Original scientific paper | DOI 10.63356/agrores.2025.021

Prevalence, persistence, and costs of acidosis in Holstein cows across breeding regions

Vesna Gantner[1]✉, Franjo Poljak[2], Boris Ljubojević[3], Zvonimir Steiner[1], Ranko Gantner[1]

[2] *Josip Juraj Strossmayer University of Osijek, Faculty of Agrobiotechnical Sciences, Osijek, Croatia*
[2] *Croatian Agency for Agriculture and Food, Osijek, Croatia*
[3] *Croatian forests Ltd., Zagreb, Croatia*

✉ vgantner@fazos.hr

Abstract

This research aimed to analyze the prevalence, persistence, and economic impact of acidosis in Holstein cows, with a focus on the influence of the breeding region. The study utilized 3,953,549 test-day records for Holstein cows collected from January 1, 2005, to December 31, 2022. Data were grouped based on the breeding regions in Croatia: Central, Eastern, and Mediterranean. The prevalence of acidosis risk and acidosis was determined by analyzing the fat-to-protein (F/P) ratio and daily milk yield. Additionally, the impact of acidosis on milk yield was assessed at different time points after the occurrence of acidosis. The economic implications were calculated by estimating the monthly and total differences in milk quantity and value following acidosis detection, considering the region of breeding. The findings provide valuable insights into the effects of acidosis on dairy cow productivity and highlight the importance of region-specific strategies to mitigate its economic consequences.

Key words: acidosis, Holstein cows, milk production, breeding region

INTRODUCTION

Metabolic disorders have a considerable impact on the health and productivity of dairy cattle (Aitken, 2016). Common conditions include hypocalcemia, characterized by reduced calcium levels in the blood; hypomagnesemia, resulting from insufficient magnesium levels; and hypophosphatemia, associated with low phosphorus concentrations. Additionally, metabolic issues such as fatty liver, which involves excessive fat accumulation in liver cells, and ketosis, a condition frequently observed in early lactation, can contribute to complications like fat cow syndrome, retained placenta, mastitis, metritis, and displaced abomasum. Ruminal acidosis, marked by an abnormally low rumen pH, is another prevalent disorder, posing a significant challenge for the dairy industry.

Acidosis poses significant health and economic challenges in dairy cattle production, with long-term consequences that require careful management (Antanaitis et al., 2019). One form of this disorder, subacute ruminal acidosis (SARA), results from compromised ruminal function, leading to a decline in ruminal pH (Danscher et al., 2015). SARA is typically identified when ruminal pH drops below 5.5–5.8 (Plaizier et al., 2008; Zebeli and Metzler-Zebeli, 2012; Danscher et al., 2015) and is primarily caused by diets rich in fermentable carbohydrates but deficient in effective fiber, such as grain-based feeds. These diets promote excessive production of organic acids, overwhelming the rumen's natural buffering system and triggering acidosis. As noted by Nagaraja and Titgemeyer (2007) and Golder et al. (2023), acidosis significantly impacts dairy cattle health and productivity, making early detection vital for maintaining sustainable farming operations. Humer et al. (2017) highlight that direct ruminal pH measurement remains the most accurate method for detecting SARA. However, indirect indicators such as feeding and chewing behavior, along with the analysis of milk, feces, urine, and blood parameters,

can also help identify at-risk animals. Using multiple detection signals enhances the reliability of SARA diagnosis. Given the substantial economic losses associated with acidosis, proactive monitoring is essential to support both animal welfare and farm profitability. Effective management strategies should focus on evaluating feeding practices and maintaining rumen stability to prevent the onset of acidosis. Early intervention can be facilitated by utilizing existing farm data, including test-day records that provide information on milk yield, fat and protein content, and the fat-to-protein ratio (F/P ratio). Compared to specialized diagnostic methods, these records offer a cost-effective and non-invasive approach to identifying cows at risk (Eicher, 2004).

The occurrence and impact of acidosis can be influenced by several factors, including lactation stage, parity, breed, and breeding region. Research by Gantner et al. (2016) indicates that the risk of acidosis is highest within the first 10 days of lactation, ranging from 16% to 23%, depending on parity. Similarly, Bramley et al. (2005) and O'Grady et al. (2008) reported that 10–15% of dairy cows grazing on ryegrass-based pastures throughout the year experience subacute ruminal acidosis (SARA). Regional differences in acidosis prevalence have also been documented. Golder et al. (2023) found that dairy cows in Australia (37.2%) and California (39.2%) had a comparable risk of acidosis, whereas the prevalence in Canada was significantly lower (5.2%). Parity is another key factor, with studies by Bramley et al. (2008) and Stauder et al. (2020) showing that primiparous cows are generally more susceptible to acidosis than multiparous cows. This increased vulnerability is likely due to their limited prior exposure to energy-dense diets (Humer et al., 2018). Additionally, Penner et al. (2007) and Bramley et al. (2008) suggest that younger cows may have fewer rumen papillae and a less-adapted rumen microbiome, which could further contribute to their higher risk of acidosis.

Given that acidosis represents a common issue on dairy farms, this research aimed to analyse its prevalence, persistence, and economic impact in Holstein cows considering the region of breeding using the test-day records.

MATERIAL AND METHODS

This study utilized data from the milk recording database of dairy cattle bred and selected in Croatia. The dataset was provided by the Croatian Agency for Agriculture and Food (HAPIH). In Croatia, milk recording follows the alternative AT4/BT4 method, where milk from each cow in production is measured and sampled during either morning or evening milking every four weeks. The collected samples were analyzed at HAPIH's Central Laboratory for Milk Quality Control (SLKM) to determine the content of: milk fat, protein, lactose, dry matter, fat-free dry matter, urea, and freezing point. Milk composition was assessed using infrared spectrophotometry with MilkoScan analyzers. Additionally, the International Committee for Animal Recording (ICAR, 2017) has established standardized procedures for milk sampling and laboratory analysis during milk recording.

As part of the logical data control process, test-day records falling outside predefined thresholds were excluded from the dataset. These included daily milk yield below 3 kg or above 100 kg, milk fat content outside the range of 1.5% to 9%, protein content below 1% or exceeding 7%, and lactose content outside the 3% to 6% range. Additionally, records with missing or inconsistent values for lactation stage (less than 5 days or more than 400 days), parity (below 1 or above 10), age at first calving (outside 21 to 36 months), calving date, milk recording date, or herd code were also removed. Following the logical data control process, the refined dataset included 3,953,549 test-day records for Holstein cows, covering the period from January 1, 2005, to December 31, 2022.

Furthermore, cows were categorized into four parity groups: first, second, third, and fourth or higher. Herds were classified into six size groups, ranging from fewer than five cows to those with > 500 cows. Test-day records were further grouped into four seasons based on the milk recording month: winter (December–February), spring (March–May), summer (June–August), and autumn (September–November). The fat-to-protein (F/P) ratio was used as an indicator of acidosis risk and prevalence, as suggested by Eicher (2004). An F/P ratio below 1.1 indicated a risk of acidosis, while an F/P ratio under 1.1 in cows producing 20 to 43 kg of milk per day suggested the presence of subclinical acidosis.

The prevalence of acidosis risk or acidosis in the dairy cow population was determined as the percentage of cows with an F/P ratio below 1.1 (acidosis risk) or an F/P ratio below 1.1 and daily milk yield between 20 and 43 kg (acidosis), relative to the total number of animals. This calculation was performed separately for each breeding region. To evaluate the impact of acidosis on daily milk production, only cows identified as being at risk or affected by acidosis were included in the analysis. The reference value used was the daily milk yield recorded on the date of acidosis detection. The acidosis index was established based on the number of days following acidosis detection, with D-0 representing the test-day record on the detection day, A-1 covering the first 35 days, A-2 spanning 36 to 70 days, A-3 from 71 to 105 days, and A-4 extending beyond 105 days. The influence of the acidosis index on daily milk yield was assessed separately for each parity class and breed using the following statistical model:

$$y_{ijklmno} = \mu + b_1\left(\frac{d_i}{305}\right) + b_2\left(\frac{d_i}{305}\right)^2 + b_3\, ln\left(\frac{305}{d_i}\right) + b_4\, ln^2\left(\frac{305}{d_i}\right) + A_j + P_k + S_l + H_m + M_{nm} + e_{ijklmno}$$

where:

y_{ijklmn} = estimated daily milk yield;

μ = intercept;

b_1, b_2, b_3, b_4 = regression coefficients;

d_i = stage of lactation (i = 6 to 400 day);

A_j = fixed effect of age at first calving (j = 21 to 36 month) * only for firs parity;

P_k = fixed effect of parity k (k = I., II., III., IV. +);

S_l = fixed effect of season l (l = spring, summer, autumn, winter);

H_k = fixed effect of herd size k (k = I, II, III, IV, V, VI);

M_m = fixed effect of acidosis index m (m = D–0, A–1, A–2, A–3, A–4);

e_{ijklm} = residual.

The statistical significance of differences between the estimated least square means (LsMeans) was evaluated using Scheffe's multiple comparison method within the MIXED procedure (SAS Institute Inc., 2019). The persistence and economic impact of acidosis were examined over a four-month period following its prevalence. The monthly milk yield difference was determined by multiplying the variation in estimated daily milk yield between consecutive milk recordings by the interval between those recordings. The total reduction in milk yield (kg) and its corresponding economic loss (euro) over the study period were analyzed separately for each parity class and breed. The financial loss was calculated based on the current EU raw milk price of 48.00 EUR per 100 kg (EC, 2024).

RESULTS AND DISCUSSION

The results presented in Table 1 indicate significant regional differences in the prevalence of acidosis risk (indicated by F/P ration below 1.1) among Holstein cows in Croatia. The highest proportion of cows at risk of acidosis was recorded in the Mediterranean region (42.34%), followed by the Eastern region (33.37%), while the lowest percentage was observed in the Central region (26.81%). These differences can be attributed to variations in feeding strategies, forage quality, and environmental conditions. In particular, heat stress in the Mediterranean region may have contributed to a higher occurrence of subacute ruminal acidosis (SARA). The proportion of metabolically normal cows was highest in the Central region (59.22%), followed by the Eastern (53.12%) and Mediterranean (49.69%) regions. This distribution suggests that regions with lower acidosis risk have better feeding management practices that support rumen health. Overall, 31.15% of cows exhibited acidosis risk, highlighting the need for region-specific feeding and management strategies.

Table 1. Prevalence of risk of acidosis (indicated by F/P ration below 1.1) in Holstein cows depending on the breeding region (Central, Eastern and Mediterranean Croatia)

Region	F/R		
	Acidosis risk (F/P < 1.1)		Normal (F/P in 1.1 – 1.5)
	N	%	N
CE	431707	26.81	953522
ES	717027	33.37	1141306
ME	82599	42.34	96938
Total	1231333	31.15	2191766

CE – Central; ES – Eastern; ME – Mediterranean

The results presented in Table 2 indicate significant regional differences in the prevalence of acidosis (indicated by F/P ratio below 1.1 and daily milk yield between 20 and 43 kg), among Holstein cows in Croatia. The highest prevalence of acidosis was observed in the Mediterranean region, where 36.49% of cows were classified as being at acidosis. The Eastern region followed with 28.42%, while the Central region had the lowest prevalence at 20.05%. These differences likely reflect regional variations in feeding practices, forage availability, and environmental conditions, with the Mediterranean region potentially experiencing more pronounced heat stress, which could negatively impact rumen function and increase the likelihood of subacute ruminal acidosis (SARA). The proportion of metabolically normal cows was highest in the Central region (77.33%), followed by the Eastern (66.25%) and Mediterranean (61.38%) regions. This trend suggests that cows in the Central region benefit from more balanced feeding strategies and better rumen health management compared to those in other regions. The overall prevalence of acidosis across all regions was 25.52%, indicating that a significant portion of the Holstein cow population is affected by this metabolic disorder. These findings emphasize the importance of targeted nutritional strategies and improved feeding management to minimize acidosis risk, particularly in regions where environmental and dietary factors contribute to its higher occurrence. Implementing adequate fiber intake, controlled carbohydrate levels, and regular metabolic monitoring could help mitigate the impact of acidosis and improve overall herd health and productivity.

Table 2. Prevalence of acidosis (indicated by F/P ratio < 1.1, and DMY in 20 - 43 kg) in Holstein cows depending on the breeding region (Central, Eastern and Mediterranean Croatia)

Region	F/P, DMY			
	Acidosis (F/P < 1.1, DMY in 20 - 43 kg)		Normal (F/P in 1.1 – 1.5, DMY out 20 - 43 kg)	
	N	%	N	%
CE	247227	20.05	953522	77.33
ES	489599	28.42	1141306	66.25
ME	57628	36.49	96938	61.38
Total	794454	25.52	2191766	70.39

CE – Central; ES – Eastern; ME – Mediterranean

The results presented in Table 3 indicate the trends in daily milk yield on the day and after acidosis risk or acidosis prevalence across different breeding regions. In all cases, milk yield was highest at the time of detection (D-0) and showed a gradual decline over subsequent milk recordings (A-1 to A-4). This pattern suggests a persistent negative impact of acidosis on milk production, reinforcing its economic significance for dairy farms.

Table 3. LsMeans of daily milk yields at and after the milk recording when acidosis risk/acidosis occurred in accordance with the breeding region

Milk recording	Parameter	Acidosis risk			Acidosis prevalence		
		Central	Eastern	Mediterranean	Central	Eastern	Mediterranean
D-0	Estimate	24,220	24,778	24,280	26,416	26,045	26,108
D-0	StdErr	0,046	0,064	0,100	0,049	0,047	0,102
A-1	Estimate	24,262	24,822	24,137	25,981	26,838	26,282
A-1	StdErr	0,047	0,065	0,102	0,047	0,0456	0,090
A-2	Estimate	24,346	24,865	24,271	25,730	26,458	25,629
A-2	StdErr	0,047	0,0641	0,101	0,046	0,0446	0,083
A-3	Estimate	24,241	24,666	23,998	25,320	25,885	25,005
A-3	StdErr	0,048	0,0645	0,103	0,045	0,0443	0,080
A-4	Estimate	24,231	24,541	24,088	25,010	25,118	24,286
A-4	StdErr	0,042	0,062	0,089	0,0434	0,043	0,071

*D-0 – milk recording when the acidosis prevalence was determined; A-1, A-2, A-3, A-4 – successive milk recordings; StdEr – standard error of estimate

For cows at risk of acidosis, initial daily milk yield (D-0) was similar across regions, ranging from 24.22 kg in Central Croatia to 24.78 kg in the Eastern region. In the Mediterranean region, cows produced 24.28 kg at the time of acidosis risk detection. Despite small fluctuations, milk yield remained relatively stable across subsequent recordings, with only slight declines observed by A-4. This suggests that cows at risk of acidosis experience a more gradual decline in production, likely due to subclinical effects rather than acute metabolic disturbances. In contrast, cows with confirmed acidosis had higher milk yields at detection compared to those only at risk, with values ranging from 26.04 kg in the Eastern region to 26.41 kg in Central Croatia. However, the decline in production was more pronounced over time. By A-4, yields had dropped to 25.01 kg in Central Croatia, 25.12 kg in the Eastern region, and 24.28 kg in the Mediterranean region. This steeper decline highlights the long-term effects of acidosis on milk production and reinforces the importance of early detection and management to mitigate production losses.

Regional differences in milk yield trends may be attributed to variations in feeding strategies, forage quality, and environmental conditions. The Mediterranean region consistently showed lower milk yields, which could be linked to higher temperatures and potential heat stress, exacerbating metabolic challenges like acidosis. In contrast, the Eastern region initially had the highest milk yields but also exhibited a notable decline over time, indicating a stronger impact of acidosis on production sustainability. Overall, these results emphasize the economic importance of managing acidosis effectively. Even a small decline in daily milk yield, when multiplied over a lactation period and across a herd, can lead to substantial financial losses. Implementing feeding strategies that promote rumen stability, monitoring early warning signs, and optimizing management practices are critical to reducing the long-term negative effects of acidosis on dairy cow performance.

Table 4 provides an overview of the estimated monthly and total differences in milk quantity and value following the detection of acidosis risk or acidosis across different breeding regions in Croatia. The data indicate both positive and negative impacts on milk production and its economic value, depending on the region and whether the cows were classified as at risk or having confirmed acidosis.

For cows at risk of acidosis in the Central region (CE), the differences in milk yield were generally negative during the first three months after acidosis risk was detected, indicating a decline in milk production. In the first month, a loss of 1.26 kg of milk per cow resulted in a monetary loss of €0.61, and by the second month, the loss had increased to 2.52 kg, amounting to €1.21. However, in the third and fourth months,

milk yield showed a slight recovery, with a small positive difference of 3.15 kg and 0.32 kg, respectively. In total, cows at risk of acidosis in the Central region experienced a slight decrease of 0.32 kg and a financial loss of €0.15 over the four months. The Eastern region (ES) presented a more pronounced impact, especially in the first month, where the milk yield decreased by 1.32 kg, resulting in a loss of €0.64. This was followed by another decrease in the second month (1.31 kg, €0.63), but the situation improved in the subsequent months, with a substantial increase in milk yield in the third (5.98 kg, €2.87) and fourth (3.78 kg, €1.81) months. Overall, cows at risk of acidosis in the Eastern region showed a significant net increase of 7.13 kg and €3.42 in milk yield and value over the four months. In the Mediterranean region (ME), cows at risk of acidosis initially experienced an increase in milk yield in the first month (4.27 kg, €2.05), followed by a sharp decrease in the second month (-3.99 kg, -€1.92). However, similar to the Eastern region, the milk yield improved significantly in the third (8.18 kg, €3.93) and fourth (negative change of -2.70 kg, -€1.30) months. Overall, cows at risk in the Mediterranean region experienced a total increase of 5.76 kg and €2.76 in milk yield and value over the four months.

Table 4. Estimated monthly and total differences in quantity and value of milk after the prevalence of acidosis risk/acidosis in accordance with the breeding region

Region	Month 1		Month 2		Month 3		Month 4		Total difference	
	kg	euro	kg	euro	kg	euro	kg	euro	kg	euro
Acidosis risk										
CE	-1,262	-0,606	-2,520	-1,210	3,149	1,512	0,315	0,151	-0,318	-0,153
ES	-1,324	-0,636	-1,313	-0,630	5,983	2,872	3,779	1,814	7,125	3,420
ME	4,271	2,050	-3,993	-1,917	8,178	3,925	-2,700	-1,296	5,757	2,763
Acidosis prevalence										
CE	13,070	6,274	7,514	3,607	12,293	5,901	9,289	4,459	42,166	20,240
ES	-23,799	-11,424	11,405	5,474	17,182	8,247	23,024	11,052	27,812	13,350
ME	-5,238	-2,514	19,592	9,404	18,712	8,982	21,577	10,357	54,642	26,228

CE – Central; ES – Eastern; ME – Mediterranean

For cows with confirmed acidosis, the Central region experienced substantial increases in milk yield and value starting from the first month after acidosis detection. In the first month, there was a positive difference of 13.07 kg (value of €6.27), followed by smaller but consistent increases over the next few months. The total difference in milk yield over four months was 42.17 kg, valued at €20.24. This suggests that while acidosis prevalence initially causes a dip in production, affected cows eventually experience a recovery, although the total losses over the four months remain significant. The Eastern region, however, exhibited a more complex pattern for cows with confirmed acidosis. The first month saw a significant loss of 23.80 kg (€11.42), but production improved in the subsequent months, particularly in the third (11.41 kg, €5.47) and fourth months (23.02 kg, €11.05). The total difference over four months was positive (27.81 kg, €13.35), indicating that cows with confirmed acidosis can recover milk production over time. The Mediterranean region experienced the highest increase in milk yield after acidosis prevalence was detected. In the first month, there was a loss of 5.24 kg (-€2.51), followed by a strong recovery in the second month (19.59 kg, €9.40) and continued improvement in the third (18.71 kg, €8.98) and fourth months (21.58 kg, €10.36). Over the four-month period, cows with confirmed acidosis showed a total gain of 54.64 kg and €26.23 in milk yield and value.

In summary, the data indicate that acidosis risk and prevalence have varying impacts on milk production and economic value depending on the region. While some regions experience initial losses, there is a tendency for milk production to recover over time, especially in the Mediterranean and Eastern regions. The findings highlight the importance of timely detection and intervention in managing acidosis to minimize long-term economic losses.

CONCLUSION

In conclusion, the results of this study highlight the varying impacts of acidosis risk and prevalence on milk yield and economic value across different breeding regions in Croatia. Cows at risk of acidosis generally experienced a decline in milk production during the initial months, with some regions showing recovery over time. In contrast, cows with confirmed acidosis showed a more complex pattern, with initial losses followed by significant recovery, particularly in the Mediterranean and Eastern regions. The findings emphasize the need for effective monitoring and management of acidosis to mitigate its negative effects on milk production and farm profitability.

REFERENCES

Aitken, P. (2016). Metabolic diseases in dairy cows. Veterinary Times. https://www.vettimes.co.uk/app/uploads/wp-post-to-pdf-enhanced-cache/1/metabolic-diseases-in-dairy-cows.pdf

Antanaitis, R., Juozaitienė, V., Malašauskienė, D., Televičius, M. & Urbutis, M. (2019). Biomarkers from automatic milking system as an indicator of subclinical acidosis and subclinical ketosis in fresh dairy cows. *Polish Journal of Veterinary Sciences*, 22(4), 685-693.

Bramley, E., Lean, I. J., Costa, N. D., & Fulkerson, W. J. (2005). Acidosis in pasture fed dairy cows: risk factors and outcomes. Joint Annual Meetin, Cincinnati, Ohio, USA, 24–28 July 2005, *Journal of Dairy Science*, 88.

Bramley, E., Lean, I. J., Fulkerson, W. J., Stevenson, M. A., Rabiee, A.R., & Costa, N.D. (2008). The definition of acidosis in dairy herds predominantly fed on pasture and concentrates. *Journal of Dairy Science*, 91, 308-321.

Danscher, A. M., Li, Š., Andersen, P. H., Khafipour, E., Kristensen, N. B., & Plaizier, J. C (2015). Indicators of induced subacute rumin.al acidosis (SARA) in Danish Holstein cows. *Acta Veterinaria Scandinavica*, 57(39), 1-14.

Eicher, R. (2004). Evaluation of the Metabolic and Nutritional Situation in Dairy Herds: Diagnostic Use of Milk Components. World Association for Buiatrics. Proceedings of World Buiatrics Congress, Québec, Canada, July 11-16, 2004.

Gantner, V., Bobić, T., & Potočnik, K. (2016). Prevalence of metabolic disorders and effect on subsequent daily milk quantity and quality in Holstein cows. *Archives Animal Breeding*, 59, 381-386.

Golder, H. M., LeBlanc, S. J., Duffield, T., Rossow, H. A., Bogdanich, R., Hernandez, L., Block, E., Rehberger, J., Smith, A. H., Thomson, J., & Lean, I. J. (2023). Characterizing ruminal acidosis risk: A multiherd, multicountry study. *Journal of Dairy Science*, 106, 3155-3175.

Humer, E., Aschenbach, J. R., Neubauer, V., Kröger, I., Khiaosaard, R., Baumgartner, W., & Zebeli, Q. (2017). Signals for identifying cows at risk of subacute ruminal acidosis in dairy veterinary practice. *Journal of Animal Physiology and Animal Nutrition*, 102(2), 380-392.

Humer, E., Petri, R., Aschenbach, J., Bradford, B., Penner, G., Tafaj, M., Südekum, K. H., & Zebeli, Q. (2018). Invited review: Practical feeding management recommendations to mitigate the risk of subacute ruminal acidosis in dairy cattle. *Journal of Dairy Science*, 101, 872-888.

ICAR, International Committee for Animal Recording (2017). Guidelines for Dairy Cattle Milk Recording, Guidelines.

Nagaraja, T. G., & Titgemeyer, E. C. (2007). Ruminal acidosis in beef cattle: The current microbiological and nutritional outlook. *Journal of Dairy Science*, 90, 17-38.

O'Grady, L., Doherty, M. L., & Mulligan, F. J. (2008). Subacute ruminal acidosis (SARA) in grazing dairy cows. *Veterinary Journal*, 176, 44-49.

Penner, G. B., Beauchemin, K. A., & Mutsvangwa. T. (2007). Severity of ruminal acidosis in primiparous Holstein cows during the periparturient period. *Journal of Dairy Science*, 90, 365-375.

Plaizier, J. C, Krause, D. O., Gozho, G. N., & McBride, B. W. (2008). Subacute ruminal acidosis in dairy cows: the physiological causes, incidence and consequences. *Veterinary Journal*, 176, 21-3.

Stauder, A., Humer, E., Neubauer, V., Reisinger, N., Kaltenegger, A., & Zebeli, Q. (2020). Distinct responses in feed sorting, chewing behavior, and ruminal acidosis risk between primiparous and multiparous Simmental cows fed diets differing in forage and starch levels. *Journal of Dairy Science*, 103, 8467-8481.

Zebeli, Q., & Metzler-Zebeli, B. U. (2012). Interplay between rumen digestive disorders and diet-induced inflammation in dairy cattle. *Research in Veterinary Science*, 93, 1099-1108.