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Circadian Lying Behaviour Assessed in a Commercial Mixed Horned Dairy Goat Herd

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Simple Summary: Management practices in working with farm animals should be constantly improved. As dairy goats are primarily animals with circadian rhythms, management should fit their needs to generate high milk yields by adapting to the natural behaviour of goats as ruminants. The present study indicates that lying behaviour follows a general circadian progression. The longest lying periods occurred at night, whilst milking times achieved the shortest lying duration.

Abstract: In general, the lying behaviour of dairy goats follows a circadian progression. As lying times might have an effect on the health, performance and welfare of dairy goats, housing conditions and management practices should follow circadian behavioural patterns. In the present study, a mixed horned herd of Bunte Deutsche Edelziege was used. Goats were housed in a commercial dairy goat farm in south Germany. During two lactation periods, 20 goats in each period were fitted with an accelerometer to detect lying behaviour. To analyse the accelerometer data, a mixed linear model was used. The highest frequencies of lying bouts (FLBs) occurred in the afternoon, and the lowest ones occurred during milking. Generally, the least square means ± SE of the FLB counts per goat ranged between 1.72 ± 0.07 (20:00–21:59 P.M.) and 2.87 ± 0.07 (12:00–13:59 P.M.). The longest lying bouts (LBD) occurred at night, and lying bouts remained relatively short in the afternoon between milking times. The maximum LBD was 52.20 ± 0.01 min/bout (at night, 02:00–03:59 A.M.), and the shortest duration was 14.31 ± 0.01 min/bout (during morning milking, 08:00–09:59 A.M.). The interactions of time and month had a significant impact on FLB and LBD ($p < 0.0001$), and so did the interactions of horn status and time ($p < 0.05$). Further research is necessary to analyse the lying behaviour of dairy goats in more detail to improve management practices.

Keywords: lying behaviour; dairy goats; daily schedule; accelerometer technique

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Citation: Maurmann, I.; Bernau, M. Circadian Lying Behaviour Assessed in a Commercial Mixed Horned Dairy Goat Herd. *Ruminants* **2023**, *3*, 111–120. https://doi.org/10.3390/ruminants3020010

Academic Editor: D. Claire Wathes

Received: 13 January 2023
Revised: 17 March 2023
Accepted: 27 March 2023
Published: 2 April 2023

1. Introduction

Goats are small ruminants that are primarily animals with circadian rhythms. Some studies describe this general circadian activity. Most of them were conducted in experimental setups with only a small number of goats [1–5], artificial light [2], goats separated by horn status [1,4,5], goats of the same age [1,5] or breeds that are not typically used for milk production in Germany [6]. To evaluate activity, some studies used video observing [1,4], observational tools or scan sampling for only some hours of the day [7].

Nevertheless, some general findings were achieved in these studies: The main activity of goats is in the middle of the day [2]. Most lying is at night, between 8 P.M. and 6 A.M. [6]. Activities outside the photophase can also be found [2,3]. For lying down, goats prefer indoors even when outdoor access exists, regardless of roof cover or not [7]. Additionally, adequate distance from other goats is needed for lying down [5] to reduce interruptions while resting [4] and increase lying times for low-ranked goats [1].

As the lying times of dairy goats were mainly used in experimental setups [1,3–6,8–11], a limited number of influencing factors can be considered. On-farm studies in commercial

dairy goat farms are lacking, but lying times might serve as an indicator for the health, performance and welfare of dairy goats, as it has already been proven in other ruminants, such as dairy cows [12]. Therefore, the housing of dairy goats should consider their natural activity and lying behaviour to promote animal welfare [13,14].

To detect lying times in goats without using time-intensive observation, accelerometer techniques serve as method of choice and are suitable in small ruminants [9,15]. In addition to the described findings of previous studies [1–7], more information of the circadian lying behaviour of dairy goats throughout lactation periods on commercial farms is necessary. Therefore, the present study aimed at evaluating circadian lying behaviour in a mixed horned dairy goat herd using the accelerometer technique. Two-hour evaluation intervals were used to provide more detailed information in order to (1) gain more information about the lying behaviour of dairy goats under commercial conditions and eventually to (2) be able to give recommendations on how to adapt goat husbandry to the circadian rhythm of goats.

2. Materials and Methods

2.1. Animals

A mixed horned herd of Bunte Deutsche Edelziegen was used in the present study. Measurements took place from April 2019 to October 2020, representing two lactation periods, with April being the beginning of lactation, and October, the end. Over time, the herd size varied due to restocking and destocking. The herd had an average size of 67.5 ± 4.1 goats. Since 2018, only horned goats had been integrated into the herd. Therefore, the ratio of horned goats increased from 41% to 57% within the study period.

2.2. Housing

The dairy goat farm was located in the north of Baden-Württemberg, south Germany. Housing and keeping were in concordance with local and national guidelines [16,17]. Goats were kept in a single-level, loose housing system (135 m^2 ground space) with open front and access to a paved outdoor area (135 m^2 ground space). Automatic feeding stations and feed store reduced the indoor area to approximately 123 m^2. Due to a replacement of the feeding system in October 2019, this lying area was enlarged to 129.5 m^2. The single-level indoor area was covered with deep straw bedding. Access to the outdoor area was granted all year (for further information, see [15]).

2.3. Milking and Feeding

Goats were milked twice a day, with times varying between 7:30 and 10:00, and 18:00 and 22:00. The mean annual milk yield evaluation of all goats in the herd resulted in 751.42 kg milk/goat (255.96 milking days) in 2019 and 766.23 kg milk/goat (258.40 milking days) in 2020. In both years, goats had an average life performance of over 3.000 kg milk (3.607 kg milk in 2019 and 3.654 kg milk in 2020).

Hay was fed four times a day: twice during milking, once at noon and once in the afternoon. In summer, grass and alfalfa were added, and depending on the weather conditions, goats grazed on pasture at different times. Two installed automatic feeding systems offered concentrated feed according to the individual milk yield. The number of daily feedings was individually calculated by the system according to the amount of concentrated feed. Access to water was given ad libitum.

2.4. Measurements

Accelerometers (MSR145WD; MSR Electronics GmbH, Seuzach, Switzerland) were attached to the hind legs of 20 randomly selected goats. Measurements took place during the course of lactation in 2019 and 2020. In both years, measurements were performed in the months of April, June and October. In 2020, additional measurements were performed in May and August. Randomly selected goats were chosen in each measurement period. Accelerometers were programmed in advance, with start time at 00:00 (with the exception

of April 2019: start at 12:00). They were fixed to the goats' legs during milking on the day before measurements started. Data were recorded every five seconds. Measurements were taken for seven consecutive days. Accelerometers were removed the day after. Details about the different measurement periods are displayed in Table 1. As displayed in Table 1, not all 20 accelerometers could be analysed for all measurement periods. Some accelerometers had to be removed earlier, or goats lost the accelerometer. These accelerometers were removed from evaluation.

Table 1. Description of the measurement periods, the number of evaluated accelerometers, the average age (mean ± SD) and the horn status of the goats equipped with accelerometers.

Details of Goats Equipped with Accelerometers/Month of Data Evaluation	Apr 2019	Jun 2019	Oct/Nov 2019	Mar/Apr 2020	May 2020	Jun 2020	Aug 2020	Oct 2020
Measurement period	04.04–11.04	08.06–14.06	28.10–03.11	28.03–03.04	02.05–09.05	13.06–19.06	01.08–08.08	03.10–09.10
Number of goats in the herd	76	72	64	72	69	67	66	65
Evaluated accelerometers (n)	19	16	19	20	19	20	20	20
Number of horned goats equipped with accelerometer	11	8	8	11	12	13	9	12
Number of hornless goats equipped with accelerometer	8	8	11	9	7	7	11	8
Mean age of horned goats (a) equipped with accelerometer	3.1 ± 3.1	2.6 ± 1.9	2.8 ± 1.0	3.4 ± 1.1	3.2 ± 1.2	3.0 ± 1.9	3.3 ± 1.0	2.8 ± 2.1
Mean age of hornless goats (a) equipped with accelerometer	7.8 ± 3.2	5.9 ± 2.5	6.1 ± 2.7	7.1 ± 1.9	7.9 ± 2.7	6.7 ± 3.4	8.0 ± 2.4	6.6 ± 3.6

Explanation: (n) = counted number; (a) = year.

2.5. Data Evaluation

Accelerometer data were analysed using MSR software (MSR Electronics GmbH) and Excel (Microsoft Corporation). For data analysis, a ten-second interval was used to remove false readings. False reading means false detection of lying-down events, which could happen due to goats scratching themselves with the hind legs or turning around while lying. To avoid these, we chose a ten-second interval for analysis. To give a general overview of lying times and lying behaviour, descriptive data are presented in Table 2.

For the evaluation of the daily course of lying behaviour, each day was divided into twelve two-hour time sections (time). Two-hour time sections were chosen to compensate for variations in daily management practices, as milking and feeding were not performed at the exact same time every day, as measurements took place in a commercial setting, not in an experimental one. LBD corresponded to the time during which the goat lay down, even if it was longer than two hours.

2.6. Statistics

For statistical analysis, the following variables were created:

- Frequency of lying bouts (n/time and goat) (FLB), representing the mean number of all lying bouts per goat that occurred in a two-hour section.
- Lying bout duration (min./bout) (LBD), representing the mean lying bout duration per time and goat, calculated by dividing the sum of all LBDs of one time by all FLBs of the same time.

To check for significant differences in the lying behaviour of goats during the day, a mixed linear model approach (PROC MIXED; SAS Institute Inc., Carrey, NC, USA) was

used. The traits FLB and LBD were the response variables. As the residuals for LBD were not normally distributed, data were transformed using the square root method. The fixed effects were time (two-hour intervals), month and year of data collection, horn status, the interactions of horn status and time, and the interactions of time and month. The age of the goats was not used in the statistical model, as age and horn status were highly correlated due to the above-explained management practices. The individual goat was used as the random effect. Degrees of freedom were computed using the Kenward and Rodger method [18]. Least square means (LSmeans) and differences of least square means were calculated for significant categorial variables or interactions and for the time variable to create diagrams of circadian lying behaviour. As data showed a balanced structure, the standard error (SE) was the same for each estimate. No SE is shown in Figure 1, as the values were too small to be seen. If interactions were significant, the results of single variables were not further interpreted. The results of LBD had to be back-transformed by squaring the estimates.

3. Results

3.1. Mean Values of Total Lying Time, Lying Bout Duration and Frequency of Lying Bouts

Table 2 shows the ordinary mean total lying time, lying bout duration (LBD) and frequency of lying bouts (FLB) per goat and day. A seasonal progression can be seen for lying times and LBD (see Table 2), with higher ones in spring and lower ones in summer, whereas for the FLB, it was exactly the opposite.

Table 2. Means and standard deviation of lying time, lying bout duration (LBD) and number of lying bouts (FLB) of goats in each month. Averaged across all goats and all days for each period.

	Apr 2019	Jun 2019	Oct/Nov 2019	Mar/Apr 2020	May 2020	Jun 2020	Aug 2020	Oct 2020
Mean lying time per goat and day (h)	12.02 ± 1.86	11.03 ± 1.41	11.75 ± 1.19	12.48 ± 1.07	10.74 ± 1.45	11.93 ± 1.23	11.56 ± 0.97	11.42 ± 1.66
LBD per goat, day and lying bout (min.)	34.19 ± 8.17	25.37 ± 5.35	30.99 ± 5.50	33.58 ± 3.58	23.51 ± 4.78	26.00 ± 4.27	22.38 ± 5.57	31.59 ± 4.47
FLB per goat and day (n)	22.17 ± 6.50	27.02 ± 5.13	23.80 ± 4.44	22.47 ± 2.53	28.65 ± 7.54	28.42 ± 6.55	32.88 ± 5.43	22.61 ± 4.53

Explanation: (h) = hour; (min) = minute; (n) = counted number.

3.2. Circadian Occurrence of Frequency of Lying Bouts (FLB) and Lying Bout Duration (LBD)

Regarding the FLB, the variables time ($p < 0.0001$), month ($p < 0.0001$), horn status ($p = 0.0017$), and the interactions of time and month ($p < 0.0001$) and of time and horn status ($p = 0.0112$) were significant. Year was not significant ($p = 0.6060$).

Regarding LBD, the variables time ($p < 0.0001$), month ($p < 0.0001$) and horn status ($p = 0.0011$), the interactions of time and month ($p < 0.0001$) and the interactions of time and horn status ($p = 0.0496$) were significant. Year was not significant ($p = 0.4158$).

The occurrence of FLB and LBD during the day can be seen in Figure 1 (Figure 1a for FLB; Figure 1b for LBD). Significant differences between the FLB and LBD of different times existed, demonstrated using superscript letters. Least square means with at least one identical superscript were not significantly different from each other.

Higher frequencies of lying bouts (FLBs) occurred in the afternoon, with the lowest FLB occurring during and after milking in the evening (Figure 1a). Generally, the least square means ± SE of FLB counts ranged between 1.72 ± 0.07 (20:00–21:59) and 2.87 ± 0.07 (12:00–13:59). The longest lying bouts (LBD) occurred at night, with 52.20 ± 0.01 min/bout (see Figure 1b; 02:00–03:59), and decreased until morning milking (08:00–09:59). Between morning and evening milking, LBD remained at a low level (see Figure 1b; 08:00–21:59) with a maximum of 20.88 ± 0.01 min/bout (see Figure 1b; 16:00–17:59). The shortest duration

of lying bouts occurred during milking in the morning, with 14.31 ± 0.01 min/bout (see Figure 1b; 08:00–09:59), and evening milking, with 15.47 ± 0.01 min./bout.

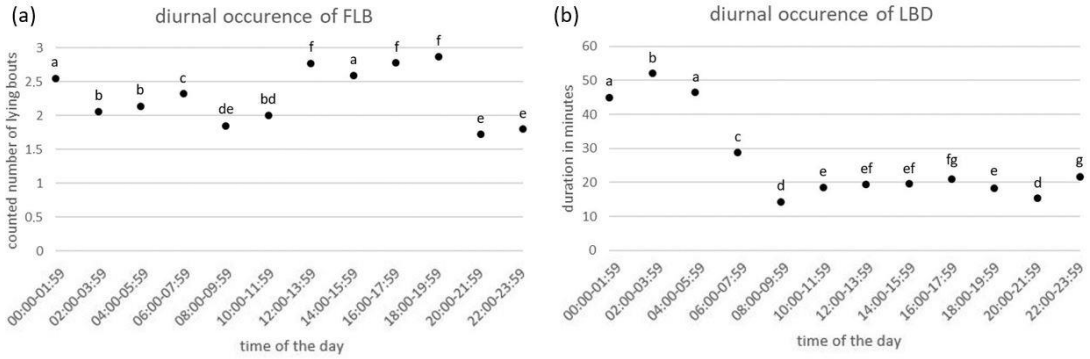

Figure 1. Results of least square means of the statistical models for FLB and LBD: (**a**) Frequency of lying bouts (FLB) per goat and time of day (2 h each). (**b**) Lying bout duration (LBD) per goat and time of day (2 h each). Means with at least one identical letter were not significantly different ($p < 0.05$) from each other.

3.3. Circadian Occurrence of FLB and LBD Regarding Horn Status

Table 3 represents the differences between FLB and LBD of horned and hornless goats at different times of the day. Hornless goats had a lower FLB than horned goats, except for time 12. The difference in horn status regarding the FLB was significant in the morning (time 4) and in the afternoon until late evening (times 6–11). At night, no significant differences between horned and hornless goats regarding the FLB could be detected (times 1–3, 12). Hornless goats had higher LBD than horned goats. Significant differences occurred several times in the morning and afternoon (times 1, 4–5, 7–9).

Table 3. Differences in LSmeans of the interactions of time and horn status. Estimates of FLB and LBD are the differences between hornless and horned values. Significance level was $p < 0.05$ and significant values are bolded.

Time	Hours	Horn Status		FLB [1]	*p*-Value	LBD [2]	*p*-Value
1	00:00–01:59	Hornless	Horned	−2.5632	0.0740	5.5105	**0.0183**
2	02:00–03:59	Hornless	Horned	−1.0981	0.4429	1.7355	0.4884
3	04:00–05:59	Hornless	Horned	−2.8164	0.4980	3.2717	0.1666
4	06:00–07:59	Hornless	Horned	−3.8934	**0.0069**	4.5856	**0.0141**
5	08:00–09:59	Hornless	Horned	−2.4920	0.0823	2.6478	**0.0440**
6	10:00–11:59	Hornless	Horned	−3.4496	**0.0165**	1.5765	0.2906
7	12:00–13:59	Hornless	Horned	−4.4796	**0.0019**	5.7530	**0.0002**
8	14:00–15:59	Hornless	Horned	−4.1028	**0.0044**	5.2980	**0.0006**
9	16:00–17:59	Hornless	Horned	−5.8415	**<0.0001**	6.4078	**<0.0001**
10	18:00–19:59	Hornless	Horned	−3.6694	**0.0108**	2.8773	0.0532
11	20:00–21:59	Hornless	Horned	−4.2489	**0.0032**	1.8260	0.1809
12	22:00–23:59	Hornless	Horned	0.3281	0.8186	2.8145	0.0823

[1] SE of FLB estimates: 0.7388. [2] SE of LBD estimates: 0.08983.

4. Discussion

This study evaluated the circadian profiles of the lying behaviour of dairy goats housed in a commercial farm located in Germany. New findings were achieved regarding circadian activity in a commercial mixed horned dairy goat herd: the circadian lying behaviour did not change over the seasons, and the milking time had a significant impact on circadian activity (FLB and LBD) as well as horn status.

4.1. Lying Times and Lying Behaviour in Seasonal Progression

The seasonal progression of lying times and lying behaviour (FLB and LBD) was detected (see Table 2). At the beginning of lactation, longer lying times (resulting from longer LBD and a lower FLB) were detected, followed by a reduction in summer (resulting from shorter LBD and a higher FLB) and a final increase at the end of lactation. This was already described and discussed by Maurmann et al. [15]. Additional data from May and August did not change this progression (see Table 2) but showed more details in the progression course. As random weeks of the year represent the current data, and information about temperature, pasture access and other influencing factors is not given, the results cannot be exactly transferred to other goat farms. However, both evaluated years generally showed similar progression (FLB, $p = 0.6060$; LBD, $p = 0.4158$), which confirmed the seasonal progression of dairy goat lying behaviour. In addition, these results can be confirmed by Sailer et al. [19], who showed the influence of seasons on the FLB in dairy goats, resulting in a higher FLB in spring than in autumn, assuming that pasture access in autumn reduced agonistic behaviour [19]. A conclusion about agonistic behaviour cannot be drawn in the present study, as this was not evaluated.

Circadian lying behaviour had the same course over all months, which can be seen in Figure 1, but the course had different levels (see Table 2). Nevertheless, the interactions of time and month were significant ($p < 0.0001$), as the levels of the course were different in each season. In spring and autumn, goats had longer LBD and a lower FLB than in summer (see Table 2). To sum up, the circadian course of lying behaviour is shown in Figure 1, but depending on the season, with that depending on the lactational stage, the level of the course was different (see Table 2).

4.2. Lying Times and Lying Behaviour in Circadian Progression

The present study evaluated lying behaviour in two-hour time sections a day. Two-hour time sections were chosen to compensate for variations in daily management practices, as milking and feeding were not performed at the exact same time every day. As a result, it was possible to show the circadian lying behaviour of goats in more detail, with differences in FLB and LBD in daily progression (see Figure 1). Other studies chose different evaluation phases: Stachowicz et al. [6] observed the circadian lying behaviour of goats with the visual inspection of plotted accelerometer data. Piccione et al. [2] divided the day in photophase and scotophase to identify differences in the lying behaviour of goats and sheep. Farsi et al. [3] divided the activity score measured using accelerometers in day and night activity, not by considering single hours. All these previous studies provided information about the difference in the lying behaviour in dairy goats between day and night. However, for daily practice in dairy goat farms, the circadian progression of lying behaviour is interesting.

The influencing factors of the circadian progression of FLB and LBD are discussed below.

4.2.1. Influence of Milking Time

Milking time had a significant impact on FLB and LBD, as the lowest values of both traits were achieved during and after milking (see Figure 1). This can be explained by the milking routine itself. Goats recognized the beginning of milking when the farmer closed the gate to the outdoor area. As the number of places in the milking parlour was limited, the other goats had to wait. This can be confirmed by findings in dairy cows, where lying behaviour was affected by the time at which cows were milked or during which they waited to be milked (e.g., [20,21]). In this study, a reason for low values after milking could be the fact that goats were fed hay during milking, so when they returned to their stable, they ate before laying down.

In the present study, the longest LBD was detected at night (00:00 to 06:00) (see Figure 1b). The present observation is in accordance with the results obtained by Stachowicz et al. [6], who detected most lying at night between 8 P.M. and 6 A.M. The longer activity

times in the evening, compared with the results obtained by Stachowicz et al. [6], might be explained by the relatively late evening milking in the present study. In further studies, the time at which goats are individually milked and that during which they wait to be milked should also be analysed in detail to give recommendations for milking routines in dairy goats.

4.2.2. Influence of Housing Conditions

During the day—between morning and evening milking—LBD remained at a low level, with around 20 min per lying bout (see Figure 1b), possibly due to the following:

(a) One hypothesis for low LBD and a high FLB during the afternoon (see Figure 1) could be increased temperatures in the stable, combined with the influence of bedding on dairy goat behaviour [22,23]. As it was confirmed in dairy cows, temperature and temperature–humidity index lead to less lying and resting in the afternoon and preferred lying down in the morning [12]. However, temperatures were not assessed in the present study.

(b) Additionally, goats prefer an adequate distance from others around them while lying [5] and prefer lying indoors even when outdoor access exists [7]. If all goats in the present study wanted to rest indoors, this could have led to dominance interactions due to space availability and warm straw bedding.

The present stable did not provide any structural elements that would have allowed goats to climb and rest in elevated spaces, which is known to increase the lying times of goats [4]. Maybe a structural change in housing conditions using visual covers or elevated levels may reduce lying interruptions [4,24]. The lack of climbing and hiding possibilities, and thus the resulting interruptions of lying, could have led to a general high level of FLB throughout the day (see Figure 1a). Nevertheless, no data—to our knowledge—are available with which lying times can be interpreted as affecting the health of dairy goats. However, this knowledge would be very important for management practices to ensure the best possible animal welfare.

In the present study, the average FLB ranged between 22 and 34 bouts/day and goat (Table 2), depending on the season, and between 1.72 and 2.87 bouts/two hours, averaged over all months (Figure 1a). Zobel et al. [8] documented a mean of 12 lying bouts/day, that is, about 1 bout/two hours. In the present study, resting in the activity area of the farm could have led to even more interruptions by other goats, especially during the afternoon, as the main activity of goats was observable at that time (Figure 1a). The main activity in a study by Piccione et al. [2] was observable during the photophase, with a cosine peak between 11:30 and 14:30. This was confirmed in the present study, as LBD during the day was shorter and the FLB was higher than at night (see Figure 1), indicating more activity throughout the day.

Additionally, the installed feeding stations and hay racks might have influenced lying behaviour due to non-existing visual covers or elevated levels. However, in dairy cows, the feeding frequency has no effects on lying behaviour [25]. In addition, grazing times and pasture access might have influenced the present data. This has to be evaluated in further studies to examine the influencing factors.

4.2.3. Influence of Horn Status, Rank and Age

Regarding FLB and LBD, the interactions of time and horn status were significant. In the present study, all young goats were horned, and most of the very old goats were hornless, as a result of the above-described management practice. In fact, age was included in horn status, and because of that, it cannot be clearly stated which one had the greatest impact. For evaluation, horn status was used, as horn status has a greater relevance in German goat keeping, as dehorning is forbidden [16] and most dairy goat breeds are naturally horned. Further studies are needed to evaluate the influence of age, as also in dairy cows, it is a hardly discussed topic [20]. However, horn status could also have an

effect on lying behaviour in mixed-horned herds, as the needs of horned goats are different from those of hornless goats [5,26–28].

A reason for the higher FLBs recorded in the afternoon (see Figure 1a) and the significant differences between horned and hornless goats at that time (see Table 3) could be a general difference in daily behaviour induced by rank. Stachowicz et al. [6] stated that the activity of young, low-ranked goats is higher than that of older, higher-ranked goats. All young goats were horned. That could be a reason for the significantly higher activity of horned goats during the afternoon. Low-ranked goats tend to rest in the activity area, especially in one-level pens [1]. In the present study, the lying area was also the activity area, which might have resulted in more interruptions and thus shorter lying times. High-ranked goats in the present study might have had priority access to the automatic feeding station and hay racks, as this is described in dominant individual ruminants [29,30]. As no rank analysis was possible in the present study, this assumption cannot be proven right now.

Another influencing factor might be that in the present study, horned and hornless goats were kept together in one herd, which is not recommended by Miranda-de la Lama et al. [31], as horned goats show more aggressive behaviour than hornless goats [5]. High-ranked (older and horned) goats may have had to defend their lying area more often, which could have led to a higher FLB and shorter LBD (see Table 3).

4.3. Further Research

Due to the presented findings, further research is necessary to constantly improve animal welfare and management practices in practical, intensive farming with dairy goats. Interesting points could be, e.g., the influence of milking routines on the lying behaviour of dairy goats in more detail and its influencing factors in groups with the same horn status or of the same age.

5. Conclusions

In general, the lying behaviour of dairy goats follows a circadian progression. The highest frequencies of lying bouts (FLBs) occurred in the afternoon, and the lowest occurred during milking. The longest lying bouts (LBD) occurred at night, and lying bouts remained relatively short in the afternoon between milking times. The interactions of time and month had a significant impact on FLB and LBD ($p < 0.0001$), showing the same course of circadian lying behaviour throughout the year as well as different levels of the course in different months. Additionally, the interactions of time and horn status (FLB, $p < 0.0112$; L D, $p = 0.0496$) were significant. Further research is necessary to analyse the lying behaviour of dairy goats in more detail to improve management practices.

Author Contributions: Conceptualization I.M. and M.B.; methodology I.M.; formal analysis I.M.; investigation I.M.; writing—original draft preparation I.M. and M.B.; writing—review and editing I.M. and M.B.; visualization I.M.; project administration M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded within the framework of the European Innovation Partnership "Landwirtschaftliche Produktivität und Nachhaltigkeit" (EIP-AGRI). The funding measure is a measure of "Maßnahmen- und Entwicklungsplan Ländlicher Raum Baden-Württemberg 2014–2020" (MEPL III). The project was funded by the state of Baden-Württemberg and "Europäischer Landwirtschaftsfond für die Entwicklung des Ländlichen Raums (ELER)".

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and was in accordance with national animal welfare law. The animal study protocol was approved by the Institutional Review Board of HfWU (protocol code 2019_01; date of 4 February 2019).

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing not applicable.

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

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