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Monitoring cow activity and rumination time for an early detection of heat stress in dairy cow

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Abstract The aim of this study was to explore the use of cow activity and rumination time by precision livestock farming tools as early alert for heat stress (HS) detection. A total of 58 Italian Friesian cows were involved in this study during summer 2015. Based on the temperature humidity index (THI), two different conditions were compared on 16 primiparous and 11 multiparous, to be representative of three lactation phases: early (15–84 DIM), around peak (85–154 DIM), and plateau (155–224 DIM). A separate dataset for the assessment of the variance partition included all the cows in the herd from June 7 to July 16. The rumination time (RT2h, min/2 h) and activity index (AI2h, bouts/2 h) were summarized every 2-h interval. The raw data were used to calculate the following variables: total daily RT (RTt), daytime RT (RTd), nighttime RT (RTn), total daily AI (AIt), daytime AI (AId), and nighttime AI (AIn). Either AIt and AId increased, whereas RTt, RTd, and RTn decreased with higher THI in all the three phases. The highest decrease was recorded for RTd and ranged from 49 % (early) to 45 % (plateau). The contribution of the cow within lactation phase was above 60 % of the total variance for AI traits and a share from 33.9 % (for RTt) to 54.8 % (RTn) for RT traits. These observations must be extended to different feeding managements and different animal genetics to assess if different thresholds could be identified to set an early alert system for the farmer.

Introduction

The first way for the ruminant to cope with climate variations is behavior, either for the finalized searching of shadow and for an increased duration of standing bouts due to the attempt to improve heat dissipation (Allen et al. 2015). Zähner et al. (2004) reported how, during the day, the increase in temperature humidity index (THI) from <30 to >70 was related to a decline in lying behavior of lactating dairy cows. This pattern was confirmed by Cook et al. (2007) within a narrow THI range, but in more stressful conditions due to hot high environmental temperature.

Since the paper by Tsai et al. (1967), we know how an increased dietary fiber intake may increase heat stress in lactating dairy cows, but the effect was not always confirmed (Magdub et al. 1982). Kelley et al. (1967) reported how environmental temperature per se may cause a shift in the acetate to propionate ratio in the rumen. More recently, Halachmi et al. (2004) and Miron et al. (2008) evidenced how reducing neutral detergent fiber (NDF) from roughage decreased the heat stress-related symptoms, namely respiratory rate and rectal temperature, increasing dry matter intake, and milk production in lactating dairy cows. However, dietary fiber is necessary in adequate supply to ensure a correct rumen activity. The same group of researcher (Adin et al. 2009), in their trial on the reduction from 18 to 12 % the amount of dietary NDF from roughage, reported a significant reduction of rumination time of a little bit less than 1 h.

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Apart from the effect due to the interaction with forage, the environmental heat stress determines a reduction in rumen motility either as contraction amplitude and frequency; this effect is direct and not mediated by a change in feed intake (Attebery and Johnson 1969). Additionally, there is an effect of intraruminal temperature on rumen metabolism. A significant evidence of this fact is the experiment of Gengler et al. (1970). They "managed" the rumen temperature of fistulated cows to compare the effect of environment temperature (thermoneutral vs heat stress) with that of intraruminal temperature per se. This way, they evidenced how an increase in intraruminal temperature determines a reduction in feed intake, leading to a decrease in volatile fatty acid production and a shift in their composition with a significant decrease in the acetate to propionate ratio.

Current availability of combined sensors systems (CSS) may represent a great opportunity to improve dairy herd management assessing climate-related distress in an early stage. Reith et al. (2014) reported a good example of the possible management by an integrated system to monitor either cow activity and rumen activity with the same collar within an integrated software.

Recording rumination time (RT) by a rumination monitoring system, based on a microphone on the neck, is a well-validated method (Byskov et al. 2014).

The proportion of the variation in RT recorded by Byskov et al. (2015), which could be explained by the variation in intakes of the different dietary fractions, decreased from 90 to 32 % when the random effects of cow (trial) and trial were excluded from the model. This reduction could be explained by the variation between cows of 48 % found in their study.

A question could be related to the possible meaning of a different partition of variability in a specific moment of the day, namely to detect possible traits involved into individual susceptibility for heat stress and to prevent possible cow at risk for digestive and metabolic problems. This may be the case reported by Soriani et al. (2013), where a shift in the rumination daytime toward the nighttime could represent a problem for the daytime rumen activity as consequence of heat stress in the hotter hours.

The abovementioned direct action on rumen activity suggests to test the possible use of rumination time as an early alert for rumen activity and diet digestibility as consequence of hot environment exposure.

Materials and methods

Animal and management conditions

The Italian Friesian dairy cows involved in this study were raised in a freestall barn at the experimental farm "Baroncina" located in Lodi, Italy (altitude 87 m above sea level, latitude 45° 18′ 52″ 20 N, longitude 09° 30′ 14″ 04 E). Cows were raised in a single pen holding a herd of 58 lactating cows, consisting of a resting area with cubicles, equipped with a forced ventilation system. Fresh potable water was available ad libitum. The cows were monitored daily for possible health-related problems and any care or treatment administered throughout the trial was recorded. The animal management in this study agrees with the current Italian law for the experimental use of farm animals (Decreto Legislativo 4 marzo 2014, n. 26).

Cows were milked twice daily (0400 and 1600 h) in a milking parlor and milk yield and quality were monthly assessed by the recording system of Italian National Breeders Association. Cows were fed a total mixed ration (TMR) prepared and distributed once daily, at 0730 ± 0030 h, for ad libitum consumption, monitoring refusals to be limited within 5 % of the supply. Its composition is reported in Table 1. The TMR offered was recorded daily and the effective dry matter from corn silage was adjusted to correspond with the planned one by an automated system installed on the TMR feeder, consisting of a near infrared analyzer incorporated in a precision feeding system (dg precision FEEDING™, Dinamica Generale, Poggio Rusco, Italy).

The controls for the comparison between two extreme environmental conditions to assess the effect of lactation phase were carried out at the beginning of the summer season (from June 7 to July 16) and involved 27 Holstein Friesian dairy cows (16 primiparous, PR and 11 multiparous, PL). At the start of the trial, the cows were reclutated to be representative of three lactation phases: early lactation (15–84 DIM), around peak of lactation (85–154 DIM), and plateau phase (155–224 DIM), with an average milk yield of 35.7 ± 7.5, 37.3 ± 9.0, and 36.6 ± 8.1 kg/d, respectively.

The controls for the assessment of the variance partition involved all the cows in the herd from June 7 to July 16.

Measurements and analyses

Microclimatic conditions Climate data just outside the barn were recorded daily during the study period by a self-powering meteorological station (iMeteo PRO, PESSL Instruments GmbH, Weiz, Austria), integrated by a local weather forecasting net. Data on wind speed were received from an anemometer of the same network of our station in the same location. Mean daily temperature and humidity and daily minimum and maximum temperature and humidity were calculated from temperature and relative humidity data recorded throughout the trial. Data were used to compute a composite climatic welfare index, the THI, according to the formula of Kelly and Bond

Table 1 Ingredients, chemical, and physical composition of the total mixed ration (TMR) during the monitored period

Item	Unit	
Corn silage	kg as fed	17.00
Meadow hay	kg as fed	6.00
Commercial concentrate	kg as fed	7.20
Corn meal	kg as fed	3.80
Sugar-beet molasses	kg as fed	1.30
Commercial mineral-vitamin pre-mix	kg as fed	0.60
Rumen-protected fats	kg as fed	0.30
Water	kg as fed	4.30
Dry matter (DM) intake	kg DM/head	22.60
Forage	% DM	49.60
Crude protein	% DM	16.70
Rumen degradable protein	% DM	11.00
Neutral detergent fiber (NDF)	% DM	30.10
Neutral detergent fiber from forage	% DM	23.60
Acid detergent fiber (ADF)	% DM	18.80
Starch	% DM	26.90
Ether extract	% DM	4.70
Ca	% DM	0.93
P	% DM	0.43
Mg	% DM	0.36
K	% DM	1.59
Na	% DM	0.39
Cl	% DM	0.61
Net energy for lactation	Mcal/kg DM	1.82
Particle size, % retained		
19.0 mm		26.8
8.0 mm		26.8
4.0 mm		18.9
Pan		27.5

(1971), as reported by Ingraham et al. (1979). Mean daily THI (Avg THI), daily minimum THI (Min THI), and daily maximum THI (Max THI) were calculated throughout the trial, and heat stress was estimated according to

Armstrong (1994). The main descriptive statistics for weather variables are reported in Table 2.

Feed and diets Representative samples of forages and concentrate mixes were collected two times during the experimental period. Chemical composition (moisture, fat, crude protein, NDF, acid detergent fiber, acid detergent lignin, starch, and ash) was determined using standard procedures, and nutritive values were calculated according to NRC (2001). The average chemical and nutritive characteristics of the diet of lactating cows were calculated for the whole period. Samples of TMR were collected weekly and analyzed for moisture by oven drying at 60 °C for 72 h. Particle size distribution on these samples was determined by the new Penn State Particle Separator system (PSPS; Kmicikewycz and Heinrichs 2014).

Milk yield Daily milk yield was recorded once at the start and once at the end of the monitoring period.

Rumination time and activity data The RT and activity index were measured using the HR-Tag rumination monitoring system (SCR Engineers Ltd.). The system consisted of rumination loggers, stationary readers, and software for processing the electronic data (Data Flow Software, SCR Engineers Ltd.). A neck collar positioned the logger on the left side of the neck. The logger contained a microphone that was able to record the distinctive sounds of regurgitation and rumination. Data were calculated and summarized in 2-h intervals and stored in the memory of the logger. The activity meter is based on accelerometer technology that records the general activity of the cow in three dimensions (Chanvallon et al. 2014), to generate an activity index (AI) expressed as bouts/time.

Data processing The RT data obtained by the automatic system were summarized in 2-h intervals (RT2h) and used to calculate the following variables: total daily RT (RTt), by adding the 2-h interval values recorded from 2400 to 2400 h of the following day; daytime RT (RTd),

Table 2 Descriptive statistics of weather variables during the monitored period

Item	Unit	Mean	Minimum	Maximum	Standard deviation
Daily mean air temperature	°C	25.8	20.0	31.0	3.17
Daily minimum air temperature	°C	20.5	15.0	26.0	2.76
Daily maximum air temperature	°C	30.7	23.0	37.0	3.32
Dew point temperature	°C	16.3	10.0	21.0	2.41
Relative air humidity	%	57.3	43.0	91.0	9.60
Temperature humidity index (THI)	°F	73.7	65.4	80.8	3.93
Wind speed	km/h	7.75	5.0	13.0	1.58

by adding the 2-h interval values recorded from 0800 to 2000 h; and nighttime AI (RTn), from 2000 to 0800 h of the following day. The same process was conducted on the activity index obtained by the accelerometer, starting from the 2-h intervals (AI2h): total daily AI (AIt), by adding the 2-h interval values recorded from 2400 to 2400 h of the following day; daytime AI (AId), by adding the 2-h interval values recorded from 0800 to 2000 h; and nighttime AI (AIn), from 2000 to 0800 h of the following day.

Statistical analysis

The first part of statistical analysis was performed to compare the less and the more stressful day within a month of the monitored period. According to Fig. 1, the first was identified in June 14 and the second was identified in July 6. The main difference between these 2 days was the THI recorded. These 2 days were selected as two extreme environmental conditions within a short period that allows a reliable comparison in time with the same cows. A descriptive statistics of weather variables throughout the study is reported in Table 2.

A first statistical analysis was conducted on the daily-based observations: RTt, RTd, and RTn; AIt, AId, and AIn.

The MIXED PROC of SAS (SAS Institute Inc. 2009) was performed according to the following model:

$$Yi = \mu + a(\text{day}) + b(\text{lactation phase})$$
$$+ c(\text{day} \times \text{lactation phase})$$
$$+ A[\text{cow(day} \times \text{lactation phase)i}] + ei$$

Where Yi is the single observation on the cow, μ is the general mean, a(day) is the effect of the day (two levels: June 14, July 6), b(lactation phase) is the effect of the lactation phase (three levels: early, peak, plateau), c(day × lactation stage) is the interaction between day and lactation phase, A[cow(day × lactation phase)i] is the effect of each cow nested within the day of observation and lactation phase, and ei is the residual error of observation.

Milk yield data were analyzed by a general linear model to assess the difference within each lactation phase between the start and the end of the monitored period.

A second statistical analysis was conducted on the hourly based observations: RT2h and AI2h.

The MIXED PROC of SAS (SAS Institute Inc. 2009) was performed according to the following model:

$$Yi = \mu + a(\text{day}) + b(\text{lactation phase}) + c(\text{time of the day}) + d(\text{day} \times \text{lactation phase}) + e(\text{day} \times \text{time of the day}) +$$
$$f \ (\text{lactation phase} \times \text{time of the day}) \ + \ A \ [\text{cow(day} \times \text{lactation phase)i}] \ + \ ei$$

Fig. 1 Daily temperatures and THI during the monitored period
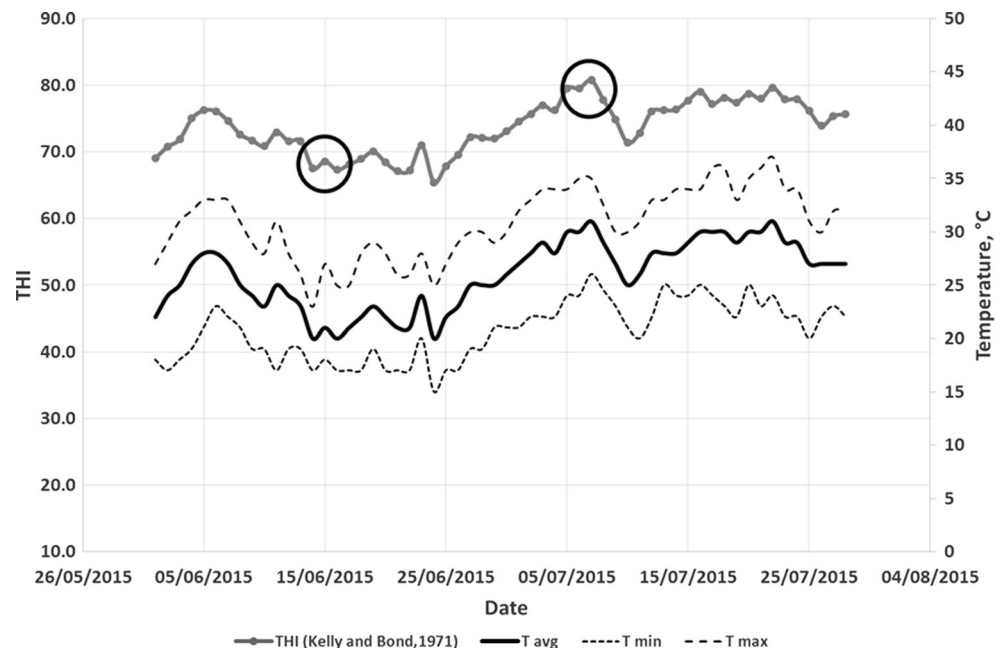
Where to the preceding model, we added c(time of the day, 12 levels, 0200, 0400, 0600, 0800, 1000, 1200, 1400, 1600, 1800, 2000, 2200, and 2400 h), e(day × time of the day) is the interaction between day of observation and time of the day, and f(lactation phase × time of the day) is the interaction between lactation phase and time of the day.

Simple correlation coefficient (Pearson) was calculated (CORR PROC of SAS, SAS Institute Inc. 2009) from the data obtained monitoring the mentioned cows during the whole period was considered here.

A separate analysis was conducted on the whole herd throughout the monitored period to assess the variance partition between day, cow nested within phase of lactation, and residual.

The VARCOMP PROC of SAS (SAS Institute Inc. 2009) with REML method was performed according to the following model:

$$Yi = \mu + a(\text{lactation phase}) + A(\text{day})$$
$$+ B[\text{cow(lactation phase)i}] + ei$$

where Yi is the single observation on the cow, μ is the general mean, a(lactation phase) is the fixed effect of the lactation phase (two levels, early + peak, plateau + late lactation), A(day) is the random effect of the day (41 levels), B[cow(lactation phase)i] is the random effect of each cow nested within lactation phase (59 levels), and ei is the residual error of observation.

Results and discussion

Date of control affected AIt, AId, and AIn, evidencing a significant increase of these variables at the time with higher THI in all the three phases was considered here, but the only significant difference within phase for AIn was recorded in cows at plateau (Fig. 2).

Very low correlations ($r < 0.29$) were found between the three activity indexes and climate variables.

Comparing milk yield at the end of the monitored period with that recorded at the start, we observed no difference for early lactating cows (35.72 ± 7.55 vs 38.40 ± 5.77) between the start and the end of the monitored period, probably because they are in the growing phase of lactation. Differently, cows at peak and at the plateau phase of lactation at the beginning of the period declined their milk yield of 17 %
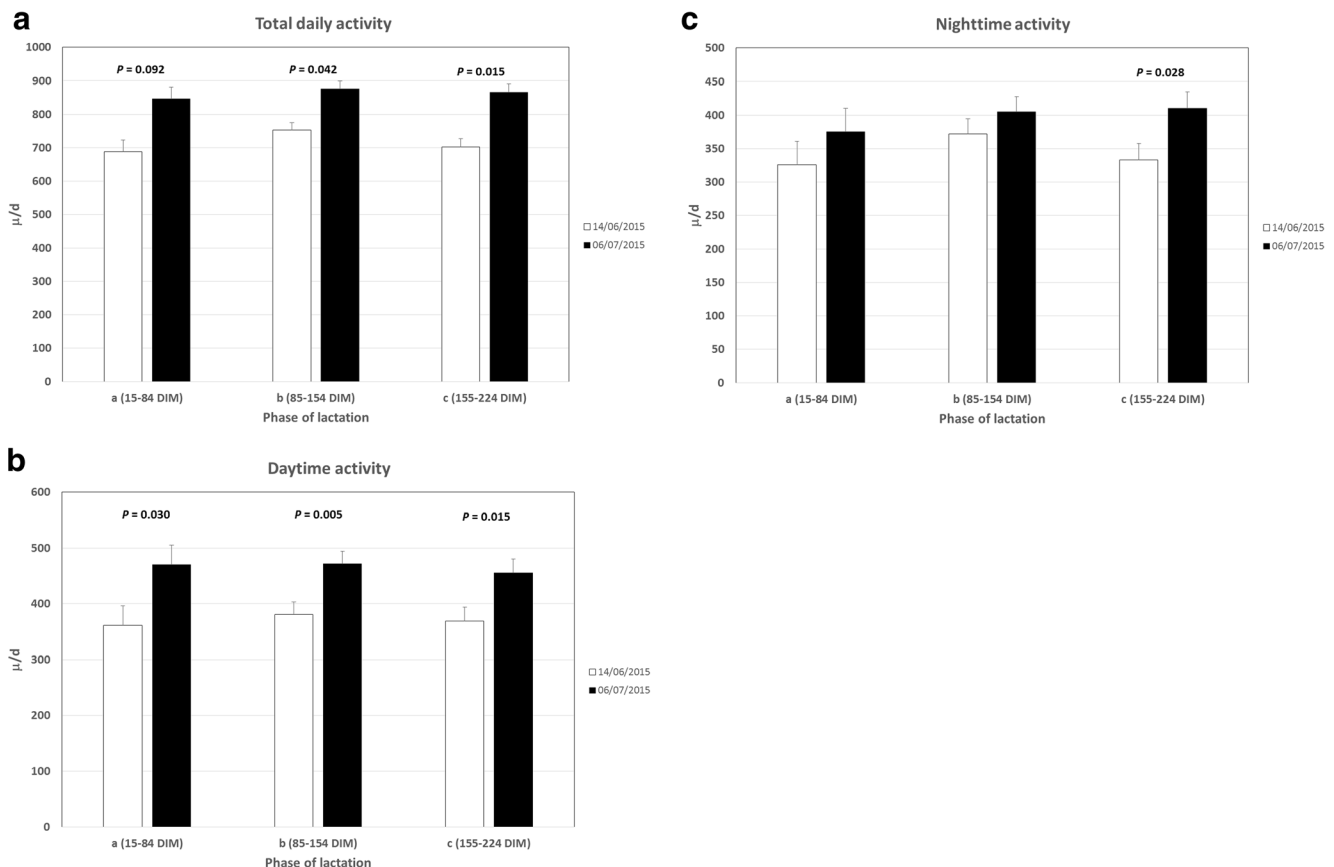

Fig. 2 Total daily (**a**), daytime (**b**), and nighttime (**c**) activity index (number of bouts/day, bouts/0800 to 2000 h, and bouts/2000 to 0800 h, respectively) in the three different phases of lactation (three levels: early, peak, plateau) at the two extreme environmental conditions during the monitored period

(37.32 ± 9.01 vs 30.97 ± 6.90) and 16 % (36.58 ± 8.11 vs 30.74 ± 4.02), respectively ($P < 0.10$), that is much greater than the expected decline in milk yield for the considered period. This observation confirms our previous results (Abeni et al. 2007) where cows in early phase of lactation resulted less susceptible to heat stress than cows in a more advanced phase; this is probably because the former partially rely on body energy mobilization for milk yield where the latter rely only on DMI, particularly depressed during heat stress.

The increase of activity index during heat stress conditions, namely during daytime, agrees with the findings by Cook et al. (2007). In their study, they did not present a partitioned time budget by day and night; however, from the change in time budget in their trial, it seems reasonable to expect a more frequent movement of the neck (that recorded by our sensors) when environmental temperature and THI increase. The same suggestion derived from the evidence by Allen et al. (2015) where increased body temperature (i.e., increased heat stress) led to increased standing time, as well as for the results by Brzozowska et al. (2014) where an increased number of steps per day was reported in cows during the summer months.

Date of control affected either RTt, RTd, and RTn, evidencing a decrease of these variables at the time with higher THI (Fig. 3). The extent of the decrease in RTt ranged from 32 % (early) to 37 % (plateau) of the value recorded in June. The highest reduction was recorded for RTd and ranged from 49 % (early) to 45 % (plateau).

There was no effect on RTt, RTd, and RTn due to phase of lactation, nor due to its interaction with day. The same was true for the measurements regarding activity.

The more pronounced decrease in RTd than RTn agrees with the knowledge reported by Christopherson and Kennedy (1983) as well as with the more recent paper by Soriani et al. (2013) during summer heat stress in Po valley. The effect of environmental temperature on rumen motility and, as consequence, on rumen activity that can elicit rumination is well documented since the papers by Attebery and Johnson (1969) and by Gengler et al. (1970).

The daily distribution of RT (Fig. 4) in both extreme days mirrored the bimodal pattern evidenced by Reith et al. (2014), but with a shift of roughly 4 h before their result; however, in the present trial, the diet was offered once daily; this way being not fully comparable from a chronobiological point of view because Reith et al. (2014) distributed the diet twice daily. The most important evidence in that figure is the dramatic gap in rumination time in the afternoon (1600 h) during the more stressful condition. This time lapse includes the
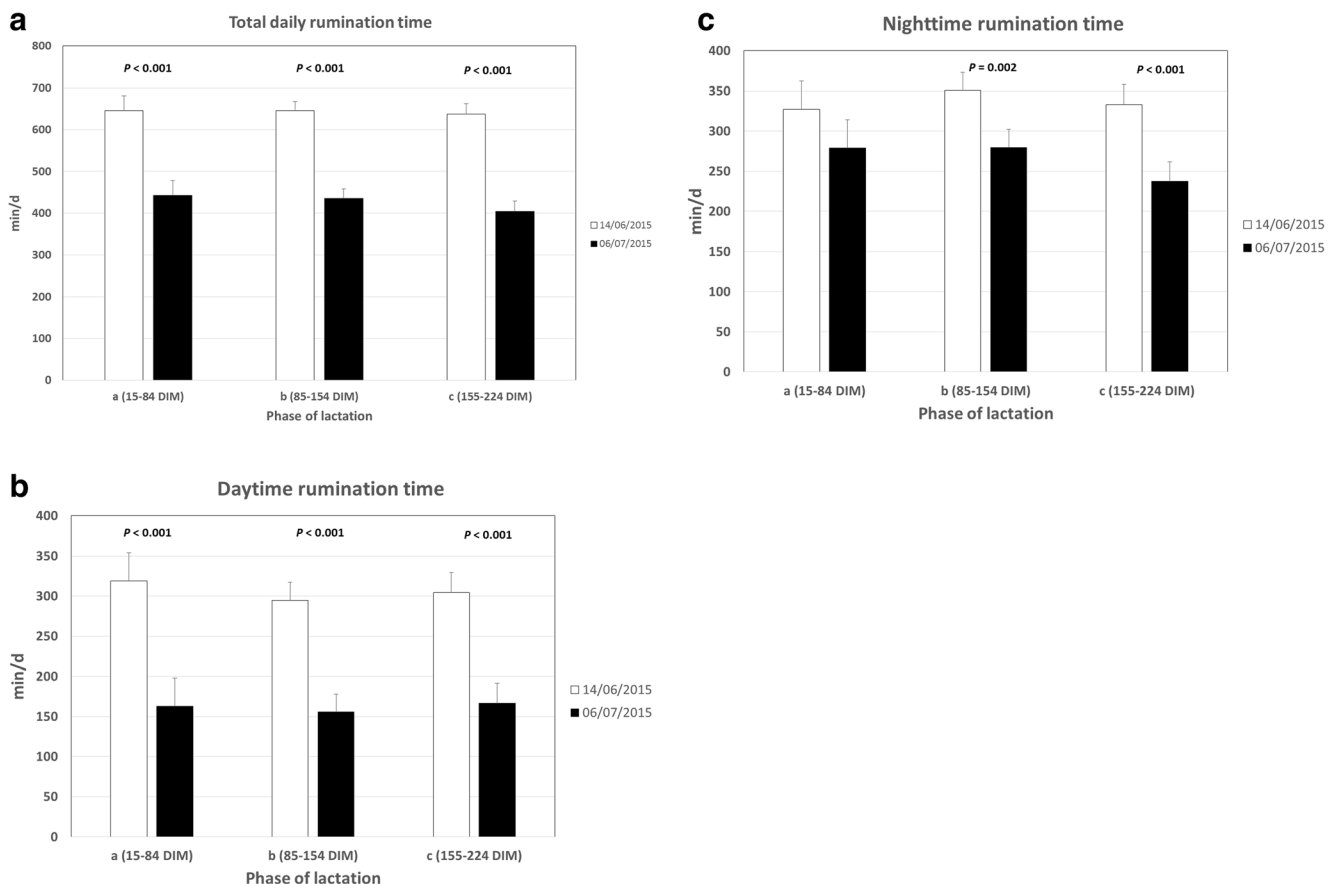

Fig. 3 Total daily (a), daytime (b), and nighttime (c) rumination time in the three different phases of lactation (three levels: early, peak, plateau) at the two extreme environmental conditions during the monitored period
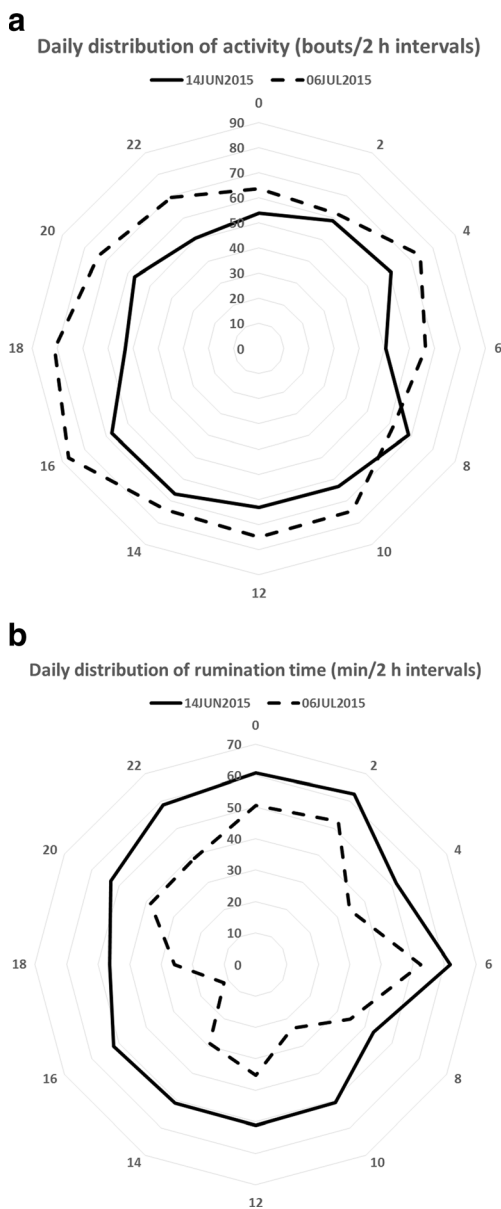
a

Daily distribution of activity (bouts/2 h intervals)

— 14JUN2015   -- 06JUL2015

b

Daily distribution of rumination time (min/2 h intervals)

— 14JUN2015   -- 06JUL2015

Fig. 4 Daily distribution (2-h intervals) of activity index (bouts/2 h, panel **a**) and rumination time (min/2 h, panel **b**) at the two extreme environmental conditions during the monitored period

milking time, and it is preceded and succeeded by two other time lapses with very low values of RT. In our opinion, the

procedures to move the cows in the waiting area before milking can affect and increase the stressful conditions of the cow, this way reducing the possibility to ruminate. We also must remember that waiting area, which was correctly dimensioned accordingly to international guidelines (1.50 m^2/cow, Fernández et al. 2009), had no wall separation from the barn and the air movement is the same originated from the general ventilation system, without additional specific devices. Probably, this more stressful area may represent a critical point for further improvement in thermal comfort for dairy cows during summer months.

We are not aware of a specific threshold of rumination time in a 2-h period, probably because this way to express rumen activity is strictly related to the availability of these new technological devices. However, it seems reasonable to suppose that an increased hazard for digestive and metabolic problems must be considered highly possible in those conditions. To our knowledge, there is no available statistical analysis on the hazard of digestive problems due to a single 2-h interval value of RT. Today, the most recent available data are from Soriani et al. (2012) and Liboreiro et al. (2015). In both papers, the authors evidenced the peripartum profile of daily rumination time according to different metabolic and uterine diseases. From their results, we try to extrapolate a threshold of 420 min/day (corresponding to 35 min/2 h on average) for the hazard of possible subclinical ketosis in the first 2 months of lactation. The value of RT2h in the afternoon during the hottest day in our study was very close to 10 min/2 h. We did not report cow with subclinical ketosis or other metabolic problems in those hottest days probably because the nighttime rumination was able to buffer the negative effect of the low rumination during daytime.

The correlations between the three rumination times (RTt, RTd, and RTn) and climate variables were also considered within lactation phase. In very early lactation, RTt and RTd had correlation coefficients ranging from −0.428 to −0.514 with air temperature (average, min, and max) and THI. These correlations slightly decline in the successive phase (values between −0.390 and −0.320). In both phases, RTn was always with correlation coefficients between −0.240 and −0.180. However, from the present data is not possible to attribute a different susceptibility of rumination activity to heat

Table 3 Analysis of variance partition among the random effect of the day (41 levels), the random effect of each cow nested within lactation phase (59 levels), and the residual error of observation

Item	Unit	Day	Variance Cow(phase)	Source Residual	Total
Total daily activity	μ/day	1078 (8.7 %)	7895 (63.9 %)	3379 (27.4 %)	12,353
Daytime activity	μ/day	320 (4.1 %)	5501 (70.2 %)	2016 (25.7 %)	7838
Nighttime activity	μ/day	335 (5.6 %)	4271 (71.3 %)	1386 (23.1 %)	5991
Total daily rumination time	min/day	2661 (33.7 %)	2677 (33.9 %)	2569 (32.5 %)	7907
Daytime rumination time	min/day	754 (17.1 %)	2127 (48.3 %)	1523 (34.6 %)	4404
Nighttime rumination time	min/day	455 (8.5 %)	2944 (54.8 %)	1979 (36.8 %)	5377

stress according to lactation phase; further research will be necessary to elucidate this aspect.

These results are consistent with the knowledge that dairy cows are able to compensate for the daytime stressful conditions if nighttime microclimate allows a recover in DMI and, as consequence, also rumination. Several attempts were made to try to exploit the ability to recover daily DMI by a shift in DMI from daytime to nighttime hours (Ominski et al. 2002; Aharoni et al. 2005; Nikkhah et al. 2008; Calamari et al. 2013). No conclusive results were obtained from those trials to be able to select a target strategy to cope with heat stress; however, the results from Nikkhah et al. (2008) evidenced a significant effect of time of TMR delivery on the particle size of refusals; this effect needs to be further studied for their potential consequence on rumen activity and health.

In our opinion, the trait of cow ability to cope with heat stress could be splitted in two separate traits: the ability to directly cope with daytime heat stress and the ability to compensate for DMI and rumination during nighttime.

The analysis of variance partition (Table 3) evidenced an important contribution due to the variation between cows for all the considered traits. In fact, the variance due to the cow within phase of lactation represents always a share above 60 % of the total variance for cow activity traits, and a share above from 33.8 % (for RTt) to 54.7 % (RTn) for the rumination time traits, being always the first source of variation.

These results confirm those from Byskov et al. (2015). If their analysis considered cow (trial), our analysis considered cow (phase), this way reducing the effect of the lactation phase which is very important in affecting rumination time (Nielsen et al. 2000).

Conclusion

This trial is the report of a very stressful period of heat stress in Po valley on a small number of cows. However, some preliminary results confirmed the same trend suggested by other researchers and, specifically about the variability between cows, encourage to plan further studies on a great number of cows in different management conditions.

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