Performance and welfare of high-yielding dairy cows subjected to 5 or 8 cooling sessions daily under hot and humid climate

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ABSTRACT

The objectives were to determine the effects of cooling of high-yielding dairy cows under a hot and humid climate on intake, milk yield, rumination time, and welfare parameters. Forty-two multiparous Israeli Holstein dairy cows were divided into 2 treatment groups and were housed in an open barn divided into 2 pens. The groups were subjected to different cooling schedules, in a crossover design as follows: cows were exposed to 5 or 8 cooling sessions per day (designated 5CS and 8CS, respectively) in the holding area of the milking parlor. Each period lasted 4 wk, and then treatments were switched for another 4-wk period. Each cooling session lasted 45 min, comprising cycles of 30 s of showering and 4.5 min of ventilation without showering. Respiration rate and rectal temperature were recorded twice per week (Monday and Thursday) at 0630 and 1600 h. Rumination and lying times were recorded automatically. Rectal temperatures were 0.16 and 1.08°C lower in 8CS than in 5CS cows in the morning and afternoon, respectively. Respiration rate was lower in 8CS than in 5CS cows in the morning (49.1 and 54.6 breaths/min, respectively), and more so in the afternoon (50.0 and 83.0 breaths/min, respectively). Dry matter intake and milk yields were 9.3 and 9.6% higher in the 8CS than in the 5CS cows (27.0 vs. 24.7 and 40.1 vs. 36.6 kg/d, respectively), with no differences in milk fat and protein contents. Daily rumination time was 7.4% longer in the 8CS than in the 5CS (440.1 and 409.6 min/d, respectively); however, rumination time per unit of dry matter or neutral detergent fiber consumed was higher in the 5CS than in the 8CS cows. Although the 8CS cows moved 3 times more to the milking area for extra cooling sessions than the 5CS ones, they spent 9.9 min/d more than the 5CS ones in lying down (484.4 and 474.5 min/d, respectively), and used more of their free time (excluding milking and feeding time) in resting than the 5CS cows: 52.0 and 43.9%, respectively. It appears that increasing the cooling frequency from

5 to 8 times per day improved their feeling of welfare, so they could spend more time lying and ruminating. In conclusion, increasing the cooling frequency of high-yielding dairy cows under hot and humid conditions from 5 to 8 times a day increased their intake and milk yield, and lowered their respiration rate and rectal temperature. Moreover, the 8CS cows spent more time resting than 5CS cows, an indication that increasing cooling frequency improved animal welfare.

Key words: heat stress, cooling frequency, animal welfare

INTRODUCTION

Heat load can noticeably affect the profitability of dairy herds (Wheelock et al., 2010) by decreasing cow feed intake, milk production, reproduction, and efficiency (Hahn, 1985; West, 2003; Berman, 2008). These negative effects are of major importance in animals of high genetic merit (Kadzere et al., 2002), because metabolic heat production increases as milk yields increase (Purwanto et al., 1990); therefore, in light of the dramatic increase in milk production in the last 25 yr, it is plausible that adverse effects of heat stress on production have intensified in the modern high-yielding dairy cow.

The adverse effects of heat stress on livestock performance are always coupled with negative effects on animal physiological and welfare parameters. The effects of heat stress are thought to be mediated by body temperature, and it was reported that rectal temperature (**RT**) increased by 0.02°C per kilogram of FCM for a cow producing >25 kg/d (Berman et al., 1985). Heat stress in ruminants also was associated with reductions in both frequency and amplitude of rumen contractions (Atteberry and Johnson, 1969) and a delay in the passage of digesta (Warren et al., 1974).

Various cooling mechanisms were reported as mitigating adverse effects of heat stress on physiological parameters and yields of dairy cows (Flamenbaum et al., 1986; Her et al., 1988; Smith et al., 2006a; Chanchai et al., 2010). However, although advances in environmental cooling systems ameliorate production losses during summer, heat stress continues to cost the dairy industry (Wheelock et al., 2010). In Israel, an intensive cool-

Received October 16, 2011.

Accepted February 29, 2012.

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ing management regimen was successfully implemented in large dairy herds in recent years. This management includes cooling sessions in the holding pen, coupled with wetting and ventilation in the feeding area. Under such intensive cooling management cows are sometimes exposed to a daily total of 7.5 h of cooling. In this intensive cooling management heat stress relief is very efficient: during the summer of 2005, milk production of cows in these herds reached up to 96% of their winter production (Flamenbaum and Ezra, 2007).

High standards of animal welfare have been and will continue to be important to the dairy industry (von Keyserlingk et al., 2009). Animal welfare standards in the livestock industry are not fully defined; however, a key concern is whether the animal is able to live a relatively natural life and exhibit natural behavior (von Keyserlingk et al., 2009). In light of this statement, we assumed that lying (Haley et al., 2000) and ruminating are important aspects of cow welfare, and that such long and intensive cooling management might bother the cows so as to impair their welfare and affect their lying and rumination times. Moreover, extra cooling sessions might increase water, electricity, and labor expenses; and perhaps satisfactory relief of heat load could be achieved with fewer cooling sessions. Therefore, the objectives of the present study were to evaluate the effects of cooling frequency (5 or 8 times per day) on intake, production, and rumination and lying times of high-yielding dairy cows under hot and humid conditions.

MATERIALS AND METHODS

Cows and Treatments

The procedures used in this study were approved by the Volcani Center Animal Care Committee. The experiment was conducted at the Volcani Center experimental farm in Bet Dagan, Israel, and continued from early July to late August (8 wk), which typically is the hottest season in Israel. Forty-two multiparous Israeli-Holstein dairy cows averaging 157 DIM (SD = 84) and 645 kg of BW (SD = 52) were housed in covered loose pens with adjacent outside yards, that were equipped with a real-time electronic individual feeding system. After 10 d of adaptation to the feeding stations, cows were divided into 2 treatment groups, each of 21 cows. Cows were stratified randomly within stratum and strata were defined according to milk production, DIM, parity, and BW. The barn was divided into 2 pens, in each of which 21 cows were housed and were subjected to different cooling schedules in a crossover design as follows: 1) the cows in the first group (**5CS**) were exposed to 5 cooling sessions per day in the hold-

ing area of the milking parlor; the cooling sessions for the 5CS began at 0410, 1015, 1210, 1700, and 1940 h; 2) the cows in the second group (**8CS**) were exposed to 8 cooling sessions per day, which began at 0425, 0700, 1015, 1225, 1500, 1700, 1955, and 2300 h. Both groups were exposed to a cooling session before each milking; the 5CS cows were brought twice and the 8CS cows 5 times per day between milkings for further cooling sessions.

Each cooling session lasted 45 min, comprising repeated cycles of 30 s of showering and 4.5 min of forced ventilation without showering. The cooling area, which was part of the holding pen, was 12 × 9 m (108 m²) and included 30 sprinklers (720 L/h each), 3 large fans (198.1 cm in diameter; capacity: 120,000 m³ of air/h each) located on the back side of the cooling area, and 4 small fans (50.8 cm in diameter; capacity: 8,800 m³ of air/h each) hung at the top of the cooling area. Each period lasted 4 wk, after which cooling treatments were switched between groups.

Cows were milked 3 times daily at 0505, 1305, and 2040 h, and milk yields were recorded electronically at each milking, and also weighed automatically after each milking with a walk-in electronic scale (S.A.E. Afikim, Kibbutz Afikim, Israel). Milk samples were collected from 3 consecutive milkings during the second and the last week of each period, and milk fat, protein, and lactose and SCC were determined by infrared analysis (standard IDF 141C; International Dairy Federation, 2000) at the laboratories of the Israeli Cattle Breeders' Association (Caesarea, Israel).

Cows were fed a typical Israeli lactating-cow ration comprising 1.75 Mcal of NE_L, 16.5% CP, and 31.5% crude NDF (Table 1). Cows were individually fed a TMR once daily at 1100 h and offered feed amounts were adjusted daily to allow 7% orts. Feed offered and orts were recorded daily for individual intake calculations.

Measurements

Ambient temperature (**AT**) and relative humidity (**RH**) were recorded every 3 h by the Israel Meteorological Service (Bet Dagan, Israel). Maximum RH and minimum AT were determined at 0300 h, and minimum RH and maximum AT were determined at 1200 h. Accordingly, the minimum and maximum temperature-humidity indexes (**THI**) were determined at 0300 and 1200 h, respectively. The following equation was used for THI calculation (Bohmanova et al., 2007):

$$\text{THI} = (1.8 \times T_{\text{db}} + 32) - (0.55 - 0.0055 \times \text{RH}) \times (1.8 \times T_{\text{db}} - 26),$$

Table 1. Ingredients and chemical composition of the diet

Composition	Value
Ingredient, % of DM	
Corn grain, ground	12.0
Barley grain, rolled	7.6
Wheat grain	4.4
Rapeseed	2.2
Soybean meal	2.4
Sunflower meal	4.5
Wheat bran	2.2
Corn gluten feed	14.7
Cottonseed	3.9
Wheat silage	9.4
Corn silage	9.7
Oats hay	9.9
Clover hay	3.7
Dried distillers grain	3.1
Soybean + molasses	2.2
Byproduct of lactose industry	3.9
Calcium salts of FA	1.7
Salt	0.8
Urea	0.4
Calcium bicarbonate	0.7
Limestone	0.5
Vitamins and minerals ¹	0.1
Chemical composition	
NE _L , ² Mcal/kg	1.75
CP	16.5
NDF	31.5
Forage NDF	17.0
Ether extract	4.4
Ca	0.9
P	0.5

¹Contained (per kg): 20,000,000 IU of vitamin A; 2,000,000 IU of vitamin D, 15,000 IU of vitamin E, 6,000 mg of Mn, 6,000 mg of Zn, 2,000 mg of Fe, 1,500 mg of Cu, 120 mg of I, 50 mg of Se, and 20 mg of Co.

²Calculated by using the NRC (2001) values.

where T_{db} is dry-bulb temperature. Energy content in milk was calculated according to NRC (2001) equations. Energy balance (EB) was calculated daily according to NRC (2001) as follows:

$$NE_c = NE_L \text{ per kilogram of DM} \times \text{DMI};$$

$$NE_m = BW^{0.75} \times 0.08 \times 1.1;$$

$$NE_p = \text{milk (kg)} \times \{[0.0929 \times (\text{fat } \%)] + [0.0547 \times (\text{protein } \%)] + [0.0395 \times (\text{lactose } \%)]\};$$

$$EB = NE_c - (NE_m + NE_p);$$

where NE_c = net energy consumed, NE_m = net energy required for maintenance, and NE_p = net energy output in milk. The conversion rate of feed DM to milk was calculated from the daily individual data.

The cows were equipped with collar-mounted tags (HR-Tags; SCR Engineers Ltd., Hadarim, Netanya,

Israel) that monitored and transmitted rumination time (Schirrmann et al., 2009). Rumination data were recorded by a special microphone that detected chewing actions by analyzing vocal signals. Data were stored in 2-h blocks and uploaded 3 times daily at the milking parlor.

The cows also were equipped with another sensor (Pedometer Plus; S.A.E. Afikim) that monitored 3 parameters: activity (steps/h), lying time (min), and lying bouts (switching between standing and lying; Higginson et al., 2009). The tag was fitted to the rear leg of each cow and the data were accumulated and transmitted to management software (AfiFarm; S.A.E. Afikim) each time the cows passed an antenna located in the milking parlor.

Respiratory rate (**RR**) and RT were recorded twice weekly. On each day, measurements were taken at 0630 and 1600 h. Rectal temperature was recorded by a clinical thermometer inserted into the rectum for 1 min. Respiration rates were measured by counting flank movements during 30 s, as recorded with a stopwatch.

Chemical Analysis

Total mixed rations were sampled weekly and DM, CP, NDF, ADF, Ca, and P concentrations were determined. Feed samples were dried at 65°C for 24 h and ground to pass through a 1.0-mm screen (Retsch S-M-100; Retsch GmbH, Haan, Germany). Samples were analyzed for N (AOAC, 1990; method 984.13), Ca (AOAC, 1990; method 935.13), and P (AOAC, 1990; method 964.06) contents. The NDF and ADF contents were determined with Ankom equipment (Ankom Technology Corp., Fairport, NY; NDF, using α -amylase and sodium sulfite). The ground samples were dried later at 100°C and analysis results were corrected accordingly. NE_L values for feedstuffs in the formulated diets were calculated according to the values of the NRC (2001).

Statistical Analysis

The data from the last 3 wk of each period were used for analysis. Continuous variables such as DMI, milk, and milk solids, efficiency, rumination, resting times, RR, and RT were analyzed as repeated measurements using the PROC MIXED of SAS software (version 9.2; SAS Institute, 2002). The model used was

$$Y_{ijklmn} = \mu + T_i + L_j + C_k + O_l + C(O)_{kj} + \text{DIM}_{ijklm} + E_{ijklmn},$$

Table 2. Least squares means of DM and energy intakes, milk and milk solids yields, energy output in milk, and energy balance and efficiency

Item	Treatment ¹			P-value
	5CS	8CS	SEM	
DMI, kg/d	24.7	27.0	0.32	<0.001
NE _L intake, Mcal/d	44.0	48.0	0.58	<0.001
Milk yield				
Milk, kg/d	36.6	40.1	0.92	<0.001
Milk energy output, Mcal/d	23.9	26.7	0.44	<0.001
FCM (4%), kg/d	32.4	36.0	0.64	<0.001
Milk solids contents and yields				
Fat, %	3.35	3.37	0.09	0.71
Protein, %	3.15	3.15	0.04	0.80
Lactose, %	4.71	4.76	0.03	0.009
TS, %	11.2	11.3	0.12	0.24
Fat, kg/d	1.19	1.32	0.03	<0.001
Protein, kg/d	1.12	1.25	0.02	<0.001
Lactose, kg/d	1.70	1.91	0.05	<0.001
SCC ($\times 10^3$)	182.0	113.0	56.0	0.11
Efficiency and energy balance				
Milk/DMI, kg/kg	1.49	1.50	0.039	0.54
Energy balance, Mcal/d	8.9	10.0	0.53	<0.001

¹Dairy cows under heat load were exposed to 5 or 8 cooling sessions per day (designated 5CS and 8CS, respectively) in the holding area. Each cooling period lasted 45 min, comprising cycles of 30 s of showering and 4.5 min of ventilation.

where Y_{ijklmn} is the dependent variable; μ = overall mean; T_i = treatment effect; $i = 1$ or 2 ; L_j = period; $j = 1$ or 2 ; C_k = cow effect; $k = 1 \dots n$; O_l = order effect; $l = 1$ or 2 ; $C(O)_{kj}$ = cow k nested in order l ; DIM_{ijklm} = DIM as a continuous variable; and E_{ijklmn} = random residual.

Treatment $\times$ period interactions were tested and found not significant for any analyzed variables; therefore, they were excluded from the model. Mean separation was performed by using the PDIF procedure with a Tukey adjustment in SAS (version 9.2). Least squares means and adjusted standard errors of the means are presented in Tables 2, 3, and 4. The significance criterion was taken as $P < 0.05$, and tendencies were reported at $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

In the present study, cooling high-yielding dairy cows 8 times daily during the hot season resulted in greater DMI and milk production, and improved the animal welfare than 5 cooling sessions per day.

The average AT and RH during the study period were $28.2 \pm 1.3^\circ\text{C}$ and $68.1 \pm 3.8\%$, respectively. Minimum, maximum, and average THI during the study period were 73.2, 82.3, and 78.4 ± 2.1 , respectively (Figure 1).

Respiration rate and RT were lower in the 8CS than in the 5CS cows (Table 3). The RR in morning and afternoon were 5.5 and 33.0 breaths/min, respectively, lower in the 8CS than in the 5CS cows ($P < 0.001$). The RT in morning records was 0.16°C lower in the

Table 3. Rumination time, rectal temperature, and respiratory rate measurements

Item	Treatment ¹			P-value
	5CS	8CS	SEM	
Rumination time, min/d	409.6	440.1	8.4	<0.001
Rumination time/DMI, min/kg	16.8	16.5	0.41	0.02
Rumination time/NDF intake, min/kg	98.9	97.0	2.4	0.02
Respiratory rate, breaths/min				
Morning	54.6	49.1	1.12	<0.001
Afternoon	83.0	50.0	1.44	0.001
Rectal temperature, $^\circ\text{C}$				
Morning: 0630 h	38.51	38.35	0.04	<0.001
Afternoon: 1530 h	39.30	38.22	0.05	<0.001

¹Dairy cows under heat load were exposed to either 5 or 8 cooling sessions per day (designated 5CS or 8CS, respectively) in the holding area. Each cooling period lasted 45 min, comprising cycles of 30 s of showering and 4.5 min of ventilation.

Figure 1. Weekly temperature-humidity indexes (THI) during the study period (8 wk).

8CS than in the 5CS cows, but in the afternoon the RT was 1.08°C lower in the 8CS than in the 5CS cows ($P < 0.001$). A threshold for markedly increased RR was identified at an air temperature of 21.3°C by Hahn (1999). Also, Berman et al. (1985) reported an upper critical AT of 25 to 26°C at which body temperature and RR started to rise, and suggested that it was independent of the cow milk yield or acclimatization state. The average AT during the present study was 28.2°C, which is generally accepted as being above the upper critical temperature. Forced ventilation was found effective elsewhere in preventing body temperature rise (Berman et al., 1985). Furthermore, in the present study, increasing the cooling (wetting and ventilation)

frequency was effective in decreasing RT and RR, which are the main empiric physiological parameters that are influenced by heat stress. Increased body temperature negatively influenced performance, by decreasing milk production and changing milk composition (Kadzere et al., 2002); however, cooling managements that diminish the increase in RR and RR caused by heat stress alleviate the decrease in DMI and, consequently, contribute to maintain high milk production.

The daily DMI was 2.1 kg (9.3%) higher in the 8CS than in the 5CS cows (Table 2). Heat stress was found to be associated with decreased DMI by several researchers (Beede and Collier, 1986; Holter et al., 1997; West, 2003). Beede and Collier (1986) suggested several physiological and metabolic aspects to describe the decrease in intake that results from thermal stress, including increased water intake, reduced gut motility, and increased RR. Cooling dairy cows was found effective in mitigating the negative effects of heat stress on DMI in several studies (Smith et al., 2006b; Chanchai et al., 2010). Moreover, it was suggested that the negative effects of heat stress are mediated by body temperature and that minimizing the increase in RT could improve nutrient intake (West, 1999); thus, the lower RT and RR in the 8CS than in the 5CS cows that were observed in the present study might be the cause of the higher DMI in the former cows.

Daily rumination time was 7.4% higher in the 8CS than in the 5CS cows ($P < 0.001$; Table 3). However, the rumination time per kilogram of DM or NDF consumed was calculated to be 1.8 and 2% higher, respectively,

Table 4. Resting and standing time measurements

Item	Treatment ¹			
	5CS	8CS	SEM	P-value
Cooling time, min/d	225	360		
Lying time, min				
Session 1 ²	254.4	251.2	5.0	0.15
Session 2 ³	111.1	122.3	4.2	<0.001
Session 3 ⁴	113.4	115.8	4.2	0.15
Total lying time, min/d	474.5	484.4	10.9	0.004
Activity time, min				
Session 1 ²	65.6	81.3	2.2	<0.001
Session 2 ³	87.1	99.8	2.3	<0.001
Session 3 ⁴	94.3	109.9	2.4	<0.001
Total activity time, min/d	131.7	148.8	4.2	<0.001
Standing time, ⁵ min/d	833.8	806.8	10.4	<0.001
Lying bouts ⁶	11.5	11.9	0.32	<0.001

¹Dairy cows under heat load were exposed to either 5 or 8 cooling sessions per day (designated 5CS or 8CS, respectively) in the holding area. Each cooling period lasted 45 min, comprising cycles of 30 s of showering and 4.5 min of ventilation.

²Between evening and morning milkings.

³Between morning and noon milkings.

⁴Between noon and evening milkings.

⁵Included cooling, feeding, and milking time.

⁶Switching position between standing and lying.

in the 5CS than in the 8CS cows ($P < 0.02$; Table 3), and this could be attributed to the lower intake in the former than in the latter. A direct decrease in rumen activity was found in cows exposed to high AT (Attenberry and Johnson, 1969). According to Beauchemin et al. (1994), high-yielding dairy cows consuming large quantities of DM tended to ruminate for more than 360 min/d; accordingly, the rumination time in the 5CS cows (409.6 min/d) was still within the physiological range that prevents detrimental effects on rumen buffer capacity and digestibility. The decreased intake and lower digesta passage rate found in heat-stressed cows also might be the reason for the increased rumination time per unit of consumption in the 5CS cows. Moreover, a positive relationship between digestibility and ambient temperatures has been reported by Lu (1989), and it was suggested by Kadzere et al. (2002) that the decreased DMI and the prolonged retention of feed in the gastrointestinal tract in response to heat load could account for the increase in digestibility, and might also explain the present finding that feed efficiency was no greater in the 8CS than in the 5CS group.

The 8CS cows produced an average of 3.5 kg/d (9.6%) more milk than the 5CS cows ($P < 0.001$; Table 2). No between-group differences in milk fat and protein contents were observed, but lactose percentage was higher in the 8CS cows ($P < 0.001$; Table 2) and SCC tended to be higher in 5CS than in 8CS ($P < 0.11$; Table 2). A negative association between SCC and lactose percentage in milk was found in Park et al. (2007), which could partly explain the lower lactose content in the 5CS group. Daily yields of fat (10.9%), protein (11.6%), and lactose (12.4%) in milk were higher in 8CS than in 5CS ($P < 0.001$). Decreased feed intake caused by heat stress has traditionally been assumed to be the main cause of decreased milk yield (Collier et al., 1982; West, 2003); therefore, the higher production in the 8CS than in the 5CS cows might be attributed to the enhanced DMI of the former. However, it should be noted that a recent study demonstrated that decreased intake accounted for only 35% of the decrease in milk yield under heat stress (Rhoads et al., 2009). Moreover, it was suggested by Rhoads et al. (2009) that when the extent and duration of heat stress exceeds a given threshold, the cumulative thermal load disrupts the relationship between nutrient intake and milk production, and milk synthesis decreases beyond the expected levels. In light of this hypothesis, we would expect an improvement in conversion of feed to milk with increasing the cooling frequency. That this did not happen in the present study (Table 2) indicates that even the 8CS cows were still under heat stress, and the increase in milk production was due to the increased DMI, and not improved feed-to-milk ratio.

The average lying time of both groups (~ 8 h/24 h) was higher than that reported by Konggaard and Krohn (1978; 7.4 h/24 h), but much lower than that reported by Ruud and Bøe (2011; 13.7 h/24 h). The low lying time in the present study could be partly attributed to the intensive cooling management in open barns and 3 milkings per day compared with nonlactating cows in freestalls in the Ruud and Bøe (2011) study. The lying time measurements in the present study revealed that, although the 8CS cows apparently were disturbed by more frequent cooling sessions and movements between the parlor and the barn, on average, they lay down 9.9 min/d more than the 5CS cows ($P < 0.001$; Table 4). Moreover, this difference was evident between morning and noon milkings, but was not recorded during the afternoon and night (Table 4). The duration of lying is a good indicator of cow comfort (Haley et al., 2000; Berman, 2006). The standing time of the 8CS cows was 27 min (3.3%) less than that of the 5CS cows ($P < 0.001$; Table 4); however, it should be noted that the sensors counted only numbers of steps but not standing time, which included feeding, cooling, and milking time. It might also be that the 5CS cows spent more of their free time standing to improve heat dissipation as explained in details by Berman (2006). The 8CS cows were inclined to stand for 135 min/d (3 extra cooling sessions) more than the 5CS ones; however, calculation of lying time as a proportion of free time revealed that the 8CS cows used 52.0% of their free time for resting, compared with 43.9% by the 5CS cows ($P < 0.001$). This finding was surprising, as we had assumed that the more frequent cooling sessions of the 8CS would prevent them from lying down and thereby impair their welfare. In fact, the 8CS cows had 17.1 min/d more activity time than the 5CS cows ($P < 0.001$; Table 4) but nevertheless, as stated above, they spent more time resting. The present results indicate that cooling the cows more frequently improved their comfort, so that they spent more time lying down than those with fewer cooling sessions.

CONCLUSIONS

Increasing the cooling session frequency from 5 to 8 times per day decreased the RT and RR, and this effect was more prominent at afternoon records, in which the 8CS cows were after a cooling session compared with the 5CS cows. The DMI and milk yield were 9.3 and 9.6%, respectively, higher in the 8CS than in the 5CS cows, but no differences between treatments in feed efficiency were observed. Daily rumination time was 7.4% higher in the 8CS than in the 5CS cows, but rumination time per unit consumed was higher in the 5CS than in the 8CS cows. Although the 8CS cows were

moved to the milking parlor for cooling sessions 3 times more per day than the 5CS cows, they lay down for 9.9 min/d more than the 5CS cows, and used a greater proportion of their free time in resting. This indicates that increasing the cooling frequency of heat-stressed, high-yielding cows helps them to feel more comfortable and thereby improves their welfare characteristics.

ACKNOWLEDGMENTS

This research was financially supported by the Israeli Cattle Breeders' Association (Caesaria, Israel). We thank the staff of the experimental dairy farm at the Volcani Center (Bet Dagan, Israel) for their assistance with animal care.

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