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Effect of evaporative cooling on heat stress mitigation and activity behavior in high-yielding dairy cows

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The present study aimed to evaluate the heat mitigation from evaporative cooling on the respiration rate (RR) and activity behavior in dairy cows under hot and dry climate in Mediterranean conditions. Twelve multiparous high-yielding Holstein dairy cows (2nd to 5th lactation) were randomly selected. Each cow was equipped with one pedometer to monitor different activity traits related to "resting" and "locomotion" behavior. The ambient temperature (AT) and relative humidity (RH) were recorded and the temperature-humidity index (THI) was calculated. A linear mixed model with repeated measurements was established to test the THI influence and cooling effect on animal traits. The RR regarding the second cooling decreased (54.6 ± 10.7) compared to the responses of cows an hour before (74.6 ± 13.1 breaths per min (bpm); $p < 0.001$). The lying behavior tended to increase after the cooling sessions, especially post-evening cooling (39 ± 4.76 bpm; $p < 0.001$). The evaporative cooling promoted a heat stress abatement by RR values and lying time behavior in dairy cows under hot and dry climate conditions.

Keywords
Dairy cow, respiration rate, heat load, temperature-humidity index, lying position

Weather and climate can pose significant challenges to farm animals, making the ability to predict climate variable effects important for ensuring animal welfare, and performances (Foroushani and Amon 2022). In the Mediterranean countries, the warm and humid climate presents a particularly high risk for dairy cattle, with July and August being the peak months for weather discomfort conditions (Segnalini et al. 2013). Heat stress can cause considerable economic losses in the dairy industry with estimated annual losses ranging from USD 897 to USD 1,405 billion in the USA alone (St-Pierre et al. 2003). Adaptability on livestock production is essential for improving system sustainability under climate and weather pressures (Segnalini et al. 2013, Ferreira et al. 2016).

Responses to heat stress can be usually characterized as acute (3–4 days) and chronic (7 days or more) phases (Spiers et al. 2018). Evaporation is the primary mechanism for heat loss in lactating cows under hot climate conditions, particularly when environmental temperatures exceed the animal body temperature (Frigeri et al. 2023). Respiration rate is a sensitive indicator of heat stress condition in cattle (West 2003) and has a critical role in regulating body temperature under heat load through endogenous heat loss via the respiratory tract (Legates et al. 1991, Bernabucci et al. 2010, Polsky and von Keyserlingk 2017). Additionally, studies in various climatic conditions have shown that cow activity patterns, notably increased standing time in warmer conditions to reduce the discomfort of heat load from the weather (Overton et al. 2002, Tucker et al. 2008, Heinicke et al. 2018).

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The positive effects of evaporative cooling on lactating cows have been extensively studied in recent years, but important gaps in our understanding remain, particularly with regard to its effectiveness in different climatic conditions and its longer-term effects on cow welfare and behavior (Berman 2006, Ortiz et al. 2015a, Spiers et al. 2018). While these studies have focused on its ability to alleviate heat stress and maintain production efficiency under high-temperature conditions, several uncertainties persist. Given the limitations of cows' physiological responses to heat stress, various relief interventions, focusing on both indirect and direct cooling approaches, have been developed and implemented on farms (Roth 2022). However, despite the benefits of evaporative cooling, key uncertainties remain regarding its impact on cow welfare and production, particularly under specific climatic conditions like the Mediterranean, as well as its long-term effects on physiological responses and behavior (Spiers et al. 2018). For instance, while evaporative cooling is the primary method for heat dissipation in dairy cows when temperatures exceed 35 °C (Burgos et al., 2007), it often provides only temporary relief (Valtorta and Gallardo 2004, Kendall et al. 2007), and the persistent issue of heat accumulation continues to challenge optimal welfare outcomes. Therefore, a clearer understanding of the extent to which evaporative cooling mitigates heat stress over time is necessary, potentially offering insights into improved welfare outcomes.

The present study aims to assess the effect of heat mitigation from evaporative cooling on the respiration rate and activity behavior of dairy cows specifically under Mediterranean climatic conditions. We hypothesize that evaporative cooling will alleviate heat load, as evidenced by reduced respiration rates and increased lying times post-cooling sections.

Material and Methods

Animals, housing, and farm management

The experiment was conducted over a period of five consecutive days in July 2016 at a commercial dairy farm in a naturally ventilated barn located in Eastern Spain (39°37'28.2"N, 0°30'28.0"W), Bétera, Valencia. The barn was approximately 137 m long and 18 m wide, and oriented NE-SW (Figure 1) with a dry manure "compost barn" area for lying and a concrete floor for feeding. In a group of 125 high-yielding Holstein dairy cows (19.73 m^2 per animal), 12 multiparous cows were randomly selected for the trial at the beginning of the experiment. The group presented similar milk yield (mean ± SD; 41.64 ± 4.01 kg), days in milk (150 ± 4.67 DIM), and parity (3 ± 1.19).

Cooling sessions occurred in a separate waiting yard located 15 m from the milking parlor and 70 m from the cowshed (Figure 1). The cooling area measured 15 × 20 m (approximately 2.4 m^2 per cow) and had a well-drained concrete floor. It was equipped with 12 low-speed ceiling fans (300 cm in diameter; 6,000 $m^3\ h^{-1}$ air capacity each) and four large side fans (2 m in diameter; 120,000 $m^3\ h^{-1}$ air capacity each) to create airflow perpendicular to the cows. Sprinklers were positioned 2.8 m above the ground (1.4 m above the cows) and distributed water across the entire cooling yard at an estimated volume of 1,800 $l\ h^{-1}$. Each 45-minute cooling session, which began before each milking at 05:00, 13:00, and 21:00 h (GMT + 02:00), consisted of an 80-second shower followed by a 4-minute ventilation period. Cows were fed ad libitum twice daily at 07:00 and 19:00 h with a total mixed ration. Animal measurements were conducted as part of daily routine care, ensuring that the farm management was not disrupted during the trial period, as no additional handling or restraining of the animals was required. The sensor was attached while the animal was restrained for routine veterinary treatment. The respiratory rate was counted visually from a distance (approx. 2 m) without disturbing the animals. All animals were treated in a species-appropriate manner throughout the study, in full compliance with Spanish law and the guidelines of the Declaration of Helsinki.

Respiration rate

The animal measurements were taken between 07:00 h (almost two hours after the first cooling and milking) and 15:00 h (GMT + 02:00 h). The respiration rate (RR) was visually observed hourly by one single person (well-trained veterinarian) counting right thoracoabdominal movements for thirty seconds and multiplying the value by two (i. e. breaths per minute, bpm); (Gaughan et al. 2000, Pinto et al. 2019). In addition to the hourly measurements, RR was recorded before, during, and after the second cooling session, resulting in a total of 12 observations per cow per day.

Activity measurements

Each cow was fitted with an IceTag3D™ activity sensor (IceRobotics, Edinburgh, UK) on a hind leg, as described by Heinicke et al. (2018). The sensor recorded data continuously (24 h / d) in the functional groups: resting behavior (total lying time, number of lying bouts and lying bout duration) and locomotion behavior (total standing time, number of standing bouts, standing bout duration and number of steps), every second and conducted day and night without interruptions.

Environmental measurements

Ambient temperature (AT) and relative humidity (RH) were recorded (barn and cooling yard, Figure 1) every 5 min using four data loggers (EasyLog USB 2+, Lascar Electronics Inc., Whiteparish, England) fixed at 3 m height inside the building. The temperature-humidity index (THI) was calculated according the following equation (NRC 1971):

$$THI = (1.8 \times Tdb + 32) - (0.55 - 0.0055 \times RH) \times (1.8 \times Tdb - 26) \qquad \text{(Eq. 1)}$$

where Tdb is dry bulb temperature (in °C) and RH is relative humidity (in %).

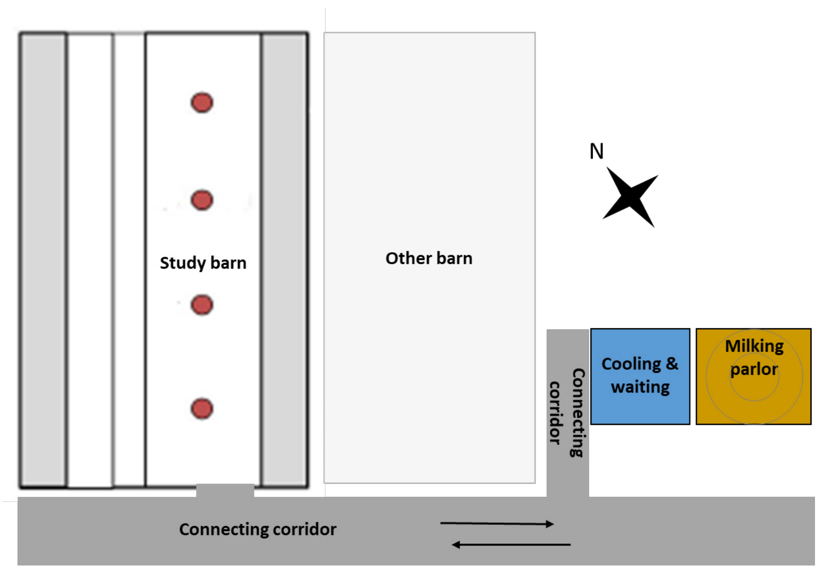

Figure 1: Layout of the study barn and position of climate sensors (EasyLog USB 2+; red dots), cooling yard (blue color) and milking parlor (yellow color)

Statistical data analysis

All of the data were summarized daily for each animal trait (physiological and behavior) at the end of the experiment. The normality test of the data was carried out using Shapiro-Wilk test and the dataset did not exhibited normal distribution ($p < 0.05$). A mixed linear models approach was performed to identify associations and mechanisms, which had an influence of cooling sessions on the cows. The model underwent training aimed to predict heat stress metrics and achieved superior performance through the fine-tuning of its hyper-parameters including the hierarchical structure of the data. The RR in bpm (n = 668), lying time in minutes per hour (n = 819), and steps per hour (n = 1633) data were included in the modeling. Lying times less than four min were assumed as a sensor record error, and those data were excluded in the modeling according to Heinicke et al. (2019) increasing the accuracy of the results. The significant variables ($p < 0.05$) supported the model to predict the respiratory rate, total lying time, and steps, where it was assumed as significant for the cooling efficiency. Additionally, the following individual cow factors lactation number, milk yield, days in milk, and pregnancy status were included as a fixed effect. The animal traits were linked to the average THI values from every 5-min interval. A linear mixed model with repeated measurements was established as non-independent observations to test the influence of THI and cooling sessions on respiration rate and activity behavior of the cows. We assumed the random effects from the given data in hierarchical groups such as animals, cooling session, and time after cooling. We split all the factors into two groups: fixed and random effects. The model can be written as:

$$Y = \mu + X\beta + Zu + e \qquad \text{(Eq. 2)}$$

where Y is an observation vector; μ is the general mean; X is the design matrix for the fixed effects; β is the vector containing the fixed effect parameters (coefficients); Z is the design matrix for the random effects; u is the vector of random effects; e is the vector of residual errors.

The null hypotheses for all tested traits were defined as the heat load having no effect on the animal individual reaction, and cooling session not affecting the RR and activity of the dairy cows. The significance level for the linear mixed model was 0.05. Generalized linear mixed models were estimated using “lme” function (Linear mixed effect) from the “nlme” R package.

Results

Environmental conditions

During the experimental period, the weather showed considerable fluctuations throughout the day as represented in the Figure 2. We observed that during daytime, the heat load was higher than compared with the nocturnal period ($p < 0.001$). The daily averages of AT, RH, and THI were recorded at 25.8 ± 3.99, 66.1 ± 13.88, and 74.1 ± 4.37, respectively. Notably, the lowest THI value occurred around 04:00 h, while the highest THI value was observed around 16:00 and 17:00 h during the experimental period.

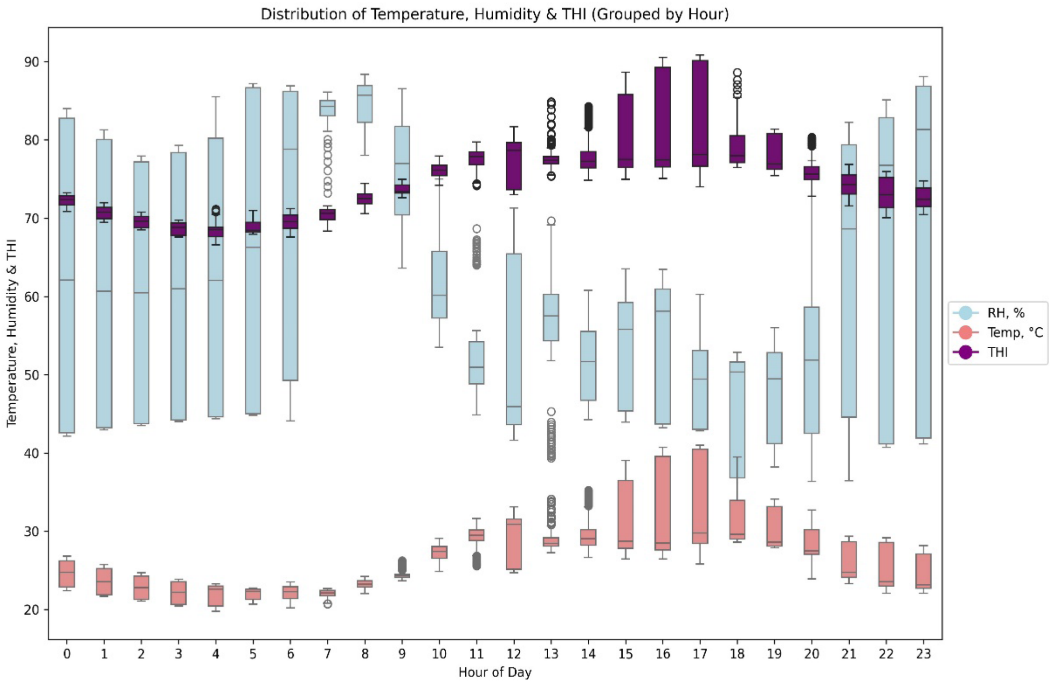

Figure 2: Average temperature-humidity index (THI; purple box-plot), average air temperature (red box-plot) and average relative humidity (RH, blue box-plot) inside the barn along 24 h measurements during the experimental period

Respiration rate

Based on the measurement size of 668 observations of RR (standing posture: 514; lying posture: 148) between 07:00 h and 15:00 h, the model revealed a marginal R^2 of 0.411 and a performance with the random effects of a conditional R^2 of 0.666, and significant values among the fixed effects, such the THI, feeding, and cooling sessions ($p < 0.001$) were demonstrated. Since the R^2 increased with random effects, we assumed the data had a hierarchical structure with the previously defined groups (animal, cooling session, and time after cooling).

According to the farm management, the cooling promoted a noticeable mitigation on the RR of the cows. Immediately during the cooling, there was a marked decrease and gradually increment every hour after cooling (Figure 3). The RR regarding the second cooling dropped down (54.6 ± 10.7) compared with the RR of cows an hour before (74.6 ± 13.1 bpm). Further, we noted a significant influence in RR ($p < 0.001$) depending on the posture of the cows, which for lying cows exhibited an average RR of 69 ± 13.6 bpm, whereas in the standing posture it was 57.9 ± 16.2. Table 1 shows values of RR of the modeling in different body postures including the cooling effect.

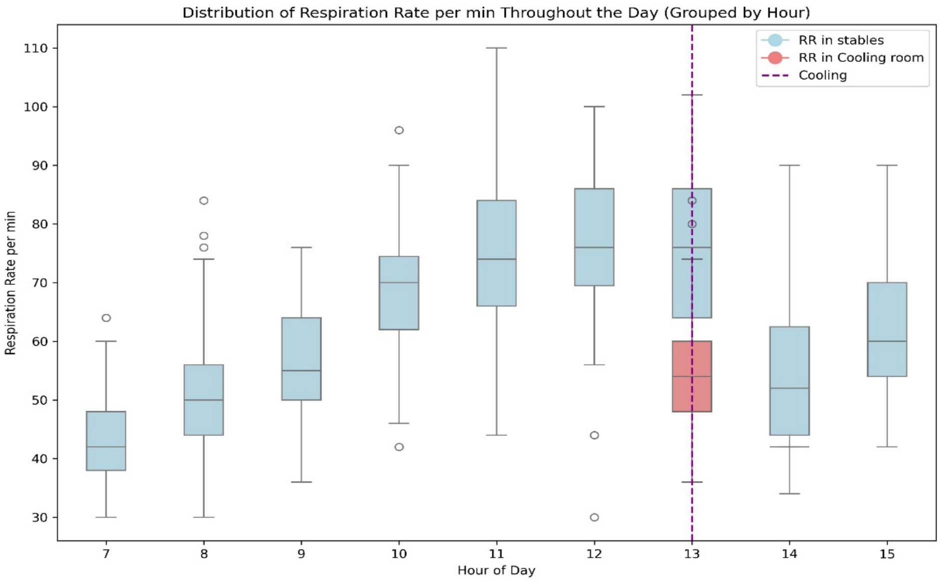

Figure 3: Respiration rate (RR) in breaths per min of dairy cows along the day measurements inside the barn (blue box-plot) and during afternoon cooling (13:00 h; red box-plot; cooling – dotted purple line)

Table 1: Respiration rate in breaths per minute of cows in standing and lying posture among hours post morning and afternoon cooling session

Subset	Mean ± SD	Minimum	Maximum	CV
Standing posture post morning cooling at 05:00 h				
After 1 h	41.82 ± 6.53	30	60	15.64
After 2 h	46.78 ± 9.11	30	76	19.48
After 3 h	53.95 ± 10.85	36	84	20.11
After 4 h +	74.62 ± 13.05	42	110	17.48
Lying posture post morning cooling at 05:00 h				
After 2 h	52.77 ± 9.44	44	74	17.88
After 3 h	60.71 ± 9.82	40	78	16.17
After 4 h +	70.63 ± 12.83	30	100	18.17
Standing posture post afternoon cooling at 13:00 h				
Cooling	54.62 ± 10.69	36	84	19.58
After 1 h	60.40 ± 14.61	34	102	24.20
After 2 h	66.18 ± 12.82	56	90	19.37
Lying posture post afternoon cooling at 13:00 h				
After 1 h	76.72 ± 11.86	56	100	15.46

SD: standard deviation; CV: coefficient of variation.

Lying behavior

The data within animals was more similar than between animals. Furthermore, in one animal observations made at the same time of the day (morning, afternoon, evening) presented similarity from day to day ($p < 0.001$).

Regarding the lying time behavior, a dataset of n = 819, our results revealed a remarkable conditional R^2 of 0.801 for the random effects, encompassing important fixed effects such as THI, lying bouts, cooling, and milking times ($p < 0.001$).

The lying behavior tended to increase after the cooling sessions ($p < 0.001$), especially with afternoon and evening cooling having a pronounced effect prompting the group to maintain in a recumbent position for an extended period. Table 2 provides the lying time of the cows in min per hour within four hours observation considering the effect of each cooling session along the day. Cows demonstrated a significant increase in the amount of time spent lying after the cooling session in the evening and this effect is further enhanced after four hours post cooling ($p < 0.001$). Our analysis suggests a significant individual animal effect on hourly lying times with a coefficient of variation of 0.41 (Figure 4). The heat load among the daytime was higher than compared with the nocturnal period ($p < 0.001$). Thus, this effect exerted a notable influence on lying behavior of the cows ($p < 0.001$).

Table 2: Lying time of the cows (n = 12) in min per hour up to four hours after each cooling session

Subset	Mean ± SD	Minimum	Maximum	CV
Morning cooling at 05:00 h				
After 1 h	11.28 ± 8.68	4.45	25.60	77.00
After 2 h	26.01 ± 13.03	5.95	52.55	50.10
After 3 h	27.70 ± 14.11	4.58	60	50.92
After 4 h +	33.65 ± 14.22	5.63	60	42.26
Afternoon cooling at 13:00 h				
After 1 h	20.36 ± 12.28	4.33	45.45	60.29
After 2 h	36.42 ± 14.54	6.72	60	39.91
After 3 h	38.85 ± 14.45	7.20	60	37.19
After 4 h +	27.32 ± 15.01	4.62	60	54.92
Evening cooling at 21:00 h				
After 1 h	36.51 ± 14.74	4.23	60	40.38
After 2 h	41.98 ± 15.16	5.42	60	36.12
After 3 h	32.57 ± 15.86	6.82	60	48.71
After 4 h +	44.51 ± 13.88	4.18	60	31.18

SD: standard deviation; CV: coefficient of variation.

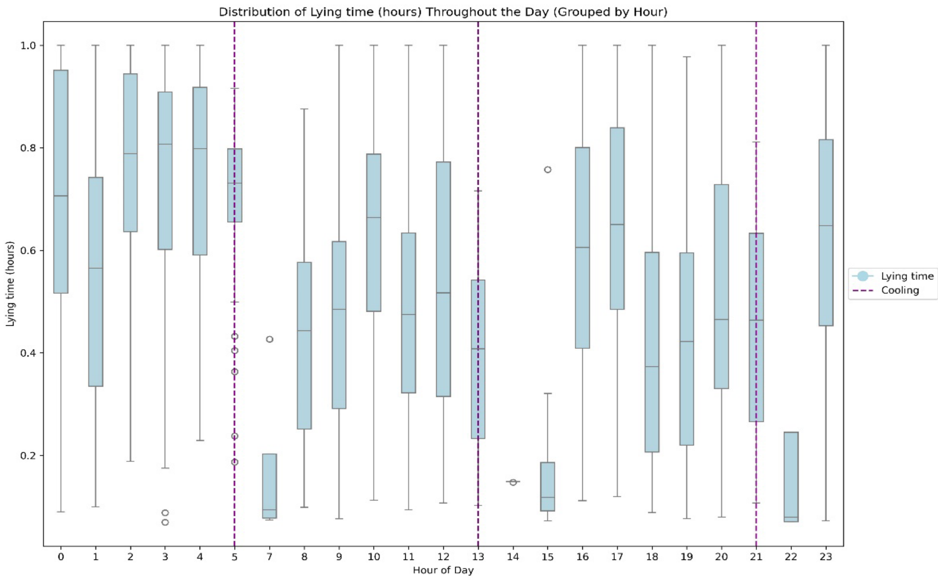

Figure 4: Hourly lying time behavior of dairy cows (n = 12, blue box-plot) and cooling sessions (purple dot lines) along the day and night during the experimental period

Step count

From a large data set (n = 1633), our results have shown a low conditional R^2 of 0.3379 in random effects to the prediction model comparing to R^2 of 0.1707 in fixed effects model. Among the fixed effects, the THI, milking time, and lying bouts demonstrated a significant influence on the model related to the steps of cows ($p < 0.001$). Immediately after cooling the step count raised, however, after four or more hours, the number of steps began to decrease ($p < 0.001$), except four hours or more post afternoon cooling. The Table 3 demonstrates the step count of the cows per hour after each cooling session. The real data demonstrated a high variance (119.94 ± 77.87) of steps data within animals and time along the day.

Table 3: Step count of the cows (n = 12) per hour up to four hours after each cooling session

Subset	Mean ± SD	Minimum	Maximum	CV
Morning cooling at 05:00 h				
After 1 h	167.37 ± 56.11	55	217	33.53
After 2 h	113.91 ± 57.69	30	216	50.65
After 3 h	111.95 ± 80.27	0	384	71.72
After 4 h +	60.51 ± 47.98	0	293	79.29
Afternoon cooling at 13:00 h				
After 1 h	150.00 ± 64.46	26	341	42.98
After 2 h	95.82 ± 78.03	0	279	81.43
After 3 h	50.77 ± 47.05	0	155	92.67
After 4 h +	95.49 ± 67.23	0	312	70.17
Evening cooling at 21:00 h				
After 1 h	126.55 ± 74.95	0	405	59.23
After 2 h	50.27 ± 52.12	0	196	103.67
After 3 h	89.94 ± 65.46	0	338	72.78
After 4 h +	40.92 ± 51.15	0	259	125.02

SD: standard deviation; CV: coefficient of variation.

Discussion

Respiration rate

Heat stress risk in dairy cows is often assessed using the THI. However, the most common animal-based indicators used to characterize the heat loads are RR and body temperature (Galán et al. 2018, Hoffmann et al. 2020). It has been known for the last years that evaporative cooling may become a heat-stress relief method in cattle, when there is a constantly exposed condition to high ambient temperatures (Ortiz et al. 2015b, Fournel et al. 2017, Spiers et al. 2018).

Due to the high THI conditions throughout the day, the cows of the present study had a gradual increase in RR every hour regarding the heat accumulation, showing a rise up to 35 bpm above their normal rate over a period of six hours. This indicated that in dairy cows the heat load conditions trigger mechanisms that promote evaporative heat dissipation, such increment in respiration rate to maintain the body temperature stable (Silanikove 2000, West 2003, Foroushani and Amon 2022). Heat loss through respiration accounted about 30% of the whole heat dissipation in dairy cows under high ambient temperatures (Zhou et al. 2022b). Consistently, in a study with ten multiparous Holstein cows in Egypt, higher values of RR were observed under conditions of THI values >68 during the entire experiment (Shehab-El-Deen et al. 2010). The authors described high values of THI in the environment and consequently, high RR of cows between 11:00 and 15:00 h. Similarly, we observed in our study elevated THI values that persisted up to 17:00 h. As a result, RR showed a significant tendency to increase in response to the THI conditions, except at 13:00 h, where a breakpoint occurred due to the cooling session. The present study showed a marked decrease of RR in the cows during the cooling session, which represent a value of 30% of bpm reduction. In a previous study, we observed a efficiency of 26% on RR mitigation using three times cooling a day in dairy cows (Pinto et al. 2019). This demonstrates a strong effect of cooling in preventing heat accumulation even during the hottest period of the day at 12:00 h (THI = 81 ± 0.84). In a study with dairy cows under heat load conditions, Tresoldi et al. (2018) observed an abatement on the RR of the animals with the cooling exposure. However, under permanent heat stress conditions, our study revealed that cooling interventions did not lead to a reduction in RR comparable to the basal level of 15 to 36 bpm (Jackson and Cockcroft 2008), when the cows were in their thermal comfort zone, as evidenced in our previous work (Pinto et al. 2020). This effect demonstrates that the RR increases with increasing ambient temperature, especially under long exposure of hot conditions, caused by heat accumulation (Pinto et al. 2020, Zhou et al. 2022a).

Previous studies have reported higher RR in lying cows compared to standing cows under heat stress conditions, due to a 42 % reduction in body surface area for heat dissipation influenced by the wind convection (Wang et al. 2018). However, in a study with dairy cows under heat stress subjected to three and eight daily cooling sessions, cows in a standing position showed 11 % higher RR than lying cows (Pinto et al. 2019). The body surface exposed to moving air is reduced when cows adopt a recumbent posture (Berman 2006). In addition, heat dissipation capacity of the cow reduces, whereas both ambient temperature and relative humidity rise above a critical point (Ouellet et al. 2021, Foroushani and Amon 2022).

Activity behavior

Heat load conditions promote a change in animal behavior. Body posture has given additional information of heat stress status of dairy cows in recent years (Heinicke et al. 2018). In the present study, lying cows showed an average RR of 12 bpm more than standing cows, likely due to reduced body surface area, which can negatively affect heat dissipation. Dairy cows prevent the body heat load primarily through skin surface (70–80 %) and, secondarily, by breathing (Zhou et al. 2022b). Cows under heat load conditions attempt to adapt the refreshment of the body by increasing the standing posture to enlarge the body surface area, thereby improving thermal exchange with the environment (Berman 2005, Stone et al. 2017, Pilatti et al. 2019). In our study, cows stood 33 minutes more per hour when the THI was high. Lying bouts increased during the same time, assuming heat load promoted discomfort for the cows in a lying posture, which may also increase step counts. Studies have shown that the duration of each lying bout decreases, and the number of steps increases with increasing heat load (Brzozowska et al. 2014).

High THI impairs cows rest, but fatigue throughout the day limits how long cows can remain standing. Prolonged standing posture is unsustainable for heat dissipation due to body fatigue, regardless of weather conditions (Heinicke et al. 2018). Previous studies with dairy cows under hot conditions demonstrated a 50 % increase in time spent standing (Allen et al. 2015), and multiparous cows spend less time lying down as THI rises (Stone et al. 2017). Body posture in dairy cows may generate a conflict between thermal comfort achieved by standing posture and the need for rest (Polsky and von Keyserlingk 2017). Our results revealed significant effects on lying behavior of cows after cooling sessions. Lying time increased throughout the day up to three hours after cooling, even when the THI reached a maximum value of 81.3. The cattle chose to lie for a short time under hot conditions to obtain a temporal rest (Herbut and Angrecka 2018). Evaporative cooling has been shown to offer a significant benefit for heat stress relief in dairy cows (Berman 2006).

The THI was a determining factor in cow behavior, whereby lower THI led to higher lying times in cows. However, THI fluctuations were more pronounced in the evening as the THI decreased. Pilatti et al. (2019) observed a preference for cows to lie down in the morning, and this preference was associated with THI readings above the comfort zone for dairy cows in the afternoon. Honig et al. (2012)

described that cows spent more of their free time (excluding milking and feeding time) resting after cooling, an indication of improved animal welfare.

We presume in our experiment that the farm management exerted an important role in alleviating heat stress conditions. As the cows were fed twice a day (07:00 h and 19:00 h), we observed that the animals spent about one hour after the cooling feeding, which was reflected in increased step counts, particularly in the evening when THI was lower. Step variability can also be influenced by factors such as age, lactation stage, milk yield, and conditions like hoof diseases or lameness (Brzozowska et al. 2014, Herbut and Angrecka 2018, Heinicke et al. 2019). Levit et al. (2021) found that cooling might stimulate the feed intake, since the cooling results in heat stress mitigation, the cows approached the feeders often and they consumed more feed per visit. Therefore, the wellbeing status includes the capacity of the cow's feed and drink, as well as the activity behavior (Hoffmann et al. 2020). Those routines that ally factors as management and environment enable to achieving conditions of reduction in the stress status.

After the evening cooling, the cows disposed to be in lying posture for a longer time, in an average of 39 ± 4.76 min per hour, compared to 24 ± 8.76 min per hour during the day. In conjunction with the cooling and the reduction of the THI value during the night to an average value of 58, there was a positive effect on the activity behavior of the cows. The activity behavior of cattle appears less intense at night by circadian rhythm (Palacios et al. 2021). Furthermore, the night cooling effect on heat refreshment in dairy cows is known in the literature (Spiers et al. 2001). In a study with dairy cows, Levit et al. (2021) found an optimal reflex on the body temperature decrease using evaporative cooling sessions during the night. The authors affirmed that night cooling was more effective than day cooling in maintaining the minimal body temperature at the same level as for continuously cooled animals. Our study indicates a positive effect of the evaporative cooling on activity in dairy cows and the increase on lying behavior after heat abatement. Wilson et al. (2023) demonstrated no significant differences on lying posture and body temperature of dairy cows using a supplemental cooling such as mist and air-cooling in the barn. We presume with that, the evaporative cooling might be more efficient on the heat abatement, consequently promoting positive effects on animal behavior.

Overall, we approached animal individual reactions to the evaporative cooling in our investigation; nevertheless, those individualities follow a pattern of heat stress abatement. Furthermore, this reaction is being developed during several hours after cooling, which is visible in RR and lying time dynamics of the cows. Future studies should take into account the individual cow responses at different times of the day when the cooling is applied.

Conclusions

Our study confirmed that the evaporative cooling promoted a heat stress abatement in lactating dairy cows under hot and dry climate conditions. Cooling sessions during the hottest part of the day lowered RR values by approximately 23 %, thereby promoting body temperature regulation in the cows. The behavior of the cows accompanied the environmental fluctuations along the day, which was pronounced the decrease of lying time under high THI conditions. Nonetheless, after cooling, the cows tended to demonstrate their well-being due to the increment on lying time, especially post-evening cooling, when demonstrated an increment up to 39 minutes per hour in recumbent position. These effects were more notable after the night cooling, when lower THI levels, along with farm management practices, contributed to longer and more uninterrupted resting periods for the cows.

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