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Effects of Lameness on Milk Yield, Milk Quality Indicators, and Rumination Behaviour in Dairy Cows

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Abstract: This study investigates the relationship between lameness, milk composition, and rumination behaviour in dairy cows by leveraging sensor-based data for automated monitoring. Lameness was found to significantly impact both rumination and milk production. Lameness was assessed in 24 multiparous Holstein dairy cows throughout early lactation (up to 100 days postpartum), utilising a 1-to-5 scale. Lameness was found to significantly impact both rumination and milk production. On the day of diagnosis, rumination time decreased by 26.64% compared to the pre-diagnosis period ($p < 0.01$) and by 26.06% compared to healthy cows, indicating the potential of rumination as an early health indicator. The milk yield on the day of diagnosis was 28.10% lower compared to pre-diagnosis levels ($p < 0.01$) and 40.46% lower than healthy cows ($p < 0.05$). These findings suggest that lameness manifests prior to clinical signs, affecting productivity and welfare. Milk composition was also influenced, with lame cows exhibiting altered fat (+0.68%, $p < 0.05$) and lactose (−2.15%, $p < 0.05$) content compared to healthy cows. Positive correlations were identified between rumination time and milk yield (r = 0.491, $p < 0.001$), while negative correlations were observed between milk yield and milk fat, protein, and the fat-to-protein ratio ($p < 0.001$). Additionally, lameness was associated with elevated somatic cell counts in the milk, although sample size limitations necessitate further validation. This study highlights the critical role of rumination and milk performance metrics in identifying subclinical lameness, emphasising the utility of automated systems in advancing dairy cow welfare and productivity. The findings underscore the importance of early detection and management strategies to mitigate the economic and welfare impacts of lameness in dairy farming.

Keywords: early detection; animal health; lameness; dairy cow

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1. Introduction

The scientific literature frequently documents the significant effects of lameness in dairy cows resulting from welfare concerns and economic concerns [1,2]. A recent analysis indicates that the prevalence of lameness ranges from 0% to 88% across several studies, whereas the frequency of severe lameness varies from 0% to 65% [3]. Lameness is a highly widespread condition impacting the welfare of cows in contemporary dairy farming [4]. It significantly negatively impacts lifespan, milk production, and reproductive efficacy [5]. Lameness is characterised as an alteration in gait caused by pain or discomfort stemming from hoof or leg injuries and diseases [6]. Lameness has been demonstrated to influence various behavioural traits, including reduced daily feed intake, diminished eating duration, decreased rumination time, and elevated feeding rate [7]. Lameness is defined by the inflammation of the corium and germinal layer, manifesting in overt signs such as aberrant gait and hoof issues [8]. Consequently, the early identification of lameness is critically important. It facilitates early management and aids in the prevention of more severe claw abnormalities, which incur expenditures nearly three times greater than those associated with moderate claw disorders [4]. Recent research indicates that lameness influences herd characteristics and dramatically affects milk quality, milk fat content, and body weight [9,10]. A lame animal enduring chronic pain may experience diminished milk production, with losses estimated between 270 and 574 kg per cow each lactation [11]. Given these factors, it is crucial to create an early, efficient, and rapid detection method to assist in managing this welfare concern on dairy farms.

Evidence suggests that understanding rumination behaviour can aid in identifying transition dairy cows susceptible to metritis, subclinical ketosis, and lameness. This information may also inform the formulation of management practices that facilitate early disease detection and prevention by addressing management problems during the transition phase [12]. Rumination is defined as the process of regurgitating, remasticating, salivating, and swallowing feed to diminish particle size and improve fibre digestion [13]. Rumination duration (the minutes a cow spends ruminating within a specified time frame) is correlated with rumen welfare since it enhances saliva production, which serves as a buffer for the ruminal pH value. The emergence of automated systems, in the early 2000s, capable of recording and storing extensive parameters associated with milk yield and bovine activity, including rumination duration, enhanced the capacity to examine variations in rumination time and its correlations with other animal-related factors [14]. The correlation between cow rumination duration and illnesses remains little explored. Understanding how cow rumination duration may impact their susceptibility to illnesses could lead to improvements in livestock management practices and ultimately benefit the overall health and well-being of the animals. Recent research results indicate that prevalent illnesses in dairy farms substantially reduce ruminating duration [15,16]. Stangaferro et al. [17] established that metabolic and digestive diseases, mastitis, and metritis adversely impact ruminating time and can be anticipated by examining variations in rumination time patterns.

Locomotion scoring systems, which are typically based on a five-point system, are extensively employed to quantify the degree of lameness in dairy cattle. The degree of impairment can be classified in a range from one point (no lameness) to five points (severe lameness) in reference to the movement of dairy cattle [18]. Research on the detection of bovine lameness has begun to progress towards automation as a result of the subjective influence of the observer and the time-consuming and laborious nature of manual observations [18]. Technologies in automatic milking systems (AMSs) and other contemporary dairy farms are monitoring and documenting escalating volumes of data regarding animal behaviour. These data can serve as early indicators for disorders like lameness and enhance our comprehension of the secondary health and welfare implications that lameness may impose on afflicted animals [19]. Automated monitoring can supplant subjective and labour-intensive visual assessments, enabling the early detection and timely treatment of at-risk animals, which is inherently beneficial [3]. Lameness is an economic issue linked to heightened work demands and reduced milking frequency in AMSs [20]. Cows that are moderately or severely lame produce less milk than non-lame cows, and milk production declines as locomotion score increases [21]. The timely and fast diagnosis of lameness enables the alleviation of suffering in affected animals, hence minimising daily milk production losses and premature culling [22].

The automation of lameness identification or rumination assessment is a significant subject in research. Nevertheless, none of these investigations concurrently examined lameness, rumination, and real-time milk quality assessment. Understanding how these factors are interconnected could provide valuable insights for improving overall herd health and productivity. By conducting comprehensive studies that consider all these variables simultaneously, researchers may be able to develop more effective strategies for managing and preventing lameness in dairy cattle. To our knowledge, there has been no effort to automatically identify lameness utilising a combination of three sensor-based indicators (milk yield, milk fat-to-protein ratio, and ruminating duration) along with a pattern analysis of these variables. However, the temporal evolution—before, during, and after diagnosis—is less frequently studied. There is a shortage of research focusing on how changes in productivity and health metrics unfold at different stages of lameness. This perspective is essential for understanding the progression and recovery aspects of lameness, which could significantly affect how farmers manage and treat affected cows.

This study aimed to utilise correlated factors obtained from existing sensors to identify clinical lameness through behavioural and milk performance data. The aim of this study was to evaluate the impact of lameness (7 days before diagnosis, on the day of diagnosis, and 7 days after diagnosis) on milk yield, milk quality indicators, and rumination.

2. Materials and Methods

2.1. Location of the Farm

This study followed the requirements outlined in the Lithuanian Law on Animal Welfare and Protection and has approval number PK012858. The experiment was conducted on a dairy farm located in Eastern Europe at coordinates 56°00′ N, 24°00′ E, from January 1 to July 2024. The farm housed approximately 1200 dairy cows.

2.2. Animals and Grouping of Cows

Healthy multiparous Holstein dairy cows, in their 2nd to 4th lactations, with an average milk yield of around 12,000 kg in the preceding lactation, were selected for the study. Cows' days in milk (DIM) ranged from 10 days to 100 days (early lactation). Over the course of the study, researchers monitored the milk yield, milk composition, and overall health of the cows.

All cows were housed year-round in an indoor, zero-grazing management scheme. The cows were confined to a barn with free stalls with DeLaval ventilation systems (DeLaval Inc., a company based in Tumba, Sweden). They were kept in a regulated setting with controlled temperature, ventilation, and bedding to guarantee uniform living conditions. Milking was conducted utilising Lely Astronaut® A3 milking robots (Maassluis, the Netherlands) including a free-traffic system. To incentivise the cows to approach the robot, a total of 2 kg/d of concentrates were administered by the milking robot. The total mixed diets were 24% corn silage, 5% grass hay, 16% grass silage, 50% grain concentrate slurry, and 5% mineral combination. Dry matter constituted 48% of the rations, comprising 20% acid detergent fibre, 39% non-fibre carbs, 28% neutral detergent fibre, and 16% crude protein. Cows were fed between 5 A.M. and 5 P.M. daily throughout the year.

All cows were provided with a total mixed ration (TMR) designed to fulfil the energy and nutritional requirements of Holstein cows weighing between 550 and 650 kg. A TMR was provided to Lithuanian Holstein dairy cows in order to satisfy their physiological requirements in accordance with the nutrient requirements of dairy cattle (NRCs) [23].

The identification of healthy and lame cows was entirely based on the herd health reports of the farm. The prompt reporting of any lameness cases allowed for timely intervention and treatment, ultimately improving the overall health of the herd. Additionally, the expertise of the veterinarian played a key role in confirming diagnoses and providing appropriate care for lame cows, further emphasising the importance of collaboration between all parties involved in maintaining herd health. The time between the onset of lameness and veterinary diagnosis and treatment was not well known. However, the veterinarian visited the farm every day (except Saturday and Sunday), so it could be assumed that the time delay was small on this farm. The veterinarian's dedication to regular farm visits ensured that any issues with lame cows were addressed promptly. By working closely with the farm staff and utilising their expertise, the veterinarian was able to provide comprehensive care that ultimately improved the overall welfare and productivity of the herd. Moreover, veterinary services were provided by the Lithuanian University of Health Sciences Large Animal Clinic, and all associated veterinarians were trained to perform the same protocols in diagnosing and treating the animals. The collaboration between the university clinic and the farmers resulted in healthier and more efficient livestock management practices.

Lameness was assessed on a scale from 1 to 5, as delineated by Thomsen et al. [24] and Sprecher et al. [25] (Table 1). Score 1 (normal gait): The cow ambulates normally, exhibiting no indications of lameness. The gait is stable, characterised by uniform strides and the absence of visible pain or limb favouring. Score 2 (uneven gait): The cow's ambulation is nearly normal, exhibiting minor abnormalities. The gait may seem irregular, and the cow may exhibit shorter strides than normal, although no definitive indications of lameness are apparent. This grade reflects minor flaws that may not greatly affect movement but show the cow is not fully sound. Score 3 (mild lameness): The cow displays an irregular gait, marked by distinctly reduced strides in one or more limbs. Despite the cow's ability to walk, evidence of lameness is clear, and discomfort is observable in her movement. This score indicates modest yet noticeable lameness. Score 4 (moderate lameness): Lameness is evident, with the cow exhibiting considerable difficulty in ambulation on one or more limbs. The cow's stride is evidently compromised, and the cow may refrain from bearing weight on the affected leg(s), exhibiting significant discomfort. Mobility is diminished. Score 5 (severe lameness): The cow exhibits significant lameness, demonstrating considerable difficulty in locomotion. The cow will probably avoid bearing weight on the injured leg(s) and may only move with considerable exertion. This score signifies intense discomfort and considerable disruption to daily functioning.

Table 1. Adapted five-point locomotion assessment for dairy cattle in accordance with Sprecher et al. [25] and Thomsen et al. [24], with binary categorisation based on Winckler and Willen [26].

Group	Score and Brief Term	Definition
Non-lame	1. Normal	Normal walking pattern without indications of abnormalities or asymmetrical weight distribution between the legs. The cow maintains a flat back while ambulating and standing in most instances.
	2. Uneven gait	The cow ambulates nearly normally, albeit with a slightly irregular gait. No apparent indications of lameness. The back may have an arched posture while ambulating but remains flat while in a standing position.

Table 1. *Cont.*

Group	Score and Brief Term	Definition
Lame	3. Mild lameness	Alteration of the normal gait rhythm due to uneven weight distribution on the legs and a reduced stride length in one or more limbs. Typically, the back is arched during ambulation, and the head is positioned lower than usual. It is frequently challenging to ascertain which leg is impacted.
	4. Moderate lameness	Manifest lameness, often accompanied by an arched back during ambulation and standing, with a distinct effort to relieve weight from one or more limbs. In most instances, cows exhibit head bobbing while ambulating. It is typically evident which legs are impacted.
	5. Severe lameness	The cow exhibits reluctance or incapacity to bear weight on the afflicted limb during ambulation or standing. Typically, there is an arched back during ambulation or standing, accompanied by head bobbing while walking.

Cows were classified as non-lame if they had ratings of 1 or 2, whereas lameness was indicated by values ranging from 3 to 5. The category "non-lame" was established by Winckler and Willen [26] to encompass animals with disability scores of 1 and 2, while the category "lame" was established for those with scores of 3 to 5.

The veterinarian diagnosed the cows with the following diagnoses: foot ulcer, digital dermatitis, and white line disease. Cows exhibiting lameness were addressed with trimming and pharmacological intervention [27]. Either a single 1 mL per 30 kg subcutaneous injection of Naxcel® 200 mg/mL (ceftiofur sodium) (Zoetis Belgium SA, Zaventem, Belgium) was given to the lame cows or nonsteroidal anti-inflammatory drugs were administered to alleviate pain. In a single instance, Melovem® 20 mg/mL (meloxicam) (Dopharma B.V., Raamsdonksveer, The Netherlands), at a dosage of 2.5 mL for a body weight of 100 kg, was administered subcutaneously.

In total, 28 cows were chosen for this study in two groups. According to health status, 14 cows were included in the group of healthy, non-lame cows, and 14 cows were included in the group of lame cows. An exact veterinary examination and the factors mentioned above served to determine each cow's health status. Data on lame cows were recorded and analysed in three stages: 7 days before diagnosis, on the day of diagnosis, and 7 days after diagnosis.

2.3. Collected Variables

Parameters including rumination time (RT) (duration of rumination in minutes per day), body weight of cow (kilograms), milk yield (MY) (kilograms of milk produced per day), milk protein content (MP) (percentage of protein in milk), milk fat content (MF) (percentage of fat in milk), milk lactose concentration (ML) (percentage of lactose in milk), and somatic cell count (SCC) (thousand/mL) were recorded using Lely Astronaut® A3 milking robots (Maassluis, The Netherlands). These parameters were recorded daily for each cow and analysed and assessed 7 days before diagnosis, on the day of diagnosis, and 7 days after diagnosis.

2.4. Statistical Analysis

Statistical analysis was performed using descriptive statistics, and the results were expressed as the mean ± standard error of the mean (M ± SE). Spearman's correlation coefficient was calculated to define the statistical relationships between the evaluated traits and the healthy and sick cow groups. The Pearson correlation (r) was used to detect the linear relationship between the investigated traits: rumination time, body weight, milk yield, milk protein content, milk fat content, milk lactose concentration, and somatic cell count. The general linear model–repeated measures analysis was used for repeated measurement in three stages: 7 days before diagnosis, on the day of diagnosis, and 7 days after diagnosis. A probability of less than 0.05 was considered reliable (p-value ≤ 0.05). All analyses were conducted using SPSS software (IBM Corp. Released 2017), IBM SPSS Statistics for Windows, Version 25.0, IBM Corporation, Armonk, New York, United States.

3. Results

The average lactation of lame cows was 2.65 ± 0.038, and that of non-lame cows was 2.04 ± 0.030, $p > 0.05$.

The body weight of lame cows was the lowest before and after the diagnosis of the disease, compared to healthy cows (Table 2). Seven days before diagnosis, lame cows weighed 782.82 kg, which was 8.44% less than the weight of healthy cows (855 kg). Seven days after diagnosis, lame cows weighed 757.28 kg, which was 11.39% less than healthy cows. During this period, lame cows experienced a further weight loss of 25.54 kg, representing a 3.26% decrease in their body weight within seven days. These results highlight a significant reduction in body weight associated with lameness, both prior to diagnosis and continuing after diagnosis, with the weight gap between healthy and lame cows increasing over time.

Table 2. Mean and standard error of investigated traits (before diagnosis—7 days before clinical diagnosis day; diagnostic day—day of clinical diagnosis; after diagnosis—7 days after diagnosis day).

Traits	Before Diagnosis (a) $\bar{x} \pm$ SE	Diagnosis Day (b) $\bar{x} \pm$ SE	After Diagnosis (c) $\bar{x} \pm$ SE	Healthy Cows (d) $\bar{x} \pm$ SE
Weight, kilograms	782.82 ± 4.731	840.00 ± 35.859	757.28 ± 7.068	852.41 ± 2.897
Rumination time	516.33 ± 2.921 ^{b}	443.93 ± 51.183 ^{a}	500.82 ± 5.575	522.20 ± 1.984
Milk yield/per day	35.21 ± 0.420 ^{b}	29.14 ± 3.54 ^{a,d}	35.39 ± 0.605	37.37 ± 0.227
Fat %	4.77 ± 0.029 ^{b}	4.92 ± 0.238 ^{a,c,d}	4.69 ± 0.051 ^{b}	4.25 ± 0.015 ^{b}
Protein %	3.65 ± 0.009	3.68 ± 0.077	3.66 ± 0.011	3.54 ± 0.006
Lactose	4.62 ± 0.005	4.56 ± 0.049 ^{c,d}	4.63 ± 0.008 ^{b}	4.60 ± 0.003 ^{b}
Somatic cell score, thousand/ml	205.78 ± 18.106	394.46 ± 279.800	241.77 ± 32.806	125.99 ± 5.805
Fat-to-protein ratio	1.31 ± 0.007	1.34 ± 0.063 ^{d}	1.28 ± 0.013	1.20 ± 0.005 ^{b}

The letters a, b, c, and d indicate statistically significant differences between traits of investigated groups ($p \leq 0.05$); $\bar{x} \pm$ SE standard error of the mean.

Statistical analysis showed significant differences in rumination time among lame cows. On the day of diagnosis, the rumination time of cows was 26.64% lower compared to seven days before diagnosis day and 26.06% lower compared to healthy cows ($p < 0.05$, Table 2).

Milk yield also exhibited the most substantial decline on the diagnosis day, with lame cows producing 28.10% less milk than before diagnosis ($p < 0.01$) and 40.46% less than healthy cows ($p < 0.05$, Table 2).

Fat content differed significantly among groups. Healthy cows had 0.68% lower fat content compared to cows on the day of diagnosis, and 0.59–0.57% lower fat content than cows in the pre- and post-diagnosis groups ($p < 0.05$). In contrast, no statistically significant differences were observed in protein content across the groups ($p > 0.05$, Table 2).

Similarly, significant differences were noted in lactose content. Healthy cows had 2.15% lower lactose content compared to cows on the day of diagnosis and 1.73% lower lactose compared to the post-diagnosis group ($p < 0.05$). However, no significant differences were detected in somatic cell counts between the groups ($p > 0.05$, Table 2).

Although the fat-to-protein ratio was 11.67% higher in lame cows on the diagnosis day compared to non-lame cows, this difference was not statistically significant ($p > 0.05$). Additionally, the overall health status of cows did not show a significant relationship with the investigated traits ($p > 0.05$, Table 2).

Correlation analysis revealed important relationships between milk composition and production traits. A strong positive correlation was found between fat content and fat-to-protein ratio (r = 0.929, $p < 0.01$), as well as between protein and fat content (r = 0.744, $p < 0.01$), indicating that higher fat content is associated with higher protein content. Conversely, significant negative correlations were observed between milk yield and fat content (r = −0.653, $p < 0.01$) and between milk yield and the fat-to-protein ratio (r = −0.604, $p < 0.01$), showing that higher milk production is associated with lower fat content (Table 3).

Table 3. Correlation between health status (healthy or lame) with investigated traits.

Correlations									
Traits	**1-Lame, 2-Non-Lame**	**Weight Kilograms**	**Rumination Time**	**Milk Yield/Per Day**	**Fat%**	**Fat-to-Protein Ratio**	**Lactose**	**Somatic Cell Score, Thousand/mL**	**Protein%**
1—lame, 2—non-lame	1								
Weight, kilograms	0.066	1							
Rumination time	−0.007	0.119	1						
Milk yield/per day	0.189	0.375 *	0.491 **	1					
Fat%	−0.340	−0.343	−0.353	−0.653 *	1				
Fat-to-protein ratio	−0.357	−0.253	−0.346	−0.604 **	0.929 **	1			
Lactose	0.189	0.007	−0.044	−0.150	0.234	0.237	1		
Somatic cell score, thousand/mL	0.168	−0.053	−0.096	−0.162	0.061	0.052	0.005	1	
Protein%	−0.193	−0.395	−0.231	−0.500 **	0.744 **	0.454 *	0.093	0.077	1

** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level (2-tailed).

Furthermore, a moderate positive correlation was identified between rumination time and milk yield (r = 0.491, $p < 0.01$), suggesting that cows with longer rumination times tend to produce more milk. However, a moderate negative correlation was found between milk yield and protein content (r = −0.500, $p < 0.01$), indicating that as milk yield increases, protein percentage tends to decline, though not as steeply as fat content (Table 3).

4. Discussion

Analysing the content of cow milk is a potentially cost-effective way to detect lameness in cows. Physiological and behavioural abnormalities in cows related to lameness are also linked to variations in milk content [28]. This study sought to delineate the individual milk composition and ruminating behaviour of dairy cows by automatically and concurrently recorded sensor data, and to quantify the impact of lameness on milk composition and rumination. These aspects will be addressed sequentially below.

On the day of diagnosis, the rumination time of cows was 26.64% lower compared to the period prior to diagnosis (7 days before clinical diagnosis) ($p < 0.01$) and 26.06% lower compared to healthy cows. These findings suggest that cows experience a significant decrease in rumination time when diagnosed with an illness. This decrease may be due to the physical discomfort or stress associated with being sick [12]. Monitoring rumination time could potentially be used as an indicator of a cow's health status, allowing for the earlier detection and treatment of illnesses [29]. Soriani et al. [30] showed that reduced rumination time (<450 min/d) during the initial days of lactation occurred in cows with preclinical illnesses or health issues [30]. According to Weigele et al. [4], eating time and the number of eating chews (jaw movements) were reduced in moderately lame cows in comparison to non-lame cows. However, no effect of moderate lameness was observed on ruminating time, the number of ruminating chews and boluses, and the average number of ruminating chews per bolus [4]. Miguel-Pacheco et al. [19] discovered that lame animals ruminated for a significantly shorter period of time each day than their sound herd companions, despite the small difference (approximately 8 min per day) [19]. Beer et al. [31] similarly discovered that the duration of rumination, the frequency of ruminating chews, and the amount of ruminating boluses were less in lame cows relative to non-lame cows [31]. Research indicates that rumination time was much higher in heifers without digital dermatitis lesions compared to those affected by digital dermatitis, which ruminated 3% less daily. Heifers exhibiting active digital dermatitis lesions ruminated 5% less than those without lesions [32]. Thorup et al. [1] noted that lameness did not influence daily ruminating behaviours, fresh matter consumption, or milk production [1]. However, our study data identified a relationship between cow rumination time, milk yield, and lameness diagnosis. The decrease in total ruminating time may be linked to a decrease in total dry matter intake, which in turn could lead to reduced fibre content in the rumen because of the reduction in total feeding time. Lastly, lameness-related pain and stress may influence rumen function directly by lowering the activity of the regions of the brain responsible for rumination [19]. It has been shown in earlier studies that ruminating leads to elevated cortisol levels [33,34]. Specifically, we found that cows with higher rumination times tended to have higher milk yields, while those with lameness diagnosis had shorter rumination times and lower milk production. This suggests that there may be a direct impact of lameness on cow rumination behaviour and subsequently on milk production.

A statistically significant mean difference was estimated upon diagnosis of the daily milk yield of cows, which was 28.10% lower compared to 7 days before diagnosis ($p < 0.01$) and 40.46% lower compared to the milk yield of healthy cows ($p < 0.05$). This indicates a clear decrease in milk production in cows after the diagnosis of lameness, with a significant difference compared to their own milk yield 7 days before diagnosis and to healthy cows. The findings suggest that diseases (subacute ruminal acidosis, ketosis, milk fever, systemic mastitis) [35–37] have a direct impact on milk production in cows, highlighting the importance of their early detection and treatment to maintain optimal productivity in dairy farming. In the entirety of the research, lame cows generally exhibited a diminished milk output, not solely on the day of diagnosis. This may suggest that lameness is a chronic condition that develops prior to the manifestation of clinical indications. The beginning of lameness may precede diagnosis and therapy significantly, remaining at a subclinical level until identified and addressed. Reduced milk output indicates that the early identification of lameness symptoms can be beneficial in mitigating economic losses. This can be attributed to the fact that lame cows laid down more than usual and were unable to consume enough fodder to produce more milk, as well as the effects of lameness on the welfare and well-being of cows [38]. The change from subclinical to clinical lameness, in addition to early lameness diagnosis, is a critical stage for identification [6]. Lameness in AMS herds has been shown to impact milk production [39]. A study of 41 AMS farms in Alberta and Ontario, Canada, found that increasing the herd-level prevalence of severe lameness (locomotion score $\geq$ 4) from 2.5% to 5% correlated with a loss in milk yield of 0.7 kg/d per cow [40]. Reader et al. [41] documented a decrease in milk production of 0.7 kg/d and 1.6 kg/d in lame cows with mobility ratings of 2 and 3 (on a scale of 0–3), respectively, in comparison to cows with a score of 1 [41]. Kofler et al. [42] demonstrated a distinct inclination towards reduced milk, fat, and protein yield in comparison to cows that had never experienced lameness. Mitigating severe lameness and general lameness in cows during the opening 100 days of lactation may serve as preliminary attainable objectives for enhancing efficiency and welfare in dairy cattle. A reduction in milk yield may be further exacerbated by delayed treatment, which may result in a reduction in caloric consumption due to increased metabolic demands and immobility. Consequently, the early detection and treatment of lameness is essential. AMSs specifically assist in identifying probable lameness. Before and after the diagnosis of clinical lameness and subclinical lameness, milk yield is reduced [43]. Sole ulcer, white line disease, and digital dermatitis are prevalent disorders that result in lameness and reduced milk production [44]. Scientific research indicates that cows afflicted with digital dermatitis produce around 5.5 kg less energy-corrected milk daily compared to healthy cows. No variations were seen in milk fat, protein content, or somatic cell count [45]. Cattle that developed foot ulcers and white line disease were higher-yielding prior to diagnosis. Their milk output declined to below the average of unaffected cows prior to diagnosis and remained down thereafter [46]. In cows experiencing second or subsequent lactation, minor digital dermatitis resulted in an average decrease in milk output of 0.65 kg per day. Nonetheless, the impact was greater for serious lesions [47]. Early intervention is crucial in maintaining milk production levels and overall cow health. By utilising AMS technology to detect lameness early on, farmers can address the issue promptly and prevent further decline in milk yield. Timely treatment can also help alleviate the pain and discomfort experienced by the cows, improving their overall welfare and productivity. In conclusion, the proactive monitoring and management of lameness is vital for optimising dairy herd performance.

Statistically significant mean differences were noted in fat content, with 0.68% lower fat content detected in healthy cows, compared to the fat content of cows on the day of diagnosis, and 0.59–0.57% lower compared to the fat content in the 7-days-before- and 7-days-after-diagnosis groups of cows ($p < 0.05$). In a recent study, comparable findings were observed: lame cows exhibited a considerably higher milk fat content (+0.65%) than healthy cows [48]. The milk fat content of lame animals is typically lower than that of their non-lame counterparts [38]. According to one study, there was a moderately negative correlation between milk fat and digital dermatitis [49]. A recent scientific investigation revealed that the milk fat content of cows afflicted by white line illness and sole ulcers was much lower than that of non-lame cows, measuring 3.80%, 3.69%, and 4.18%, respectively [50]. According to some research [51,52], animals that are lame and those that are not lame exhibit no differences in milk fat or protein. The milk fat content of lame cows in the current study was significantly higher than that of healthy cows. The findings may be explained by the hypothalamo–pituitary–adrenocortical (HPA) axis's detrimental impact on non-lame cows when compared to lame cows because of the new stress event. Lameness is characterised by pain and a stress cascade that activates the HPA axis. This stimulation results in the secretion of corticotropin-releasing hormone (CRH) and arginine vasopressin (AVP). Both CRH and AVP induce the anterior lobe of the pituitary gland to release adrenocorticotropic hormone (ACTH). In response to ACTH, the adrenal cortex synthesises cortisol, which equips the organism to manage stress by mobilising energy reserves. The impact of cortisol on metabolism is significant, affecting glucose, protein, and lipid metabolism, which may influence numerous metabolites [48].

Statistically significant mean differences in lactose content were detected, with 2.15% lower lactose content in healthy cows compared to lactose content of cows on the day of diagnosis and 1.73% lower compared to the 7-days-after-diagnosis group of cows ($p < 0.05$). Our research indicates that lame cows exhibit reduced levels of milk lactose content. Antanaitis et al. [53] identified analogous findings. The cows' lameness led to diminished nutrient absorption and assimilation due to heightened stress and pain, together with increased oxidative agents, resulting in markedly reduced average monthly levels of protein, fat, and lactose production compared to non-lame cows [54]. Lactose tends to drop when udder inflammation is either clinical or subclinical. The lowering of lactose percentage (LP) in milk during mastitis has three major causes: (1) Secretory cells are damaged by inflammation and infection, which reduces LP synthesis. (2) A significant amount of lactose is lost in urine due to the disruption of tight junctions and the altered permeability of the basal membrane that separates blood and milk. (3) Mastitis pathogens use available milk lactose as a substrate, reducing LP and increasing lactic acid in milk. During mammary tissue inflammation, a rise in Na^+ and Cl^- helps maintain osmotic equilibrium. Na^+ from the external environment is the primary ion responsible for increased electrical conductivity and the salty taste of milk [55].

A positive correlation was observed between rumination time and milk yield ($r = 0.491$, $p < 0.001$). A negative correlation was observed between milk yield, fat, protein, and fat-to-protein ratio ($p < 0.001$). Soriani et al. [30] observed analogous results while monitoring the rumination pattern during the transition period to examine its associations with metabolic variables, milk yield, and health status, reporting a positive correlation between ruminating time and milk yield ($r = 0.36$) [30]. In the prior study, increased rumination duration correlated with higher milk production. For each additional hour of daily rumination, milk yield is anticipated to rise by 1.26 kg per day [56]. Dado and Allen [57] similarly discovered that high-producing cows exhibited fewer ruminating bouts daily; nevertheless, each bout was prolonged, leading to an overall increase in daily rumination duration [57]. The components of milk, specifically fat, are influenced by rumen activity [58]. DeVries et al. [59] highlighted the strong correlation between total daily rumination time and the probability of developing subacute ruminal acidosis (SARA). Indeed, rumination duration serves as an effective indicator of a cow's capacity to manage a SARA issue. The correlation between daily rumination duration and milk constituents may be influenced by two factors: a straightforward dilution impact resulting from varying milk production as well as the differential availability of precursors at the udder level, stemming from rumen activity and absorption. The present investigation finds it challenging to distinguish these potential consequences. The increased milk yield associated with prolonged rumination time indicates the primary significance of the former factor. This was further corroborated by the elevated fat output in cows with increased rumination [58].

Our investigation revealed that the SCC level in milk was elevated in the group of lame cows compared to healthy cows. Nevertheless, the results were inconclusive, likely attributable to the limited sample size of animals. Our results agree with prior studies that identified a statistically significant correlation between the occurrence of lameness in cows and average SCC in AMS cows [60]. A newly published study indicated that an elevated herd average SCC correlated with an increased frequency of clinical lameness [39]. Archer et al. [61] established an inverse correlation between SCC and movement scoring in cattle [61]. In a Canadian study, Bouffard et al. [62] employed the SLS to ascertain lameness prevalence and discovered that 25% of the evaluated cows were lame [62]. The correlation analysis results obtained by Zhang et al. [38] indicated that the mammary gland may serve as an additional source of endotoxins in the bloodstream of dairy cows, in addition to the rumen. The claws may be directly affected by the endotoxin that is translocated into the systemic circulation, or it may induce the production of other disease-causing agents, such as biogenic amines, which subsequently elicit lameness [38]. Additionally, lame cows spend a greater amount of time standing than lying down, which minimises the exposure of their mammary glands to bedding bacteria [8]. Research indicates that cows with foot ulcers exhibited a considerably greater somatic cell count compared to healthy cows [63]. The likelihood of foot ulcers during early lactation was 1.70 times higher in cows with elevated somatic cell counts compared to those without elevated somatic cell counts within the first 100 days of milking [64]. Consequently, we must acknowledge that dairy cows with elevated SCC may concurrently exhibit a greater prevalence of lameness due to management deficiencies. Addressing these management deficiencies is crucial to improve overall herd health and productivity. By implementing better practices for hoof care, cleanliness, and overall animal welfare, these farms can work towards reducing both somatic cell counts and lameness issues. It is important for farmers to prioritise proactive measures to prevent these issues from arising, ultimately leading to a healthier and more successful operation.

According to the data, non-lame cows had a lower fat-to-protein ratio on the day of diagnosis compared to lame cows, which was 11.67% greater. Nevertheless, the difference did not reach a statistically significant level ($p > 0.05$), indicating that additional research might be necessary to comprehend the possible connection between lameness and milk composition. Heuer et al. [65] demonstrated that cows with a fat-to-protein ratio over 1.5 faced an elevated risk of ketosis, displaced abomasum, ovarian cysts, lameness, and mastitis. Lame cows often experience greater energy deficits due to mobility issues that reduce feed intake and increase stress levels. This imbalance can result in the higher mobilisation of body fat reserves, elevating milk fat content relative to protein. Additionally, studying a larger sample size may help determine whether there is a true correlation between lameness and milk composition. Overall, these findings suggest that there is a potential relationship worth exploring further to improve the overall health and well-being of dairy cows.

5. Conclusions

Our study highlights the promising potential of sensor-based indicators for accurately detecting lameness in dairy cows. On the day of diagnosis, we observed a significant reduction in rumination time and milk yield, both compared to the period seven days prior to diagnosis and to healthy cows. Additionally, a decrease in milk lactose concentration was found on the day of diagnosis. These findings suggest that changes in rumination, milk yield, and lactose levels could serve as early indicators of lameness. Integrating real-time milk quality assessment with gait analysis may enable dairy farmers to make more informed management decisions, improving animal welfare and reducing economic losses. While the limited sample size may affect the generalizability of these results, further research with a larger and more diverse sample is needed to confirm these findings. Despite these limitations, the study provides valuable insights into lameness detection, stress, and cattle welfare, which could inform better agricultural practices and treatments.

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