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Survival analysis and risk factors for goat mortality among breeding goats in Gazelle District, Papua New Guinea

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Abstract

Mortality in goats limits production and productivity, particularly in smallholder and extensive grazing systems, where resources for health interventions and management practices are often limited. This study investigates risk factors for goat mortality using Cox proportional hazards regression modelling at the Papua New Guinea (PNG) University of Natural Resources and Environment (PNGUNRE) breeding farm from 2020 to 2023. A non-parametric survival analysis and multivariable Cox regression were used to assess biological and clinical variables. The mean mortality rate was 32%. Health status and severity of clinical symptoms significantly influenced mortality rates. Bucks had a 91% higher risk of death compared to does (LR $\chi^2 = 0.04$; $p = 0.84$), while kids faced significantly higher risks (LR $\chi^2 = 68.82$; $p < 0.001$). Goats with body conditions of 3 and 4 were 8 and 17 times more likely to survive than extremely thin ones ($p = 0.01$). Overall body condition significantly impacted mortality risk (LR χ^2, $p < 0.001$). Poor FAMACHA anaemic scores (D and E) increased the hazard of death ($p < 0.001$), while healthy goats had a 17-fold higher survival chance (HR = 14.97, $p = 0.08$). Our evaluation indicated that the causes of goat mortality were multifactorial and involved complex interactions among various factors. These findings support developing strategies to enhance goat health, welfare, and productivity in breeding farm settings. Management practices should meet the specific needs of different sex and class groups, with special attention to breeding does, kids, male goats, body condition monitoring, and anaemic conditions. Regular training for farmers on modern husbandry practices and data recording could also improve farm management. Additionally, enhanced veterinary services and resource allocation are crucial for reducing mortality rates. This work provides a template for improving goat farm health management strategies in PNG, emphasizing a comprehensive and practical approach.

Keywords: Goat mortality, Papua New Guinea, Risk factors, Small ruminant, Survival analysis

Introduction

Papua New Guinea (PNG), the largest island state in Oceania and second largest globally, is situated south of the equator. It comprises the eastern part of New Guinea and smaller islands such as New Britain, New Ireland, Manus, and Bougainville (FAO, 2011). Although PNG has significant agricultural potential, goat farming remains underdeveloped. Goats, introduced over 140 years ago (APAAri, 2021), are culturally undervalued compared to other livestock like pigs and poultry (Joku, 2024). Consequently, only a small percentage of rural farmers rear goats for livelihood (Bourke & Harwood, 2009).

A 2002 estimate placed PNG's goat population at approximately 20,000, with no recent updates (Quartermain, 2002). The country relies heavily on imports, spending $72.3 million on goat and sheep meat in 2022, primarily from Australia and New Zealand (OEC, 2022). Nevertheless, the rising demand for goat milk and meat has spurred some growth, with farmers in coastal areas establishing goat farms (Vincent & Low, 2000; Quartermain, 2001).

Despite these developments, goat farming in PNG faces persistent challenges, including low-quality pastures, heat stress, parasitic diseases, poor breeding practices, and limited animal health services (Manyeki *et al.,* 2022). High mortality rates, especially among kids, further constrain production. These losses result from parasitism, inbreeding, poor feeding, and inadequate management (Ayalew, 2007).

Goat mortality rates worldwide are influenced by factors such as climate, disease prevalence, and management practices (Wong *et al.,* 2021). In sub-Saharan Africa, these rates are notably higher due to limited access to veterinary services and frequent disease outbreaks (Kagucia *et al.,* 2020; OECD/FAO, 2021; Kichamu *et al.,* 2024). Gastrointestinal (GI) parasites, which thrive in humid tropical regions like PNG, are a major cause of goat mortality globally (Koinari *et al.,* 2013). A study conducted in PNG's Eastern Highlands documented a 20.2% mortality rate among pre-weaning kids, primarily attributed to parasitism and poor nutrition (Asiba, 1987; Asiba, 1995; Quartermain, 2004). Poor management practices that fail to address these adverse conditions further expose goats to factors contributing to higher mortality rates (Yitagesu & Alemnew, 2022).

The University of Natural Resources and Environment (UNRE) farm in East New Britain Province reflects these challenges. Over a 7-10 year period, its goat population grew from 10 to over 250 under a semi-intensive system. However, the absence of regular health services, vaccinations, and deworming programs led to rising mortality, particularly after 2017. Common causes of death included dog attacks, drowning, and structural issues in housing. Parasitism, initially a minor issue, became more significant with herd expansion. In 2022, 20 goats introduced from the Eastern Highlands exhibited higher GI parasite burdens, necessitating Fenbendazole treatment.

This study aims to identify and analyze risk factors influencing goat mortality at the UNRE farm. Specifically, it evaluates factors such as sex, class, body condition score, FAMACHA score, reproductive status, health status, and other covariates. These insights are expected to guide strategies for improving goat farming practices in PNG, reducing mortality rates, and enhancing productivity.

Materials and Methods

Study site

The study was conducted at a goat breeding farm owned by the University of Natural Resources and Environment (UNRE), Vudal Campus, Gazelle District, East New Britain Province. Collectively, PNG experiences two seasons: dry (June to September) and wet (December to March). The monthly rainfall has an average range of 250 - 350 mm and the temperature averages between 26 - 28°C. Humidity is relatively high, ranging between 70 – 90%. The weather conditions can be unpredictable throughout the year exceeding an annual rainfall of 2,500 mm. PNG has one of the wettest climates in the world with most downpours occurring in the highlands which is the cooler region of PNG while along the coasts and in the plains, it is usually hot and humid throughout the year. The factors affecting the climatic condition in PNG are the trade winds and the movement of the South Pacific Convergence Zone (SPCZ), a zone of high-pressure rainfall zone that migrates across the Pacific south of the equator (World Bank – Climate Change Knowledge Portal, 2020). The studys site geographic coordinate reference is a latitude of -4.3489° or 4° 20' 56" south, longitude 152.00419° or 152° 0' 15" east and altitude of 50 metres (164 feet) above sea level (Figure 1).

Study animal

The goat flock were breeds of the feral genotype of PNG which consists of mixed breeds of Saanen, Toggernburg and Alpine breeds. In 2008, the research site was established and started crossbreeding and evaluating local genotypes by introducing initial local breeding flocks (2 Buck and 8 Does) from Erap farm and the National Agriculture Research Institute

(NARI) in Morobe Province, PNG. These cross-breeds were bred to improve breeding stock, increase population and meet market demands within the communities and province.

Data collection

The mortality data was collected from farm records and through verbal interviews with goat farm supervisors and field workers and were entered into an Excel spreadsheet. The time goats got to the farm through purchase, transfer or by birth was the starting point, and the time of death was the failure time. Daily precipitation data were taken from the UNRE climate data collection substation. The average precipitation was calculated and recorded for kids at their birth date. Censored observations were goats that left the farm by transfer or unknown cause of death.

The methodological issues encountered during data collection or record sampling included the low skill and literacy levels of local farmers, the absence of a proper record-keeping system with all raw data kept as hard copies prone to damage, and cultural beliefs that sometimes-overruled research protocols. Despite these challenges, the farm's proximity to the University campus made it accessible, and the local community was friendly and willing to participate. The farm was suitable for longitudinal studies, and there was research collaboration with skilled personnel. However, limitations included the lack of skilled personnel to manage animals, the absence of proper data collection methods and data storage systems, insufficient funding for farmer training, and inadequate infrastructure, including water sources, pasture management, and small land size.

Data description

The goat mortality dataset was acquired from a single breeding farm located at the Papua New Guinea University of Natural Resources and Environment (PNGUNRE), spanning 2020 to 2023. This dataset comprises information from 73 individual goats, including variables such as unique goat ID, sex, birth date, breeding hierarchy class (referred to as "Class"), breed classification, body condition score (BCS), FAMACHA anaemic score (FAMACHA), reproductive status, parturition count, health status, faecal consistency score, reported disease symptoms, goat outcomes (deceased, alive, censored), and date of death, if applicable. The time variable range spanned 1,423 days, equivalent to 3.9 years.

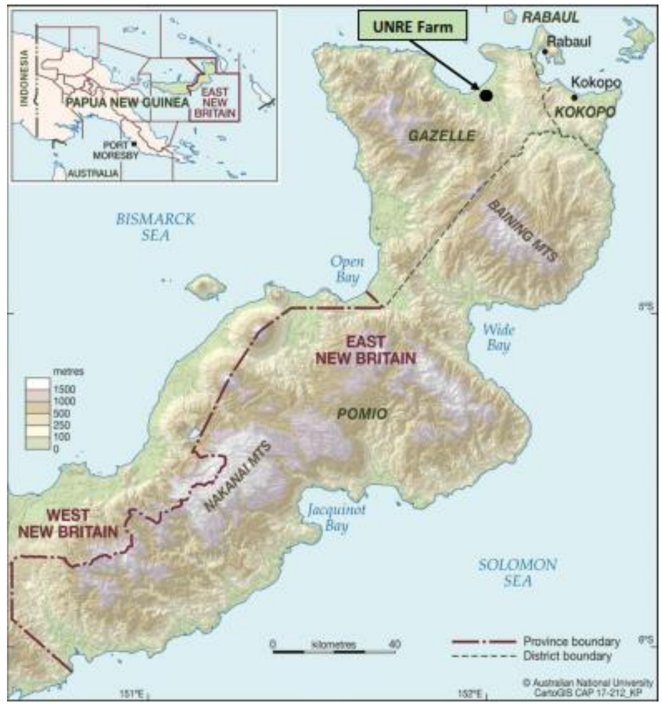

Figure 1: Map of East New Britain Province, Papua New Guinea (Gabriel *et al.,* 2017)

The dataset offered a comprehensive view of goat mortality patterns in a controlled breeding setting. It enables an analysis of how different goat traits and health conditions affect survival, crucial for effective breeding and research management.

The categorical variables in the goat mortality dataset included sex (female and male), class (breeding buck, breeding doe, buck, doe, kid, and wether), breed (Alpine, Saanen, Toggernburg, Toggernburg x Alpine, and Toggernburg x Saanen), BCS (1, 2, 3, 4, and 5), FAMACHA anaemic score (A, B, C, D, and E), reproductive status (fertile, matured, post-partum, pregnant, immature, and open), parturition count (0, 1, 2, and 3), health status (censored/sold, healthy, high internal parasitic infection, live birth, low internal parasitic infection, moderate internal parasitic infection, and still birth), faecal consistency score (1, 1.5, 2, 2.5, and 3), symptoms (mild symptoms, moderate symptoms, more symptoms, no symptoms for censored/sold, significant symptoms, and some symptoms), current status (censored/sold, alive, and dead), and died or (no and yes).

Data exploration and univariable analyses

Data exploration was initiated in a Microsoft Excel spreadsheet, followed by summary statistical analyses using STATA v.14 (StataCorp LLC, College Station, TX, USA) (StataCorp., 2015). To ensure the integrity of our data and analysis, we cleaned the Excel spreadsheet by addressing missing values and correcting typographical errors in the names of goat breeds. Data visualization techniques, such as histograms, box plots, and bar plots, illuminated data distribution for numerical and categorical variables. Continuous variables were summarized by counts, mean, median, standard deviation, minimum, and maximum, while categorical variables were presented as counts and percentages.

In the analysis of the goat mortality dataset from the PNGUNRE breeding farm (2020 – 2023), survival analysis was utilized. This approach examines time-to-event data, where the time between an origin point and a specific event endpoint was measured. For instance, goats were tracked from birth to the onset of death/censored survival time. Survival analysis is typically suited for prospectively collected data, like cohort studies and clinical trial records (Kartsonaki, 2016).

Initially, the Nelson-Aalen estimator, denoted as $\hat{H}(t)$, for the cumulative hazard rate function which takes the form in equation 1, was applied.

$$\hat{H}(t) = \sum_{j:tj \leq t} \frac{dj}{nj} = \sum_{j:tj \leq t} \hat{h}j \cdot \quad \text{… equation 1}$$

Where: d_j is the number of individuals who have an event at time t_j, where $j = 1, \ldots, k$, and n_j is the number of individuals at risk just prior to t_j. This non-parametric method helps estimate hazard accumulation over time in survival analysis, particularly for right-censored data. It is useful for visualizing cumulative hazard patterns, especially with incomplete data, and offers insights into hazard changes throughout the study (Kartsonaki, 2016). Survival probabilities were calculated alongside Kaplan-Meier (or product-limit) estimator (Kaplan & Meier, 1958) of the survival function, see equation 2 below.

$$\hat{S}(t) = \prod_{j:tj \leq t} \frac{nj - dj}{nj} \quad \text{… equation 2}$$

This is to provide an insight into the shape of the survival function for each group and give an idea of whether or not the groups are proportional (i.e. the survival functions are approximately parallel). Also, the tests of equality across strata was considered to explore whether or not to include the predictor in the final model. The log-rank test was used (see equation 3 below), to compare Kaplan-Meier survival curves (Figures 2a – k).

$$X^2 = \frac{(\sum_{j=1}^{J} Oj - Ej)^2}{\sum_{j=1}^{J} \frac{V_j^2}{nj}} \quad \text{… equation 3}$$

This test compares the observed with the 'expected' number of failures if there were significant differences in survival patterns among different groups, providing insights into factors influencing goat survival (Kartsonaki, 2016). It has an asymptotic χ^2 distribution under the null hypothesis. The degrees of freedom are p (the number of groups minus 1).

Age at death (a time-to-event variable) for each goat was computed as the difference between birth and death dates. Univariable Cox proportional hazards (see equation 4 below), sought to discern links between individual variables and outcomes (dead, alive, or censored).

$$h(t|X) = h_0(t).\, exp(\beta X) \quad \text{… equation 4}$$

Where $h(t/X)$ is the hazard function at time t for an individual with covariate X; $h_0(t)$ is the baseline hazard function at time t, , representing the hazard when x=0; $exp(\beta X)$ is the exponential function of the covariate X and its associated regression coefficient β; β is the coefficient representing the effect of the covariate X on the hazard. The baseline hazard is the hazard when, in the case of a single covariate, the covariate is equal to zero. The main assumption implied is the proportional hazards assumption, which is that the hazard ratio (HR), that is the ratio of the hazard function to the baseline hazard, is constant over time. The use of the exponential function ensures that the hazard is positive (Kartsonaki, 2016).

All predictors with a p-value of 0.2 – 0.25 or less were considered for inclusion. An elimination scheme was used because all the predictors in the data set are variables that could be relevant to the model. If the predictor has a p-value greater than 0.25 in a univariable analysis it is highly unlikely that it will interact with and contribute significantly to the multivariable model.

Multivariable Cox proportional hazards modelling

Cox proportional hazards regression was employed to assess associations between time-to-event and other variables. For multivariable modelling, variables lacking statistical significance in both log-rank tests and univariable Cox models were considered for inclusion based on scrutiny (Hosmer *et al.,* 2008; Kleinbaum & Klein, 2012). Although the impacts of individual goats on survival may be limited, their combined effects or roles as confounders cannot be dismissed. A systematic approach was then employed. In constructing the multivariable model for the dataset, all candidate variables were methodically assessed for their relevance to the outcome. Variables showing significant associations in preliminary analyses or considered theoretically important were initially included. This step aimed to capture potential confounders that might affect the relationship between the variables of interest and the mortality outcome. This systematic approach aimed to bolster the study's reliability by minimizing the impact of confounding variables on the final results. Subsequently, likelihood ratio tests facilitated stepwise comparisons between a full model and reduced models, progressively excluding non-significant variables. Final model retention hinged on statistical significance ($p < 0.05$) or substantial HR changes in other significant variables upon removal, indicating the influence of confounding (Harrell, 2015; Steyerberg *et al.,* 1999). The Parsimony principle guided complexity, curbing over-fitting. We considered biological plausibility and prior knowledge when deciding variable inclusion. This strategy robustly assessed variables' importance within the covariate context, identifying key survival predictors while controlling confounding effects. Statistical modelling for the study was conducted using STATA v.14 (StataCorp LLC, College Station, TX, USA) (StataCorp., 2015).

Results

The studied goat mortality dataset spanning 2020 to 2023 at the PNGUNRE revealed key insights (Table 1). With 73 observations, the mean BCS was around 2.71 (SD = 0.96), indicating mean moderate goats' body conditions. The number of parturition occurrences had a median of 1.0 and a mean of 1.2 (SD = 0.97) for the 32 qualified goats. Faecal consistency, from 65 goats had a mean score of approximately 1.78 (spread easily) (SD = 0.74), with some variability (Table 1). The mean mortality rate was 0.32 (SD = 0.47) ≈ 32%. These statistics represent a specific timeframe and setting within our study.

For the sex variable (including 17 events among females and 6 events in male goats), the log-rank test yielded a chi-square statistic of 0.04 with a corresponding p-value of 0.84. No significant evidence exists to reject the null hypothesis of equality of survivor functions between female and male goats, hence the survival experiences between the two sexes are similar (Figure 2a). For the reproductive class, significant differences were observed in the survivor functions. Notably, the breeding doe exhibited one observed event, compared to an expected value of 11.16; the doe exhibited four observed events, contrasting with an expected value of 3.18; the Kid showed 18 observed events, surpassing the expected value of 3.90. Conversely, breeding buck, buck, and whether classes had no observed events, and their expected values were relatively low. The overall chi-squared statistic calculated as 73.89 yielded a $p < 0.001$(Figure 2b). The log-rank test for the equality of survivor functions among different breed categories revealed variations in the survivor functions among the distinct breeds. Toggernburg and Saanen breeds showed the highest observed events with 7 and 6, respectively, whereas Toggernburg x Saanen crosses exhibited the lowest with only 1 observed event. The calculated chi-squared statistic was 4.13, with a p-value of 0.39, hence the suggestion of no strong evidence for unequal survivor functions among the breeds (Figure 2c).

With consideration for the body condition scores (BCS), goats categorized with BCS values of 2 exhibited the highest observed events, with 15, compared to an expected value of 7.51. The calculated chi-squared statistic was 20.16, yielding a $p < 0.001$ (Figure 2d). In the FAMACHA anaemic score analysis, the result revealed notable dissimilarities in survivor functions. Particularly noteworthy is the elevated observed events count among goats classified with FAMACHA anaemic score of E, with 14 observed events, as compared to an expected value of 4.98. The computed chi-squared statistic amounted to 24.14, yielding a statistically significant $p < 0.001$ (Figure 2e). For the reproductive status, the dataset revealed significant differences in survival distributions among the various reproductive statuses of the goats ($\chi^2 = 52.10$, $p < 0.001$). Notably, the immature goats demonstrated the highest observed event count, while the fertile and non-pregnant goats had no observed events (Figure 2f).

Furthermore, the analysis of the different levels of the parturitions indicated that there were three observed events (deaths) among goats with no

Table 1: Animal-level description of goats from Papua New Guinea University of Natural Resources and Environment (PNGUNRE) included in the study, 2020 to 2023

Variable (n)	Category	Number	Percentage	Notes (if any)
Sex (73)	Male	48	65.7	
	Female	25	34.3	
Reproductive class (73)	Breeding buck	3	4.1	
	Breeding doe	24	32.9	
	Buck	5	6.9	
	Doe	8	11.0	
	Kid	30	41.1	
	Wether	3	4.0	
Reproductive status (73)	Fertile	2	2.7	
	Matured	25	34.3	
	Post- partum	5	6.9	
	Pregnant	10	13.7	
	Immature	26	35.6	
	Open (non-pregnant)	5	6.9	
Breed (73)	Alpine	16	21.9	
	Saanen	17	23.3	
	Toggernburg	12	16.4	
	Toggernburg x Alpine	21	28.8	
	Toggernburg x Saanen	7	9.6	
Body condition score (BCS)* (73)	1	6	8.2	Mean BCS ± SD for the whole 73 goats was 2.7 ± 0.9
	2	27	37.0	
	3	24	32.9	
	4	14	19.2	
	5	2	2.7	
FAMACHA score (73)	A	3	4.1	
	B	13	17.8	
	C	18	24.7	
	D	22	30.1	
	E	17	23.3	
Number of parturitions (73)	0	49	67.12	The mean ± SD for the 73 goats was 0.5 ± 0.9.
	1	13	17.81	
	2	7	9.59	
	3	4	5.48	
#Faecal consistency score (65)	1	23	35.4	Mean ± SD for the whole 65 goats was 1.8 ± 0.7
	1.5	12	18.4	
	2	10	15.4	
	2.5	10	15.4	
	3	10	15.4	
Mortality status (73)	Alive	39	53.4	Mean ± SD for mortality was 0.3 ± 0.5
	Dead	23	31.5	
	Censored (sold)	11	15.1	

*BCS was ranked from 1 – 5 where 1 = extremely thin and 5 = extremely fat/obese (Ghosh *et al*., 2019); The number of parturitions until the period of the research was classified as aparturient (0), mono-parturient (1), di-parturient (2), and tri-parturient (3); and #Faecal consistency was ranked from 1 – 3 where 0 = normal pellets (firm but not hard, original form is distorted slightly after dropping to the floor and settling); 1 = soft (does not hold form, piles but spreads slightly); 2 = runny (spreads readily); and 3 = watery (liquid consistency, splatters) (Dorny *et al*., 2011; Ortenzi *et al*., 2023)

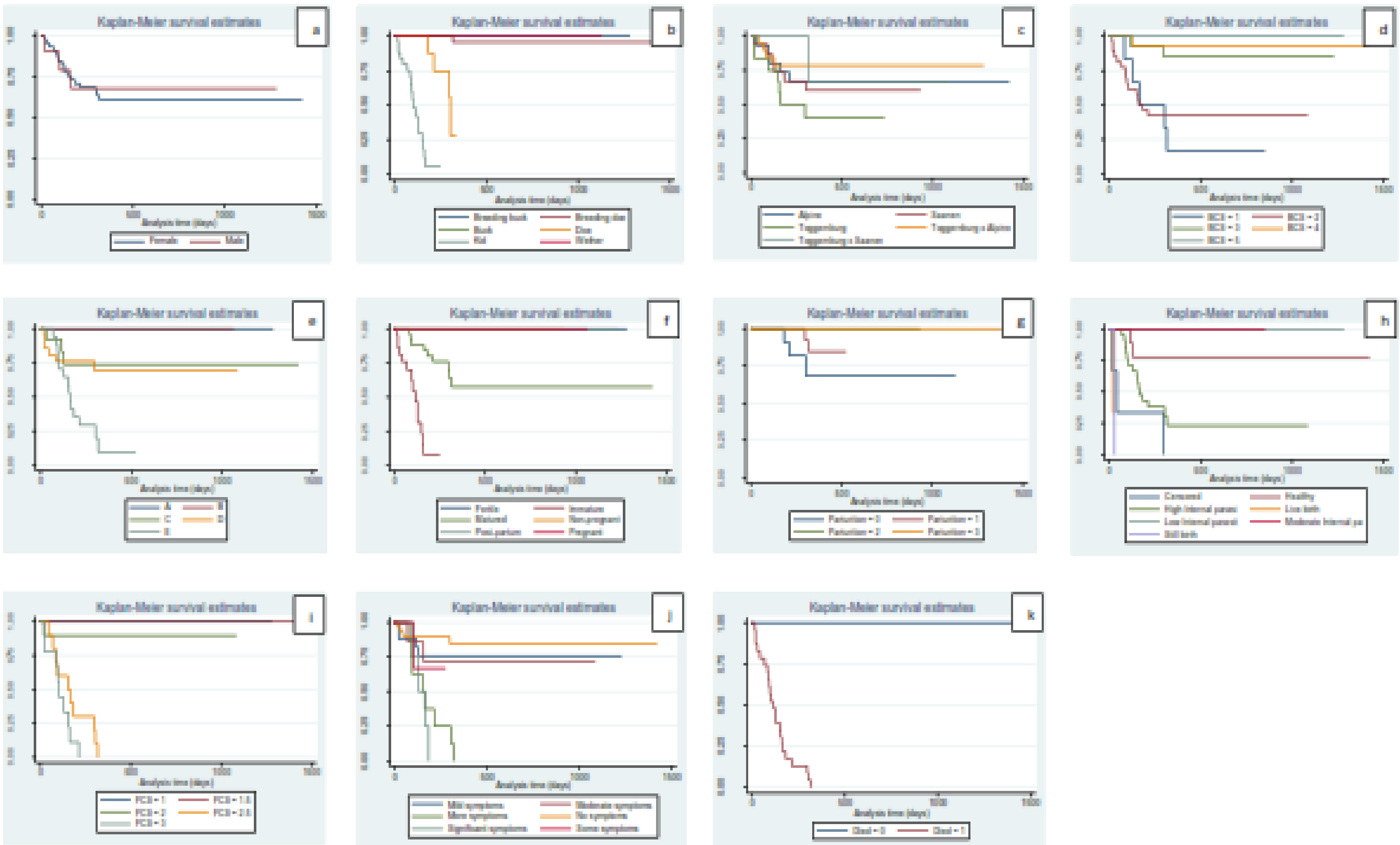

Figure 2a – k: Kaplan-Meier survival estimates of goats based on descriptive variables: a). for sex variable; b). reproductive class variable; c). for breed variable; d). for body condition score variable; e). for FAMACHA anaemic score variable; f). for reproductive status variable; g). for number of parturition variable; h). for health status variable; i). for faecal consistency score variable; j). for degree of affection (symptom) variable; and k). for mortality status variable.
Note that bigger images are available as supplementary figures 2a – k

recorded parturitions, two observed events for goats with one recorded parturition, and no observed events for goats with either two or three recorded parturitions. The chi-squared statistic was calculated as 4.42 with 3 degrees of freedom, resulting in a p-value of 0.22 (Figure 2g). There were statistically significant disparities in survival distributions across different health statuses (χ^2 = 79.65, p < 0.001). Notably, goats with high internal parasitic infection exhibited a significantly higher observed event count, indicating a potential link between the health status and mortality rate. Moreover, goats categorised as censored and live births showed differences in survival patterns compared to the healthier groups, suggesting that these health statuses may play a role in influencing survival outcomes (Figure 2h). The analysis of different faecal consistency scores indicates significant variations in survival distributions among the goats (χ^2 = 78.87, p < 0.001). Notably, goats with a faecal consistency score of 2.5 exhibited the highest observed event count, suggesting that goats with this score might be more susceptible to mortality. Conversely, goats with a faecal consistency score of 1 or 1.5 showed no observed events during the study period, indicating a potential association with improved survival outcomes (Figure 2i).

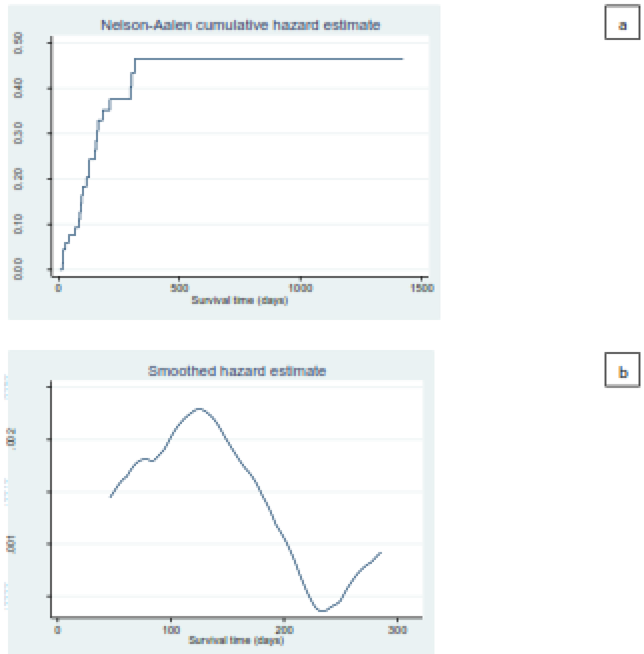

Figure 3a: The Nelson-Aalen cumulative hazard estimate for changes in risk of goat mortality evaluated over > 300 days; **3b.** The smooth hazard estimate curve to visualize the changing hazard rates over time within the goat mortality dataset

Similarly, the analysis of survival curves revealed statistically significant differences in survival experiences among goats with varying symptom severities (χ^2 = 27.96, p < 0.001). These findings suggest that the exhibited symptoms play a crucial role in influencing the mortality rates of goats on the breeding farm. Notably, goats with more symptoms and no symptoms exhibited observed event counts that deviated from expected values, indicating a potential link between these categories and survival outcomes (Figure 2j). Finally, the survival analysis, along with the subsequent log-rank test brought to light a significant and profound distinction in survival experiences among goats categorized by the history (record) of mortality status (χ^2 = 88.31, p < 0.001). The observed event counts for goats, which was expected and used as a check statistic to verify the robustness of the records used, classified dead goats as greatly exceeding the anticipated counts, while those categorized as alive displayed a deviation from the expected frequencies. These results indicate a noteworthy association between mortality status and survival probabilities among the goats, an indication that a host of factors may interplay e.g., to collectively contribute to the differing mortality rates (Figure 2k). The Nelson-Aalen cumulative hazard estimate visually shows how the risk of goat mortality changes over time in our dataset. Steeper parts of the curve indicate higher mortality rates, while flatter sections suggest relatively stable rates (Figure 3a). Inflection points and jumps highlight shifts and censored observations, respectively. The most recent recorded day of goat mortality from the evaluation was on day 316, following which no further event (mortality) was observed. Similarly, the smooth hazard estimate curve, which offers a clear visualization of the changing hazard rates over time within our goat mortality dataset displays fluctuations in the risk of events, such as goat deaths, as time progresses, with an initial peak post-120 days, followed by a descending curve until approximately 240 days before the next peak began to occur (Figure 3b).

Based on data from 71 subjects included in the univariable Cox proportional hazard model, the association between sex and mortality risk was not significant although the males had slightly less risk of death (0.91 versus 1.0) compared to females (likelihood ratio (LR) $\chi^2 = 0.04$; p = 0.84) (Table 2). For the class variable of goats and risk of mortality, the HR indicated that the does (4.43E+10) and kids (6.39E+11) are at significantly higher risks of death compared to other classes of goats (likelihood ratio $\chi^2 = 68.82$; p < 0.001) (Table 2). Out of the 23 goats that died, 18 of them were kids (an observation, which aligned with our analysis. The hazard evaluation for breeds was non-significant (p-value of 0.45); only the Toggernburg breed was two-fold likely to die compared to the Alpine reference (p = 0.192). All other breeds and crosses were comparable to the Alpine.

Compared to extremely thin goats, those with body conditions of 3 and 4 are likely to survive 8 and 17 times more than the extremely thin ones respectively (p = 0.01). The BCS has a significant impact on the risk of mortality among goats based on the LR χ^2 (p < 0.001). Using the FAMACHA scores, compared to the goats with FAMACHA scores of A (red-to-deep pinkish conjunctiva of the lower eyelid), goats with a score of D and E (goats suffering anaemia) were significantly more likely to suffer from the increased hazard of death (p < 0.001) (Table 2). Hence, FAMACHA anaemic score significantly impacts the risk of goat mortality (p < 0.001). With an LR χ^2 of 47.77 (p < 0.001), there was a strong relationship between reproductive status and mortality. However, only the matured goats were significantly more likely to die (4.28E+09, p < 0.001) compared with the fertile goats; all the other categories did not run on the model. In addition, the number of parturitions did not affect the hazard of death LR χ^2 of 5.43 (p < 0.14) (Table 2).

For the relationship between the health statuses of goats and hazard of mortality, compared to censored or sold goats (reference level), healthy goats have higher chances of survival 17-fold, whereas goats with live births exhibited a non-significantly higher hazard (HR = 14.97, p = 0.08). All the other categories were either insignificant or unanalyzable. It will also appear that the higher the symptoms, the higher the hazard of mortality as goats with more (HR = 6.0; p = 0.004) and significant symptoms (HR = 6.5; p = 0.01) were 6 or 7-folds more likely to die compared to those with mild symptoms (LR $\chi^2 = 19.90$; p = 0.001) (Table 2). Symptoms were based on scores on a panel of observations including bloody or non-bloody diarrhoea, worms in faeces, loss of appetite, fever, rough hair coat, protruded abdomen, bottled jaw, and injuries from predators or dog attack (Supplementary Table 1).

The faecal consistency was considered on a linear scale using a cumulative time at risk of 26,942 hours (3 years). The Cox regression analysis demonstrated a highly significant association between faecal consistency and mortality (LR $\chi^2 = 57.70$; p < 0.001). The HR for faecal consistency was estimated as 26.845, indicating a substantial increase in the hazard of mortality with higher faecal consistency scores (p < 0.001, Table 2). Other details of the results are available in Table 2.

In the multivariable Cox proportional hazard model, we included all variables controlling for confounding factors. We cautiously selected covariates, including non-significant ones, for the multivariable model, recognizing their potential influence and role in capturing complex interactions. However, we have a challenge related to convergence due to the flat region resulting in a missing likelihood, hence; we are unable to construct a suitable multivariable model for this study.

Discussion

The analysis of the equality of survivor functions using the 11 variables revealed important outcomes relevant for drawing some significant inferences for breeding goat farms. These can basically be classified into three viz: health and health parameter-related, reproduction-related and other issues. The importance of health management practices in goat breeding, particularly in addressing internal parasitic infections, which could have substantial implications on goat welfare and production were obviousIn addition, the specific monitoring and managing of symptoms among goats were significant in our results. While it is known that symptoms are precursors to full clinical and pathological conditions in livestock, investment in effective symptoms monitoring will be cost effective to intervene appropriately. This should provide further insights in informing strategies for enhancing goat welfare and health management practices, thereby reducing mortality rates and improved productivity in the breeding farm setting.

Similarly, faecal consistency, particularly, the pasty and watery faeces is a known multifactorial indicator of gastrointestinal health and overall well-being in goats. In this work, the more diarrhoeic the goat, the higher the likelihood of mortality. Diarrhoeic goat lose body water, physiologically unhealthy and are prone to death (Zaki *et al.,* 2010). In addition, the worse off the FAMACHA anaemic score (tending towards E), the higher the mortality rate of goats. It is known that the standardized score is an indication of

Table 2: Univariable Cox-proportional hazard model to determine covariates of time to goat mortality due to gastro-intestinal parasitism in a goat farm, Papua New Guines, 2020 – 2023

Variable	Level	Hazard Ratio	Standard Error	z	P value	95% Confidence Interval
Sex	Female	Ref.	Ref.	Ref.	Ref.	Ref.
	Male	0.91	0.43	-0.20	0.84	0.36 – 2.31
Class	Breeding buck	Ref.	Ref.	Ref.	Ref.	Ref.
	Breeding doe	1.32E+09	.	.	.	.
	Buck	1.24E-09	.	.	.	.
	Doe	4.43E+10	5.22E+10	20.79	<0.001	4.39E+09 – 4.46E+11
	Kid	6.39E+11	8.56E+11	20.29	<0.001	4.62E+10 – 8.83E+12
	Wether	7.58E-10	.	.	.	.
Breed	Alpine	Ref.	Ref.	Ref.	Ref.	Ref.
	Saanen	1.23	0.75	0.34	0.73	0.38- 4.03
	Toggernburg	2.15	1.26	1.31	0.19	0.68- 6.79
	Toggernburg x Alpine	0.71	0.48	-0.51	0.61	0.19- 2.66
	Toggernburg x Saanen	0.73	0.80	-0.29	0.77	0.09 - 6.25
BCS	1	Ref.	Ref.	Ref.	Ref.	Ref.
	2	0.82	0.42	-0.39	0.70	0.30 - 2.26
	3	0.12	0.10	-2.5	0.01	0.02- 0.64
	4	0.07	0.07	-2.45	0.01	0.01 - 0.58
	5	4.38E-16	1.37E-08	0	1	0
FAMACHA anaemic score	A	Ref.	Ref.	Ref.	Ref.	Ref.
	B	2.08E-09	1.06	0	1	0
	C	1.80E+09	.	.	.	.
	D	2.31E+09	1.64E+09	30.42	<0.001	5.76E+08 - 9.26E+09
	E	8.32E+09	5.38E+09	35.36	<0.001	2.35E+09 - 2.95E+10
Reproductive status	Fertile	Ref.	Ref.	Ref.	Ref.	Ref.
	Immature	4.05E+10	.	.	.	.
	Matured	4.28E+09	2.31E+09	41.1	<0.001	1.49E+09 - 1.23E+10
	Non-pregnant	1.03E-10	.	.	.	.
	Post-partum	1.03E-10	.	.	.	.
	Pregnant	3.78E-11	.	.	.	.
Number of parturitions	0	Ref.	Ref.	Ref.	Ref.	Ref.
	1	0.39	0.36	-1.02	0.30	0.06- 2.38
	2	7.08E-18	1.58E-09	0	1	0
	3	7.08E-18	2.08E-09	0	1	0
Health status[#]	Censored (sold)	Ref.	Ref.	Ref.	Ref.	Ref.
	Healthy	0.06	0.06	-2.95	0.003	0.01- 0.40

	High internal parasitic infection	0.35	0.23	-1.63	0.10	0.10 - 1.24
	Live birth	14.97	22.81	1.78	0.08	0.76 - 296.45
	Low internal parasitic infection	5.13E-22	.	.	.	.
	Moderate internal parasitic infection	3.49E-21	.	.	.	.
	Still birth	9.13	13.76	1.47	0.14	0.14 - 175.05
Faecal consistency	Linear scale	26.85	16.78	5.26	<0.001	7.89 - 91.37
Symptoms	Mild symptoms	Ref.	Ref.	Ref.	Ref.	Ref.
	Moderate symptoms	1.20	1.04	0.21	0.83	0.22- 6.58
	More symptoms	6.02	3.74	2.88	0.004	1.78- 20.37
	No symptoms	0.63	0.44	-0.66	0.51	0.16 - 2.51
	Significant symptoms	6.50	4.75	2.56	0.01	1.55- 27.26
	Some symptoms	1.83	2.06	0.53	0.59	0.20 - 16.71
Goat died	No	Ref.	Ref.	Ref.	Ref.	Ref.
	Yes	8.77E+16	2.31E+24	0	1	0

[#] Health statuses were based on apparent observations of the health of the goats using sentience (capacity to experience feelings and sensations, to have affective consciousness, subjective states that have a positive or negative valence) (Minnig *et al.*, 2021)

anaemia in ruminant livestock, which may be an indication of heavy endo- and ectoparasites, or some other infectious diseases causing anaemia in goats (Kusiluka *et al*., 1998; Matthews, 2016). Our findings align with earlier results by Mpofu *et al.* (2020), which demonstrated that goats with higher faecal consistency scores, indicative of gastrointestinal health, had substantially increased mortality risks. This suggests that gastrointestinal issues could be a major contributor to goat mortality on the farm (Mpofu *et al.*, 2020). It emphasizes the necessity of maintaining good digestive health through appropriate nutrition and parasite control. Furthermore, goats displaying severe symptoms were at a higher risk of mortality, highlighting the importance of early symptom detection and prompt veterinary intervention, as opined by McGuirk (2008), to improve survival rates for dairy calves and heifers.

With a worsening anaemic condition, the body condition of animals may also regress, it is therefore not surprising that our results revealed that the lower the BCS, the higher the likelihood of mortality among the studied goats. This finding should assist the animal health managers in goat farms to design appropriate multi-evaluative measures to improve goat productivity, well-being, and longevity in breeding environments. These findings are consistent with research by Ghosh *et al.* (2019), which emphasized the value of BCS in assessing goat health, and the report on FAMACHA score by Kaplan *et al.* (2004). Goats with lower BCS values were more likely to experience mortality, reaffirming the findings of Ghosh and colleagues. This underscores the need for regular body condition assessments and tailored nutritional strategies to maintain optimal health and body condition in the goat population. Similarly, goats with higher FAMACHA scores, indicating anaemia, exhibited increased mortality risks, as also noted in the study by Kaplan *et al.* (2004). This finding reinforces the crucial role of effective parasite control measures (Kaplan *et al.*, 2004). in preventing goat deaths.

While the reproductive class of goats significantly influenced both goat mortality and survival in this study, we did not investigate its direct contribution to overall health conditioning. However, it is known that optimum health is a predictor of optimum productivity in livestock. It is important to further investigate the specific factors contributing to these reproduction-linked survival differences in order to optimise goat welfare and productivity. The heightened mortality risk observed among matured goats, particularly those that have given birth previously, corroborates the research by Kagucia *et al.* (2020). This highlights the importance of proper management during and after pregnancy, with particular attention to the nutritional needs and health monitoring of breeding does Kagucia *et al.* (2020). Additionally, the association between high internal parasitic infection and mortality is consistent with studies by Hoste *et al*. (2011), further emphasizing the crucial role of parasite management and routine health checks in preventing goat deaths.

Although the sex, breed and number of parturitions were not significant in this analysis, we cannot dismiss that they may have a certain degree of influence on goat mortality. Perhaps, a more robust sample size, consideration for other unmeasured factors, and additional covariates may yield more insightful conclusions regarding these variables. Smith & Sherman (2022) have shown varying mortality rates based on sex and class of goats. In our analysis, we observed that females had a lower mortality rate than males, similar to the findings of Smith & Sherman (2022). Perhaps, the differences in physiological and behavioural traits between the sexes may have played a role (Armson, *et al*., 2020). Females tend to exhibit higher adaptability to farm conditions and may experience lower stress levels during management practices. Furthermore, the class distribution revealed that breeding does and kids were more susceptible to mortality, a trend documented in studies by (Smith & Sherman, 2022), an indication that these classes may require more specialized care and attention to reduce mortality rates. Finally, the "goat died" variable, as a composite measure of various factors and conditions leading to goat deaths, resonates with the complex interplay of factors affecting goat survival on the farm, as previously discussed in studies by Dukti (2007) and Roeber *et al.* (2013). This underscores the multifactorial nature of goat mortality and the need for a comprehensive approach to management and health interventions.

The Nelson-Aalen cumulative hazard estimate and the smooth hazard estimate curve supported the robustness of our models. While the plot of the Nelson-Aalen cumulative hazard estimate helps us understand the changing mortality dynamics among goats at the PNGUNRE breeding farm from 2020 to 2023, the smooth hazard estimate curve indicates periods of higher hazard, signifying elevated risk, while troughs suggest relatively lower hazard and decreased risk. This observation assisted in identifying critical time intervals with varying mortality dynamics and temporal patterns of goat mortality at the PNGUNRE breeding farm from 2020 to 2023, thereby shedding light on the unobserved underlying factors that may have influenced survival outcomes at the time of the study.

The inability to construct a suitable multivariable Cox proportional hazard model was a limitation in the study. Despite diligent attempts to restore convergence by reverting to previous iterations, persistent obstacles hindered the progress. These challenges may have originated from multicollinearity among predictor variables, sparse data within specific categories, or the influence of outliers on likelihood calculations. In pursuit of a stable and dependable model, a comprehensive assessment of variables and their interrelationships becomes imperative. Strategies aimed at mitigating multicollinearity, exploring regularization techniques, and investigating anomalous data patterns could potentially offer remedies for these issues. Given the significance of resolving these challenges, our data analysis culminated with the evaluation of Kaplan-Meier survival curves and univariable Cox proportional hazards modelling.

In conclusion, our analysis of goat mortality data at PNGUNRE farm from 2020 to 2023 highlights the multifaceted nature of factors influencing goat survival. These findings should support the development of effective strategies for enhancing goat health, welfare, and productivity in breeding farm settings. The implication of our study is as follows: 1). To mitigate goat mortality, it is imperative to tailor management practices to the specific needs of different sex and class groups, as suggested by Smith & Sherman (2022). 2). Special attention should be given to breeding does, kids, and males to reduce their vulnerability (Smith & Sherman, 2022). 3). Regular monitoring of body condition, FAMACHA scores, and symptom detection should be integrated into farm routines, in line with Kaplan *et al.* (2004) and McGuirk (2008). 4). The findings also emphasize the significance of parasite control, particularly in preventing anaemia (Kaplan *et al.,* 2004), and maintaining gastrointestinal health through proper nutrition and disease management Mpofu *et al.* (2020).

We recommend further research with more robust and larger datasets to validate and expand upon these findings. It is necessary to explore specific factors contributing to the observed survival disparities to develop targeted interventions for improving health outcomes among the goat population. Additionally, investigating genetic factors influencing susceptibility to mortality, as suggested by Dukti (2007), could offer a deeper understanding of goat survival dynamics. A longitudinal study tracking the impact of management interventions based on these findings would contribute to sustainable goat farming practices and improved welfare, as highlighted by Armson *et al.* (2020). Future endeavours, perhaps in the form of a nationwide study, should be driven by larger datasets to yield more robust estimates. This expansion would mitigate the impact of sparse data and outliers, enhancing the reliability of results and enabling a more comprehensive exploration of the factors influencing goat mortality risks.

Finally, this research not only advances our knowledge of goat mortality in breeding farms but also provides actionable insights to enhance goat health, reduce mortality rates, and ultimately improve the sustainability and productivity of goat farming operations.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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