Indian Journal of Animal Sciences **95** (2): 130–135, February 2025/Article
https://doi.org/10.56093/ijans.v95i2.155242

Survival analysis of length of life and length of productive life in Landlly sows

CHHAYA RANI[1], ANUJ CHAUHAN[1], INDRASEN CHAUHAN[2], SNEHASMITA PANDA[3], BHARAT BHUSHAN[1], GYANENDRA KUMAR GAUR[4] and TRIVENI DUTT[1]

ICAR- Indian Veterinary Research Institute, Izatnagar-243122, Bareilly, India

Received: 17 August 2024; Accepted: 26 March 2025

ABSTRACT

Survival traits are of major importance in pig breeding as replacing a sow cost more than maintaining a sow in the herd for additional parity. The objective of this study was to determine the factors affecting the longevity of Landlly pigs by employing survival analysis. Both conventional Cox regression and the Fine-Gray subdistribution hazard model were used in the analyses. The data were collected during the year 2014 to 2021, from the Swine Production Farm, ICAR-IVRI, Bareilly. The average length of life (LL) of Landlly sows are 186 days at the farm, as most of the sows are quickly removed (culled) from the herd after completing the first parity, while some sows are selected for more than one farrowing leading to their average length of productive life (LPL) on the form to be 349 days making the length of life (LL) is smaller than the length of productive life (LPL). The winter season (November-February) was harmful to the survival of Landlly piglets. The initial years of birth had protective effects on the LL, while it had hazardous effects on the LPL. The sows became safe from combined risks of removal after crossing parity 1 and parity 2, and they had longer LL. Similarly, after crossing Parity 1 and Parity 2, the sows became safe from risks of removal due to culling, and they had longer LL. The sows also had higher hazards of death after crossing Parity 1 and Parity 2. The sows had longer LPL if they crossed Parity 1 and Parity 2. It was found that birthweight had a highly protective effect against risks of removal, and sows with higher birthweight had a longer LL. No effect of age at the first farrowing on LPL could be found. The birthweight must be sufficiently higher in Landlly pigs to achieve a longer LL, which could be achieved with better nutrition of sows during pregnancy. To ensure longer LL and LPL of sows, the new-born piglets need to be protected during winter seasons. Culling the sows in later parities will secure longer LL and LPL, saving the costs associated with raising replacement gilts.

Keywords: Competing risks, Cox regression, Fine-Gray regression, Landlly pigs, Longevity

Due to genetic and environmental variations, a female's lifetime production is not constant (Suwanasopee *et al.* 2005). For the farmer, a long productive life is important, and for the animal's well-being, it is highly desirable. According to research, prolonging herd longevity will boost lifetime yield and productive days, which will increase profitability. By lowering the demand for replacement heifers, major methane emissions sources, longer lifespans can also lower greenhouse gas emissions. The productive length of the sow is influenced by several genetic and environmental factors, including sow biology, breed composition, management, housing, season, nutrition, and age at first farrowing (Engblom *et al.* 2009). Sows are usually removed from the herd because of reproductive difficulties, old age, and illness (Stalder *et al.* 2004). According to the findings of various studies, around 15% to 20% of sows are culled after the first parity and more than 50% are culled before their fifth parity due to fertility problems, lameness, illness, and advanced age, resulting in greater operating expenses in commercial pig farming (Stalder *et al.* 2004, Engblom *et al.* 2007). For commercial pig breeding herds, the survival traits are essential productivity indicators as they involve sow productivity as well as the effectiveness of the swine operation. Survival traits are of major importance in pig breeding because it costs more to replace a sow than it does to maintain a sow in the herd for additional parity (Hoge and Bates 2011). Additionally, improving sow longevity can help pig producers to make more profit by lowering replacement gilt costs and associated development, isolation, and acclimation costs (Stalder *et al.* 2004). Lower replacement rates reduce production costs, minimize the potential of disease transmission from gilts to sows, and increase profit margins (Engblom *et al.* 2009, Hoge and Bates 2011). Longevity selection can improve welfare and produce more robust pigs capable of coping with potentially unusual farming conditions. Furthermore, older sows are more likely to have been exposed to the diseases

Present address: [1]ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, [2]ICAR-Indian Veterinary Research Institute, Mukteshwar, Uttarakhand, India, [3] Fisheries and Animal Resources Development Department, Bhubaneswar, India, [4]Indian Council of Agriculture Research, New Delhi-110012, India. ✉Corresponding author email: chhayasingh451@gmail.com

found on a farm and, as a result, can supply progeny with better immunity (Sobczynska *et al.* 2013).

Determining the factors affecting longevity helps to ensure proper management practices of the pigs and enhance the profitability of the pig farms. The scientific knowledge on the factors affecting longevity in Landlly pigs is lacking. Therefore, this study was formulated to assess the factors affecting length of life and length of productive life in Landlly pigs.

MATERIALS AND METHODS

Study population: The study was carried out on crossbred Landlly pigs. The Landlly pig has been developed by crossing Landrace and Ghurrah pigs at the Swine Production Unit. In Landlly Pig, Landrace and Ghurrah have their inheritance levels fixed at 75% and 25%, respectively. The production unit is located at 28°N latitude and 79°E longitude at a height of 564 feet above mean sea level. The temperature varies from 4.80°C in winter to 44.40°C in summer, and the relative humidity ranges from 45% to 85%. The Landlly pig shows good performance for litter size, and it can be maintained with low input by the pig farmers (Naha *et al.* 2020). The current breeding policy for the Landlly pig necessitates a regulated mating system with five sire lines. The sows are generally culled after completing 30-36 months of age, corresponding to 4th and 5th parity. The sows are culled for the reasons such as low productivity, low fertility and lameness. The major causes of the mortality are pneumonia, pneumoenteritis and catarrhal enteritis.

Data collection: The data were collected during the year 2014 to 2021. For each sow identity number, date of birth, season of birth, year of birth, parity of dam, date of first farrowing, and date of exits were retrieved from the data registers of Landlly sows maintained at the Swine Production Unit. The difference between the date of birth and the date of exit was used to calculate the failure time for the length of life (LL). Similarly, the difference between the date of first farrowing and the date of exit was used to calculate the failure time for the length of productive life (LPL). The LL dataset consisted of records on 1305 sows while the LPL dataset contained records on 147 sows. In the LL dataset, 1041 sows were culled and 104 sows died during the study period. Fifty sows were removed from the flock for research purposes. LPL dataset had culling records of 107 sows and mortality records of only 5 sows. The last date of data collection was 23/07/2021, and the sows that were present in the flock on this date were recorded as 'right censored'. The season of birth was divided into three categories (November-February, March-June and July-October). The year had seven levels while the parity of the dam had four levels for the LL dataset and three levels for the LPL dataset.

Statistical techniques: The non-parametric survival analyses of the length of life (LL) and length of productive life (LPL) of the sows were estimated by the product-limit method of Kaplan and Meier (1958):

$$S_t = \Pi_{i:t_i \le t}\left(1 - \frac{d_i}{n_i}\right)$$

where t_i refers to the duration of study at any point i. d_i and are n_i the mortality up to point i and the number of individuals at risk just prior to t_i (Kaplan and Meier 1958) respectively. The semi-parametric Cox proportional hazards model was fitted as follows:

$$\lambda(t|X) = \lambda_0(t)\exp\{\beta X\}$$

where $\lambda(t|X)$ refers to the hazard for the failing individual. The hazard is a function of two components: some unspecified 'baseline' hazard given by $\lambda_0(t)$ and a set of covariates given by X acting multiplicatively on the baseline hazard in a time-independent manner (Cox 1972). β is the vector of regression coefficients for covariates given by X. Proportionality of the Cox model was assessed by scaled Schoenfeld residuals against transformed event time. In case of failure of proportionality assumption, the above basic model was extended to incorporate the time-varying coefficient as follows:

$$\lambda(t|z(t)) = \lambda_0(t)\exp\{\beta X + \gamma X g(t)\}$$

where β and γ are coefficients referring to time-fixed and time-varying covariates, respectively (Zhang *et al.* 2018). To circumvent the problems arising from the small size of LPL dataset, Firth's bias reduction was applied (Firth, 1993) to the Cox regression of LPL dataset. Since there were two causes of removal of sows (mortality and culling) competing with each other in the LL dataset, the Fine-Gray model proposed by Fine and Gray (1999) was used for regression analysis of the two outcomes taking into account the competing risks. The semi-parametric proportional regression model for the subdistribution hazard function is represented as:

$$\lambda^*(t|X) = \lambda_0^*(t)\exp\{\beta X\}$$

The 'subdistribution hazard' $\lambda^*(t \mid X)$ is the hazard for an individual who either fails from cause k or does not fail, and in case of no failure, the individual has an infinite failure time for cause k. Subdistribution hazard is a function of some unspecified 'baseline' hazard $\lambda_o^*(t)$ and a set of covariates defined by X. β denotes the vector of regression coefficients for different covariates. As in the case of Cox regression, the covariates act to multiply the baseline sub-distribution hazard in a time-independent manner.

Data analysis: For the survival analysis of LL, the explanatory variables were the year of birth, season of birth, parity of dam, and birth weight. Year of birth, season of birth, parity of dam, and age at first farrowing were the explanatory variables for LPL. The regression modeling of LL data was performed in two ways: first, considering the all-cause risk of removal of sows from the herd (culling and mortality together) by traditional Cox regression, and second, taking the risks of culling and mortality as competing risks by Fine-Gray model. LPL data was analyzed by Cox regression considering only the risk of removal due to culling, as most of the sows were removed from the herd by culling (107 sows) and mortality records were only 5 in number. The R package 'survival' was used for survival analysis (Therneau *et al.* 2000 and 2022). 'coxphf' package (Heinze *et al.* 2023) was used to implement Firth's bias reduction applied to the Cox model (for LPL dataset). For competing risks analysis, the Fine-Gray subdistribution hazard model implemented in the 'cmprsk' package (Gray 2022) was used. The 'ggfortify' package (Tang *et al.* 2016, Horikoshi and Tang 2016), the 'smoothHR' package (Meira-Machado *et al.* 2013, Araújo and Meira-Machado 2022), and the base R were used for the generation of the plots. Before Cox regression, the linearity assumption of birthweight for LL data was checked. This was followed by the test of proportionality of all the covariates for both LL and LPL. All the analyses were executed in R statistical environment, R version 4.1.2 (R Core Team 2021).

RESULTS AND DISCUSSION

Kaplan–Meier curves: There is a steep fall within 250 days after birth for LL, followed by an almost linear downward fall (Fig. 1). There were a total of 1305 records of animals completing their life cycle for the period 2014 to 2021. Out of this, most of the animals (1041) were culled, accounting for about 79.77% of the total animals. One hundred and four animals (7.97%) died within the period (Table 1). The mean and median survival times for LL were 186 and 90 days, respectively. For LPL, the survival curve has almost a linear downward fall until 700 days after the first farrowing, followed by a flat curve for the next 100 days, and finally, the curve plunges to the horizontal line (Fig. 2). There were only 1, 9, and 9 disposals of the females within the first 30 days, between 31 to 60 days, and 61 to 90 days after the first farrowing. Of the total 147

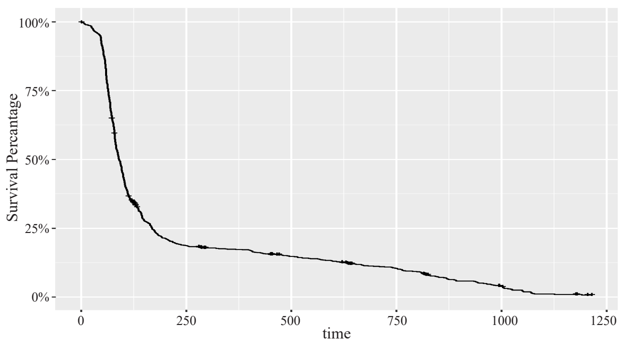

Fig. 1. Plot of Kaplan–Meier curve showing survival against time for length of life (LL) of Landlly pigs. Surv is survival probability.

Table 1. Summary of culling, mortality and censoring statistics

	Length of Life (LL)		Length of Productive Life (LPL)	
	Number of exits	Percent contribution	Number of exits	Percent contribution
Culling	1041	79.77	107	72.79
Mortality	104	7.97	5	3.40
Censoring	110	8.43	35	23.81
Others	50	3.83	0	0.00
Total	1305	-	147	-

Fig. 2. Plot of Kaplan–Meier curve showing survival against time for length of productive life (LPL) of Landlly pigs. Surv is survival probability.

records of the first farrowing, 107 females were sold and only 5 females died. The mean and median survival times for LPL were 349 and 349 days, respectively. The censored records accounted for 8.43% and 23.81% of LL and LPL datasets, respectively.

Cox regression analyses

Cox regression analysis of length of life: The results of the Cox regression for all-cause risk of removal for LL are presented in Table 2, showing estimates of hazard ratios of the covariates along with their 95% Confidence Intervals (CIs) and actual p-values. Table 3 shows the estimates of hazard ratios along with 95% Confidence Intervals (CIs) and actual p-values for culling and mortality, accounting for competing risks. Following the recommendations of Schneider (2015), the dichotomisation of results as 'significant' and 'non-significant' was consciously avoided.

As shown in Table 2, parity 2 had a higher hazard of all-cause risk of removal of the sows from the herd as compared with Parity 1 (hazard ratio: 1.05, 95% CI, 0.89

Table 2. Hazard ratios from the Cox hazards model for all-cause risk of removal for the length of life

Risk factor	Hazard Ratio	95% Lower CI	95% Upper CI	p-value
Parity2 (Ref.Parity1)	1.05	0.89	1.25	0.55
Parity3(Ref.Parity1)	0.82	0.67	1.00	0.05
Parity4(Ref.Parity1)	0.38	0.18	0.79	0.01
Season2(Ref.Season1)	0.88	0.71	1.08	0.21
Season3(Ref.Season1)	0.63	0.49	0.81	0.00
Year	1.21	1.16	1.25	0.00
Birthweight	0.39	0.30	0.52	0.00
Parity2*time	0.9998	0.9991	1.0004	0.49
Parity3*time	1.0001	0.9993	1.0008	0.88
Parity4*time	1.0030	0.9997	1.0063	0.07
Season2*time	0.9993	0.9984	1.0003	0.17
Season3*time	0.9994	0.9983	1.0005	0.27
Year*time	0.9993	0.9991	0.9995	0.00
Birthweight*time	1.0004	0.9994	1.0014	0.42

CI = confidence interval; time = time to event; Year = year of birth; Parity*time, Season*time, Year*time, and Birthweight*time denote adjustments of these factors with time in the model

Table 3. Hazard ratios from the Fine-Gray subdistribution model for length of life (accounting for competing risks)

	Culling				Mortality			
Risk factor	Subdistribution Hazard Ratio	2.5% CI	97.5% CI	p-value	Subdistribution Hazard Ratio	2.5% CI	97.5% CI	p-value
Parity2 (Ref.Parity1)	1.07	0.92	1.24	0.37	0.77	0.46	1.29	0.32
Parity3 (Ref.Parity1)	0.88	0.74	1.05	0.14	1.02	0.62	1.69	0.93
Parity4 (Ref.Parity1)	0.48	0.27	0.86	0.01	1.51	0.48	4.74	0.48
Season2(Ref.Season1)	1.00	0.85	1.18	1.00	0.83	0.48	1.43	0.50
Season3(Ref.Season1)	0.80	0.66	0.97	0.03	0.63	0.32	1.23	0.18
Year	1.03	1.00	1.06	0.06	1.16	1.04	1.30	0.01
Birthweight	0.86	0.68	1.08	0.18	0.29	0.13	0.65	0.00

CI = confidence interval; time = time to event; Year = year of birth.Parity1 and Season1 in parentheses are respective reference categories for the categorical covariates, with parity having four levels and season of birth having three levels

to 1.25). Parity 3 and Parity 4 had a protective effect as compared to Parity 1. The sows born in March-June and July-October had a lower risk of removal from the herd as compared with those born in November-February. With the passage of each year, there was an increase in the hazard of removal of the sows from the herd (hazard ratio: 1.21, 95% CI, 1.16 to 1.25). Birthweight had a highly protective effect against overall risks of removal (hazard ratio: 0.39, 95% CI, 0.30 to 0.52). With the increase in birthweight, the overall risk of removal decreased linearly, indicating lower birthweight was associated with higher hazard and vive-versa (Fig. 3). As compared with Parity 1, Parity 2 had a higher hazard of risk of removal of the sows from the herd due to culling while Parity 3 and Parity 4 had a protective effect. This is similar to the all-cause risk of removal of the sows. Contrary to this, Parity 2 had a protective effect whereas Parity 3 and Parity 4 had higher hazard for mortality as compared with Parity 1. The sows born in March-June and July-October had a lower risk of mortality as compared with those born in November-February. November-February and March-June had similar effects on culling while July-October had protective effects against the risk of removal due to culling. Similar to the all-cause risk of removal of the sows, year of birth had higher hazards for both culling and mortality while birthweight had protective effects against the risks of removal due to both culling and mortality (Table 3).

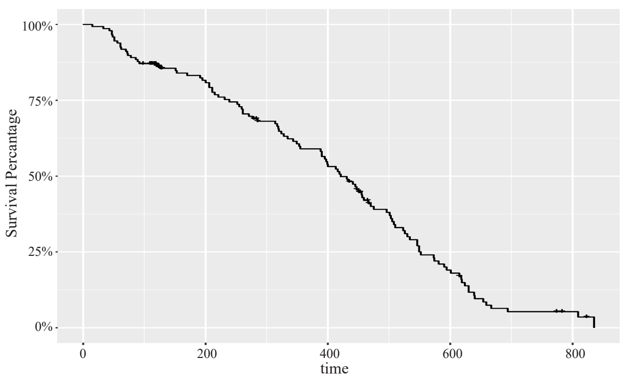

Fig. 3. Plot of log (hazard ratio) against birthweight of Landlly pigs. With increase in birthweight, there was decrease in the overall risk of removal of sows from the herd. 2.0 kg is the default reference chosen by the smoothHR package. HR is hazard ratio.

Cox regression analysis of length of productive life: As depicted in Table 4, Parity 2 had a higher hazard of risk of removal of the sows from the herd due to culling while Parity 3 had a protective effect as compared with Parity 1 for the LPL. The sows born in March-June and July-October had a lower risk of culling from the herd as compared with those born in November-February. With the passage of a year, there was a decrease in hazards for the LPL due to culling. The age at the first farrowing had a very small effect on the risk of removal due to culling, which can safely be ignored.

In this study, the average length of life (LL) of Landlly sows at the farm was 186 days as most of the sows were rapidly culled after completing the first parity and average length of productive life (LPL) of the sows selected for more than one farrowing at the farm was 349 days. Estimated LL and LPL were less than those found in the study by Sobczynska *et al*. (2013), where the average LL and LPL for Polish Landrace were 986 and 600 days, respectively. In a recent study, Rani *et al*. (2024) used linear model to study

Table 4. Hazard ratios from the Cox hazards model for risk of removal due to culling for the length of productive life (with Firth's bias reduction)

Risk factor	Hazard Ratio	95% Lower CI	95% Upper CI	p-value
Parity 2 (Ref. Parity 1)	1.01	0.63	1.61	0.98
Parity 3 (Ref. Parity 1)	0.84	0.49	1.46	0.54
Season2 (Ref. Season1)	0.70	0.29	1.70	0.43
Season3 (Ref. Season1)	0.76	0.31	1.88	0.55
Year	0.73	0.55	0.97	0.03
Age at first farrowing	1.0018	0.9994	1.0042	0.14
Year*time	1.0002	0.9995	1.0009	0.54

CI = confidence interval; time = time to event; Year = year of birth. Parity1 and Season1 in parentheses are respective reference categories for the categorical covariates, with parity and season of birth each having three levels. Year*time denotes adjustments of year with time in the model the longevity traits (length of life and length of productive life) in Landlly sows. Sevón-Aimonen and Uimari (2013) reported LPL for Finnish Landrace and Finnish Yorkshire sows to be 482 and 452 days, respectively. In other studies, the average LPL in Large White Yorkshire sows in the USA and crossbred sows in Sweden was reported to be 485 days (Engblom *et al.* 2009, Hoge and Bates 2011). The average LL and LPL in the current study were also less than those reported by Tarres *et al*. (2006) for Large White sows in Switzerland, Yazdi *et al*. (2000) for Landrace sows in Sweden, Heusing *et al*. (2005) in German Landrace and Large White, and Meszaros *et al*. (2010) for Austrian Landrace sows.

The length of life and the length of productive life are influenced by many factors. Serenius and Stalder (2007) reported that the length of productive life in sows was influenced by age at first farrowing. They have further reported that the sows with younger age at first farrowing tended to remain in the breeding herd for longer periods. Knauer *et al*. (2010) reported that the stay-ability of a sow to the fourth parity is influenced by age at first farrowing, in addition to other factors, such as farm, entry age, age at puberty and lactation feed intake. Yazdi *et al*. (2000) reported a significant effect of age at first farrowing on the longevity of Swedish Landrace sows. Using Cox proportional hazards model, Hoge and Bates (2011) reported a significant association between age at first farrowing and growth with the longevity of Yorkshire females. In the current study, however, the effect of age at the first farrowing on LPL could safely be ignored.

From the current study, it could be generalized that the sows became safe from combined risks of removal after crossing Parity 1 and Parity 2, and they had longer LL. Similarly, after crossing Parity 1 and Parity 2, the sows became safe from risks of removal due to culling, and they had longer LL However, the sows had higher hazards of death after crossing Parity 1 and Parity 2. The sows became safe from the risks of removal after crossing Parity 1 and Parity 2, and they had longer LPL. Zotti *et al*. (2017) have reported that sow parity has effects on litter development in the early age of piglets. The neonates are prone to development of hypothermia as a result of sudden drop in winter temperature culminating in death. In this study, it was found that the winter season (November-February) was harmful to the survival of Landlly piglets, and this negatively affected both LL and LPL. The initial years of birth had protective effects for the LL, while it had hazardous effects on LPL. In the initial years, greater number of first farrowing sows was removed due to culling, and this was reflected in the hazardous effects of the initial years of birth on LPL. Conversely, the exits due to culling and death of the sows since their birth to final disposal from the herd were lower in number in the initial years, and this manifested as protective effects of the initial years of birth for the LL. In the current study, it was found that birthweight had a highly protective effect against risks of removal and sows with higher birthweight had a longer LL. It has been shown that the low birthweight in Large White X Landrace crossbred pigs negatively affects not only the female piglet survival and growth rate but also the longevity of female swine (Magnabosco *et al.* 2015, Magnabosco *et al.* 2016). During early life, the piglet birthweight affects the litter development (Zotti *et al.* 2017). The birth weight is also correlated to the protection of piglets from cold environment. It has been reported long ago that the newborn piglets with higher birthweight perform better in a cold environment compared to those with lower birthweight, as piglets with higher birthweight have lower surface-area/body volume ratio and are less prone to heat loss in cold environments (Stanton *et al.* 1973). For the piglets with low birthweight, it is difficult to stand and reach the heat protection provided by dam, resulting in the heat loss (Kammersgaard *et al.* 2011).

CONCLUSION

To achieve a longer length of life, the birthweight must be sufficiently higher in Landlly pigs, which could be achieved with better nutrition of sows during pregnancy. The new-born piglets need to be protected during winter seasons, and this will ensure that sows will have longer length of life and length of productive life. Since the removal rate is high and a large proportion of removed females are young, the longevity of the average sow has the potential to be improved on the farm. The producer needs to focus on the hazard factors causing the removal of the sows. The improvement of longevity traits will be possible through the control of environmental factors (such as nutrition and management intervention). It is also desirable to cull the sows in later parities to ensure a longer length of life and length of productive life. This will save the costs associated with raising replacement gilts.

REFERENCES

Araújo A and Meira-Machado L. 2022. smoothHR: Smooth hazard ratio curves taking a reference value v1.0.4 (R package version 1.0.4), https://CRAN.R-project.org/package=smoothHR.

Cox D R. 1972. Regression models and lifetables (with discussion). *Journal of the Royal Statistical Society, Series B* **34**: 187–220.

Engblom L, Lundeheim N, Dalin A M and Andersson K. 2007. Sow removal in Swedish commercial herds. *Livestock Science***106**,76–86.

Engblom L, Lundeheim N, Schneider M del P, Dalin AM and Andersson K. 2009. Genetics of crossbred sow longevity. *Animal* **3**: 783–90.

Fine J P and Gray R J. 1999. A proportional hazards model for the subdistribution of a competing risk. *Journal of American Statistical Association* **94**(446): 496–509.

Firth D. 1993. Bias reduction of maximum likelihood estimates, *Biometrika* **80**: 27-38.

Gray B. 2022. cmprsk: Subdistribution analysis of competing risks v2.2-11 (R package version 2.2-11). https://CRAN.R-project.org/package=cmprsk.

Heinze G, Ploner M, Jiricka L and Steiner G. 2023. coxphf: Cox Regression with Firth's Penalized Likelihood v1.13.4 (R package version 1.13.4). https://CRAN.R-project.org/

package=coxphf.

Heinze G. and Schemper, M. 2001. A solution to the problem of monotone likelihood in Cox regression. *Biometrics* **57**(1): 114-9.

Heusing M, Hamann H and Distl O. 2005. Genetic analysis of lifetime performance and fertility traits in the pig breeds Large White, German Landrace and Pietrain. *Zuchtungskunde* **77**: 15–34.

Hoge M D and Bates R O. 2011. Developmental factors that influence sow longevity. Journal of Animal Science **89**(4): 1238–45.

Horikoshi M and Tang Y. 2016. ggfortify: Data visualization tools for statistical analysis results. https://CRAN.R-project.org/package=ggfortify.

Kammersgaard T S, Pedersen L J, Jørgensen E. 2011. Hypothermia in neonatal piglets: interactions and causes of individual differences. Journal of Animal Sci*ence* **89**: 2073-85.

Kaplan E L and Meier P. 1958. Nonparametric estimation from incomplete observations. *Journal of American Statistical Association* **53**: 457-81.

Knauer M, Stalder K J, Serenius T, Baas TJ and Berger T J. 2010. Factors associated with sow stayability in 6 genotypes. *Journal of Animal Sciences* **88**: 3486-92.

Magnabosco D, Bernardi M L, Wentz I, Cunha, E C P and Bortolozzo F P. 2016. Low birth weight affects lifetime productive performance and longevity of female swine. *Livestock Science* **184**: 119–25.

Magnabosco D, Cunha E C P, Bernardi M L, Wentz I and Bortolozzo F P. 2015. Impact of the birth weight of Landrace X large white dam line gilts on mortality, culling and growth performance until selection for breeding herd. *Acta Scientiae Veterinariae* **43**: 1274.

Meira-Machado L, Cadarso-Suárez C, Gude F and Araújo A. 2013. smoothHR: An R package for pointwise nonparametric estimation of hazard ratio curves of continuous predictors. *Computational and Mathematical Methods in Medicine* e745742. doi:10.1155/2013/745742.

Meszaros G, Palos J, Ducrocq V, Solkner J. 2010. Heritability of longevity in Large White and Landrace sows using continuous time and grouped data models. *Genetics Selection Evolution* **42**: 1–13.

Nagashima K. and Sato, Y. 2017. Information criteria for Firth's penalized partial likelihood approach in Cox regression models. *Statistics in Medicine* **36**(21): 3422–36.

Naha B C, Gaur G K, Saini, B L, Sahoo N R and Boro P. 2020. Genetic and phenotypic trend for growth performance in Landlly pigs. *The Indian Journal of Animal Sciences* **90**: 296-8.

R Development Core Team. 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/

Rani C, Chauhan A, Chauhan I, Vaishnav S, Ajay K A, Panda S, Bhushan B and Dutt T. 2024. Genetic analysis for reproductive and longevity traits in Landlly sows. *The Indian Journal of Animal Sciences* **94**(10): 859–65.

Schneider J. W. 2015. Null hypothesis significance tests. A mix-up of two different theories: the basis for widespread confusion and numerous misinterpretations. *Scientometrics* **102**: 411–32.

Serenius T and Stalder K J. 2007. Longevity is impacted by farm management, leg conformation, sow's own prolificacy, and sow's origin parity and genetics. *Animal* **1**:745-50.

Sevón-Aimonen M L and Uimari P. 2013. Heritability of sow longevity and lifetime prolificacy in Finnish Yorkshire and Landrace pigs. *Agricultural and Food Science* **22**: 325–30.

Sobczynska M, Blicharski T and Tyra M. 2013. Relationships between longevity, lifetime productivity, carcass traits and conformation in Polish maternal pig breeds. *Journal of Animal Breeding and Genetics* **130**(5): 361–71.

Stalder K J, Knauer M, Baas T J, Rothschild M F and Mabry J W. 2004. Sow longevity. *Pig News and Information* **25,** 53N–74N.

Stanton H G L, Brown J and Mueller R L. 1973. Interrelationships between maternal and neonatal factors and thermoregulation in fasted neonatal swine (*Sus domesticus*). *Comparative Biochemistry and Physiology* **44**: 97-105.

Suwanasopee T, Mabry J, Koonawootrittriron S, Sopannarath P and Tumwasorn S. 2005. Estimated genetic parameters of non-productive sow days related to litter size in swine raised in Thailand. *Thai Journal of Agricultural Science* **38**(3-4): 87-93.

Tang Y and Horikoshi M Li W. 2016. ggfortify: Unified interface to visualize statistical result of popular R packages. *The R Journal* **8**(2): 478-49.

Tarres J, Bidanel J P, Hofer A, Rosendo A and Ducrocq V. 2006. Analysis of longevity and exterior traits on Large White sows in Switzerland. *Journal of Animal Science* **84**, 2914–24.

Therneau T M, Grambsch P M. 2000. Modeling survival data: extending the cox model. *Springer*, New York.

Therneau T M. 2022. A Package for Survival Analysis in R v3.3-1 (R package version 3.3-1). https://CRAN.R-project.org/package=survival.

Yazdi M, Rydhmer L, Ringmar-Cederberg E, Lundeheim N and Johansson K. 2000. Genetic study of longevity in Swedish Landrace sows. *Livestock Production Science* **63**: 255–64.

Zhang Z, Reinikainen J, Adeleke K A, Pieterse M E and Groothuis-Oudshoorn C G M. 2018. Time-varying covariates and coefficients in Cox regression models. *Annals of Translational Medicine* **6**(7): 121.

Zotti E, Resmini F A, Schutz L G, Volz N and Milani R P. 2017. Impact of piglet birthweight and sow parity on mortality rates, growth performance, and carcass traits in pigs. *Revista Brasileira de Zootecnia* **46**(11): 856-62.