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Impact of puerperal disorders on early culling and milk production in Slovak Spotted dairy cows

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Abstract: Puerperal diseases are major postpartum complications in dairy cattle and may compromise both survival and production performance. This study evaluated how specific puerperal diseases influence early culling risk and standardised 305-day milk traits in Slovak Spotted cows. A total of 792 animals were clinically assessed during early postpartum and classified as healthy or affected by ketosis, metritis, retained foetal membranes, parturient paresis, or by comorbid diseases, defined as the concurrent occurrence of two or more disorders. Logistic regression models indicated that ketosis was associated with the highest odds of culling compared with healthy cows (odds ratio = 2.23; $P = 0.05$). The multivariable model had a predictive discrimination of 0.75, as indicated by the area under the receiver operating characteristic curve, suggesting moderate performance. After excluding the cows culled during the puerperium to avoid bias from incomplete lactation data, the dataset was restricted to 546 animals. Within this group, metritis was associated with the lowest 305-day milk yield, with an average decrease of 1 124 kg compared with healthy cows ($P < 0.05$). Protein content was slightly lower in cows affected by puerperal disease ($P < 0.05$), with no significant differences in milk yield, fat or lactose content, nor lactation persistency index. Parity and sire line still remained the primary determinants of variation in milk traits. The results can be used to support decision-making in herd health management and genetic improvement strategies aimed at enhancing cow longevity and production efficiency.

Keywords: cattle; dairy performance; lactation; postpartum; reproduction

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During the puerperium period, dairy cows face major physiological and metabolic demands as they begin milk production and recover from calving. Uterine inflammation in dairy cows negatively affects their reproductive performance, including reduced fertility and increased culling rates (Molina-Coto and Lucy 2018). Stress related to calving, particularly in cases of dystocia or twin births, can further exacerbate uterine trauma and infection risk, complicate recovery and increase the likelihood of puerperal diseases (Dubuc et al. 2010).

Metritis is one of the most common postpartum infections, affecting 10% to 30% of cows, and can progress to endometritis if left unresolved, resulting in reduced milk yield and reproductive performance (Bicalho et al. 2017; Sheldon and Owens 2017). Retained foetal membranes remain a key predisposing factor, with necrotic placental tissue fostering bacterial growth and infection (Sepulveda-Varas et al. 2015; LeBlanc 2020). Ketosis, driven by negative energy balance in early lactation, impairs immune function, reduces milk production, and predisposes cows to metritis and reduced milk production. Severe cases may also predispose individuals to other disorders and contribute to substantial economic losses and culling (Cainzos et al. 2022). Parturient paresis, caused by low blood calcium levels around calving, is associated with reduced production and increased susceptibility to puerperal diseases (Mann et al. 2019).

Cows experiencing clinical diseases within 21 days postpartum have 305-day milk production on average 410 kg less and have lower pregnancy rates (Carvalho et al. 2019). Postpartum diseases in dairy cows contribute to reduced fertility and increased risk of culling (Gilbert 2016; Dubuc and Denis-Robichaud 2017). The aetiology of these complications is multifactorial, influenced by herd management, genetic background, and environmental conditions (Ribeiro et al. 2016). Therefore, the objective of this study was to evaluate how the occurrence of puerperal diseases influenced early culling decisions and affected 305-day milk production in Slovak Spotted cows.

MATERIAL AND METHODS

Data collection and processing. From January 2022 to September 2023, a nucleus herd of 792 Slovak Spotted dairy cows was monitored, with a focus on their immediate postpartum period in the calving barn. Daily clinical assessments by trained zootechnicians, under veterinary supervision, were performed in the calving barn for the first five days post-calving, according to the farm protocol. Examinations of puerperal health status included daily rectal temperature measurements, ketone concentration measurements on day 5 via dipstick, and a visual assessment of each cow. Animals showing no clinical signs were returned to the production group. Cows exhibiting any disorder received targeted therapies, such as antipyretics, antibiotics, infusions, or oral supplements, tailored to the specific condition. Culling was performed in cases of a poor prognosis or lack of response to treatment.

The dataset was manually reviewed and edited before statistical analysis. Disease categories included metritis, ketosis, retained foetal membranes (RFM), parturient paresis (PP) and comorbid diseases (CD), referring to cows diagnosed with more than one of these diseases. Classification was based on information recorded in clinical notes and treatment records, including drug distribution data. Each cow was assigned to one of six categories: category 0 for healthy cows, categories 1 to 4 for single-disease diagnoses (metritis, ketosis, RFM and PP, respectively), and category 5 for comorbid disease. Subclinical forms of these disorders were not included in the classification. Metritis was recorded when systemic anti-inflammatory therapy and intrauterine rifaximinum were recorded concurrently, and either elevated rectal temperature or retained placenta was noted. This combination of records was used to distinguish metritis treatment from non-puerperal disease treatment. Ketosis was observed when the blood ketone concentration was ≥1 mmol/l or when monensin administration was recorded, accompanied by supportive clinical notes. RFM was identified directly from the clinical notes. PP was recorded when downer cows received routine intravenous infusion in accordance with the herd health protocol. Comorbid diseases were identified using the same criteria and included cows that fulfilled definitions for more than one disease. An overall health status variable was then created with three categories, reflecting the presence of none (0), a single (1), or multiple (2) disorders, respectively.

The culling status was coded as a binary variable, where 1 indicated culling during the puerperium (including death or transfer to abattoir) and 0 indicated retained cows in the herd. Parity, sire line

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and breed type were considered categorical factors. Parity was coded as a categorical factor with levels 1 to 4, while parities 5 to 11 were merged into a single category due to having less than 50 observations in each level. Sire line (30 individual lines) was also coded as a categorical factor; sire lines represented by less than 10 cows were combined into an "others" category. Breed type was included as a categorical factor with three levels defined according to pure-bred proportion: S_0 (≥87.5%), S_1 (75–87.4%), and S_2 (50–74.9%).

Blood ketone concentrations, daily rectal temperatures measured on days 1–5 after calving (t_1–t_5) and milk traits were included as continuous variables. Milk traits (milk yield, fat percentage, protein percentage, lactose percentage, and the lactation persistency index) were expressed as standardised 305-day lactation values. After excluding cows culled during the puerperium to avoid bias from incomplete lactation, the dataset was restricted to 546 cows (hereafter "retained cows") grouped by disease category. Analyses of this subset focused solely on milk yield as the primary measure of production.

Statistical analyses. Statistical analyses were conducted to evaluate the impact of puerperal diseases on culling outcomes and milk production traits. All analyses, except for logistic regression and distribution analysis, were performed using SAS software (v9.4, SAS Institute Inc., Cary, NC, USA).

Logistic regression was performed using Python 3.12.7 (v3.12, Python Software Foundation, Wilmington, DE, USA), which allowed for the explicit specification of the healthy category as the reference level in the multi-category disease predictor. Normal distribution testing and logistic regression both utilised the statsmodels 0.14.4 (Seabold and Perktold 2010), SciPy 1.13.1 (Virtanen et al. 2020), and scikit-learn 1.5.1 (Pedregosa et al. 2011) libraries.

Descriptive statistics were first used to characterise disease prevalence, culling frequencies and milk production in the analysed group of animals. Testing for normal distribution was performed for milk traits as continuous variables. In the restricted subset of retained cows, average milk yield was compared between disease categories (1–5) using t-tests. This was followed by Dunnett's post hoc procedure to assess differences between the group of healthy cows (category 0) and all other categories, to identify the highest disease-associated decrease. Moreover, the effect of the disease was also assessed using a one-way analysis of variance (ANOVA). To determine the effect of disease occurrence on milk traits, a stepwise modelling approach was used. First, categorical predictors (overall health status, culling status, breed type, sire line and parity) were evaluated using ANOVA.

Continuous predictors (ketone concentration and rectal temperature) were assessed by a linear regression model defined as follows:

$$Y = \beta_0 + \beta_1 + \text{ketones} + \beta_2 t_1 + \beta_3 t_2 + \beta_4 t_3 + \\ + \beta_5 t_4 + \beta_6 t_5 + \varepsilon \quad (1)$$

where:
Y – observed value of a given milk trait;
β_0 – intercept;
β_1 to β_6 – regression coefficients;
t_1–t_5 – rectal temperatures;
ε – residual error.

Variables with $P < 0.05$ were carried forward into a multivariable general linear model (GLM). In each GLM, overall health status, lactation number and sire line were included to assess their influence on milk traits, according to the model:

$$Y_{ijk} = \mu + HS_i + SL_j + P_k + \varepsilon_{ijk} \quad (2)$$

where:
Y_{ijk} – observed value of a given milk trait;
μ – intercept;
HS_i – effect of overall health status;
SL_j – effect of sire line;
P_k – effect of parity;
ε_{ijk} – residual error.

Differences in milk traits between culled and retained cows across overall health status categories were first assessed by t-tests. To further evaluate factors associated with culling, logistic regression was applied to determine the odds of culling during the puerperium. Categorical disease status was entered as a predictor, with healthy cows set as the reference category. Continuous predictors included milk traits and standardised lactation length (days). Other categorical predictors were excluded from the multivariable model due to complete or quasi-complete separation. Results were reported as odds ratios, and model discrimination was evaluated using receiver operating characteristic curves with calculation of the area under the curve (AUC) using the following model:

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$$\log\left(\frac{\pi_i}{1-\pi_i}\right)=\beta_0+\sum_{k=1}^{K-1}\beta_{D,k}I\left(\text{disease}_i=k\right)+\beta_1\text{SLL}_i+\beta_2\text{MY}_i+\beta_3\text{F}_i+\beta_4\text{P}_i+\beta_5\text{L}_i+\beta_6\text{LPI}_i \tag{3}$$

where:

π_i – probability of culling during puerperium for cow i;
β_0 – intercept;
$\beta_{D,k}$ – coefficient for disease category k;
β_{1-6} – regression coefficients for continuous predictors (SLL, MY, T, P, LPI);
$I(\cdot)$ – indicator function;
SLL – standardised lactation length;
MY – milk yield (kg);
F – fat (%);
P – protein (%);
L – lactose (%);
LPI – lactation persistency index.

RESULTS AND DISCUSSION

Continuous variables of milk traits were assumed to follow a Gaussian distribution a priori (Schneider et al. 2023). However, because a subset of the herd was drawn exclusively from cows admitted to the calving barn, a preselection effect may have occurred. As a result, deviations from the normal distribution were found. Histograms and quantile–quantile plots were inspected for each variable. The Shapiro–Wilk test, known for its high statistical power and wide preference for assessing normality (Ghasemi and Zahediasl 2012), was used to formally evaluate distributional bias, as shown in Electronic Supplementary Materials (ESM) Figure S1. Significant deviations from normal distribution were observed for all milk traits ($P < 0.001$). Parametric methods were nevertheless employed to preserve model interpretability and statistical power; the resulting violation of normality assumptions was considered a limitation.

Distribution of sire lines and lactation groups is summarised in ESM Table S1. A small number of paternal lines dominated in the analysed group of cows, with the five most frequent sires (HW 047, HRA 003, HRA 001, DLL 001, and RMN 023) together accounting for more than 60%. Cows at the first to third lactations represented 76.6% of observations. The distribution of parity was skewed towards first through third lactations, indicating an early-parity bias in the dataset. Similarly, it was reported by Lean et al. (2023) that 81.2% of Holstein cows in the early postpartum period were in first to third lactations. Rilanto et al. (2020) and Vergara et al. (2014) demonstrate that metabolic and calving complications lead to increased culling in older cows, resulting in a postpartum herd dominated by cows in lower lactations.

Prevalence of puerperal diseases and their effects on milk yield. While 632 (79.9%) cows remained clinically healthy, 159 (20.1%) exhibited one or more disorders. Among affected animals, ketosis was diagnosed in 79 (10.0%), metritis in 30 (3.8%), parturient paresis (PP) in 13 (1.6%), retention of foetal membranes (RFM) in 28 (3.5%) and comorbid diseases (CD) in 9 (1.1%). Incidence of puerperal disorders by parity is presented in Figure 1. Ketosis was the most frequent disorder, particularly in first-lactation cows, consistent with the findings of Santschi et al. (2016). The incidence of parturient paresis began to rise in the third lactation, differing from Espiritu et al. (2025), who reported its onset in the fourth lactation. These deviations from earlier reports may reflect limited sample sizes in higher-lactation groups or herd-specific management practices.

Figure 2 compares milk traits across disease categories. The average milk yield in cows diagnosed with ketosis was slightly higher than that of healthy controls. The higher milk yield observed in the ketosis group is unexpected and may reflect incidental variability in the dataset rather than an underlying biological cause. Indeed, many stud-

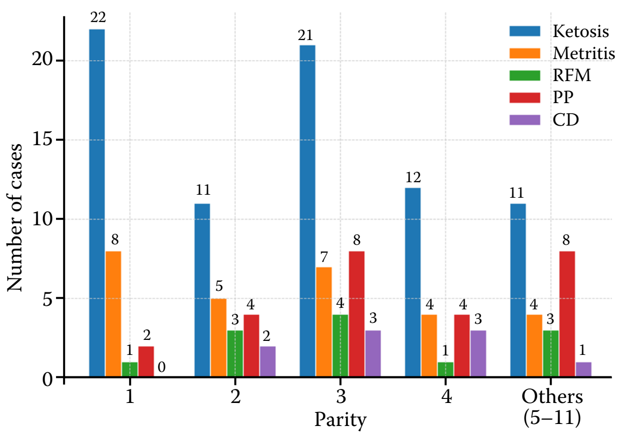

Figure 1. Prevalence of diseases by parity
CD = comorbid diseases; PP = parturient paresis; RFM = retained foetal membranes

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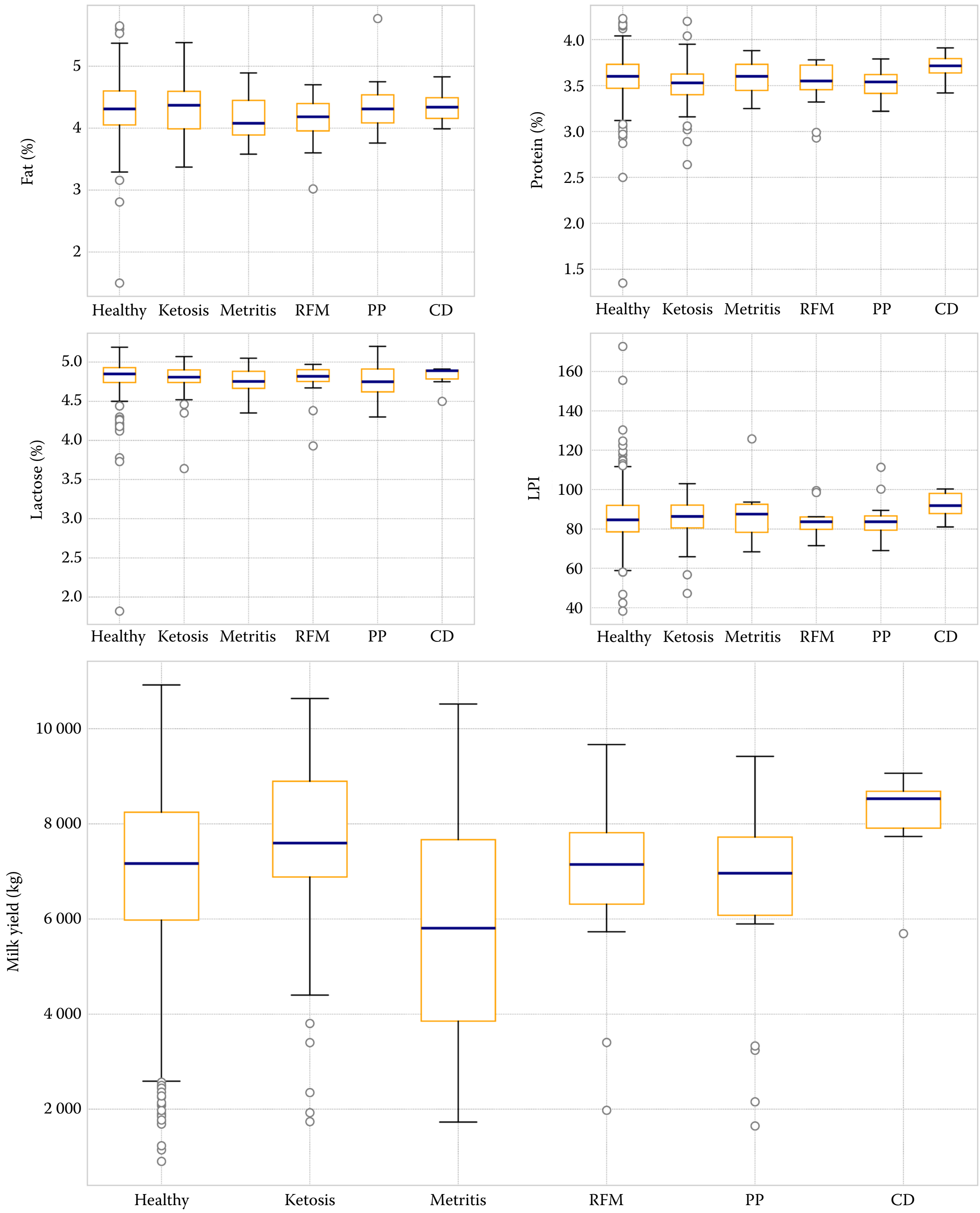

Figure 2. Average value of each milk trait across disease category

CD = comorbid diseases; LPI = lactation persistency index; PP = parturient paresis; RFM = retained foetal membranes

ies have reported reduced production in cows suffering from ketosis (Song et al. 2021; Huang et al. 2024). On the other hand, it is generally recognised that high-producing animals are more susceptible to ketosis (Ha et al. 2022). The percentages of fat and protein varied minimally among the groups.

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On the contrary, lactose concentration and lactation persistency index were lower in diseased animals, with the highest declines observed in metritis and comorbid cases. These results are consistent with Bondan et al. (2021), who showed that energy diverted toward immune responses in cows with postpartum disorders reduces lactose synthesis.

After excluding culled cows, the healthy group comprised 479 observations, while diseased categories contained between 5 and 51 animals. Average milk yields varied from 5 905 kg (metritis) to 7 910 kg (CD). Table 1 presents the average milk yield in cows that were not culled. Milk yield was significantly influenced by disease category (Table 2; $P < 0.01$). The highest and statistically significant decrease was observed in cows with metritis, which produced 2 293 kg less milk than healthy cows. All other disease categories were not statistically significant.

Pairwise *t*-tests (ESM Table S2) revealed that cows with metritis produced 1 280 kg less milk than healthy cows ($P < 0.05$). This observation aligns with previous reports of reduced milk yield in cows affected by metritis (Piccardi et al. 2016; Figueiredo et al. 2021; Zavadilova et al. 2021). In contrast, cows with ketosis produced 1 730 kg more milk than those with metritis ($P < 0.01$), while cows with comorbid diseases (CD) exceeded the metritis group by 2 005 kg ($P < 0.05$). No other pairwise comparisons reached significance. Consistent with these results, the overall model indicated a significant effect of puerperal disease on milk yield ($P < 0.01$). Dunnett's test (Table 3) confirmed that only the metritis group differed significantly from healthy cows (adjusted $P < 0.05$). Although ketosis and CD groups showed higher average yields than healthy cows, their confidence intervals overlapped those of healthy cows, suggesting that these differences likely arise from random variation rather than a true biological effect.

The effect of puerperal diseases on milk traits. A stepwise modelling approach was used to quantify the extent to which puerperal disorders affect milk traits. Such sequential selection of variables

Table 1. Descriptive statistics of milk yield by disease category

Disease	n	$\bar{x}$	95% CI		SD	SE	Min.	Max.
Healthy	446	7 185.53	7 027.11	7 343.95	1 631.42	77.3	1 688	10 920
Ketosis	51	7 634.98	7 166.50	8 103.46	1 842.07	257.94	1 739	10 635
Metritis	18	5 905.00	5 116.43	6 693.57	2 224.90	524.41	1 912	9 258
RFM	10	7 193.90	6 135.92	8 251.88	1 829.18	578.44	3 404	9 668
PP	16	6 337.69	5 501.28	7 174.10	2 463.63	615.91	1 649	9 421
CD	5	7 910.20	6 413.99	9 406.41	1 328.51	594.13	5 694	9 064

CD = comorbid diseases; CI = confidence interval; PP = parturient paresis; RFM = retained foetal membranes; SD = standard deviation; SE = standard error

Table 2. Least squares means for milk yield with the effect of each disease

Model	Milk yield (kg)				
R^2	0.024				
P-value	0.008				
	Category	Estimate	SE	t-value	P-value
	intercept	8 042.50	807.20	9.96	<0.001
	healthy	−1 168.90	811.82	−1.44	0.150
	ketosis	−598.06	844.77	−0.713	0.479
Disease occurrence	metritis	−2 292.79	902.48	−2.54	0.011
	RFM	−1 261.50	988.62	−1.28	0.202
	PP	−1 587.83	932.08	−1.70	0.089
	CD	0	–	–	–

CD = comorbid diseases; PP = parturient paresis; RFM = retained foetal membranes; SE = standard error

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Table 3. Differences in adjusted milk yield by Dunnett's test by disease category

Disease	*n*	Difference	Difference 95% CI		*P*-value
Ketosis	63	570.85	53.1	1 088.64	0.144
Metritis	24	–1 123.89	–1 934.41	–313.37	0.033
RFM	12	–92.6	–1 226.21	1 041.01	1.00
PP	18	–418.93	–1 349.69	511.83	0.905
CD	6	1 168.90	–425.25	2 763.05	0.556

CD = comorbid disease; CI = confidence interval; PP = parturient paresis; RFM = retained foetal membranes

is widely recognised as beneficial, as it simplifies the model-building process and helps prevent overfitting the model with unnecessary predictors (Xi et al. 2024). In univariable linear regressions of continuous predictors on milk traits (Table 4), neither blood ketone concentration nor rectal temperatures on days 1–5 after parturition explained a significant proportion of variance in any trait (all $P < 0.05$; $R^2 \leq 3.33\%$). Only rectal temperature on day 3 postpartum showed a weak but statistically significant association with the lactation persistency index ($P < 0.05$), but its contribution to explaining the variation was minimal. While both temperature and ketone measurements were recorded, neither showed a meaningful relationship with milk traits, and were therefore omitted from subsequent analyses.

One-way analysis of variance (ANOVA; Table 5) confirmed that overall health status did not affect milk traits (all $P \geq 0.05$), whereas culling status, lactation order and sire line each showed a significant effect ($P < 0.001$).

Based on one-way ANOVA results, multivariable generalised linear models were constructed (ESM Tables S3–S7). All five models were statistically significant ($P < 0.01$). Results indicate that puerperal health status contributed minimally to the observed variation in milk traits, after adjusting

Table 4. Effect of ketone level and rectal temperature on milk traits

Factor	Milk yield (kg)	Fat (%)	Protein (%)	Lactose (%)	LPI
R^2	0.017	0.027	0.017	0.015	0.033
			P-value		
Ketone bodies	0.570	0.697	0.211	0.361	0.224
t_1	0.498	0.272	0.392	0.208	0.641
t_2	0.247	0.198	0.505	0.392	0.058
t_3	0.128	0.286	0.172	0.514	0.822
t_4	0.573	0.482	0.951	0.844	0.165
t_5	0.678	0.151	0.173	0.016	0.221

LPI = lactation persistency index; t_1–t_5 = rectal temperatures recorded on days 1–5 postpartum

Table 5. Effect of disease occurrence, culling, breed type, sire line and parity on milk traits

Factor	Milk yield (kg)		Fat (%)		Protein (%)		Lactose (%)		LPI	
	R^2	*P*-value	R^2	*P*-value	R^2	*P*-value	R^2	*P*-value	R^2	*P*-value
Disease occurrence	0.001	0.873	0.002	0.061	0.011	0.029	0.008	0.079	0.003	0.445
Culling	0.208	<0.001	0.001	0.458	0.014	0.003	0.041	<0.001	0.001	0.878
Breed type	0.007	0.082	0.002	0.606	0.001	0.795	0.001	0.818	0.005	0.270
Sire line	0.054	0.004	0.069	0.000	0.078	<0.001	0.147	<0.001	0.671	0.001
Lactation number	0.086	<0.001	0.004	0.802	0.006	0.562	0.084	<0.001	0.556	<0.001

LPI = lactation persistency index

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Table 6. Incidence and odds ratios of culling in cows with puerperal diseases relative to healthy cows

Disease category	Retained	Culled	Total	Disease comparison	OR	95% CI		*P*-value
Healthy cows	479	153	632	ketosis vs healthy	2.23	0.991	5.01	0.052
Ketosis	52	27	79	metritis vs healthy	1.51	0.393	5.91	0.553
Metritis	20	10	30	RFP vs healthy	1.01	0.112	9.25	0.993
PP	11	2	13	PP vs healthy	1.61	0.302	8.72	0.578
RFM	16	12	28	CD vs healthy	1.84	0.204	16.70	0.586

CD = comorbid diseases; CI = confidence interval; OR = odds ratio; PP = parturient paresis; RFM = retained foetal membranes

for lactation number and sire line, which emerged as the principal drivers of production performance. Milk yield (ESM Table S3) increased significantly in second-lactation cows ($P < 0.05$), and LPI was higher in fourth-lactation cows ($P < 0.05$). Fat percentage (ESM Table S4) was higher in lines HRA 001, HRA 004 and HRA 007 ($P < 0.05$). Protein concentration (ESM Table S5) was most strongly associated with HRA 007 ($P < 0.01$) and MAF 038 ($P < 0.001$). No significant predictors were identified for lactose percentage (ESM Table S6) and lactation persistency index (ESM Table S7).

Culling and risk odds. Differences in milk traits between culled and retained cows within each disease category are presented in ESM Table S8. Among healthy cows, culling was associated with lower milk yield (–2 118.74 kg; $P < 0.001$), protein percentage (–0.10%; $P < 0.001$), and lactose percentage (–0.14%; $P < 0.001$) compared with retained cows. Culled cows affected by a single puerperal disease produced 1 000.31 kg less milk than retained cows. In cows with two concurrent disorders, the lactation persistency index was significantly higher in culled animals compared with retained counterparts (+20.6 units; $P < 0.01$), although this result is likely influenced by the low frequency of animals in this category. Other milk traits did not differ significantly.

As shown in Table 6, the incidence of culling varied significantly by disease occurrence. Culling was least frequent in cows with PP and most frequent in those cows with CD and RFM. Ketosis showed the strongest association (Table 6) with early culling compared with healthy cows (OR 2.23; 95% CI 0.99–5.01; $P = 0.05$). Similarly, Tufarelli et al. (2024) reported that the rate of early culling increased significantly in animals with subclinical ketosis. The remaining puerperal disorders displayed weaker associations, with estimates near 1, suggesting no clear difference in culling risk.

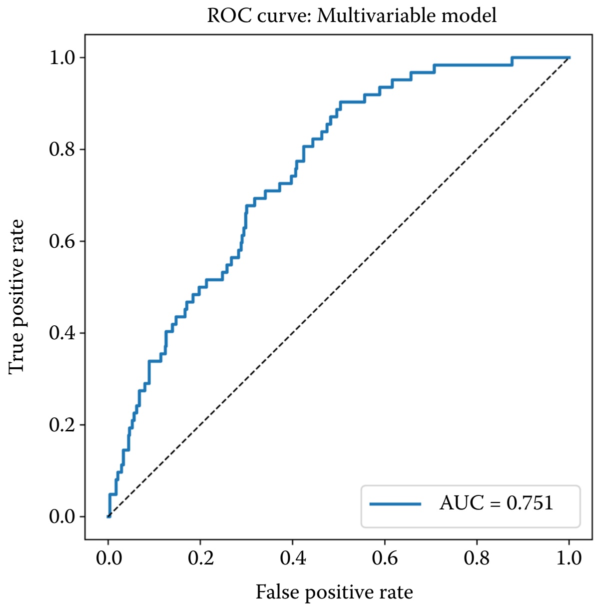

Figure 3. ROC curve for the multivariable culling-risk model

AUC = area under the curve; ROC = receiver operating characteristic

The receiver operating characteristic (ROC) curve (Figure 3) shows an area under the curve (AUC) of 0.75, indicating moderate discriminative ability. This suggests that the model correctly differentiates between culled and retained cows in approximately 75.1% of cases. The curve's deviation from the diagonal line shows that the set of predictors provides useful, though not perfect, separation between animals at high and low risk of early culling.

CONCLUSION

This study found that 20% of cows developed puerperal disorders during the early postpartum period. Ketosis was associated with the highest odds

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of early culling, with an odds ratio of 2.23 ($P = 0.05$) compared with healthy cows. Among cows that remained in the herd, metritis reduced the 305-day milk yield by an average of 1 124 kg. Puerperal disorders had a minimal effect on milk composition. Instead, parity and sire line mainly explained variation in milk yield, fat, protein, lactose and persistency. The results of this research are consistent with the strategy of the Slovak Association of Slovak Spotted Cattle Breeders to incorporate health trait recording, particularly reproductive health, into joint routine evaluations in Europe in accordance with international standards.

Conflict of interest

The authors declare no conflict of interest.

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