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## Heat stress and feeding behaviour of dairy cows in late lactation

Mirco Corazzin , Alberto Romanzin , Vinicius Foletto , Carla Fabro , Francesco Da Borso ,  
Mario Baldini , Stefano Bovolenta  and Edi Piasentier 

Dipartimento di Scienze Agroalimentari, Ambientali e Animali, University of Udine, Udine, Italy

### ABSTRACT

Heat stress is one of the most important problems that dairy cows have to face and the use of cooling systems is becoming more and more important. The first reaction that has the animal to cope with the environmental variations is to modify its behaviour. This study was aimed to investigate the effect of heat stress and a cooling system on the feeding behaviour of Italian Holstein Friesian dairy cows in late lactation. Two experiments were performed. In the first experiment, eight dairy cows were firstly kept 7 d under thermoneutral condition, and then under mild heat stress (temperature humidity index, THI, ranging between 72 and 78) for others 7 d. The second experiment consisted of 8 dairy cows used in a two-period cross-over design where the treatment was the use or not of a sprinkler system for cooling cows under mild heat stress. Cows were equipped with a noseband pressure sensor able to detect rumination and eating time, number of rumination and eating chews, number of rumination boluses and rumination intensity. Heat stress reduced rumination time, number of rumination chews and boluses ( $p < .05$ ), and tended to reduce the number of eating chews ( $p < .10$ ). Cooled cows increased rumination and eating time ( $p < .05$ ), rumination intensity ( $p < .01$ ), and the number of rumination and eating chews ( $p < .05$ ). In conclusion, feeding behaviour was deeply influenced even by mild heat stress, which was effectively improved by the use of a sprinkler system.

### HIGHLIGHTS

- Mild heat stress reduced rumination time, number of rumination chews and boluses of dairy cows in late lactation
- Cooling cows with sprinklers was effective in alleviating heat stress in terms of feeding behaviour

### ARTICLE HISTORY

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### KEYWORDS

Rumination time; eating time; sensor; cooling; sprinkler



## Introduction

Heat stress is one of the most important problems that dairy cows face in a large part of the world (Hempel et al. 2019) as the world's temperature is rising (IPCC 2018). From this point of view, Gunn et al. (2019) estimated a milk production loss in the U.S.A. of about 170 kg/cow/decade in the next years and that heat abatement systems such as shading, forced ventilation or fans, will be increasingly required to reduce economic losses for dairy farmers.

Heat stress results in body hyperthermia because cows can not sufficiently dissipate the heat that derives from the environment, from rumen fermentations or its metabolic heat from digesting feed (West 2003). Consequently, the temperature-humidity index (THI) was proposed as an indirect value for assessing

the severity of heat stress in cattle. In particular, values of THI higher than 72 lead to heat stress in dairy cows (Armstrong 1994; Ravagnolo et al. 2000), but in cows producing more than 35 kg/d milk heat stress begins at THI of 68 (Collier et al. 2012). Recently, Mader et al (2010) developed a comprehensive climate index that can be used for assessing both heat and cold stress as it considers not only the ambient temperature and humidity, but also the wind speed and solar radiation. It is widely known that heat stress reduces the milk yield and the dry matter (DM) intake, conversely data about the effect of heat stress on milk quality are not conclusive and often contradictory (Bernabucci et al. 2015; Cowley et al. 2015).

The coping strategies used by dairy cows for high temperatures include behaviour modification (Abeni and Galli 2017). Nowadays there is the availability of

**CONTACT** Prof. Mirco Corazzin  [mirco.corazzin@uniud.it](mailto:mirco.corazzin@uniud.it)  Dipartimento di Scienze Agroalimentari, Ambientali e Animali, University of Udine, 33100 Udine, Italy

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equipment for continuous monitoring of the feeding behaviour of dairy cows. To this purpose, RumiWatch system is already validated and currently used both under indoor and outdoor conditions (Ruuska et al. 2016; Romanzin et al. 2018). Interestingly, Maia et al. (2020) reported that digestive physiology of heat-stressed cows could be related to variation in rumination time. Therefore, understanding the feeding behaviour of dairy cows subjected to high THI by heat abatement techniques can be useful for improving the management of dairy cows during heat stress.

Many heat mitigating systems have been studied in the past (Becker and Stone 2020). Evaporative cooling subtracts ambient heat to make water pass from liquid to vapour. Among these systems, sprinkler is one of the most common in dairy cattle farms (USDA 2016). Many studies showed that sprinklers reduce body temperature and respiration rate and increase milk yield (Chen et al. 2016; Kaufman et al. 2020). Conversely, to our knowledge, much less information is available on the effect of sprinklers and heat stress on the feeding behaviour (e.g. rumination time and eating time) of dairy cows (Porto et al. 2017; Maia et al. 2020).

This study aimed to investigate the effect of mild heat stress and the sprinkler system on the feeding behaviour of dairy cows in late lactation.

## Material and methods

Two experiments were conducted in summer season to assess the effect of heat stress (Experiment 1) and a cooling system (Experiment 2) on the feeding behaviour of dairy cows.

### Experiment 1

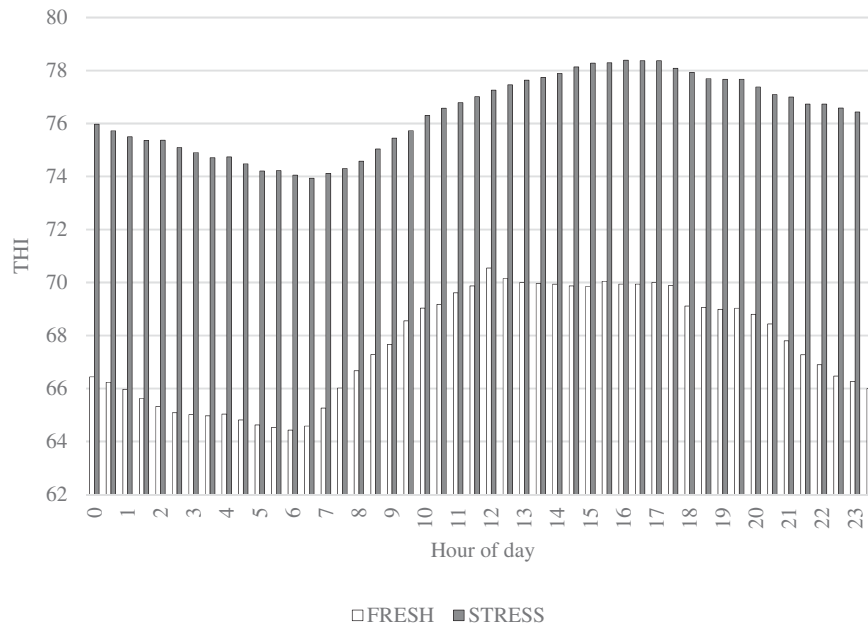
The trial was performed at the experimental farm of the University of Udine (Azienda Agraria Universitaria Antonio Servadei). Eight multiparous (range: 4–7 lactations), nonpregnant, low-producing ( $15 \pm 2.2$  kg/d of milk; mean  $\pm$  SD) Italian Holstein Friesian dairy cows in late lactation (min 255; max 282 days in milk) were used. The choice of considering cows in late lactation was made to avoid the possibility to have animals under negative energy balance, a condition that could influence the feeding behaviour (Moore and De Vries 2020). The animals were tie-stall housed in  $25 \times 10 \times 4$  m barn. The stall width was 1.25 m and the distance between cows was 2.50 m. The humidity and temperature of the barn were recorded every second and averaged every 30 min by four mini-data loggers (FT-102; Econorma SAS, Italy) positioned 50 cm above

the cows. The temperature-humidity index (THI) was calculated using the formula of Yousef and Johnson (1985).

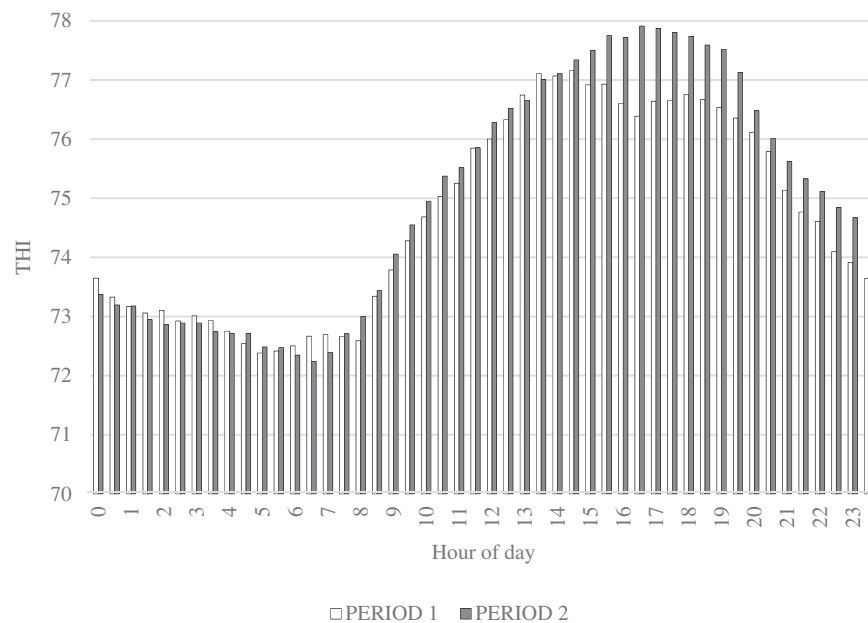
After an adaptation period of three weeks where cows were kept at environmental and thermoneutral condition (THI lower than 72) the trial started. The trial consisted of two experimental periods. The first period (FRESH) lasted 7 days and cows were kept at THI lower than 72, then cows were kept at barn environmental conditions, THI higher than 72, for other 7 days (STRESS). Cows were kept in thermoneutrality using a longitudinal fan positioned in the upper part of the barn. Animals' health was regularly checked by a veterinarian. Figure 1 shows the average diurnal patterns of THI in FRESH and STRESS periods. Dairy cows were milked twice a day at 8:00 h and 18:00 h.

### Experiment 2

The trial was performed at the experimental farm and in the same barn of Experiment 1. Eight tie-stall housed Italian Holstein Friesian dairy cows were considered. The humidity and temperature were recorded and THI calculated as reported in Experiment 1. Before the experimental phase, cows were all kept at THI lower than 72 for two weeks with the same fan of Experiment 1. Cows were used in a two-period cross-over design. The treatment was the use (COOLED) or not (HEAT) of a sprinkler system for cooling the cows. The eight multiparous and nonpregnant cows were divided into two groups of four animals balanced for milk yield ( $12.4 \pm 3.91$  vs.  $13.7 \pm 2.57$  kg/d;  $p > .10$ ) and days in milk ( $304 \pm 10.7$  vs.  $299 \pm 9.5$  d;  $p > .10$ ). One group was maintained at environmental temperature (HEAT) with a THI higher than 72 in the first experimental period (PERIOD 1; 7 days) followed by a second period (PERIOD 2; 7 days) where cows were cooled with a sprinkler system (COOLED). The other group received the same treatments, but in the opposite order during the two experimental periods. Considering the findings of Cowley et al. (2015), a washout period of 10 days (THI  $< 72$ ) was included between PERIOD 1 and PERIOD 2. The cows belonging to HEAT and COOLED group were kept in the same barn at a minimum distance of 9 m, but these groups were separated by insulating panels. Figures 2 and 3 show the average diurnal patterns of THI in HEAT and COOLED cows, respectively. The sprinkler system consisted of an aluminium sprinkler line (5 m length, 2 cm diameter) with three sprinklers nozzles placed 3.5 m above ground level. This automatic system sprayed water for 30 s every 10 min, and the output per nozzle



**Figure 1.** Average diurnal patterns of temperature-humidity index (THI) during first period (thermoneutral conditions, FRESH) and during the second period (heat stress condition, STRESS) in Experiment 1.



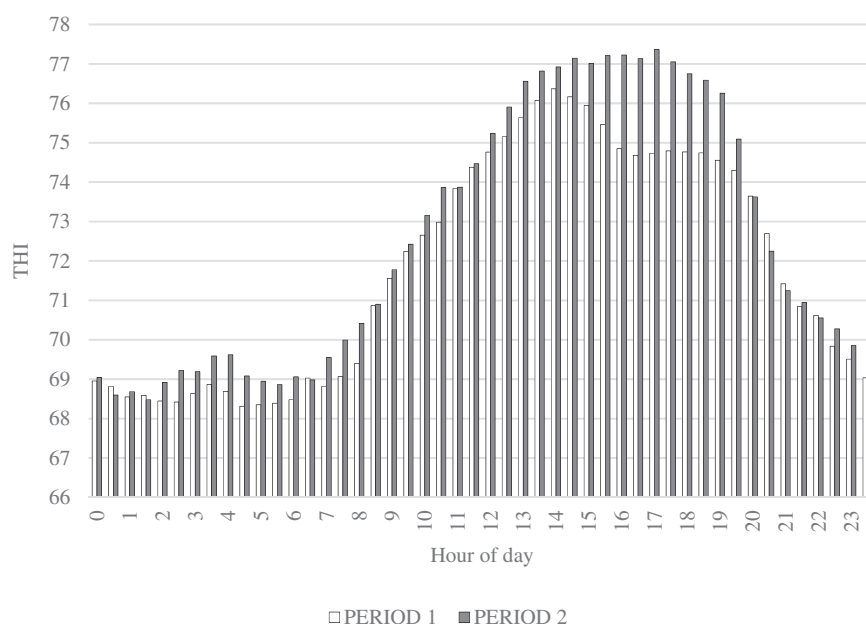
**Figure 2.** Average diurnal patterns of temperature-humidity index (THI) during heat stress (HEAT) of PERIOD 1 and PERIOD 2 in Experiment 2.

was 0.46 L/min. Cows were milked twice a day at 08:00 h and 19:00 h.

### Feed and milk

During the adaptation, washout, and experimental periods, cows had continuous access to water and were individually fed with sorghum silage, 6 kg dry matter and hay (long form) *ad libitum* before morning

milking. Also, cows were supplemented twice a day during milkings with a total of 9.2 kg DM of concentrate mixture made up of maize (426 g/kg), soybean (215 g/kg), wheat bran (157 g/kg), sunflower meal (81 g/kg), wheat middlings (78 g/kg), minerals and vitamins (44 g/kg). Feeds samples were collected every two days and dried at 65 °C in a forced draft oven for 48 h and analysed following AOAC International (2016) procedures for crude protein (CP), and neutral



**Figure 3.** Average diurnal patterns of temperature-humidity index (THI) during cooling (COOLED) of PERIOD 1 and PERIOD 2 in Experiment 2.

detergent fiber (NDF) (Goering and Van Soest 1970). The energetic value of feeds was assessed and expressed as net energy for lactation (NEI) (Agabriel 2010).

During the last 3 days of each experimental period, milk yield was recorded as the weight of milk produced per day by each cow, and milk samples were collected and immediately processed for fat content analysis using MilkoScan FT6000 (FOSS Electric, Hillerød, Denmark) and following ISO (2013). The average values per individual were considered for statistical analysis. Fat corrected milk at 4% (FCM; Gaines 1928) was calculated.

### Measurements

During all the experimental periods, individual DM intake (DMI) of cows was determined before morning milking considering the weight of daily feed offered and refused.

Rectal temperatures (RT) of cows were recorded at 6:00 h, 14:00 h, and 22:00 h using a digital thermometer (GIMA, Milan, Italy) inserted three cm in the rectum for three min.

Dairy cows were equipped with a noseband pressure sensor (RumiWatch system, ITIN-HOCH GmbH, Liestal, Switzerland). The raw data obtained was processed with RumiWatch Converter (ITIN-HOCH GmbH, Liestal, Switzerland) and converted into min/hour. Then, these data were analysed as min/day. The variables related to feeding behaviour were: rumination

and eating time (min/day), number of rumination and eating chews (no./day), number of rumination boluses (no./day) and rumination intensity (no. chews/bolus). To deeper understand the effect of heat stress and the cooling system on feeding behaviour of animals, the hourly patterns of rumination and eating time were also recorded.

As for milk, the values of DMI, RT, and of the variables related to animals' behaviour recorded during the last three days of each experimental period were averaged per individual and then used for statistical analysis.

### Statistical analysis

The analysis was performed using R software, vers. 3.4.0 (R Core Team 2017). Normality of data distribution was assessed using Shapiro–Wilk test.

In Experiment 1, all variables were subjected to paired sample *t*-test for assessing the differences between periods (FRESH, STRESS). In the case of non-normality, Wilcoxon Signed-Rank test was used. Additionally, the effect of the heat stress on the hourly behaviour of dairy cows was evaluated with a mixed model for repeated measures (Wang and Goonewardene 2004), considering period (FRESH, STRESS) and hour of the day as repeated factors, while cow was the random factor. Also, the period  $\times$  hour of the day interaction was included in the model. If this interaction was at least tendentially significant, the

differences between periods were assessed at specific hour of the day (Park et al. 2009).

In Experiment 2, the effect of cooling on variables related to performance and behaviour of dairy cows under heat stress were analysed as cross over design. In the case of non-normality, the variables were transformed for parametric testing. The model adopted considered the effects of treatment (COOLED, HEAT) and experimental period (PERIOD 1, PERIOD 2) as fixed effect and the cow as random effect. The fixed effect of the sequence with which the cows received the treatment was also considered. Additionally, the effect of the sprinkler system as cooling technique on the hourly behaviour of dairy cows was evaluated with a mixed model for repeated measures (Wang and Goonewardene 2004), considering the period (PERIOD 1, PERIOD 2) and hour of the day as repeated factors and treatment (COOLED, HEAT) and sequence as fixed factors. Also, the treatment  $\times$  hour of the day interaction was tested into the model. If this interaction was at least tendentially significant, the differences between treatments were assessed at a specific hour of the day (Park et al. 2009).

In the text, values are reported as mean  $\pm$  SD; *p*-values less than 0.05 and 0.10 were considered significant and as a tendency towards significance, respectively.

## Results

### Experiment 1

Considering the average diurnal patterns, the average THI was 67.6 (min 64.4, max 70.5); and 76.4 (min 73.9, max 78.4) in the FRESH and STRESS period, respectively (Figure 1).

The hay offered had 90% DM, 8% DM CP, 71% DM NDF, and 5 MJ NEI/kg DM. The sorghum silage had 27% DM, 7% DM CP, 59% DM NDF, and 6 MJ NEI/kg DM. The concentrate had 21% DM CP, 24% DM NDF, and 8 MJ NEI/kg DM.

Exposure to high THI values (STRESS) led to a higher RT ( $p < .01$ ), and to a 12% decrease in milk yield ( $p < .05$ ). Heat stress reduced DMI ( $p < .01$ ) by 15%. This effect was particularly evident in forage. In fact, the percentage of the forages intake by cows was reduced in heat-stressed dairy cows ( $p < .01$ ; Table 1).

As shown in Table 2, heat stress also affected the behaviour of dairy cows. In particular, heat stress reduced rumination time ( $p < .05$ ), number of rumination chews ( $p < .05$ ) and boluses ( $p < .05$ ), without significantly influencing rumination intensity and eating time ( $p > .10$ ). On the other hand, heat stress tended to reduce the number of eating chews ( $p < .10$ ).

**Table 1.** Effect of heat stress on rectal temperature, milk yield and dry matter (DM) intake of dairy cows (Experiment 1).

Item	Treatment		SED	<i>p</i> Value
	FRESH	STRESS		
Rectal temperature (°C)	38.5	39.2	0.12	<.01
FCM (kg/d)	14.7	12.9	0.78	.04
Intake				
Forage (%DM)	46.9	40.0	1.31	<.01
Total feed (kg DM)	16.2	13.8	0.63	<.01

FRESH: dairy cows kept at thermoneutral condition; STRESS: dairy cows kept under heat stress; SED: standard error of the difference; FCM: fat corrected milk; DM: dry matter.

**Table 2.** Effect of heat stress on feeding behaviour of dairy cows (Experiment 1).

Item	Treatment		SED	<i>p</i> Value
	FRESH	STRESS		
Rumination time (min/d)	510.9	330.0	56.73	.02
Eating time (min/d)	241.0	205.3	19.26	.11
Rumination chews (no./d)	28,572	17,064	3560.6	.01
Eating chews (no./d)	13,309	9659	1761.1	.08
Boluses (no./d)	542.0	344.2	60.12	.01
Rumination intensity (no. chews/bolus)	49.2	46.7	2.61	.38

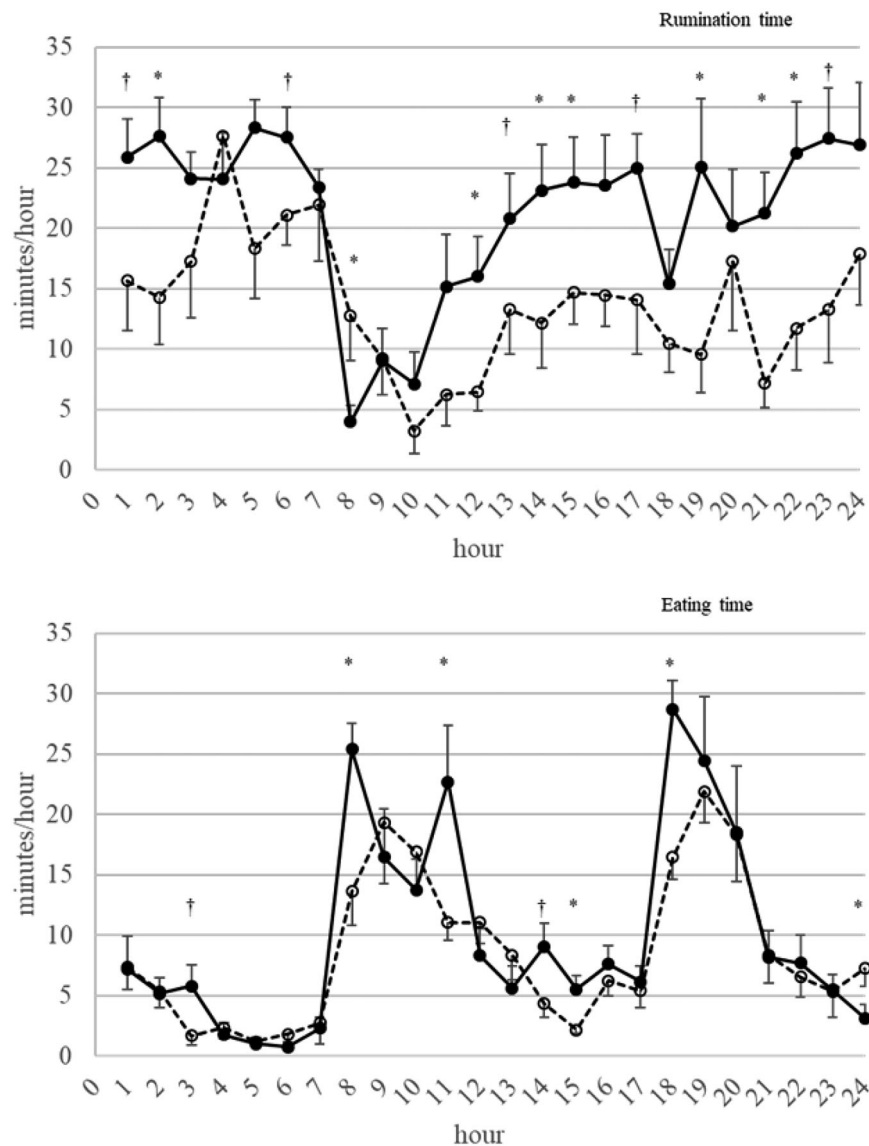
FRESH: dairy cows kept at thermoneutral condition; STRESS: dairy cows kept under heat stress; SED: standard error of the difference.

Figure 4 shows the hourly patterns of rumination and eating time of animals belonging to FRESH and STRESS. The main effect of experimental period (FRESH, STRESS) was significant for rumination ( $p < .05$ ) time, but not for eating time ( $p > .10$ ; data not reported in Tables) confirming the results obtained with the statistical model that took into account the average daily behaviour (min/d; Table 2). The period  $\times$  hour interaction tended to be significant ( $p = .06$ ) and significant ( $p < .01$ ; data not reported in Tables) for rumination and eating time, respectively. It means that heat-stressed cows tended to reduce or reduced rumination time at 01:00 h ( $p < .10$ ), 02:00 h ( $p < .05$ ), 06:00 h ( $p < .10$ ), 12:00 h ( $p < .05$ ), 13:00 h ( $p < .10$ ), 14:00 h ( $p < .05$ ), 15:00 h ( $p < .05$ ), 17:00 h ( $p < .10$ ), 19:00 h ( $p < .05$ ), 21:00 h ( $p < .05$ ), 22:00 h ( $p < .05$ ) and 23:00 ( $p < .10$ ), and had higher rumination time at 08:00 h ( $p < .05$ ). On the other hand, heat-stressed cows reduced or tended to reduce eating time at 03:00 h ( $p < .10$ ); 08:00 h ( $p < .05$ ), 11:00 h ( $p < .05$ ), 14:00 h ( $p < .10$ ), 15:00 h ( $p < .10$ ) and 18:00 h ( $p < .01$ ), but had higher eating time at 24:00 h ( $p < .05$ ).

### Experiment 2

During non-cooling (HEAT) of PERIOD 1, the average THI was 74.7 (min 72.4, max 77.2), while, during non-





**Figure 4.** Mean  $\pm$  SEM of rumination and eating time (min/h) in FRESH (dairy cows at thermoneutral condition; solid line) and STRESS (dairy cows under heat stress; dotted line) period. A mixed model analysis for repeated measures showed that the experimental period (FRESH, STRESS)  $\times$  hour of the day interaction tended to be significant ( $p = .06$ ) and significant ( $p < .01$ ) for rumination and eating time, respectively. Pairwise comparisons between periods within specific hour of the day were reported. Experiment 1. † =  $p < .10$ ; \* =  $p < .05$ .

**Table 3.** Effect of heat stress on rectal temperature, milk yield and dry matter (DM) intake of dairy cows (Experiment 2).

Item	Treatment		RMSE	p Value
	COOLED	HEAT		
Rectal temperature ( $^{\circ}$ C)	39.0	39.8	0.27	<.01
FCM (kg/d)	13.1	11.5	1.08	<.01
Intake				
Forage (% DM)	46.3	39.3	4.61	<.01
Total feed (kg DM)	15.6	13.0	0.87	<.01

COOLED: use of a sprinkler system; HEAT: dairy cows kept under heat stress; RMSE: root mean square error; FCM: fat corrected milk; DM: dry matter.

cooling (HEAT) of PERIOD 2, the average THI was 75.0 (min 72.2, max 77.9) (Figure 2). During cooling (COOLED) of PERIOD 1, the average THI was 71.8 (min 68.3, max 76.4), while, during cooling (COOLED) of PERIOD 2, the average THI was 72.5 (min 68.5, max 77.4) (Figure 3).

The hay offered had 91% DM, 7% DM CP, 65% DM NDF, and 5 MJ NEI/kg DM. The sorghum silage had 26% DM, 6% DM CP, 52% DM NDF, and 6 MJ NEI/kg DM. The concentrate had 18% DM CP, 23% DM NDF, and 7 MJ NEI/kg DM.

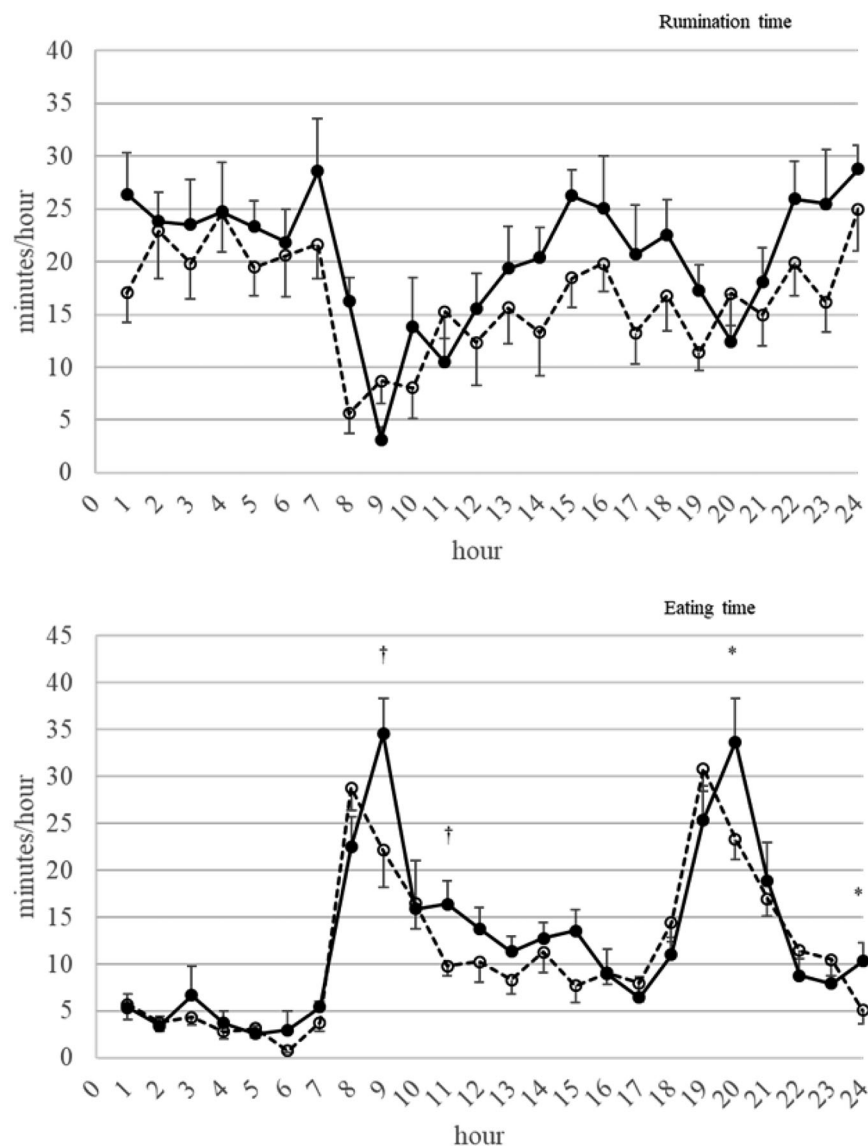
The use of sprinklers reduced RT ( $p < .01$ ), and increased 14% milk yield ( $p < .01$ ). COOLED cows showed higher total DMI ( $p < .01$ ; 20% on average) and forages intake ( $p < .01$ ) than HEAT cows (Table 3).

**Table 4.** Effect of heat stress on feeding behaviour of dairy cows (Experiment 2).

Item	Treatment			$p$ Value
	COOLED	HEAT	RMSE	
Rumination time (min/d)	493.9	397.9	76.38	.01
Eating time (min/d)	302.4	268.8	32.95	.04
Rumination chews (no./d)	27,612	21,182	5201.4	.01
Eating chews (no./d)	17,512	13,840	2638.3	<.01
Boluses (no./d)	494.0	413.6	112.19	.15
Rumination intensity (no. chews/bolus)	52.6	47.6	3.10	<.01

As shown in Table 4, the use of sprinklers modified the behaviour of heat-stressed dairy cows. In particular, COOLED cows increased rumination time ( $p < .05$ ), number of rumination chews ( $p < .05$ ) and rumination intensity ( $p < .01$ ), but had no effect on the no. of boluses ( $p > .10$ ). Considering eating behaviour, COOLED cows showed higher eating time ( $p < .05$ ) and number of eating chews ( $p < .01$ ) than HEAT cows.

Figure 5 shows the hourly patterns of rumination and the eating time of COOLED and HEAT cows. The main effect of experimental treatment (COOLED, HEAT) was significant for rumination ( $p < .05$ ), and tended to be significant for eating time ( $p < .10$ ),



**Figure 5.** Mean  $\pm$  SEM of rumination and eating time (min/h) in COOLED (dairy cows cooled with the use of a sprinkler system; solid line) and HEAT (dairy cows under heat stress; dotted line). A mixed model analysis for repeated measures showed that the treatment (COOLED, HEAT)  $\times$  hour of the day interaction was not significant ( $p > .10$ ) for rumination time, but significant ( $p < .01$ ) for eating time. Pairwise comparisons between treatments within specific hour of the day were reported. Experiment 2. † =  $p < .10$ ; \* =  $p < .05$ .



confirming the results obtained with the statistical model that took into account the average daily behaviour (min/d; Table 4). However, the treatment  $\times$  hour interaction was not significant for rumination time ( $p > .10$ ), but significant for eating time ( $p < .01$ ; data not reported in Tables). Considering rumination time, these results indicate that COOLED cows increased rumination time, but its pattern over time was not different between COOLED and HEAT cows (Figure 5). Conversely, these results indicated that COOLED and HEAT cows had different patterns over time for eating time. In particular, COOLED cows had higher values at 20:00 h ( $p < .05$ ) and at 24:00 ( $p < .05$ ), and tended to had higher values at 09:00 h ( $p < .10$ ) and at 11:00 h ( $p < .10$ ) than HEAT cows (Figure 5).

## Discussion

In both experiments, during STRESS and HEAT periods, the THI was never lower than 72 and never higher than 78 and, consequently, cows could be considered under constant mild heat stress (Armstrong 1994; Ravagnolo et al. 2000). Also during cooling period of Experiment 2 the threshold of 72 of THI was exceeded for part of the day, and in this case spraying on cows had a limited effect on environmental conditions.

During STRESS and HEAT periods, cows increased RT, which is consistent with the fact that during heat stress dairy cows are unable to dissipate body heat. Indeed, Liu et al. (2019) reviewed that THI significantly affects RT. Heat stress (STRESS) reduced the total DMI and the milk yield in agreement with many other studies (Bouraoui et al. 2002; Cowley et al. 2015; Rejeb et al. 2016). As explained by Gorniak et al. (2014), a THI around 78 can lead to an increase in the maintenance requirements of energy by 10–30% and, on the other hand, the reduction of DMI allows a reduction of the heat increment due to lower rumen fermentation, feed digestion, and metabolism, which results in less nutrient availability for milk production. It is interesting to note that STRESS reduced the forage intake which is consistent with the above discussion, in fact, forages are digested by cows less efficiently and, therefore, generate a higher metabolic heat load than concentrates (Reynolds et al. 1991).

As expected, the use of the sprinklers in cows subjected to mild heat stress (COOLED vs. HEAT) reduced RT. At the same time, DMI increased with a positive effect on milk production. Chen et al. (2016) showed that, during the summer period, the use of sprinklers for two days increased milk yield and reduced the body temperature without affecting the DMI of cows.

However, the same authors explained that two days of treatment with sprinklers may not be enough to observe variations in the DMI of dairy cows.

Rumination time is very variable depending on many factors such as milk yield, chemical and physical characteristics of the diet (Beauchemin 2018). The average value observed in the present study (FRESH), 511 min/d, was higher than that observed by De Vries et al. (2009), 491 min/d, in dairy cows producing 40 kg of milk/d and fed with 45% DM of forage. The average eating time, 241 min/d (FRESH), was within the range reported in the review paper of Beauchemin (2018), 141–507 min/d, and was similar to the average value reported in the same paper, 284 min/d. In the present study, cows under heat stress (STRESS) reduced rumination time and, as shown above, reduced milk production, total DMI, and forage intake. In agreement with these results, other studies showed that, during summer, THI is negatively associated with milk production and DMI (Moallem et al. 2010; Soriani et al. 2013). Church (1988) explained that a reduced rumination time reduces the passage of digesta in the gastrointestinal tract and, therefore, also the possibility to ingest further feed by cows. However, considering the results of this study, it seems that during heat stress, the reduction of forage intake had a role in increasing the passage of rumen digesta to the other compartments of the digestive tract, and consequently reducing the rumination time. It is interesting to note that the reduction in rumination time was accompanied by a reduction in rumination chews and number of boluses, but not by a reduction in rumination intensity. The interpretation of the intensity of rumination is complex. Antanaitis et al. (2019) explained that high chews per bolus occur in healthy animals, but also in animals fed high percentages of concentrate in the diet as a regulatory mechanism to counteract a possible reduction in ruminal pH. Considering the hourly patterns of rumination, animals under heat stress (STRESS) reduced the rumination time for most of the day compared to FRESH both at night and during the day. Maia et al. (2020) found that heat stress affected the rumination pattern of Holstein crossbred dry cows during the day with the lowest rumination time values in the afternoon of the hot days. Conversely, in the present study, rumination times in heat-stressed animals did not follow clear trends between day and night. The difference could be because Maia et al. (2020) subjected cows to much higher and variable THI values, from 74.6 to 92.9, compared to those in the present study. Interestingly, Soriani et al. (2013) showed that the daily percentage of nocturnal

rumination increased only with maximum daily THI higher than 85. STRESS period reduced the DMI and tended to reduce the number of eating chews per day. Taking into account our results, we can speculate that, during heat stress, the reduction in DMI was due to a reduction in meal size rather than eating time. However, this hypothesis was not confirmed by the results of Experiment 2 where the increased DMI was also accompanied by an increase in eating time. Galán et al. (2018) reviewed that the reduction in DMI is associated with a reduction in eating time. Conversely, Beauchemin (2018) failed to detect a correlation between these two variables. Considering the hourly patterns and contrary to Polsky and Von Keyserlingk (2017), animals under heat stress did not increase eating time at night compared to daytime hours, probably because THI was higher than 72 during the day hours and presented little variation.

The use of sprinklers in COOLED animals increased the rumination time and rumination chews. These results can be explained, as previously described, by the fact that COOLED cows increased total DMI and forage intake. Moreover, cooled cows had similar hourly patterns of rumination than heat-stressed animals, but with a lower average value. Also, sprinklers had a positive effect on eating time. In fact, cooled cows did not only increase eating time, but also the eating chews. In agreement with the present study, Karimi et al. (2015) observed that the use of a sprinkler system in heat-stressed dry cows in late gestation increased DMI, rumination time and (numerically) eating time. Chen et al. (2013), observed a 40% increment in feeding time in cows exposed to sprinklers. The results of this study clearly showed that sprinklers modified the DMI and feeding behaviour of cows by improving the milk yield and, therefore, we can speculate that this cooling system reduced the heat load of the dairy cows subjected to mild heat stress.

## Conclusions

Even a mild heat stress ( $73 < \text{THI} < 78$ ) deeply affected the feeding behaviour of Italian Holstein Friesian dairy cows in late lactation. In particular, there was a reduction in the time and number of chews of rumination, and the number of boluses. Cooling with sprinklers was effective in alleviating heat stress in terms of feeding behaviour. In fact, cooled cows increased both rumination and eating time. In order to improve the knowledge on the mitigation of heat stress by cooling systems, further studies with longer monitoring

summer critical period and different sprinkler characteristics such as flow rate and timing are needed.

## Ethical approval

The procedures related to the study were following EU Directive 2010/63/EU, the Italian legislation (DL no. 26, 4 March 2014), and the rules of University of Udine. The study was approved by the ethical committee of University of Udine (Prot. No.4/2017).

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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## ORCID

Mirco Corazzin  <http://orcid.org/0000-0002-6921-3210>  
 Alberto Romanzin  <http://orcid.org/0000-0001-9750-0607>  
 Vinicius Foletto  <http://orcid.org/0000-0002-4589-8411>  
 Carla Fabro  <http://orcid.org/0000-0002-1891-3778>  
 Francesco Da Borso  <http://orcid.org/0000-0002-5438-3823>  
 Mario Baldini  <http://orcid.org/0000-0001-6669-0823>  
 Stefano Bovolenta  <http://orcid.org/0000-0002-6307-6809>  
 Edi Piasentier  <http://orcid.org/0000-0001-6507-9360>

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