dairy

MDPI

Article

Evaluating Rumination Time Changes During Estrus in Dairy Cows

Mária Mičiaková [1,*], Peter Strapák [1], Eva Strapáková [2] and Iveta Szenciová [3]

[1] Institute of Animal Husbandry, Slovak University of Agriculture in Nitra, Trieda Andreja Hlinku 2, 949 76 Nitra, Slovakia; peter.strapak@uniag.sk
[2] Institute of Nutrition and Genomics, Slovak University of Agriculture in Nitra, Trieda Andreja Hlinku 2, 949 76 Nitra, Slovakia; eva.strapakova@uniag.sk
[3] Department of Biology, Faculty of Education, J. Selye University in Komárno, Bratislavská cesta 3322, 945 01 Komárno, Slovakia; szenciovai@ujs.sk
* Correspondence: maria.miciakova@uniag.sk; Tel.: +421-37-641-4416

Abstract: This study evaluated the impact of estrus on changes in rumination over 24 h using data from the DataFlow™ II program and the Heatime RuminAct device, encompassing 634 estrous cycles of dairy cows. During the reference period, three days before estrus, cows spent an average of 511 min per day ruminating. One day before estrus, the total rumination time decreased to 503 min per day. During estrus, rumination time further decreased to 481 min, reflecting a reduction of 31 min per day (6.2%) compared to the pre-estrus reference period. After estrus ended, we observed an immediate increase in rumination time, with post-estrus levels comparable to pre-estrus values. Using a linear model, we assessed the influence of the herd and individual cows on changes in rumination time during estrus compared to the reference period. Our findings confirm the notable impact of estrus on rumination in dairy cows. The reduction in rumination time was most pronounced in heifers (−66 min, −13%), followed by first-lactation cows (−36 min, −7%) and multiparous cows (−16 min, −4%). The influence of the lactation stage was significant, with cows in early lactation showing a greater reduction in rumination compared to cows in later stages. Additionally, high-milk-yielding cows exhibited slightly lower rumination times during estrus, reflecting the interplay between diet composition and energy demands. These results underscore the role of parity, lactation stage, milk yield, and individual differences in shaping rumination behavior during estrus. Behavior-monitoring systems proved valuable for detecting estrus and managing reproduction in dairy herds. Our results showed a notable 6.2% reduction in rumination during estrus, highlighting its potential as a reliable indicator in regions like Slovakia, where economic challenges impact dairy farming sustainability.

Keywords: reproduction; rumination time; dairy cattle; monitoring; precision livestock farming

Academic Editor: Robert J. Van Saun

Received: 29 July 2024
Revised: 12 January 2025
Accepted: 20 January 2025
Published: 22 January 2025

Citation: Mičiaková, M.; Strapák, P.; Strapáková, E.; Szenciová, I. Evaluating Rumination Time Changes During Estrus in Dairy Cows. *Dairy* **2025**, *6*, 5. https://doi.org/10.3390/dairy6010005

1. Introduction

Accurate estrus detection in dairy cows is crucial for maximizing the economic efficiency of dairy farms, particularly in Europe, where dairy farming plays a central role in agriculture. The EU's milk production has grown significantly, rising from 134 million tons in 2004 to 154 million tons in 2023, with cows' milk comprising 96% of this total. Despite this growth, the EU's share of global milk production has decreased from 21.4% to 17.1%, as milk production has expanded worldwide [1]. Germany, France, the Netherlands, Italy, and Poland together account for about two-thirds (64.7%) of EU milk production, with

Germany contributing over 21% alone. In contrast, milk production in Slovakia has shown a significant downward trend, decreasing by 18.75% over the past 20 years [2]. In 2004, Slovakia had 231,874 registered dairy cows, but, by 2023, this number had fallen to just 188,432. Concurrently, Slovakia's total milk production dropped from 1,047,200 tons in 2004 to 807,421 tons in 2023, placing Slovakia 21st out of the 27 EU member states in terms of milk production [3].

The decrease in dairy cow numbers and milk production in Slovakia and other parts of Central Europe is largely attributed to economic factors. Farmers face increased financial pressure due to low milk prices and high market competition, which makes it increasingly difficult to maintain profitable dairy operations. At the same time, dairy producers are under pressure to modernize their operations and invest in new technologies to remain competitive. These socio-economic challenges affect herd management practices, including reproductive management and estrus detection, highlighting the need for efficient monitoring systems that can help optimize productivity and herd health in a changing agricultural environment.

The internal and external manifestations of estrus are regulated by estrogens, primarily 17β-estradiol, which reaches its peak concentration one day before estrus ([4–6]). One of the primary effects of these steroids is an increase in restlessness, which negatively impacts both feed intake and rumination time. Additionally, estrogens reduce animals' appetite, closely linked to reduced feed intake [6]. Phillips and Schofield [7] observed a decrease in feed intake during estrus by 5 to 20%, which is also associated with weight loss in animals in estrus [8].

In this context, rumination appears to be a more suitable indicator of estrus compared to traditional methods, such as assessing the standing reflex or counting mounting attempts [9,10]. Adin et al. [11] recorded average daily rumination times ranging from 428 to 482 min, with an approximate 17% decrease (74 min) during estrus. This reduction is closely associated with increased locomotion, which is recognized as one of the primary behavioral signs of estrus [12].

Despite the importance of these findings, accurate estrus detection remains challenging, especially as herd sizes increase, reducing farmers' ability to maintain individual contact with each animal. Consequently, milk producers, veterinarians, and nutrition experts are increasingly reliant on rumination records as a fundamental factor for monitoring dairy cow health. These records enable the early detection of health issues before clinical symptoms arise and milk production declines significantly. They also provide data for enhancing feeding practices to support rumen health.

Using electronic monitoring devices that detect changes in behavior and physiological parameters, such as rumination, represents a modern approach with substantial potential. These devices utilize acoustic sensors to record specific rumination sounds, which are then analyzed to separate them from other sounds related to feeding [13]. By combining activity monitoring with rumination tracking, these systems can provide highly accurate insights into the onset of estrus and other critical phases of the reproductive cycle.

Based on previous findings, we hypothesize that estrus in dairy cows significantly reduces rumination time and that this reduction is influenced by factors like parity, lactation stage, and individual differences between cows. We further hypothesize that after estrus, rumination time returns to levels comparable to pre-estrus values.

The objective of this study was to evaluate the impact of estrus on changes in rumination time in dairy cows. Additionally, we also evaluated the possible effect of the independent variables parity, lactation stage, milk yield, and individual differences between animals on variations in rumination time during the reference period (before and after estrus) compared to the values during estrus.

2. Materials and Methods

The Ethics Committee for the Protection of Animals Used for Scientific and Teaching Purposes of the University of Agriculture in Nitra, based on Decree-Law No. 377/2012 Coll. of Law, Article 1 (8) (a), takes the view that this type of project utilizing agricultural animals does not fall under the legislation for the protection of animals used for scientific purposes because it is considered a "non-experimental agricultural procedure".

2.1. Animals and Housing

Baseline data collection was conducted on two farms. The first farm, located near Dvorníky at coordinates 48.5975° N, 18.1295° E, is situated at an elevation 150–200 m above sea level. This farm houses 120 Holstein dairy cows in free-stall barns equipped with straw-bedded cubicles. Heifers are reared on deep bedding, which is replaced every 20 days.

The second farm, located in Oponice at coordinates 48.4618° N, 18.1488° E, and approximately 180–200 m above sea level, houses 350 Holstein dairy cows in free-stall barns with concrete floors covered with rubber mats.

To monitor rumination and activity, Heatime RuminAct collars (SCR Engineers Ltd., Netanya, Israel) were used on both farms. These devices aid in maintaining optimal herd health and productivity, enhancing reproductive management, and improving cost efficiency. This contributes significantly to the farms' economic resilience in the competitive dairy industry.

Dairy cows were inseminated for the first time at 63 and 84 days postpartum, respectively. The average calving-to-conception interval was 113 days on Farm 1 and 121 days on Farm 2. Estrus detection was performed using a combination of activity monitoring with the Heatime RuminAct system (SCR Engineers Ltd., Netanya, Israel) and visual observation. The Heatime RuminAct system, which records rumination, activity, and estrus-related behavior, was employed to monitor rumination time. Calving occurred year-round, with artificial insemination carried out by the farm manager on Farm 1 and by technicians from the AI association on Farm 2. Pregnancy diagnosis was performed via ultrasonography between 25 and 30 days after insemination and later confirmed through rectal palpation at approximately 60 $\pm$ 5 days post-AI.

2.2. Composition and Nutritional Characteristics of TMR

The cows on both farms are fed a Total Mixed Ration (TMR) ad libitum. The TMR provided to the cows was carefully formulated to meet their nutritional needs. On the first farm, the TMR consists of grass and maize silage, while, on the second farm, the TMR includes corn and alfalfa silage. Feeding is carried out twice daily on Farm 1, with feed pushed up every 8 h, beginning at 5:30 a.m. On Farm 2, feeding is carried out at 4:00 a.m., with feed pushed up every 8 h.

The composition of the TMR for Herd 1 (High-Fiber TMR) and Herd 2 (Low-Fiber TMR) is as follows (Table 1).

Table 1. Composition and nutritional characteristics of Total Mixed Ration (TMR) provided to dairy cows.

Parameter	Herd 1 (High-Fiber TMR)	Herd 2 (Low-Fiber TMR)
Dry Matter (%)	55.0	50.5
Neutral Detergent Fiber (NDF, % of DM)	35.0	28.0
Acid Detergent Fiber (ADF, % of DM)	23.0	18.0
Crude Protein (% of DM)	16.5	17.0
Starch (% of DM)	22.0	30.0
Net Energy for Lactation (NEL, Mcal/kg)	1.56	1.65
Main Forages	Corn silage, grass silage, alfalfa hay	Corn silage, alfalfa hay
Supplemental Feeds	Soybean meal, mineral mix	Corn gluten, mineral mix

2.3. Data Collection

We monitored the rumination behavior of 180 Holstein cows, including 32 heifers (from Herd 1) and 148 lactating cows (50 dairy cows from Herd 1 and 98 from Herd 2), starting in July 2019. Over the study period, which extended until November 2022, data were collected on rumination time and estrus behavior across 634 estrus cycles (263 estrus cycles of dairy cows from Herd 1, 293 estrus cycles of dairy cows from Herd 2, and 78 heifers estrus cycles from Herd 1). The estrus day (d0) was defined as the day of artificial insemination. A 24 h period was measured from midnight to midnight. According to the technology provider, the peak estrus day was determined by a significant change in locomotion activity compared to the same time interval during the preceding seven days.

The lactation stages of the evaluated cows were divided into three categories: up to 80 days post-calving ($\leq$80 days), 81 to 150 days post-calving, and 151 days or more post-calving ($\geq$151 days). For Herd 1, the number of cows in each lactation stage was 79 ($\leq$80 days), 76 (81–150 days), and 107 ($\geq$151 days), while, for Herd 2, the corresponding numbers were 158 ($\leq$80 days), 104 (81–150 days), and 32 ($\geq$151 days). In Herd 1, rumination behavior was monitored for 78 heifers, 141 primiparous cows, and 121 multiparous cows. In Herd 2, the evaluated cows included 96 primiparous and 198 multiparous individuals. These groups allowed us to assess changes in rumination time during estrus relative to the lactation stage, parity, and milk production.

For milk production, cows were categorized into two groups based on daily milk output. In Herd 1, 218 cows produced less than 34.29 kg·day^{-1}, while 122 cows produced 34.29 kg·day^{-1} or more. Similarly, in Herd 2, 138 cows produced less than 34.29 kg·day^{-1}, and 156 cows produced 34.29 kg·day^{-1} or more.

Cows were inseminated 8 to 12 h after the system registered the "heat index", which is considered the optimal window for successful insemination based on the system's algorithm. The heat index, ranging from 35 to 100, classifies cows as in estrus when their locomotion activity surpasses the threshold. In Herd 1, successful insemination occurred in 164 cases, while, in Herd 2, there were 110 successful cases.

During the monitoring period, stable temperatures ranged from 5 °C to 25 °C. When temperatures exceeded this range, automatic cooling systems, including water sprayers and ventilation, were activated to minimize heat stress, which could otherwise negatively impact productivity, reproduction, and behavior. Data collection concluded in November 2022, followed by analysis and interpretation to achieve a detailed understanding of the study's results.

2.4. Measurement of Rumination Time

The rumination behavior of dairy cows was monitored using the Heatime RuminAct system, which recorded data in minutes at 2 h intervals throughout the day. For analysis, 24 h rumination summaries (min·d^{-1}) were obtained from the DataFlow™ II program (SCR Engineers Ltd., Netanya, Israel), a platform designed to process and analyze data from monitoring devices like the Heatime RuminAct collars. This system tracks key behavioral parameters, including rumination, activity, and estrus signs, offering valuable insights into animal health, reproduction, and productivity.

Each cow wore a collar equipped with an acceleration sensor that continuously measured rumination and distinguished feeding and rumination activities from those associated with estrus. The raw data, collected at 2 h intervals, were processed using a microprocessor and transferred in real time via an antenna to DataFlow™ II software. These intervals were then averaged to provide daily rumination values (min·d^{-1}) for analysis. Additionally, the Heatime RuminAct system recorded locomotion activity, which has been the subject of our previous research [14].

Daily evaluations of rumination and estrus signs were conducted over three defined periods: three days before estrus, the day of estrus (considered the insemination day), and three days after estrus. The day of estrus was precisely defined using the HeatimeRuminact system, which identifies estrus by comparing the behavior of the same animal over the preceding seven days. The system also determines the optimal time for insemination, marking it with green indicators: light green for a good time to inseminate and dark green for the ideal time to inseminate.

To assess the effects of specific factors on changes in rumination, data from 634 estrous cycles were analyzed. Cows were grouped by parity as follows: heifers (0-parity, n = 78), primiparous cows (1-parity, n = 237), and multiparous cows (2 or more parities, n = 318). Based on the lactation stage, cows were divided into three groups: within 80 days postpartum (n = 236), 81 to 150 days postpartum (n = 180), and 151 or more days postpartum (n = 139). These stages were defined using DataFlow™ II software, which calculated the number of days from calving to estrus onset.

Milk yield was another factor considered, with cows classified into two groups based on average daily production: low-yielding cows (<34.29 kg/day, n = 277) and high-yielding cows ($\geq$34.29 kg/day, n = 356). Milk yield was calculated as the average daily production over the 10 days preceding estrus to avoid the confounding effects of estrus-related changes in milk yield.

Rumination time and estrus behavior were evaluated daily across all groups during the reference period (three days before estrus), the estrus day, and the three days following estrus, categorized by both parity and milk yield.

2.5. Statistical Analyses

For data preparation and statistical analysis, we utilized SAS 9.4 and Enterprise Guide 7.1 software (SAS Institute Inc., Cary, NC, USA, 2011). To evaluate rumination parameters, we calculated descriptive statistics, focusing on factors like parity, lactation stage, and average daily milk yield, measured 10 days prior to estrus onset.

Differences in rumination among groups of dairy cows, categorized by parity, lactation stage, and milk yield, were analyzed for each day of the reference period and the day of estrus using paired *t*-tests. Variations in rumination during the reference period and estrus were further assessed through one-way analysis of variance (ANOVA), with mean differences tested using Scheffe's method.

To understand the influence of herd, parity, lactation stage, milk yield, and individual variability on changes in rumination during estrus compared to the reference period (three

days before and three days after estrus), linear models were employed. The equations are outlined as follows:

$$Y_{ijklmn} = \mu + H_i + P_j + SL_k + M_l + I_m + e_{ijklmn}$$

Y_{ijklmn} represents changes in rumination during estrus relative to the reference period.

μ is the intercept, denoting the overall mean.

H_i indicates the fixed effect of the herd, categorized into two levels (Herd 1 and Herd 2).

P_j accounts for parity, with three levels (0: heifers; 1: primiparous cows; 2: multiparous cows).

SL_k refers to lactation stage, classified into three categories (1: within 80 days post-calving, 2: 81–150 days post-calving, 3: 151 days or more post-calving).

M_l corresponds to milk yield, divided into two levels (1: $<$34.29 kg·day^{-1}; 2: $\geq$34.29 kg·day^{-1}).

I_m represents individual variability among the 180 observed cows.

e_{ijklmn} denotes the residual error, reflecting random or unmeasured factors.

Post hoc analyses were conducted using Duncan's multiple range tests to identify differences in rumination across factor levels.

Additionally, Pearson correlation analysis was applied to explore the relationships between rumination patterns during the reference period and estrus.

3. Results

3.1. The Effect of Estrus on Variations in Dairy Cow Rumination Time

The impact of estrus on changes in 24 h rumination time was analyzed in two dairy cow herds based on data collected during the reference periods and estrus.

In Herd 1, cows ruminated for an average of 556 min per day on the third day before estrus (day -3). Rumination time then gradually declined, reaching 553 min on day -2 and 529 min on day -1 and dropping further to 509 min during estrus. After estrus ended, an immediate increase in rumination time was observed, rising to 548 min on the first day post-estrus (day 1) and subsequently stabilizing between 540 and 546 min over the subsequent days (days 2 and 3) during the three-day reference period after estrus (Figure 1).

In Herd 2, rumination time remained relatively stable at 471–472 min during the three days before estrus (days -3, -2, and -1). During estrus, rumination decreased to 452 min, reflecting the physiological changes associated with estrus. Following estrus, rumination increased to 466 min on the day^1 post-estrus and stabilized between 463 and 465 min over the subsequent days (days 2 and 3) (Figure 1).

The Pearson correlation analysis revealed correlations between rumination times across various time points in the reference period and estrus. The strongest correlations were observed between consecutive days within the pre-estrus period, indicating a consistent rumination pattern as estrus approached. In particular, high correlation coefficients between the last three days of the reference period suggest that rumination behavior remains stable prior to the onset of estrus (Table 2).

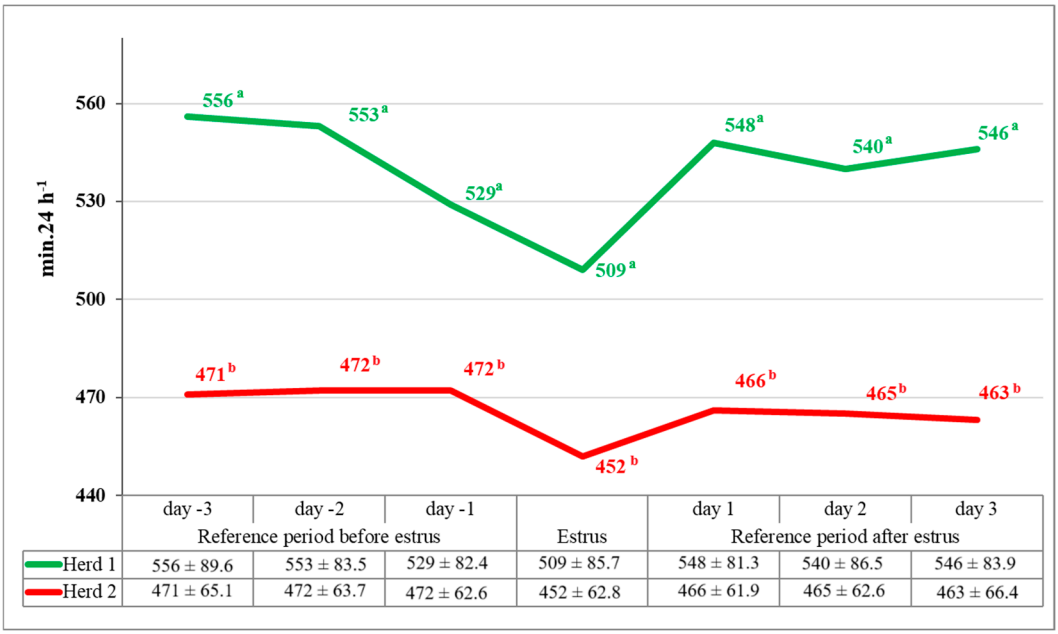


Figure 1. Testing differences in rumination time between herds during estrus and the reference period (n = 634). Data presented are based on 634 estrus cycles monitored from 180 Holstein cows (32 heifers and 148 lactating cows) across two herds; Herd 1 contributed 340 estrus cycles from lactating cows and 78 cycles from heifers, while Herd 2 contributed 294 estrus cycles from lactating cows, collected between July 2019 and November 2022. Variations in the results are represented by standard deviations (SD), and statistically significant differences are indicated by different letters (a, b) at a level of $p < 0.05$.

Table 2. Pearson correlation coefficients of rumination time parameters during reference period and estrus in cows (n = 634).

		Reference Period Before Estrus			Estrus	Reference Period After Estrus		
		day -3	day -2	day -1		day 1	day 2	day 3
Reference period before estrus	day -3	1.00000	0.78548 <0.0001	0.67199 <0.0001	0.48161 <0.0001	0.63656 <0.0001	0.63832 <0.0001	0.61579 <0.0001
	day -2		1.00000	0.74310 <0.0001	0.48090 <0.0001	0.66260 <0.0001	0.66720 <0.0001	0.62133 <0.0001
	day -1			1.00000	0.43812 <0.0001	0.64358 <0.0001	0.64963 <0.0001	0.55277 <0.0001
Estrus					1.00000	0.50006 <0.0001	0.51747 <0.0001	0.48343 <0.0001
Reference period after estrus	day 1					1.00000	0.76660 <0.0001	0.72004 <0.0001
	day 2						1.00000	0.78290 <0.0001
	day 3							1.00000

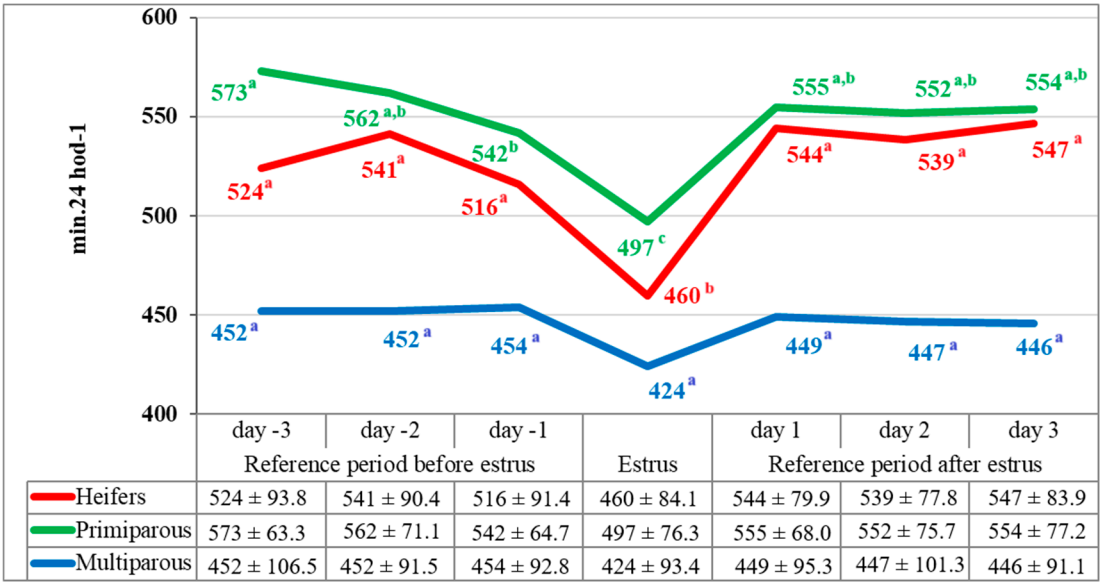
3.2. The Effect of Parity on Variations in Cow Rumination Time During Estrus

In Herd 1, during the reference period before estrus (days -3 and -2), the average rumination time per 24 h was highest in primiparous cows, with values ranging from 562 to 573 min·d^{-1}. Heifers followed, with a range of 524 to 541 min·d^{-1}, while multiparous cows had the lowest values at 452 min·d^{-1} on both days. These results indicate a parity-related difference in rumination activity, with primiparous cows maintaining the highest rumination times during this period.

On day -1 (one day before estrus), a noticeable reduction in rumination activity was observed across all groups. Heifers showed a decrease to 516 min·d^{-1} (a reduction of 25 min·d^{-1} or 8%), primiparous cows decreased to 542 min·d^{-1} (a reduction of 20 min·d^{-1} or 4%), and multiparous cows decreased to 454 min·d^{-1} (a reduction of 2 min·d^{-1} or less than 1%).

During estrus (day 0), rumination times reached their lowest values. Heifers recorded 460 min·d^{-1} (a decrease of 56 min·d^{-1} or 11% compared to day -1), primiparous cows decreased to 497 min·d^{-1} (a reduction of 45 min·d^{-1} or 8%), and multiparous cows had the lowest rumination time of 424 min·d^{-1} (a decrease of 30 min·d^{-1} or 7%). This trend highlights the significant reduction in rumination activity during estrus, particularly in heifers and primiparous cows.

In the reference period after estrus (days 1, 2, and 3), rumination times increased across all groups, returning to levels comparable to or slightly exceeding those observed during the reference period before estrus. Heifers showed an increase from 460 to 547 min·d^{-1} ($p < 0.05$), primiparous cows increased from 497 to 555 min·d^{-1} ($p < 0.05$), and multiparous cows increased from 424 to 446 min·d^{-1} ($p < 0.05$). These findings suggest a recovery in rumination activity following estrus, with parity influencing the magnitude of recovery (Figure 2).



	day -3	day -2	day -1	Estrus	day 1	day 2	day 3
	Reference period before estrus				Reference period after estrus		
Heifers	524 ± 93.8	541 ± 90.4	516 ± 91.4	460 ± 84.1	544 ± 79.9	539 ± 77.8	547 ± 83.9
Primiparous	573 ± 63.3	562 ± 71.1	542 ± 64.7	497 ± 76.3	555 ± 68.0	552 ± 75.7	554 ± 77.2
Multiparous	452 ± 106.5	452 ± 91.5	454 ± 92.8	424 ± 93.4	449 ± 95.3	447 ± 101.3	446 ± 91.1

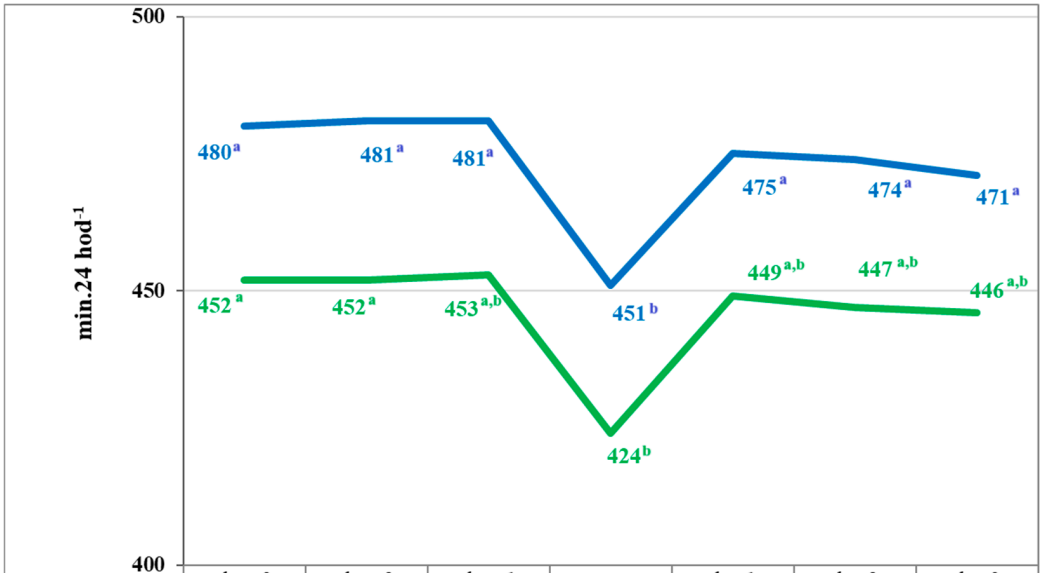
Figure 2. Changes in rumination time of dairy cows during the reference period and estrus according to parity for Herd 1 (heifers: n = 78; primiparous cows: n = 141; multiparous cows: n = 121). Values marked with different letters (a; b; c) indicate differences within the same color line.

In Herd 2, during the reference period before estrus (days -3 and -2), the average rumination time per 24 h was higher in primiparous cows, ranging from 480 to 481 min·d^{-1}, compared to multiparous cows, which ranged from 452 to 453 min·d^{-1}. This indicates a parity-related difference in rumination activity, with primiparous cows showing higher values during this period.

On day -1 (the day before estrus), a slight decrease in rumination time was observed in both groups. Primiparous cows decreased to 481 min·d^{-1}, while multiparous cows dropped to 451 min·d^{-1}.

During estrus (day 0), rumination time reached its lowest values in both groups. Primiparous cows recorded 451 min·d^{-1}, a slight decrease compared to the previous day. Multiparous cows exhibited a more pronounced reduction, dropping to 424 min·d^{-1}.

In the reference period after estrus (days 1, 2, and 3), rumination time gradually recovered in both groups. Primiparous cows increased their rumination time to 475 min·d^{-1} on day 1 and stabilized around 474 to 471 min·d^{-1} on days 2 and 3. Multiparous cows showed a similar recovery pattern, increasing to 449 min·d^{-1} on day 1 and stabilizing between 446 and 447 min·d^{-1} on days 2 and 3 (Figure 3).



	day -3	day -2	day -1		day 1	day 2	day 3
	Reference period before estrus			Estrus	Reference period after estrus		
Primiparous	452 ± 74.0	452 ± 72.6	453 ± 73.0	424 ± 72.6	449 ± 71.0	446 ± 71.8	446 ± 72.0
Multiparous	480 ± 58.5	481 ± 56.9	481 ± 54.8	451 ± 55.5	475 ± 55.3	474 ± 55.5	471 ± 62.2

Figure 3. Changes in rumination time of dairy cows during the reference period and estrus according to parity for Herd 2 (primiparous cows: n = 96; multiparous cows: n = 198). Values marked with different letters (a; b) indicate differences within the same color line.

When testing the differences in rumination time among heifers and primiparous and multiparous cows over a 24 h period during the reference period before estrus, significant differences were observed between groups. On day -3, differences were found between primiparous and multiparous cows in Herd 1 ($p < 0.05$) and between heifers and multiparous cows in Herd 2 ($p < 0.01$). On day -2, differences were noted between heifers and primiparous cows in Herd 1 ($p < 0.05$) and between heifers and multiparous cows in Herd 2 ($p < 0.001$). On day -1, significant differences were observed between heifers and primiparous cows in Herd 1 ($p < 0.05$) and between heifers and multiparous cows in Herd 2 ($p < 0.01$).

At the time of estrus (day 0), significant differences in rumination time were observed between heifers and primiparous cows ($p < 0.05$), between heifers and multiparous cows ($p < 0.01$), and between primiparous and multiparous cows in Herd 2 ($p < 0.01$). During the reference period after estrus, on day 1, significant differences were found between heifers and multiparous cows in Herd 2 ($p < 0.01$). On day 2, differences were noted between heifers and primiparous cows in Herd 1 ($p < 0.05$) and between heifers and multiparous cows in Herd 2 ($p < 0.001$). On day 3, differences were observed between heifers and multiparous cows in Herd 2 ($p < 0.01$).

These results highlight the variability in rumination time according to parity and herd, suggesting that parity-specific and herd-specific factors influence the rumination behavior of dairy cows during estrus and its associated periods (Table 3).

Table 3. Testing the differences in cows' rumination time according to parity and the herd during the reference period (days -3, -2, and -1 relative to estrus), estrus (day 0, considered the day of peak locomotion activity and insemination), and the post-estrus period (days 1, 2, and 3).

Indicator			Number of Lactations	Difference of Averages	*t*-Test	P
Reference period	day -3	Herd 1	0 vs. 1	−49.3	−4.15	0.99
			0 vs. 2	−33.5	−2.33	0.21
			1 vs. 2	15.9	1.44	<0.05
		Herd 2		−27.5	−3.18	<0.01
	day -2	Herd 1	0 vs. 1	−20.2	−1.7	0.09
			0 vs. 2	−8.2	−0.6	0.54
			1 vs. 2	12	1.17	0.24
		Herd 2		−28.7	−3.4	<0.001
	day -1	Herd 1	0 vs. 1	−25.8	−2.21	<0.05
			0 vs. 2	−7.2	−0.54	0.59
			1 vs. 2	18.6	1.85	0.07
		Herd 2		−27.6	−3.28	<0.01
Estrus		Herd 1	0 vs. 1	−37.3	−3.25	<0.05
			0 vs. 2	−38.2	−3	<0.01
			1 vs. 2	−0.9	−0.09	0.93
		Herd 2		−27.5	−3.27	<0.01
Reference period	day 1	Herd 1	0 vs. 1	−10.1	−0.94	0.35
			0 vs. 2	2.4	0.19	0.85
			1 vs. 2	12.5	1.2	0.23
		Herd 2		−25.7	−3.12	<0.01
	day 2	Herd 1	0 vs. 1	−13.1	−1.2	0.23
			0 vs. 2	10.6	0.83	<0.05
			1 vs. 2	23.7	2.11	<0.05
		Herd 2				<0.001
	day 3	Herd 1	0 vs. 1	−7.1	−0.61	0.54
			0 vs. 2	7.7	0.61	0.54
			1 vs. 2	14.8	1.41	0.16
		Herd 2		−24.6	−2.87	<0.01

0—heifers; 1—primiparous cows; 2—multiparous cows; P—significance.

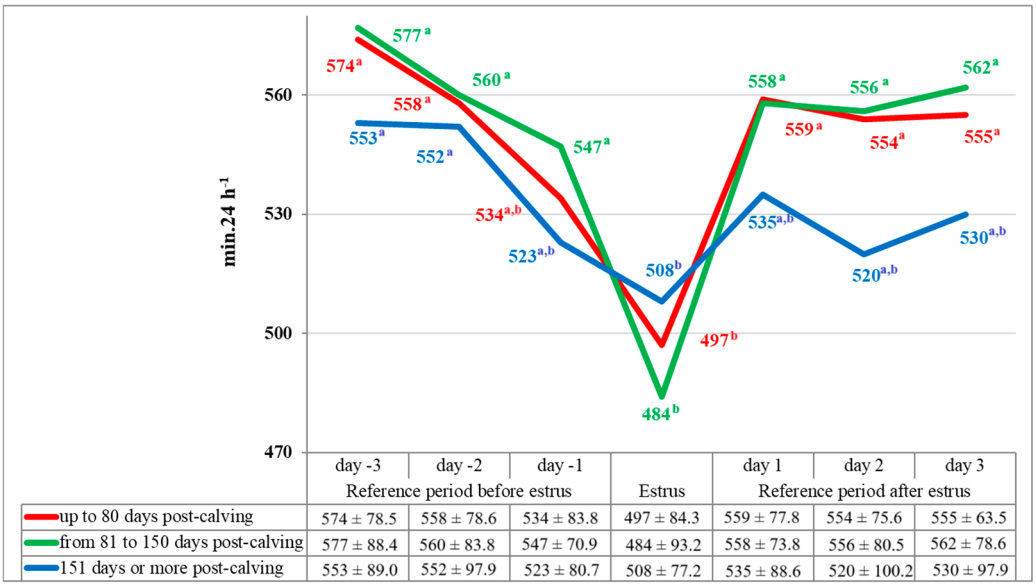
3.3. The Effect of Lactation Stage on Variations in Dairy Cow Rumination Time

In a group of dairy cows from Herd 1 at different lactation stages, significant variations in rumination time were observed across three periods: up to 80 days post-calving, from 81 to 150 days post-calving, and 151 days or more post-calving.

For cows in the early lactation stage (up to 80 days post-calving), the average rumination time during the reference period of three days before estrus (day -3, day -2, and day -1) was 574, 558, and 534 min·d^{-1}, respectively. Rumination dropped significantly to 497 min·d^{-1} during estrus ($p < 0.05$), followed by a recovery to 559, 554, and 555 min·d^{-1} on days 1, 2, and 3 post-estrus, respectively.

In mid-lactation cows (81 to 150 days post-calving), rumination levels were higher during the pre-estrus reference period, with averages of 577, 560, and 547 min·d^{-1} for day -3, day -2, and day -1, respectively. Rumination declined to 484 min·d^{-1} during estrus, reflecting a significant reduction ($p < 0.05$). Post-estrus recovery was observed, with rumination increasing to 558, 556, and 562 min·d^{-1} on days 1, 2, and 3, respectively.

For late-lactation cows (151 days or more post-calving), rumination was relatively stable before estrus, with averages of 553, 552, and 523 min·d^{-1} for day -3, day -2, and day -1, respectively. A decline to 508 min·d^{-1} occurred during estrus, followed by an increase to 535, 520, and 530 min·d^{-1} on days 1, 2, and 3 post-estrus, respectively (Figure 4).



	day -3	day -2	day -1	Estrus	day 1	day 2	day 3
	Reference period before estrus				Reference period after estrus		
up to 80 days post-calving	574 ± 78.5	558 ± 78.6	534 ± 83.8	497 ± 84.3	559 ± 77.8	554 ± 75.6	555 ± 63.5
from 81 to 150 days post-calving	577 ± 88.4	560 ± 83.8	547 ± 70.9	484 ± 93.2	558 ± 73.8	556 ± 80.5	562 ± 78.6
151 days or more post-calving	553 ± 89.0	552 ± 97.9	523 ± 80.7	508 ± 77.2	535 ± 88.6	520 ± 100.2	530 ± 97.9

Figure 4. Changes in rumination time of dairy cows during the reference period and estrus based on lactation stage for Herd 1 (≤80 days: n = 79; 81–150 days: n = 76; ≥151 days: n = 107). Values marked with different letters (a; b) indicate differences within the same color line.

In Herd 2, the evaluation of rumination time across different lactation stages revealed significant differences before, during, and after estrus for cows in three lactation periods: up to 80 days post-calving, from 81 to 150 days post-calving, and 151 days or more post-calving.

For cows in early lactation (up to 80 days post-calving), the average rumination time during the reference period of three days before estrus (day -3, day -2, and day -1) was 471, 473, and 474 min·d^{-1}, respectively. During estrus, rumination significantly decreased to 453 min·d^{-1} ($p < 0.05$). Recovery occurred in the post-estrus period, with rumination increasing to 467, 465, and 461 min·d^{-1} on days 1, 2, and 3, respectively.

For mid-lactation cows (81 to 150 days post-calving), rumination time during the pre-estrus reference period was slightly lower, with averages of 466, 467, and 468 min·d^{-1} for day -3, day -2, and day -1, respectively. A significant drop to 449 min·d^{-1} was observed during estrus ($p < 0.05$), followed by a gradual increase to 464, 465, and 462 min·d^{-1} on days 1, 2, and 3 post-estrus.

In late-lactation cows (151 days or more post-calving), rumination times were higher in the pre-estrus reference period, with averages of 484, 482, and 482 min·d^{-1} for day -3, day -2, and day -1, respectively. A reduction to 460 min·d^{-1} occurred during estrus, followed by recovery to 472, 470, and 472 min·d^{-1} on days 1, 2, and 3 post-estrus, respectively (Figure 5).

By analyzing the differences in total rumination time across 24 h for dairy cows grouped by lactation stage and herd, we identified statistically significant variations using a one-way ANOVA, followed by Scheffe's post hoc test. In Herd 1, significant differences were observed on day -1 between lactation stages 2 and 3 ($p < 0.05$). Additionally, in Herd 2, a highly significant difference was detected on day -2 between stages 1 and 3 ($p < 0.001$). On the day of estrus, no statistically significant differences were found in either herd, but trends suggested potential variations between lactation stages 2 and 3 in Herd 1 ($p = 0.08$). During the reference period after estrus, significant differences were observed in Herd 1 on day 1 between stages 1 and 3 ($p < 0.05$) and on day 2 between stages 1 and 3 ($p < 0.05$), as well as between stages 2 and 3 ($p < 0.05$) (Table 4).

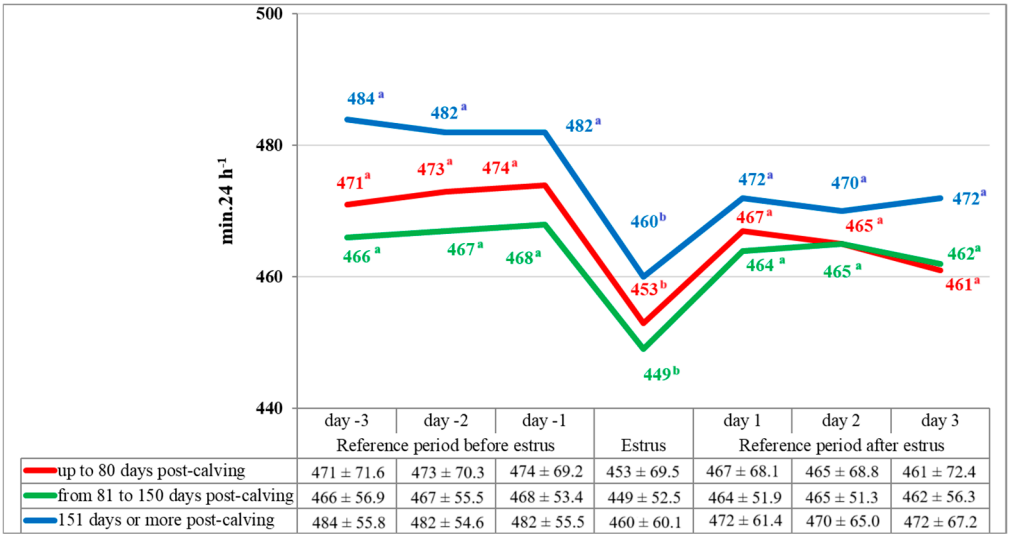


Figure 5. Changes in rumination time of dairy cows during the reference period and estrus based on lactation stage for Herd 2 (≤80 days: n = 158; 81–150 days: n = 10; ≥151 days: n = 32). Values marked with different letters (a; b) indicate differences within the same color line.

Table 4. Testing the differences in cows' rumination time according to lactation stage and herd during the reference period (days -3, -2, and -1 relative to estrus), estrus (day 0, considered the day of peak locomotion activity and insemination), and the post-estrus period (days 1, 2, and 3).

Indicator			Stage of Lactation	Difference of Averages	*t*-Test	P
Reference period before estrus	day -3	Herd 1	1 vs. 2	−3.45	−0.26	0.8
		Herd 2		4.78	0.6	0.55
		Herd 1	1 vs. 3	20.78	1.69	0.09
		Herd 2		−12.86	−1.13	0.26
		Herd 1	2 vs. 3	24.23	1.82	0.07
		Herd 2		−17.64	−1.56	0.13
	day -2	Herd 1	1 vs. 2	−2.04	−0.16	0.88
		Herd 2		5.67	0.73	0.47
		Herd 1	1 vs. 3	6.51	0.55	0.58
		Herd 2		−29.17	−3.14	<0.001
		Herd 1	2 vs. 3	8.55	0.69	0.49
		Herd 2		−14.74	−1.33	0.19
	day -1	Herd 1	1 vs. 2	−13	−1.04	0.3
		Herd 2		6.04	0.8	0.43
		Herd 1	1 vs. 3	11.24	0.92	0.36
		Herd 2		−8.26	−0.73	0.47
		Herd 1	2 vs. 3	24.24	2.15	<0.05
		Herd 2		−14.3	−1.28	0.2
Estrus		Herd 1	1 vs. 2	12.14	0.85	0.4
		Herd 2		4.13	0.55	0.59
		Herd 1	1 vs. 3	−11.29	−0.94	0.35
		Herd 2		−4.73	−0.4	0.7
		Herd 1	2 vs. 3	−23.43	−1.8	0.08
		Herd 2		−8.86	−0.75	0.46

Table 4. *Cont.*

Indicator			Stage of Lactation	Difference of Averages	*t*-Test	P
Reference period after estrus	day 1	Herd 1	1 vs. 2	1.71	0.14	0.89
		Herd 2		2.17	0.29	0.77
		Herd 1	1 vs. 3	24.54	2	<0.05
		Herd 2		−5	−0.41	0.68
		Herd 1	2 vs. 3	22.82	1.89	0.06
		Herd 2		−7.17	−0.6	0.55
	day 2	Herd 1	1 vs. 2	−2.35	−0.19	0.85
		Herd 2		−0.88	−0.12	0.91
		Herd 1	1 vs. 3	33.38	2.59	<0.05
		Herd 2		−5.03	−0.4	0.69
		Herd 1	2 vs. 3	35.73	2.67	<0.05
		Herd 2		−4.15	−0.33	0.74
	day 3	Herd 1	1 vs. 2	−6.59	−0.57	0.57
		Herd 2		−0.8	−0.1	0.92
		Herd 1	1 vs. 3	24.8	2.09	<0.05
		Herd 2		−10.39	−0.79	0.44
		Herd 1	2 vs. 3	31.39	2.4	<0.05
		Herd 2		−9.59	−0.73	0.47

1—cows up to 80 days post-calving; 2—cows from 81 to 150 days post-calving; 3—cows 151 days or more post-calving. P—significance.

3.4. The Effect of Milk Yield on Variations in Dairy Cow Rumination Time During Estrus

In Herd 1, dairy cows were divided into two groups based on daily milk production: low-producing cows (<34.29 kg) and high-producing cows (≥34.29 kg). During the reference period before estrus, rumination time was relatively balanced between the groups. On day -3 and day -2 before estrus, low-producing cows had average rumination times of 545 and 549 min·d^{-1}, while high-producing cows averaged 578 and 560 min·d^{-1}. On day -1 before estrus, a slight decrease was observed, with averages of 518 and 548 min·d^{-1} for the two groups, respectively.

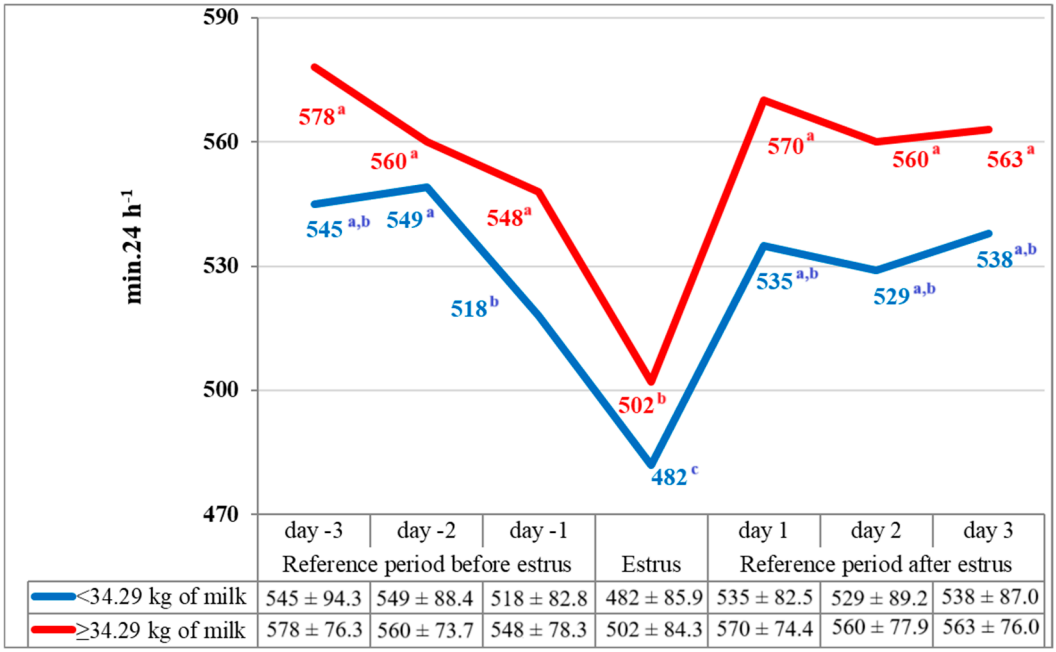
During estrus, rumination time dropped significantly in both groups. Low-producing cows recorded an average of 482 min·d^{-1}, while high-producing cows averaged 502 min·d^{-1}, showing a difference of 20 min.

In the reference period after estrus (days 1, 2, and 3 post-estrus), rumination time gradually increased. Low-producing cows had averages of 535, 529, and 538 min·d^{-1}, while high-producing cows showed averages of 570, 560, and 563 min·d^{-1} (Figure 6).

Although high-producing cows demonstrated slightly higher rumination times overall, the differences between the two groups were relatively small and statistically insignificant ($p > 0.05$). This indicates that the milk production level has only a minimal effect on variations in rumination time before and after estrus.

In Herd 2, dairy cows were divided into two groups based on daily milk production: low-producing cows (<34.29 kg) and high-producing cows (≥34.29 kg). During the reference period before estrus, rumination time was relatively stable in both groups. Low-producing cows recorded averages of 463, 463, and 465 min·d^{-1} on days -3, -2, and -1, respectively, while high-producing cows had averages of 477, 479, and 479 min·d^{-1}.

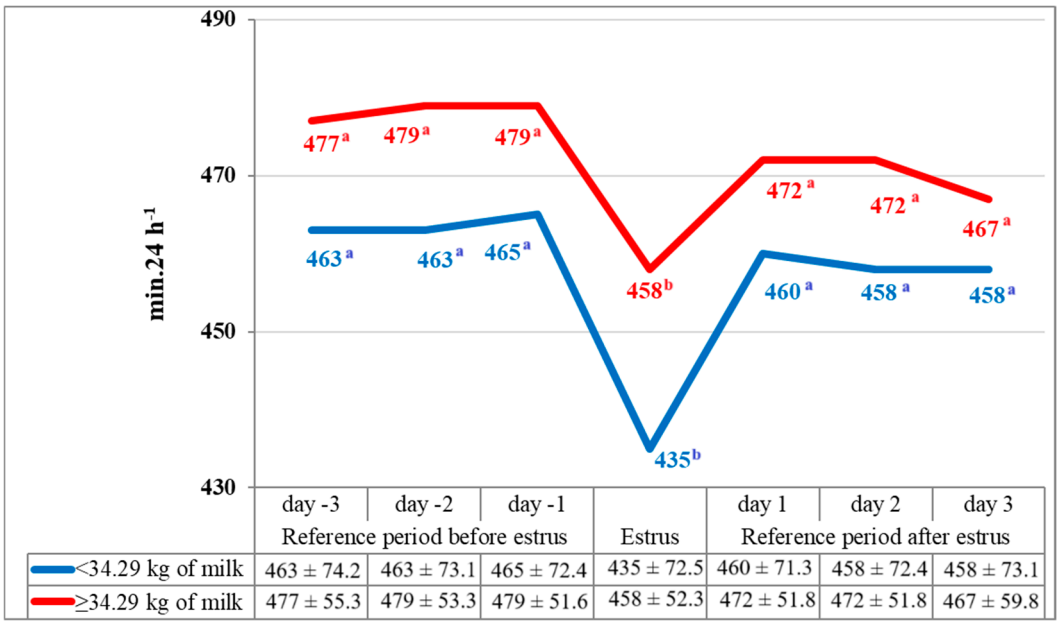
During estrus, rumination time decreased significantly in both groups. Low-producing cows averaged 435 min·d^{-1}, while high-producing cows averaged 458 min·d^{-1}, showing a clear reduction compared to the reference period.



	day -3	day -2	day -1		day 1	day 2	day 3
	Reference period before estrus			Estrus	Reference period after estrus		
<34.29 kg of milk	545 ± 94.3	549 ± 88.4	518 ± 82.8	482 ± 85.9	535 ± 82.5	529 ± 89.2	538 ± 87.0
≥34.29 kg of milk	578 ± 76.3	560 ± 73.7	548 ± 78.3	502 ± 84.3	570 ± 74.4	560 ± 77.9	563 ± 76.0

Figure 6. Changes in rumination time of dairy cows during the reference period and estrus based on milk yield for Herd 1 (<34.29 kg·day^{-1}, n = 218; ≥34.29 kg·day^{-1}, n = 122). Values marked with different letters (a; b; c) indicate differences within the same color line.

In the reference period after estrus (days 1, 2, and 3 post-estrus), rumination time gradually increased. Low-producing cows showed averages of 460, 458, and 458 min·d^{-1}, while high-producing cows recorded averages of 472, 472, and 467 min·d^{-1} (Figure 7).



	day -3	day -2	day -1		day 1	day 2	day 3
	Reference period before estrus			Estrus	Reference period after estrus		
<34.29 kg of milk	463 ± 74.2	463 ± 73.1	465 ± 72.4	435 ± 72.5	460 ± 71.3	458 ± 72.4	458 ± 73.1
≥34.29 kg of milk	477 ± 55.3	479 ± 53.3	479 ± 51.6	458 ± 52.3	472 ± 51.8	472 ± 51.8	467 ± 59.8

Figure 7. Changes in rumination time of dairy cows during the reference period and estrus based on milk yield for Herd 2 (<34.29 kg·day^{-1}: n = 138; ≥34.29 kg·day^{-1}: n = 156). Values marked with different letters (a; b) indicate differences within the same color line.

Although high-producing cows consistently showed higher rumination times across all phases, the differences between the two groups were relatively modest. Statistical significance is indicated by the use of superscript letters (a, b) in the graph, showing

meaningful differences primarily during estrus. This suggests that the milk production level influences rumination patterns, particularly during the estrus phase.

When testing the differences in total rumination time in 24 h between Herd 1 and Herd 2, significant differences ($p < 0.05$) were observed primarily in Herd 1 during specific days of the reference period. In the reference period before estrus, significant differences in Herd 1 were noted on day -3 ($p < 0.01$) and day -1 ($p < 0.01$), while no significant differences were confirmed in Herd 2. During estrus, a significant difference was observed in Herd 1 ($p < 0.05$), but not in Herd 2.

In the reference period after estrus, Herd 1 showed significant differences on day 1 ($p < 0.001$), day 2 ($p < 0.001$), and day 3 ($p < 0.05$). However, no significant differences were found in Herd 2 on any of the evaluated days after estrus (Table 5).

Table 5. Testing the differences in cows' rumination time according to milk yield and herd during the reference period and estrus.

Indicator			Difference of Averages	*t*-Test	P
Reference period before estrus	day -3	Herd 1	−33.08	−3.52	<0.01
		Herd 2	−10.23	−1.47	0.14
	day -2	Herd 1	−11.43	−1.28	0.2
		Herd 2	−12.39	−1.83	0.07
	day -1	Herd 1	−30.11	−3.33	<0.01
		Herd 2	−11.12	−1.68	0.1
Estrus		Herd 1	−19.92	−2.08	<0.05
		Herd 2	−10.41	−1.56	0.12
Reference period after estrus	day 1	Herd 1	−34.54	−3.95	<0.001
		Herd 2	−9.38	−1.43	0.15
	day 2	Herd 1	−31.31	−3.25	<0.001
		Herd 2	−10.15	−1.52	0.13
	day 3	Herd 1	−24.56	−2.71	<0.05
		Herd 2	−6.22	−0.87	0.4

P—significance.

These findings suggest that the rumination behavior of cows in Herd 1 is more sensitive to changes in the estrus cycle compared to Herd 2.

3.5. Statistical Analysis of Factors Affecting Dairy Cow Rumination During Estrus and Reference Periods

This study explored the role of various factors—including herd, parity, lactation stage, and milk yield—on changes in dairy cow rumination during the reference period (before estrus and after its conclusion) and estrus itself (Table 6).

Table 6. Examining the impact of selected factors on changes in cows' rumination time during estrus compared to the reference periods before and after estrus.

Factor of Influence	DF	Mean Squares	F Value	P	R^2
Herd	1	19,980.22	7.1	<0.01	
Parity	1	202.94	0.07	0.7884	
Lactation stage	2	15,933.03	2.83	0.0602	0.53
Milk yield	1	1331.18	0.47	0.492	
Factor of individual	180	664,310.48	1.31	<0.05	

P—significance; R^2—reliability of the estimate; DF—degrees of freedom.

Using a linear model, we determined the effects of the herd (F = 7.1. $p < 0.01$) and individual variability on alterations in rumination behavior during estrus when compared to the reference periods.

We observed differences in rumination time during estrus based on the results of post hoc tests at herd, parity, and lactation stages (Table 7).

Table 7. Post hoc test analysis of the effect of selected factors on variations in cow rumination time during estrus compared to the reference period before and after estrus.

Indicator	Level	Mean	Number	Duncan Grouping
Herd	1	−4.636	266	A
	2	56.569	340	B
Parity	heifers	75.295	78	A
	primiparous	33.919	234	B
	multiparous	14.253	294	C
Lactation stage	heifers	75.295	78	A
	up to 80 days	17.452	222	B
	81 to 150 days	31.787	168	B
	151 days or more	21.105	138	B
Milk yield	<34.29 kg of milk	32.204	348	A
	≥34.29 kg of milk	26.330	258	A

Level of significance $\alpha = 0.05$ (values labeled with different letters are considered to differ significantly).

4. Discussion

Based on the hypothesis proposed at the start of this study, we speculated that estrus significantly reduces rumination time in dairy cows, with the reduction influenced by factors like parity, lactation stage, and individual animal differences. Our findings do not reject this hypothesis, as we observed a significant decrease in rumination time during estrus, confirming previous studies. Additionally, the results indicate that rumination time returned to pre-estrus levels after estrus, supporting the expected pattern. The results clearly demonstrate a reduction in rumination time during estrus for both herds, followed by a recovery and stabilization of rumination during the reference period after estrus.

This reduction in rumination time during estrus is closely linked to changes in cows' daily behavior, particularly their lying time. Brehme et al. [14] report that estrus-induced restlessness decreases the total lying time in dairy cows, with some cows not lying down at all during estrus. Because cows spend most of their rumination time lying in stalls [13,15,16], the reduction in lying time directly impacts rumination. Dairy cows typically ruminate for 400 to 600 min per day, depending on their diet, and our study confirmed this, recording rumination times between 503 and 517 min during the reference period. These values align with previous findings, although Adin et al. [11] observed slightly lower rumination times in their study, ranging from 428 to 482 min.

Our study's evaluation of the impact of estrus on changes in rumination time in dairy cows corroborated the conclusions of Phillips and Schofield [7], who observed a 5 to 20% reduction in feed intake and rumination during estrus. This reduction is closely linked to the decrease in body weight of cows in estrus [8]. Reith et al. [16] found a decrease in rumination time by −61 min, 24 h^{-1} (−19.6%) on the day of estrus, which is a more pronounced decrease compared to our study's findings in Holstein cows (−6.2%). Adin et al. [11] also observed a decrease in rumination time during estrus (−74 min, 24 h^{-1}, or −17%), which they attributed to increased locomotion activity, an early external sign of estrus behavior. Reith and Hoy [12] confirmed a reduction in rumination during estrus, with the lowest value being 335 min, 24 h^{-1} (−74%). Cows naturally coming into heat

exhibited a decrease in rumination time, while cows with induced estrus displayed only minor changes in their behavioral patterns during estrus [17].

The effect of the herd on rumination time can be attributed to differences in management practices, including feeding strategies and feed composition. As highlighted in our study, cows from different herds were fed diets with varying fiber content, which directly influenced their rumination behavior. Herd 1 was provided a Total Mixed Ration (TMR) with higher structural fiber, promoting longer rumination times, while Herd 2's TMR contained less fiber, reducing rumination. This supports findings by Adin et al. [11] that diet composition significantly affects rumination duration. These dietary variations underline the importance of considering herd-specific feeding practices when interpreting rumination data.

In addition to differences between herds, there is inherent variability among individual cows in the time spent eating. The coefficient of variation (CV) for eating time (min/d) among cows is about 17% [18], but the CV is three- to four-fold greater for feeding time. Some meal characteristics are highly variable among cows. Frequency of meals (no./24 h) and overall meal duration are unique for individual cows, whereas eating rate and meal size are fairly consistent among cows [19].

Parity also influenced rumination time, as heifers and primiparous cows showed greater reductions during estrus compared to multiparous cows. This can be explained by the increased physiological and behavioral sensitivity of younger cows to estrous hormonal changes, leading to greater restlessness and reduced rumination. Additionally, multiparous cows may be better adapted to estrus-related disruptions due to their experience, as they exhibit less pronounced changes in locomotion and feeding behaviors. These findings align with Reith et al. [16], who noted a more significant reduction in rumination in primiparous cows compared to multiparous cows during estrus.

Reith et al. [16] also studied the impact of estrus on changes in rumination time in dairy cows, finding an average reduction of −98 min, 24 h^{-1} in primiparous cows and −69 min, 24 h^{-1} in multiparous cows during estrus compared to the reference period. The differences between primiparous and multiparous cows were statistically significant, with primiparous cows showing a more pronounced reduction (−29 min, 24 h^{-1}). Our study did not confirm such a decrease in rumination time (−36 min and −16 min, 24 h^{-1} for primiparous and multiparous cows, respectively), and it did not support higher rumination times in multiparous cows compared to primiparous cows, as reported by Maekawa et al. [20]. Pahl et al. [21] calculated an average rumination time of 293 min, 24 h^{-1} for primiparous cows and 430 min, 24 h^{-1} for multiparous cows, which are generally lower than the values recorded in our study for Holstein cows (−223 min, 24 h^{-1} for primiparous and −73 min, 24 h^{-1} for multiparous cows). This difference could be related to the milk production levels and the composition and structure of the diet, especially the dry matter and fiber content.

In line with our observations of the effect of lactation stage and milk yield on rumination time, our findings suggest that dietary factors, particularly fiber and dry matter content, may influence rumination time during both the reference period and estrus. Pahl et al. [21] also noted that differences in diet can significantly affect rumination time, particularly in relation to milk yield. High-producing cows tend to have shorter rumination periods, possibly due to the higher energy content of their diet, which often includes less fiber. This contrasts with lower-producing cows, who may have diets with higher fiber content, resulting in longer rumination times. The interaction between diet, milk production, and rumination behavior provides a valuable perspective on how management practices can optimize cow welfare and production during reproductive phases.

Pahl et al. [21] also noted a reduction in rumination time of −68 min, 24 h^{-1} for primiparous cows and −80 min, 24 h^{-1} for multiparous cows one day before insemination, a more significant decrease compared to our findings (−11 and −10 min, 24 h^{-1}, respectively). On the day of insemination, considered the day of estrus, Pahl et al. [21] recorded a reduction in rumination time (−74 min, 24 h^{-1} for primiparous and −76 min, 24 h^{-1} for multiparous cows) compared to the pre-estrus reference period. Similarly, our study observed a more pronounced decrease in rumination during estrus compared to the last day of the reference period (−50 and −71 min, 24 h^{-1} for primiparous and multiparous cows, respectively). Notably, rumination times returned to reference period levels one day after insemination, a pattern also reported by Adin et al. [11] and Reith and Hoy [12], who both noted decreases in rumination during estrus and insemination compared to the reference period.

Reith et al. [16] further studied the impact of milk production on changes in rumination time, observing lower rumination values in low-producing cows (446 and 407 min, 24 h^{-1} for high and low producers, respectively) during the reference period compared to our findings (−69 and −62 min, 24 h^{-1}). During estrus, Reith et al. [16] confirmed a decrease in 24 h rumination time to 337 min, 24 h^{-1} for high-producing cows (over 40 kg of milk) and 395 min, 24 h^{-1} for low-producing cows (up to 40 kg of milk). In our study, we observed a decrease in rumination time based on milk production, with Holstein cows showing rumination times of 489 and 479 min, 24 h^{-1} for cows producing less than and more than 34.3 kg of milk, respectively. These findings suggest that cows with lower milk production tend to have higher rumination times, likely due to the higher fiber content in their diet. Reith et al. [16] similarly concluded that high-producing cows experience a more intense decrease in rumination during estrus compared to other production groups, consistent with our findings. This behavior can be attributed to the composition of the diet, with low-producing cows receiving diets higher in dry matter while high-producing cows are fed higher-energy diets with lower fiber content, which is necessary to support their high milk yield. Diets with a higher proportion of concentrated feeds and lower fiber content are known to reduce rumination time [19,21,22].

Overall, our study confirms that estrus significantly impacts both rumination time and locomotion activity in dairy cows. The marked reduction in rumination time during estrus is likely driven by increased restlessness and heightened locomotion, behaviors closely associated with estrus. Monitoring these behavioral changes is crucial for gaining insights into both the reproductive status and the overall health of dairy cows.

Accurately identifying estrus is essential for the effective management and reproduction of dairy herds. Our previous research [23] highlighted an increase in locomotion activity as a key behavior of cows in estrus, and this current study supports those findings by emphasizing the inverse relationship between rumination time and locomotion activity during estrus. These results underline the importance of using advanced monitoring systems, such as the Heatime RuminAct, that provide real-time data on rumination and locomotion activities. Implementing these technologies on dairy farms can improve estrus detection, enhance reproductive management, and, ultimately, increase both the productivity and welfare of dairy cows.

5. Conclusions

Based on the results of our study, we observed a decrease in the rumination time of cows during estrus. The study also highlighted the impact of herd-specific factors on rumination behavior. Cows from Herd 1, which were fed a Total Mixed Ration (TMR) with higher fiber content, exhibited longer rumination times both before and during estrus compared to cows from Herd 2, which were provided a lower-fiber TMR. Specifically,

during the reference period, cows in Herd 1 ruminated for an average of 556 min per day, while those in Herd 2 averaged 471 min per day. During estrus, rumination times decreased to 509 min in Herd 1 and 452 min in Herd 2. These differences underscore the role of dietary composition and management practices in shaping rumination behavior. Furthermore, individual variability among cows contributed significantly to the observed changes in rumination time. The linear model analysis confirmed that both herd and individual factors had a significant effect on rumination behavior during estrus compared to the reference period ($p < 0.01$). This highlights the importance of considering both group-level and individual-level differences when interpreting rumination data for estrus detection. These findings underscore the importance of monitoring rumination behavior to enhance estrus detection and reproductive management in dairy cows. Implementing advanced monitoring systems, such as the Heatime RuminAct collars used in this study, can provide valuable insights into the reproductive status and overall health of cows. By tailoring herd management practices to account for dietary, parity, and individual differences, farmers can improve estrus detection accuracy and optimize reproductive performance, particularly in economically challenging regions like Slovakia.

Author Contributions: Conceptualization, P.S. and M.M.; methodology, P.S. and M.M.; statistical analysis, E.S.; writing—original draft preparation, P.S. and M.M.; writing—review and editing, M.M. and I.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the KEGA (Cultural and Educational Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic), project 017SPU-4/2022, the Grant Agency of Faculty of Agrobiology and Food Resources, SUA, in Nitra 9/2024—The use of activity and rumination sensors for detecting estrus and early diagnosis of the mammary gland and hoof diseases in dairy cows—and the Grant Agency of the Slovak University of Agriculture in Nitra 06-GA-SPU-2024—Utilization of smart technologies in cattle farm management, about milk production and quality, dairy cow health, and reduction of pigeon populations.

Institutional Review Board Statement: This article does not contain any studies with human or animal subjects and does not require IACUC/IRB/Ethics Committee approval, because the research involves collecting data from DataFlow™ II farm software and data on achieved milk yield were linked from Dairy Comp 305 parlor software and AfiFarm™ Herd Management. The study did not involve direct contact with animals.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available upon reasonable request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Economics, A. Agricultural Economics. Available online: https://agricecon.agriculturejournals.cz (accessed on 5 November 2024).
2. DATAcube. Available online: https://datacube.statistics.sk/?fbclid=IwAR0zZdxbFLCeP3KHLCcfPF4dUdYOq (accessed on 5 November 2024).
3. Milk and Milk Product Statistics. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Milk_and_milk_product_statistics (accessed on 5 November 2024).
4. Allrich, R.D. Endocrine and Neural Control of Estrus in Dairy Cows. *J. Dairy Sci.* **1994**, *77*, 2738–2744. [CrossRef] [PubMed]
5. Roelofs, J.; López-Gatius, F.; Hunter, R.H.F.; van Eerdenburg, F.J.C.M.; Hanzen, C. When Is a Cow in Estrus? Clinical and Practical Aspects. *Theriogenology* **2010**, *74*, 327–344. [CrossRef] [PubMed]
6. Mondal, M.; Rajkhowa, C.; Prakash, B.S. Relationship of Plasma Estradiol-17β, Total Estrogen, and Progesterone to Estrus Behavior in Mithun (*Bos frontalis*) Cows. *Horm. Behav.* **2006**, *49*, 626–633. [CrossRef] [PubMed]
7. Phillips, C.J.C.; Schofield, S.A. The Effect of Environment and Stage of the Oestrous Cycle on the Behaviour of Dairy Cows. *Appl. Anim. Behav. Sci.* **1990**, *27*, 21–31. [CrossRef]

8. Maltz, E.; Devir, S.; Metz, J.H.M.; Hogeveen, H. The Body Weight of the Dairy Cow. I. Introductory Study into the Body Weight Changes in Dairy Cows as a Management Aid. *Livest. Prod. Sci.* **1997**, *48*, 175–186. [CrossRef]
9. Sveberg, G.; Refsdal, A.O.; Erhard, H.W.; Kommisrud, E.; Aldrin, M.; Tvete, I.F.; Buckley, F.; Waldmann, A.; Ropstad, E. Behavior of Lactating Holstein-Friesian Cows during Spontaneous Cycles of Estrus. *J. Dairy Sci.* **2011**, *94*, 1289–1301. [CrossRef] [PubMed]
10. Roelofs, J.B.; van Eerdenburg, F.J.C.M.; Soede, N.M.; Kemp, B. Pedometer Readings for Estrous Detection and as Predictor for Time of Ovulation in Dairy Cattle. *Theriogenology* **2005**, *64*, 1690–1703. [CrossRef] [PubMed]
11. Adin, G.; Solomon, R.; Nikbachat, M.; Zenou, A.; Yosef, E.; Brosh, A.; Shabtay, A.; Mabjeesh, S.J.; Halachmi, I.; Miron, J. Effect of Feeding Cows in Early Lactation with Diets Differing in Roughage-Neutral Detergent Fiber Content on Intake Behavior, Rumination, and Milk Production. *J. Dairy Sci.* **2009**, *92*, 3364–3373. [CrossRef]
12. Reith, S.; Hoy, S. Relationship between Daily Rumination Time and Estrus of Dairy Cows. *J. Dairy Sci.* **2012**, *95*, 6416–6420. [CrossRef] [PubMed]
13. Schirmann, K.; Chapinal, N.; Weary, D.M.; Heuwieser, W.; von Keyserlingk, M.A.G. Rumination and Its Relationship to Feeding and Lying Behavior in Holstein Dairy Cows. *J. Dairy Sci.* **2012**, *95*, 3212–3217. [CrossRef] [PubMed]
14. Brehme, U.; Stollberg, U.; Holz, R.; Schleusener, T. ALT pedometer—A new sensor-aided measurement system for improvement in oestrus detection. *Res. Agric. Eng.* **2006**, *52*, 1–10. [CrossRef]
15. Österman, S.; Redbo, I. Effects of Milking Frequency on Lying down and Getting up Behaviour in Dairy Cows. *Appl. Anim. Behav. Sci.* **2001**, *70*, 167–176. [CrossRef] [PubMed]
16. Reith, S.; Brandt, H.; Hoy, S. Simultaneous Analysis of Activity and Rumination Time, Based on Collar-Mounted Sensor Technology, of Dairy Cows over the Peri-Estrus Period. *Livest. Sci.* **2014**, *170*, 219–227. [CrossRef]
17. Schweinzer, V.; Gusterer, E.; Kanz, P.; Krieger, S.; Süss, D.; Lidauer, L.; Berger, A.; Kickinger, F.; Öhlschuster, M.; Auer, W.; et al. Comparison of Behavioral Patterns of Dairy Cows with Natural Estrus and Induced Ovulation Detected by an Ear-Tag Based Accelerometer. *Theriogenology* **2020**, *157*, 33–41. [CrossRef] [PubMed]
18. Dado, R.G.; Allen, M.S. Variation in and Relationships Among Feeding, Chewing, and Drinking Variables for Lactating Dairy Cows. *J. Dairy Sci.* **1994**, *77*, 132–144. [CrossRef] [PubMed]
19. Vasilatos, R.; Wangsness, P.J. Feeding Behavior of Lactating Dairy Cows as Measured by Time-Lapse Photography. *J. Dairy Sci.* **1980**, *63*, 412–416. [CrossRef]
20. Maekawa, M.; Beauchemin, K.A.; Christensen, D.A. Effect of Concentrate Level and Feeding Management on Chewing Activities, Saliva Production, and Ruminal pH of Lactating Dairy Cows. *J. Dairy Sci.* **2002**, *85*, 1165–1175. [CrossRef] [PubMed]
21. Pahl, C.; Hartung, E.; Grothmann, A.; Mahlkow-Nerge, K.; Haeussermann, A. Rumination Activity of Dairy Cows in the 24 Hours before and after Calving. *J. Dairy Sci.* **2014**, *97*, 6935–6941. [CrossRef] [PubMed]
22. Krause, K.M.; Combs, D.K.; Beauchemin, K.A. Effects of Forage Particle Size and Grain Fermentability in Midlactation Cows. II. Ruminal pH and Chewing Activity. *J. Dairy Sci.* **2002**, *85*, 1947–1957. [CrossRef] [PubMed]
23. Mičiaková, M.; Strapák, P.; Strapáková, E. The Influence of Selected Factors on Changes in Locomotion Activity during Estrus in Dairy Cows. *Animals* **2024**, *14*, 1421. [CrossRef] [PubMed]