = -0.546$, $P < 0.01$), which was the one with the highest prolificacy. The values corresponding to the quartile of farms with the highest SR within the most productive farms were established as targets to be improved, which were ≥88.5% of piglets BA and 83.2% of piglets TB. Nevertheless, the direct associations shown between the piglet's survival and prolificacy and other productive factors, such as the age of piglets at weaning, the farrowings per sow and year and the farrowing interval, suggest the convenience of modeling the risk of PWM on farms to have its own target of survival index to be improved.

Lay Summary

Sow prolificacy and preweaning piglet mortality have increased parallelly on commercial farms. This loss of piglets is a concern of efficiency and animal welfare, and it requires the improvement of piglet survival by reducing the number of stillborn piglets and piglet mortality during lactation, paying particular attention to hyperprolific sows (≥15 total piglets born per litter). Data from 580 commercial farms with an average inventory of 809,768 sows have been analyzed to propose two predictive models based on several reproductive parameters and two survival rate targets with the aim of reducing this problem, which are ≥88.5% of piglets born alive and ≥83.2% of total piglets born.

Key words: animal welfare, piglet livability, preweaning mortality, prolificacy, survivability

Abbreviations: BA, piglets born alive; F, fostered piglets; PWM, preweaning piglet mortality; PWSY, number of piglets weaned per sow and year; SB, stillborn piglets; SR, survival rate; SRBA, survival rate of born alive piglets; SRTB, survival rate of total born piglets; T, transferred piglets; TB, total piglets born; VIF, variance inflation factor; W, weaned piglets

Introduction

The global increase in pig production (Lassaletta et al., 2019) is partially due to the general and constant improvement achieved through years of genetic selection of hyperprolific lines and their generalized and widespread use in commercial farms. Hyperprolificacy is considered when litters have 14 or more total piglets born (**TB**) (Dallanora et al., 2017), although Caballer (2017) raises this threshold for 16 or more TB piglets per parity. Nevertheless, Kobek-Kjeldager et al. (2020) consider that a hyperprolific sow is one giving birth to more piglets than its number of functional teats, although this definition is questionable for rustic breeds with lower numbers of teats or for old sows with partial loss of functional teats. Nevertheless, the increased number of TB piglets considerably prolongs farrowing duration, and decreases the piglets' average weight at birth and their vitality, thus negatively affecting the piglets' survival (Ward et al., 2020).

The aforementioned circumstances have altered what previously could be considered a low rate of mortality or good survival for piglets before weaning. Therefore, preweaning piglet mortality (**PWM**) has become a major problem in current intensive pig production (Muns et al., 2013). PWM on European commercial sow farms oscillates around 12.3%, representing approximately a loss of 39 million piglets born alive (**BA**) per year and the number of stillborns (SB) represents an additional 8% of TB (Muns et al., 2013). However, recent studies have estimated that the average PWM on commercial farms is even higher than previously reported around 15%-20% (Koketsu et al., 2021a; Farmer, 2022), even in well-managed operations.

The current concern about animal welfare also puts the spotlight on the aggravated PWM and impaired welfare of hyperprolific sows and their litters (Peltoniemi et al., 2020). Although some experts have seen increased PWM as an

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unavoidable aspect in the reproduction of very prolific sows (Edwards, 2002; Baxter and Edwards, 2018), to reduce this PWM values should be considered within the concerns of sustainable farming.

To avoid these piglet losses, it is necessary to study piglet survival during farrowing and lactation, as well as evaluating the factors involved in piglet mortality. The increase of piglet survival would improve not only the sow performance but also animal welfare, survival being an essential parameter to assess welfare status on pig farms (Kielland et al., 2018). In this context, another productive parameter defined as "piglet livability", the percentage of potentially viable piglets a sow can raise (Pourabedin, 2019), has emerged.

Several studies on piglet mortality during lactation and the relationship with other productive parameters such as perinatal survival or piglet growth have been addressed (e.g., Panzardi et al., 2013; Koketsu and Iida, 2020). Other authors have also proposed genetic evaluation models for increasing piglet survival and birth weight in breeding programs, and have estimated the genetic parameters of these traits (Knol et al., 2002; Su et al., 2007).

The objective of this work is to assess preweaning piglet survival at the farm level in Spanish commercial herds, as well as study its variation throughout sows' reproductive life, and the association with several reproductive parameters. The final aim of the study is to establish survival rates (**SRs**) to serve as a benchmark for each farm productivity level.

Interested readers in reducing PWM are encouraged to explore relevant strategies in Kirkden et al. (2013), Alexopoulos et al. (2018), Tucker et al. (2021), and Farmer and Edwards (2022).

Materials and Methods

Data source

The dataset analyzed in the present study comes from the BDporc databank (www.bdporc.irta.es) within the framework of a collaboration agreement between the Institute of Agrifood Research and Technology (IRTA) and the Department of Animal Production of the University of Cordoba. The BDporc is a database that aggregates and brings together around 40% of the census of breeding sows in Spain. This research data corresponded to a sample of 580 anonymous commercial farms distributed throughout Spain, with a total census of 809,768 commercial breeding sows.

Productive parameters computed at the farm level correspond to litters weaned in the year 2021, and those analyzed in the present study were the following annual farm averages: number of TB and BA piglets, number of weaned piglets (**W**), number of fostered (**F**) and transferred (**T**) piglets, number of piglet losses during lactation, the mean number of sows on the farm, number of piglets weaned per sow and year (**PWSY**), number of farrowings per sow and year, farrowing interval (d), number of farrowings per culled sow, age of culling (mo), age at the first farrowing (d) and piglets' weaning age. Using those data, the following new variables were obtained for every farm (Quintanilla Aguado, 2003):

Survival rate of TB piglets (**SRTB**): percentage of piglets surviving at weaning over the piglets TB. $SRTB = 100 - [(TB + F - T - W)/(TB + F - T) \times 100]$.

Survival rate of BA piglets (**SRBA**) or survival during lactation: percentage of the piglets BA that survive from birth to weaning. $SRBA = 100 - [(BA + F - T - W)/(BA + F - T) \times 100]$.

SRTB and SRBA were also computed separately in each parity (from the first to greater than or equal to eighth parity).

Classification of farms into categories

The farms were classified into groups according to their annual productivity in terms of PWSY, which is the most accepted parameter as an indicator of sow herd productivity (Koketsu et al., 2017). Therefore, assuming that the most productive farms should be those with the best balance between prolificacy and SRs, it was decided to evaluate their productive parameters as references with which to compare the rest of the farms. The group of farms in the quartile with the highest PWSY (i.e., those in the quartile with the highest PWSY) was subsequently split into quartiles according to their SRs. The objective was to compare, within the farms with high PWSY, the groups of farms with the lowest (Q1; $N = 36$) and the highest (Q4; $N = 36$) SR. The classification of the farms into these categories was done to elucidate if it is possible to simultaneously meet excellent productivity levels without detrimental piglet losses.

Statistical analysis

IBM SPSS 22 software and R 4.2.2 statistical software were used for dataset statistical analyses. Descriptive statistics for all analyzed variables were computed. Subsequently, Pearson correlation coefficients between the prolificacy and SR per parity (for both TB and BA) were calculated to estimate their possible linear association.

In addition, the descriptive statistics of the grouped farms according to their PWSY were calculated, and parametric tests were applied after assessing normality using skewness and kurtosis calculations. According to Kline (2023) skewness values should fall within the range of −3 to 3, and kurtosis values between -8 and 8 for the studied variables to be considered normal. Specifically, a Student's t test was used to analyze the distribution of differences between the group of farms with the highest SR and the group of farms with the lowest ones. For the cases in which differences were significant, the effect size (known as Cohen's d) was calculated; d provides a measure of the relevance of the differences found. Cohen (1988) provides benchmarks for effect size classification levels to define small ($d = 0.20$ to <0.50), medium ($d = 0.50$ to <0.80), and large ($d \geq 0.80$) effects.

Finally, beta regression models were developed using the *betareg* (Zeileis et al., 2016) package from R statistical software to estimate SR from all the analyzed farms based on the productive variables. The beta regression is an extension to the generalized linear models, which is specially designed for modeling percentage variables such as the SRTB and SRBA (Ferrari and Cribari-Neto, 2004). The estimated models were validated considering the fulfillment of the hypotheses related to homoscedasticity and multicollinearity. The latter was assessed using the variance inflation factor (**VIF**); according to Ringle et al. (2015), VIF values greater than 5 indicate problematic multicollinearity among the variables in the regression model. Additionally, the same independent variables were used for the homogeneity of both models.

Table 1. Descriptive statistics for the productive factors of the commercial pig farms studied ($N = 580$)

	Mean	Standard deviation	Percentiles		
			25	50	75
Number of total piglets born	15.36	1.99	13.96	14.83	16.91
Number of piglets born alive	14.06	1.72	12.85	13.60	15.45
Number of piglets weaned	12.03	1.40	11.00	11.72	13.03
Number of piglets dead during lactation	2.03	0.75	1.51	1.97	2.50
Survival rate of piglets born alive	85.70	4.40	83.05	85.94	88.53
Survival rate of total born piglets	81.81	7.01	77.13	81.29	87.71
Mean number of sows in the farm (in 1 yr)	1396.13	1206.11	536.25	982.50	1954.00
Number of piglets weaned per sow per year	29.38	3.56	27.03	28.90	31.94
Farrowing's per sow and year	2.44	0.08	2.41	2.45	2.49
Farrowing interval (d)	149.68	5.47	146.68	148.94	151.63
Farrowing's per culled sow	4.52	0.98	4.04	4.56	5.03
Culled sow age (mo)	32.53	4.91	30.00	33.00	35.00
The first Farrowing Age (d)	388.05	43.41	365.50	382.00	409.00
Piglets weaning age (lactation length, d)	25.10	3.14	23.00	25.00	27.00

Results

Descriptive statistics of the reproductive and productive variables associated with piglet survivability and productivity in the whole farm data set are shown in Table 1. The average productivity of the analyzed farms was 29.38 PWSY, with a maximum of 39.18 and a minimum of 15.06 PWSY. The average prolificacy was 15.36 TB and 14.06 BA piglets, while the average of piglets weaned per litter was 12.03. Mean lactation length (i.e., age of piglets at weaning) was 25 d.

Regarding piglet survivability, most farms lost between 1 and 3 BA piglets per litter, with a mean of 2.03 piglets lost or dead. These numbers corresponded to a mean SRBA or survival during lactation of 85.70% piglets BA. When considering the SRTB (which also considers SB piglets), this percentage decreased to 81.81%.

Correlation between survival and prolificacy per cycle

First, descriptive statistics of piglet survival and prolificacy per parity are shown in Table 2. The highest SR was achieved at the first farrowing, with means of 84.35% and 90.67% for SRTB and SRBA, respectively. The SRBA decreased until fourth parity, with the lowest mean rate (82.75%), to later increase until greater than or equal to eighth parity (88.01%). In contrast, the SRTB decreased until the sixth parity, with the lowest mean rate (75.18%), increasing in the following parities to reach a mean of 76.94% at the eighth or higher parity.

The litter sizes behaved in the opposite direction to the survivability, increasing from the first until 4th parity, where the prolificacy reached its maximum (means of 16.03 TB and 14.69 BA), to decrease thereafter (Figure 1).

Pearson correlation coefficients (r) between prolificacy and SR within parity are shown in Table 3. SR is negative and significantly correlated to prolificacy within most parities, with the highest negative correlation in the most prolific parities. Thus, the strongest antagonism between SRBA and prolificacy was obtained in the third and fourth parities ($r = -0.460$ and $r = -0.452$, respectively, $P < 0.01$). Similarly, SRTB showed the strongest negative correlation to the number of TB in the fourth parity ($r = -0.546$, $P < 0.01$).

Survival rate on farms with the highest productivity

Piglet survival is related to farm productivity, assessed through PWSY. Table 4 shows the descriptive statistics of the analyzed variables for those farms gathered in the quartile with the highest productivity ($N = 145$), with a mean of 34.18 PWSY. In this group, the mean SR during lactation decreased to 79.88%, with an average of 2.28 piglets dead before weaning. However, it is worth mentioning that the farm with the highest productivity (39.18 PWSY) showed a piglet survivability of 93.89% piglets BA, above the mean SR of farms with the highest survival (88.48% BA).

Table 5 shows the descriptive statistics of analyzed reproductive parameters for the subgroups of the most productive farms (among the 145 farms with the highest PWSY) in the quartiles with the lowest and the highest SR ($N = 36$ per group). The large effect size of this grouping on prolificacy can be observed, SR and number of piglets dead during lactation, which showed divergent values between these two farm sets (Q1 vs. Q4). The group with the highest mean prolificacy (16.78 BA, Q1) had the lowest mean survival during lactation (81.69%), whereas the farms in the quartile of the highest survival (90.81%, Q4) showed a notably lower prolificacy (16.50 TB and 15.13 BA).

It was also observed that farms with the highest survival during lactation showed shorter lactation lengths, and consequently lightly lower farrowing intervals and a higher number of farrowings per sow and year, when compared with the group of farms with lower survivability; a lower but significant effect size was identified for these variables. These same trends were shown by the groups with the lowest and the highest SRTB (Table 5).

These results confirm significant differences between piglet survival and prolificacy and suggest a certain association with the piglet´s age at weaning and the associated variables farrowing interval and farrowings per sow and year. Other productive parameters such as culling sow age or the first farrowing age did not show significant differences with the SR.

Table 2. Descriptive statistics for the survival rate and the prolificacy (piglets total born and born alive) at each parity (N = 580 farms)

	N records per parity	Survival rate for piglets total born					Survival rate for piglets born alive				
		Mean	Standard deviation	Percentiles			Mean	Standard deviation	Percentiles		
				25	50	75			25	50	75
Piglet survivability in first Pa[1]	338,880	84.35	7.71	79.62	83.76	89.21	90.67	7.61	86.01	89.99	95.43
Piglet survivability in second Pa	285,908	82.39	6.69	78.38	82.62	86.45	87.91	6.34	83.97	88.28	91.78
Piglet survivability in third Pa	245,949	77.54	5.85	73.91	77.73	81.69	83.72	5.53	80.25	83.65	87.58
Piglet survivability in fourth Pa	215,606	75.86	6.55	72.15	75.89	79.77	82.75	6.15	79.09	82.92	86.49
Piglet survivability in fifth Pa	190,416	75.34	6.50	71.25	75.39	79.13	83.06	6.11	79.09	83.15	86.66
Piglet survivability in sixth Pa	159,643	75.18	7.39	70.74	75.28	79.24	83.95	7.39	79.45	83.85	87.79
Piglet survivability in seventh Pa	119,576	75.55	9.11	70.66	75.40	80.31	84.89	9.25	79.79	84.89	89.43
Piglet survivability in greater than or equal to eighth Pa	118,211	76.94	11.45	70.57	76.49	82.69	88.01	12.36	80.85	87.62	94.62

	N records per parity	Total born					Born alive				
		Mean	Standard deviation	Percentiles			Mean	Standard deviation	Percentiles		
				25	50	75			25	50	75
Prolificacy in first Pa	338,880	14.59	1.79	13.45	14.13	15.97	13.57	1.64	12.44	13.27	14.83
Prolificacy in second Pa	285,908	15.05	1.98	13.58	14.40	16.83	14.09	1.79	12.73	13.58	15.62
Prolificacy in third Pa	245,949	15.85	2.19	14.26	15.29	17.81	14.67	1.92	13.26	14.22	16.31
Prolificacy in fourth Pa	215,606	16.03	2.22	14.45	15.41	17.77	14.69	1.88	13.29	14.25	16.29
Prolificacy in fifth Pa	190,416	15.90	2.16	14.39	15.38	17.60	14.41	1.79	13.11	14.04	15.86
Prolificacy in sixth Pa	159,643	15.67	2.08	14.25	15.23	17.16	14.04	1.68	12.80	13.74	15.23
Prolificacy in seventh Pa	119,576	15.35	2.05	13.89	14.83	16.68	13.63	1.63	12.46	13.37	14.68
Prolificacy in greater than or equal to eighth Pa	118,211	14.87	2.14	13.38	14.45	16.22	13.05	1.80	11.86	12.77	14.14

[1]Pa, parity.

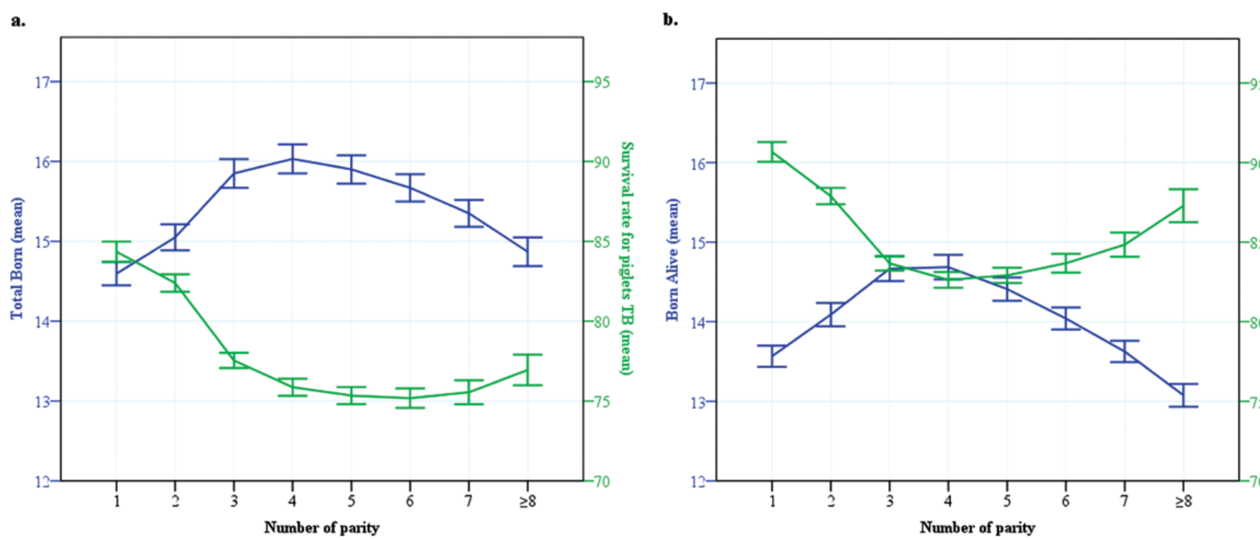

Figure 1. Comparison between (a) survival rate for piglets total born (**TB**) and TB prolificacy according to sow parity; (b) survival rate for piglets BA and BA prolificacy according to sow parity (N = 580 farms).

Beta regression for modeling piglet survival based on productive parameters

The beta regression models for SRBA and SRTB were developed using data from 580 farms, with the aim of knowing the association between survivability and the analyzed productive parameters. These models for SRBA and SRTB are shown in Tables 6 and 7, respectively.

The model developed for SRBA (Table 6) has a Pseudo R^2 of 0.75 and a significance $\varphi < 0.001$; which indicates that the model explains 75% of the variability of the SRBA. All variables used in the model are relevant to explain the SRBA, except the first farrowing age. The proposed model shows that the most relevant variable showing a very significant and negative association with SRBA is the number of BA piglets

Table 3. Pearson correlation coefficients (r) between the survival rate and the prolificacy (piglets total born and born alive) according to the number of parities (N = 580 farms)

	BA in first Pa[3]	BA in second Pa	BA in third Pa	BA in fourth Pa	BA in fifth Pa	BA in sixth Pa	BA in seventh Pa	BA in greater than or equal to eighth Pa
Survival rate of piglets BA[1]	−0.176***	−0.448***	−0.460***	−0.452***	−0.368***	−0.232***	−0.035	−0.150***
	TB in first Pa	TB in second Pa	TB in third Pa	TB in fourth Pa	TB in fifth Pa	TB in sixth Pa	TB in seventh Pa	TB greater than or equal to eighth Pa
Survival rate of piglets TB[2]	−0.239***	−0.503***	−0.533***	−0.546***	−0.508***	−0.396***	−0.226***	−0.241***

[1]BA, born alive.
[2]TB, total born.
[3]Pa, parity.
*** = $P < 0.01$.

(estimated regression coefficient $\hat{\beta} = -0.393$) followed by the PWSY and farrowing interval, both showing a highly significant and positive association with SRBA ($\hat{\beta} = 0.184$and 0.018, respectively). In addition, the age at weaning was also positively associated with this SR during lactation ($\hat{\beta} = 0.006$), whereas the farm number of sows was negatively associated with SRBA ($\hat{\beta} = -1.22E - 0.5$), both variables with a lower level of significance.

Likewise, the model developed for the SRTB (Table 7), which also takes into account the SB as piglet losses, has also been validated with a high level of significance (φ ≤ 0.001) but with a lower explained variation than the previous model (Pseudo R^2 = 0.42). Most variables used to build the model seem to be relevant to explaining SRTB with the exception of farrowing interval and piglet weaning age. The proposed model for SRTB shows that the most relevant variable is prolificacy for TB piglets, negatively associated with SRTB ($\hat{\beta} = -0.261$), whereas PWSY and age at the first farrowing showed a positive association with SRTB ($\hat{\beta} = 0.105$ and 0.002, respectively). The estimated regression coefficient on the number of sows on the farm also suggests a negative association with SRTB ($\hat{\beta} = -2.61E - 0.5$), but with a lower level of significance.

Discussion

The present work addresses the study about piglet survivability and other related reproductive parameters from data gathered in the Spanish Pig Database BDporc. Together with the management techniques implemented in each farm, and that it was not possible to register, the animals' genetics is possibly one of the most important variation factors. However, for confidentiality reasons, the genetic origin of the farms studied has not been evaluated, but these sows correspond to modern commercial lines of international companies; therefore, these findings can be extrapolated beyond Spain. The sample of 580 Spanish farms analyzed had a mean numerical productivity of 29.37 PWSY, a figure slightly lower than the values presented by Lavery et al. (2019) in a study about hyperprolific sows (31.3 PWSY). The mean prolificacy of the studied farms (15.35 TB and 14.06 BA piglets) is considered high prolificacy (Dallanora et al., 2017), despite being notably lower than that described by Pedersen (2020) for Danish sows (19.4 TB). The prolificacy of the Spanish farms has significantly increased in recent years from 23.78 PWSY in 2009 (Babot et al., 2010). However, simultaneously, in one decade, the PWM increased from 11.9% to 14.4% and the prolificacy increased in 1.9 piglets BA in Spain (Koketsu et al., 2021a); although according to the BDporc, which is a larger database, from 2012 to 2021, BA increased from 12.12 to 14.68 (a yearly mean increase of 0.47 BA) and PWM from 10.18% to 15.42% (Tusell et al., 2022). Besides that, the recent study of Farmer (2022) indicated a PWM between 15% and 20% of all piglets born during the farrowing process or in early lactation. These results are similar to the current SR of the farms studied, with 81.83% and 85.73% for TB and BA, respectively.

The estimated correlations between SR and prolificacy confirm what had already been stated by other authors; e.g., Su et al., (2007) already indicated that there is a marked negative association between prolificacy and piglet survivability. The strongest antagonism is observed in those parities with the highest prolificacy, implying that the association between

Table 4. Descriptive statistics for the productive factors for the 25% of farms with the highest annual productivity (piglets weaned per sow per year) (N = 145 farms)

	Mean	Standard deviation	Percentiles		
			25	50	75
Number of piglets weaned per sow per year	34.18	1.64	32.86	33.79	35.24
Number of piglets total born	17.79	1.28	17.16	17.96	18.68
Number of piglets born alive	16.22	1.03	15.67	16.29	16.85
Number of piglets weaned	13.94	0.69	13.41	13.82	14.38
Number of piglets losses during lactation	2.28	0.67	1.77	2.32	2.78
Survival rate for piglets born alive (or lactation survival rate)	79.88	5.56	76.49	79.51	83.24
Survival rate for piglets total born (during farrowing and lactation)	86.08	3.62	83.51	85.85	88.48
Number of sows on the farm	1,692.20	1,169.10	783.50	1,321.00	2,585.50
Farrowing's per sow and year	2.45	0.05	2.43	2.45	2.48
Farrowing interval (d)	148.84	2.83	147.24	148.76	150.43
Farrowing's per cull sow	4.32	0.74	3.94	4.37	4.80
Cull sow age (mo)	30.88	3.50	29.00	31.00	33.50
First farrowing age (d)	385.02	30.56	368.00	383.00	402.00
Piglets weaning age (d)	25.41	2.12	24.00	26.00	27.00

prolificacy and survivability is especially relevant in the most productive cycles. A previous study in the United Kingdom (KilBride et al., 2012) also indicated that the PWM increased dramatically (from 8.6% to 23.3%) when the litter size increased from ≤10 to ≥14 piglets per litter. Other studies also confirm that the largest litters show a higher mortality rates before weaning (Damgaard et al., 2003; Hellbrügge et al., 2008; Koketsu et al., 2021a, 2021b).

This lower SR may be explained by different factors. On the one hand, a large litter size can go together with a longer duration of farrowing, increasing the probability of dystocia and intrapartum hypoxia, directly affecting the survival of the piglets (Lay et al., 2002). On the other hand, an increase in litter size goes with lower piglet weight at birth, which decreases their survivability. Piglets with low birth weight have an increased risk of stillbirth (Quiniou et al., 2002) and mortality probability increases as birth weight decreases (Fix et al., 2010). In this context, Moreira et al. (2020) reported that the average weights at birth are up to 43% lower in litters from sows with high prolificacy (≥14 TB piglets) compared to those from sows with low prolificacy. In short, the current results confirm that a large litter size can be considered a risk factor for animal welfare because it is associated with a decrease in piglet survival (Baxter et al., 2013). What is more, the progressive increase in litter size can also have unfavorable effects on the body condition of breeding sows, which might potentially hinder the subsequent gestation and lower the age of sows at culling (Hypor, 2021).

Trying to reduce and minimize both stillbirths and lactation mortality to improve SRTB and SRBA firstly requires having a differentiation protocol and a good register of losses, to finally implement the appropriate measures in each case, especially good management. Therefore, SRTB is the most reliable parameter when it is not possible to guarantee the correct farm entry of data to differentiate between piglets stillborn and piglets dead during lactation.

Piglet survival varies throughout the reproductive cycles (parities) of the sows due to the performance of colostrum production, its concentration of immunoglobulin, and the variation in birth weight of piglets within the litter, which are different between cycles (Carney-Hinkle et al., 2013; Wegner et al., 2016; Amatucci et al., 2022). Therefore, to study and guarantee piglet survival, we must consider the sow number of farrowings, the sow census structure (parities distribution), and the number of farrowings when culling sows. In the present study, the highest SR was observed in the first farrowing (84.35% and 90.67% for SRTB and SRBA, respectively), in concordance with previous studies (e.g., Klimas et al., 2020). Subsequently, there is a progressive decrease in survival until fourth parity for SRBA and sixth parity for SRTB, with a later recovery. Conversely, to the results obtained by Koketsu et al. (2006), who observed that litters of older sows have a higher risk of PWM because of a greater variation in birth weight, in the present study, the survivability increased in the latest parities of the sows. Unfortunately, records of piglet birth weight were not available for the current study. Furthermore, the large litter sizes can lead to increased competition for resources among piglets, resulting in higher mortality rates and poorer growth.

Considering that SR is directly associated with farm productivity, the quartile of farms with the highest annual productivity (mean of 34.18 PWSY) was studied to know how PWM affects farms with the highest PWSY since it is the main indicator of the productive efficiency of a pig farm (Koketsu et al., 2017). On average in these farms 2.28 piglets died during lactation, above the average results of the total population of farms; but within this group, there were also farms with a high SR. So, the percentile of farms with the highest survivability among farms with high productivity reached a SRBA of 88.48% and a SRTB of 83.24%. These figures could be established as a target to improve animal welfare by means of increasing piglet preweaning survival. The results point out that it is compatible, and obviously desirable, for commercial farms to meet high productivity and low piglet mortality. It would be of interest to know what management procedures are being implemented in those farms to transfer their husbandry practices to other farms; for example, in the farm with the highest productivity, which had a SRBA of 93.89%.

Table 5. Comparison (mean) of the productive factors between the 25% of farms with the lowest and the highest survival rate for piglets born alive and total born (N = 145 farms)

	Survival rate for piglets born alive or during lactation							Survival rate for piglets total born						
	Q1[1]			Q4[2]			Effect size[3]	Q1[1]			Q4[2]			Effect size[3]
	Mean	S[4]	K[5]	Mean	S[4]	K[5]		Mean	S[4]	K[5]	Mean	S[4]	K[5]	
Survival rate for piglets born alive	81.69	−1.15	0.54	90.81	1.79	4.86	5.14***	82.94	−0.06	0.12	88.73	−0.64	1.43	1.76***
Survival rate for piglets total born	76.07	1.11	1.38	84.27	1.24	1.95	1.84***	73.21	−0.18	−1.10	87.21	1.00	0.27	4.56***
Number of piglets total born	18.58	0.59	0.13	16.50	−0.10	0.20	2.13***	18.72	0.30	0.83	16.69	−0.22	−0.12	1.72***
Number of piglets born alive	16.78	0.52	1.01	15.13	0.20	0.02	2.22***	16.78	0.65	0.66	15.50	0.25	−0.66	1.30***
Number of piglets weaned	13.70	0.62	0.35	13.73	0.76	−0.15	0.05	13.92	1.56	2.54	13.72	0.79	0.23	0.27
Number of piglets losses during lactation	3.08	1.29	1.62	1.40	−1.37	3.83	5.09***	2.87	0.31	0.79	1.78	−0.96	1.43	1.78***
Number of sows on the farm	1863.31	0.53	−0.73	1577.72	0.79	−0.46	0.26	1549.22	0.85	−0.55	1686.06	0.70	−0.57	0.12
Number of piglets weaned per sow per year	33.53	0.55	−0.50	33.92	1.17	0.84	0.26	34.05	1.18	−1.70	33.90	1.19	0.82	0.09
Farrowing's per sow and year	2.45	−0.95	1.68	2.47	0.09	0.02	0.47**	2.45	−0.20	−0.82	2.47	−0.02	−0.00	0.52**
Farrowing interval (d)	149.19	1.05	2.05	147.76	0.02	0.09	0.50**	149.16	−0.17	−0.81	147.76	0.16	0.13	0.55**
Farrowing's per culled sow	4.12	−0.44	0.18	4.47	−0.42	0.42	0.47	4.20	0.00	−0.66	4.28	−0.40	−0.25	0.10
Culled sow age (mo)	30.14	−0.74	0.23	31.44	−0.94	1.25	0.38	30.39	−0.19	0.42	30.44	−0.66	0.02	0.01
First farrowing age (d)	390.42	−0.24	0.08	383.22	0.04	−0.06	0.23	392.19	−0.28	−0.27	378.03	1.01	−0.56	0.44
Piglets weaning age (d)	25.67	1.21	2.25	24.22	0.22	−0.56	0.78***	25.92	0.66	0.85	24.61	0.06	−0.78	0.73***

[1]Q1, 25% of farms with the lowest survival rate.
[2]Q4, 25% of farms with the highest survival rate.
[3]Effect size (Cohen's d) classification levels (Cohen, 1988): small (d = 0.20 to <0.50), medium (d = 0.50 to <0.80), and large ($d \geq 0.80$) effects.
[4]Skewness.
[5]Kurtosis.
***$P < 0.01$. **$P < 0.05$.

Table 6. Beta regression for modeling the survival rate for piglets born alive based on reproductive parameters (N = 580 farms)

	Coefficient	Standard error	Z value	P value	VIF[1]
(Intercept)	−0.863	0.296	−2.920	0.003***	
Number of piglets born alive	−0.393	0.009	−44.841	<2.00E−16****	4.69
Number of sows on the farm	−1.22E−05	6.11E−06	−2.001	0.045*	1.09
Number of piglets weaned per sow per year	0.184	0.004	42.274	<2.00E−16****	4.96
Farrowing interval (d)	0.018	0.002	8.886	<2.00E−16****	2.61
First farrowing age (d)	−2.46E−04	1.74E−04	−1.413	0.157	1.08
Piglets weaning age (d)	0.006	0.004	1.787	0.074*	2.42
φ	269.64	15.83	17.04	2.00E−16****	

Pseudo R^2: 0.75; φ is the precision parameter of the model (it influences the variance of the dependent variable).
[1]VIF, variance inflation factor: values > 5 indicates problematic multicollinearity among the variables in the regression model (Ringle et al., 2015).
****$P < 0.001$. ***$P < 0.01$. *$P < 0.1$.

Table 7. Beta regression for modeling the survival rate for piglets total born based on reproductive parameters (*N* = 580 farms)

	Coefficient	Standard error	*Z* value	*P* value	VIF[1]
(Intercept)	1.886	0.615	3.066	0.002***	
Number of piglets total born	−0.261	0.014	−19.152	<2.00E−16****	3.44
Number of sows on the farm	−2.61E−05	1.28E−05	−2.029	0.042**	1.08
Number of piglets weaned per sow per year	0.105	0.008	13.306	<2.00E−16****	3.69
Farrowing interval (d)	−0.002	0.004	−0.425	0.670	2.57
First farrowing age (d)	0.002	3.99E−04	4.670	3.01E−06****	1.08
Piglets weaning age (d)	0.006	0.008	0.830	0.406	2.41
φ	48.333	2.826	17.1	<2.00E−16****	

Pseudo R^2: 0.42; φ is the precision parameter of the model (it influences the variance of the dependent variable).
[1]Variance inflation factor: values of >5 indicate problematic multicollinearity among the variables in the regression model (Ringle et al., 2015).
*****P* < 0.001. ****P* < 0.01. ***P* < 0.05.

Obviously, to obtain a high performance of PWSY there are different factors, but a very good handling of animals and facilities is a major condition. In this regard, Farmer and Edwards (2022) indicate some measures to increase piglet survival, such as optimizing the farrowing environment, and assisting the BA piglets with a good supervision of the critical points around farrowing, providing nurse sows or artificial milk.

The comparison of reproductive parameters of the two groups of farms with extreme survivability scores within farms with the highest annual productivity showed that farms with the highest SR had the lowest prolificacy, confirming the influence of prolificacy in piglet survivability. In addition, these farms had the lowest age of piglets at weaning, in accordance with Planinc et al. (2012), who indicated that the higher losses during lactation were related to longer lactations. Other factors, such as a number of farrowings per sow and year and farrowing interval, have also shown an association with piglet survivability but with a limited effect size. In any case, those farms in the quartile with the highest SR showed the best results for those parameters. It can be hypothesized that a low farrowing interval is indicative of good sow management (Torres-Novoa and Hurtado-Nery, 2007) and, therefore, good supervision would be expected during the perinatal period in these well-handled sows, which would improve piglet survivability (Holyoake et al., 1995).

The regression model for SRBA shows a high goodness of fit (75%), prolificacy (in terms of piglets BA) being the most relevant explanatory variable but associated negatively (i.e., an increase of prolificacy for piglets BA is associated with a lower SR) in concordance with that observed by other authors (Damgaard et al., 2003; Su et al., 2007; Hellbrügge et al., 2008; KilBride et al., 2012; Koketsu et al., 2021a, 2021b). To a lesser extent, an older age of piglets at weaning, is also relevant, increasing the SRBA. In this respect, prolonging the lactation length has a direct effect on the farrowing interval; therefore, a higher age at weaning increases the farrowing interval (Correa et al., 2014; Keyho et al., 2018). Consequently, in the proposed model, a larger farrowing Interval is also positively associated with SRBA. However, this is apparently contradictory to the fact that the quartile of farms with the highest SRBA had a lower piglet age at weaning and a lower farrowing interval; but it must be considered that this regression model was performed with the total number of farms and not only with the farms with the highest PWSY. What is more, fewer days of lactation could wrongly mean fewer days to die; but most PWM (50%–80%) occurs during their first week of life, with the most critical period being within the first 72 h (Koketsu et al., 2006). However, it could be hypothesized that a late weaning age would give an opportunity to some low-weight piglets that are euthanized at weaning because they have a low probability of nursery (Fix et al., 2010); while if stockmen shorten lactation length, they would be just trading one late death loss for another in nursery, which is a phase with much lower mortality rates (Wisener et al., 2021). In this regard, Larriestra et al. (2006) indicate that lightweight at weaning (≤3.6 kg) is a significant predictor of mortality in the nursery. In another vein, Lawlor and Lynch (2007) recommended increasing the duration of lactation to improve litter performance. In any case, according to the Council Directive 2008/120/EC, weaning piglets under 21 d is not permitted (European Council, 2008).

Furthermore, the model for the SRTB is also highly significant, but with lower Pseudo R^2; that is, the model explains 42% of the variability of the SRTB accuracy. This lower goodness of fit may be attributed to the fact that SRTB also considers SB piglets, and some associated factors with SB include sow genetics (behavioral and physiological traits), stress, diseases, litter weight, as well as supervision and duration of farrowing (perinatal asphyxia) (Cozler et al., 2002; Kirkden et al., 2013; Edwards and Baxter, 2014), and, unfortunately, this information was not available for inclusion in the models. In alignment with the previous model, the most relevant variable is prolificacy, in this case in terms of piglets TB, which negatively influences SRTB. Moreover, a greater age of the sow at the first farrowing is associated with higher survival of TB, because these older gilts are more mature and also have better lifetime performance (Malanda et al., 2019).

Finally, it should be mentioned that the higher annual productivity (PWSY), the higher the survival in both models (SRBA and SRTB). This reinforces the SR results of the percentile of farms with the highest survivability among farms with high annual productivity, suggesting that high productivity can be compatible with the proposed SR targets (which are >88.48% and >83.24% for SRBA and SRTB, respectively). In addition, a smaller farm size also positively influences SRBA and SRTB, which may be due to a greater availability of time to attend farrowings on small farms (Torres-Novoa and Hurtado-Nery, 2007).

Conclusions

While hyperproliphic sows may sound like a positive development in terms of efficiency, there are concerns about the implications of the progressive decrease in piglet survival. The SR depends directly on the sows' prolificacy and is linked to farm productivity. The parities with higher prolificacy are those with lower SR. Therefore, sows of third and fourth parities and their litters should be monitored, and their handling improved during farrowing and early lactation.

The mean values of the quartile of farms with the highest survival within the most productive farms are suggested as targets for SR to be improved, which are >88.5% and >83.2% BA and TB piglets, respectively. Nevertheless, the direct associations shown between survivability, prolificacy, and other productive parameters suggest a specific target of survival to be improved for each farm, classifying sows and their litters based on their expected risks. The regression models proposed in this work, based on the influence of some sows' productive variables on piglet survival, can be used to predict survivability and to establish objectives of PWM on commercial farms; although their prediction capacity needs to be addressed in further research.

This study does not assess variables, such as piglet birth weight, sow genetics, or facilities; and nor does it evaluate interannual and seasonal variations in SR. In a country like Spain, with significant climate variations, these factors could potentially explain part of the variations in the SR. Therefore, these variables should be the focus of future research to enhance piglet survivability. Nevertheless, despite these limitations, this study provides valuable information about the current SR trend and its association with the main productivity parameters.

Overall, the study of the welfare implications of hyperprolific sows is necessary in terms of understanding the underlying biological mechanisms and developing effective strategies for improving survivability.

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