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Short Communication

Sprinkler flow rate affects physiological, behavioural and production responses of Holstein cows during heat stress

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Abstract

Heat stress is a major challenge for dairy cows in summer. Sprinklers at feed bunks are commonly used to cool cows. These sprinklers use groundwater, which is becoming limited. There is a need to explore a more efficient use of this precious resource. Eighteen lactating Holstein cows were randomly subjected to three sprinkler flow rates in a crossover design. These rates were 0.5, 1.25, and 2.0 L/min. The average temperature humidity index of the shed was 86.7 during the study. The cows in the 1.25 and 2.0 L/min groups had 0.6 °C and 0.9 °C lower rectal temperatures, respectively, than the 0.5 L/min group. Similarly, the 1.25 and 2.0 L/min groups had lower respiration rates than the 0.5 L/min group. The daily milk yield was approximately 5 kg/d higher in the 1.25 and 2.0 L/min groups, which were not detectably different from each other, than the 0.5 L/min group. The cows in the 0.5 L/min group spent less time feeding than those in the 1.25 and 2.0 L/min groups. These results suggested that sprinkler flow rates greater than 0.5 L/min produced desirable responses by the cows. The flow rate 1.25 L/min appeared to be more efficient as it used 37.5% less groundwater compared with 2.0 L/min.

Keywords: cow performance, heat stress, sprinkler cooling, welfare
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Holstein Friesian cows are known for their high milk yield. They are popular in the commercial dairy sector of Pakistan. Heat stress is a major challenge for these animals owing to the longer summer season with high ambient temperatures (35 - 40 °C) and relative humidity (30 - 50%) in the area (Butt *et al.*, 2020). Mitigating the effects of heat stress requires substantial investments in energy and water.

Spraying dairy cows with water in the holding pen or at the feed bunk is common practice as it lowers body temperature and respiration rate (Kendall *et al*., 2007; Chen *et al*., 2013; 2016), and improves feed intake and milk yield (Keister *et al*., 2002). Owing to the recent decrease in global groundwater, studies have focused on strategies to reduce the use of water to cool dairy cows (Chen *et al.*, 2016). Sprinkler flow rates of 1.3 and 4.9 L/min had similar effects on physiological responses of cows to heat load but produced a 73% difference in water use (Chen *et al.*, 2016). Similarly, Tresoldi *et al*. (2019) concluded that a sprinkler flow rate of 4.9 L/min had poor efficiency compared with 3.3 L/min, as the additional water did not result in increased biologically relevant cooling. These studies were conducted in Mediterranean climates with an average temperature humidity index in the range of 76 to 78. A recent study with Nili Ravi buffaloes revealed a sprinkler flow rate 1.25 L/min was more efficient than one of 2.0 L/min during subtropical summers (Bah *et al.*, 2021). Because water is projected to be scarce in Pakistan by 2030 (Mustafa *et al*., 2013), holistic strategies for water conservation in the dairy sector are important nationally.

The objective of this study was to evaluate the effects of various sprinkler flow rates on the performance of lactating Holstein Friesian cows in a typical corporate dairy farm setting during the subtropical summer. Performance of these cows was assumed to be similar, irrespective of the sprinkler flow rates.

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The study was conducted at the Dairy Animal Training and Research Centre, University of Veterinary and Animal Sciences (UVAS), Lahore, Ravi Campus, Pattoki, Pakistan (31°03'43.9” N 73°52'36.1” E), in June 2019. All the experimental procedures complied with the institutional guidelines of the Ethical Review Committee of the University of Veterinary and Animal Sciences, Lahore (Dr/16:19-01–2021).

Eighteen lactating Holstein Friesian cows with an average daily milk yield of 19.4 ± 1.2 kg, 130.5 ± 9.8 days in milk, and 2.7 ± 0.1 parity were selected for the study. The cows were housed in the southernmost pen of a naturally ventilated freestall shed with steel roofing and a concrete floor. The pen was 50 m long (east-west) and 13.5 m wide. It was divided into three partitions with at least 16 freestalls in each partition. The heights of the ridge and eaves of the shed were 12 and 7 m, respectively. A polyvinyl water pipe (5.08 cm diameter) was installed at a height of 1.9 m along the feed bunk with four sprinkler nozzles. These nozzles were set at 2 m apart, fitted with a solenoid valve to control the flow rate, and sprayed water over a 180-degree radius at the back of the cows. The 14 m-long feed bunk was separated from the standing area with a post and rail system. The concrete standing area in front of the feed bunk was provided with a 2.50 m wide rubber mat of 1.5 cm thickness. The cows stood on the rubber mat while feeding and cooling under the sprinklers. The freestalls were bedded with 15 cm deep sand, which was cleaned and levelled at 07h00 daily. The pens were rebedded twice during the trial. The partitions at the two ends of the southern pen had one water trough each, and the one in the middle had three. The cows had continuous access to an outdoor open area adjacent to each partition. The pen had eight industrial fans (Model FS-75, Bilal Electronics, Lahore, Pakistan) (blade length 60 cm, width 15 cm) two pairs of fans above the resting area and four single fans above feeding area, at heights of 2.25 and 3.04 m above the ground, respectively. The total mixed ration offered to cows consisted of 88.9% oat silage and 11.1% concentrate. The concentrate consisted of 33.5% maize grain, 25% canola meal, 30% wheat bran, 10% molasses, 0.5% premix and 0.5% lime. Each group was provided with water ad libitum. The cows were milked in a 6 × 6 herringbone milking parlour (GEA Farm Technologies GmbH-Westfalia surge D-59199 Bönen, Germany) at 05h30 and 17h30 daily.

The cows were randomly divided into three groups of six cows each. Four sprinklers were installed in each treatment pen. The sprinkler flow rates were 0.5, 1.25, and 2.0 L/min, with a single pen being used for the application of each treatment. By shifting cows between pens, the treatments were applied in a three-period crossover design with seven days per period (Table 1). The first four days of each period allowed the cows to adapt to their new environment and the data were collected during the remaining three days.

Table 1 Experimental design for application of water-cooling treatments to lactating Holstein-Friesian dairy cows

Week	Group of cows (N = 6/group)		
	1	2	3
1	0.50 L/min	1.25 L/min	2.00 L/min
2	1.25 L/min	2.00 L/min	0.50 L/min
3	2.00 L/min	0.50 L/min	1.25 L/min

The sprinkler nozzles produced showering with a droplet size almost similar to that of raindrops to wet the cows for evaporative cooling. The sprinklers were turned on manually from 07h00 until 17h30 in a 12-minute cycle, with the water on for three minutes, followed by a nine-minute period during which the water was off. When the water was off, the fans were turned on to promote evaporative cooling. The 2.0 L/min treatment was chosen because it was the flow rate used traditionally by the local dairy industry. The other two treatments were chosen as strategies that would reduce the use of water for cooling dairy animals. Table 2 provides further characterization of the sprinkler system. The pens were sufficiently separated that the nozzles nearest the dividing fence did not spray cows in an adjacent pen. The water spread in the 0.5 L/min group was wide enough to cover the back of a single cow standing at the feed bunk. However, it might have not been sufficient for more than one cow to be sprayed at the feed bunk, thereby potentially compromising the heat abatement of cows in this treatment group.

Table 2 Characteristics of the water spray provided by each of the sprinkler flow rate treatments

Characteristic	Sprinkler flow rates, L/min		
	0.50	1.25	2.00
Water spread			
Perpendicular to feed alley, m	0.78	0.82	0.84
Parallel to feed alley, m	1.23	1.30	1.44
Area covered, m^2	0.95	1.07	1.21
Distance between nozzles, m	2.03	2.03	2.03

The ambient temperature (T) (°C) and relative humidity (RH) (%) of the shed and the adjacent outdoor pen area were taken with a digital thermo-humidity meter (HTC1, Shenzhen, China). The readings were taken three times (06h00, 13h00, and 15h00) at a height of 2.3 m in the middle of the shed. The same meteorological measures were recorded at the same height and time in the outdoor open area. Averages of 13h00 and 15h00 were presented as characterizing the afternoon, and measurements recorded at 06h00 were used to characterize the morning. The temperature-humidity index (THI) was calculated as (Kelly & Bond, 1971):

$$THI = (1.8T + 32) - (0.55 - 0.0055RH)(1.8T - 26)$$

Milk yield of individual cows was recorded with meters installed at the milking parlour. Feed and water intake data were measured as group data and were not presented. Rectal temperature (RT) and respiration rate (RR) were recorded of all cows between 13h00 and 14h00. Rectal temperature was recorded with a digital thermometer (Certeza, FT-707, Hamburg, Germany) and RR was measured by counting movements of the abdomen. The 24-hour feeding, standing, and lying time behavioural data on individual cows were collected with the Nedap CowControl system (Nedap N.V., Groenlo Netherlands). This system has a leg and neck data logger attached to individual cows and records information on the feeding, lying, and standing behaviour of the cows. This information was accessed via the system software. The physiological and behavioural measures were used as a proxy for the welfare indicators of the cows.

The data were analysed using SAS (SAS Institute Inc., Cary, North Carolina, USA). The data from individual cows collected on the last three days of each period were averaged, with the averages then assessed for normality using the Shapiro–Wilk test. The normally distributed data were subjected to analysis of variance using PROC MIXED with the following model:

$$Y_{ijk} = \mu + t_i + w_j + c_k + e_{ijk}$$

where: Y_{ijk} = a dependent variable,
μ = the overall mean,
t_i = the fixed effect of treatment i, where i = 1, 2, or 3, corresponding to the three flow rates,
w_j = the fixed effect of week j, where j = 1, 2, or 3,
c_k = the random effect of cow, where k = 1 ton, and
e_{ijk} = the random error.

The least square means were separated using the PDIFF option with Tukey's adjusted *P*-values. Differences were considered significant at $P \leq 0.05$ and tendencies at $P < 0.10$. The behavioural data for length of feeding and lying bouts were subjected to non-parametric ANOVA (Kruskal-Wallis test) using PROC NPAR1WAY because log transformation of these variables did not achieve normality, and median values from these analyses have been presented.

The average morning (06h00) and afternoon (between 13h00 and 15h00) temperatures, RH, and THI indicated the potential for severe heat stress (Table 3). The average afternoon temperature and THI were 7.5 °C and 4.1% higher than the morning, respectively. The average outdoor temperature was 2.7 °C higher and the RH 30.7% lower than the inside in the afternoon. The THI was also 3.7 points higher in the outdoor open area in the afternoon. The high RH inside the pen, compared with the outdoor open area, could be attributed to showering. The difference between morning and afternoon temperatures and THI values suggested that the heat load was less in the morning. A THI that incorporates the effects of environmental temperature with relative humidity is commonly used to determine the severity of heat stress (De Rensis *et al*., 2015; Polsky & Von Keselink, 2017). In this study, a high afternoon THI value in the pen indicated that the cows were under moderate heat stress (Armstrong, 1994). High THI values, that is, greater than 75, can have a severe negative impact on the milk production of dairy cows (De Rensis *et al*., 2015).

Table 3 Summary of meteorological conditions in the morning at 06h00 and the afternoon average of data recorded at 13h00 and 15h00 in June 2019 (n = 126)

Measurements	Morning			Afternoon		
	Mean	SD	Range	Mean	SD	Range
Inside pen						
Temperature, °C	29.2	1.2	27.1 - 30.5	36.7	2.4	33.3 - 40.1
Humidity, %	86.8	10.7	72 - 99	57.3	14.5	40 - 84
Temperature-humidity index	82.6	2.9	78.4 - 86.6	86.7	3.5	81.8 - 92.3
Outside open area						
Temperature, °C	26.6	1.4	23.9 - 28.5	39.4	4.3	29.9 - 42.9
Humidity, %	60.2	11.8	44 - 82	26.6	19.9	10 - 72
Temperature-humidity index	75.0	2.1	72.0 - 78.6	90.3	7.5	81.5 - 100.1

The daily milk yield was 4.5 and 5.5 kg/d higher for the 1.25 and 2.0 L/min sprinkler flow rate groups, than the 0.5 L/min group, respectively (P <0.0001) (Table 4). However, no difference was observed in the milk yield when the cows were subjected to the higher flow rates (P >0.05). Chen *et al.* (2016) reported that cows cooled with 1.3 and 4.9 L/min of water had similar milk yields. This supported the present findings and substantiated the possibility of reducing water usage in cooling dairy cows in a typical commercial dairy farm setting. About 50% of the reduction in milk yield under heat stress has been attributed to decreased feed intake (Wheelock *et al*., 2010), with the remainder being caused by other physiological mechanisms (Baumgard & Rhoads, 2012). Hence, the similar milk yield at flow rates of 1.25 and 2.0 L/min might be attributed to similar levels of heat abatement and consequent physiological responses of cows that were exposed to these treatments (Bah *et al.*, 2021).

The cows in the 0.5 L/min group had 0.6 °C and 0.9 °C higher body temperature than those in the 1.25 and 2.0 L/min groups, respectively (P <0. 0001) (Table 4). However, the 1.25 and 2.0 L/min groups had similar body temperature (P >0.05). No difference was observed in the RR between the 1.25 and 2.0 L/min groups (58.0 and 56.1 breaths/min, respectively (SE = 1.61 breaths/min) (P >0.05), whereas the 0.5 L/min group had 8.6 and 10.5 more breaths/min than the 1.25 and 2.0 L/min groups, respectively (P <0.05) (Table 4). It is well documented that spray cooling in the holding pen and at feed bunk lowers body temperature and respiratory rate (Kendall *et al.*, 2007; Chen *et al.*, 2013). Compared with 0.5 L/min rate, the 1.25 L/min and 2.0 L/min rates reduced the body temperature and respiration rate of cows to a similar extent. The 1.25 and 2.0 L/min treatments might have had more water dripping down the bodies of the cows. Such dripping could carry away the heat from the animal's body (Tresoldi *et al.*, 2018). Possibly the upper rates (1.25 and 2.0 L/min) had more water for evaporative cooling relative to the low rate (0.5 L/min), thereby reducing the heat load. Chen *et al.* (2015) reported that water rates of 1.3 L/min and 4.5 reduced the body temperature and RR to a similar extent, which is consistent with current findings. Chen *et al.* (2016) revealed that sprinkler flow rates 1.3 and 4.9 L/min had similar effects on cattle responses to heat load. The 1.25 and 2.0 L/min flow rates were better for cow welfare than 0.5 L/min as these treatments lowered the rectal temperature and respiratory rate of the cows effectively. Physiological measures have been reported to describe the health and biological functioning component of animal's welfare (Polsky & Von Keyserlingk, 2017).

The treatments affected the time budgets of the cows (Table 4). The cows in the 0.5 L/min group spent significantly less time feeding than cows in the 1.25 and 2.0 L/min groups (P <0. 0008) (Table 4). No difference was observed in feeding time between the 1.25 and 2.0 L/min groups (P >0.05) Table 4). On average, the single feeding bout duration was 10.9 min. The cows in the 0.5 L/min group had significantly shorter feeding bout length than the 1.25 L/min group (P <0.0130) (Table 4). However, there was no effect of sprinkler flow rates on feeding bout frequency (P =0.2820) (Table 4). The average feeding bout frequency was 21.1 number/24 h. Contrary to the current findings, Chen *et al.* (2016) reported that cows spent 5.9

hours for both 1.3 and 4.9 L/min flow rates. Tresoldi *et al.* (2019) reported 5.8 and 5.9 hours total time near the feed bunk area for cows subjected to 4.9 and 3.3 L/min sprinkler flow rates, respectively. In the current study feeding time was not the same as time near the bunk whether feeding or not. The duration of cooling was also different from the measurement of Tresoldi *et al.* (2019). The current study had 11 hours cooling, whereas Tresoldi *et al.* (2019) had 24. This could explain the difference in the findings between these studies. The various sprinkler flow rates had no effect on the total lying time in cows (P =0.7263) (Table 4). Total lying time ranged from 487.0 to 508.7 min per 24 hours (SE =12.38). On average, a single lying bout lasted 45.6 min. The treatments did not differ in the number of lying bouts (P =0.159). Chen *et al.* (2016) and Tresoldi *et al.* (2019) reported an average lying time per 24 hours of 12.1 and 12.7 hours, with 11 and 10 lying bouts per 24 hours, respectively. These differences might be attributed to the differences in THI. In these studies (Chen *et al.*, 2016; Tresoldi *et al.*, 2019), the maximum THI was 78, whereas in the current study even the minimum THI was above 80. There was no difference in the 24-hour standing time among treatments (P =0.4884). Similarly, cows did not differ in standing bout duration in the sprinkler flow rates (P =0.6486). The 0.5 L/min group had the highest (13.6) standing bout number compared with the 1.25 and 2.0 L/min groups (P =0.03580). The increased feeding and lying time in the 1.25 and 2.0 L/min groups could also be attributed to the better welfare of the cows.

Table 4 Effect of sprinkler flow rate on production, physiological and behavioural responses of lactating Holstein Friesian cows in June 2019 (N = 18)

Variables	Sprinkler flow rate, L/min			SE	*P*-Value
	0.5	1.25	2.0		
Milk yield, Kg	13.2[a]	17.7[b]	18.7[b]	0.67	<0.0001
Rectal temperature, °C	39.2[a]	38.6[b]	38.3[b]	0.07	<0.0001
Respiration rate, breaths/min	66.6[a]	58.0[b]	56.1[b]	1.61	<0.0001
Time spent feeding, min	234.2[a]	280.5[b]	278.8[b]	16.84	0.0008
Feeding bout length[1], min bout	8.0[a]	10.0[b]	9.0[ab]	-	0.0130
No of feeding bouts	20.5	21.0	21.8	0.71	0.2820
Time spent standing, min	929.2	953.5	943.8	20.34	0.4884
Standing bout length, min	45.1	46.5	44.4	1.51	0.6480
No of standing bouts	13.6[a]	12.6[b]	12.6[b]	1.03	0.0358
Total lying time, min	508.7	487.0	494.1	12.38	0.7260
Lying bouts length[1], min/bout	40.0	40.0	40.0	-	0.2018
No of lying bouts	12.4	11.4	11.3	0.43	0.1590

[a,b,c] Within a row, means with a common superscript were not detected as being different with probability P = 0.05
[1] Values were presented as median and non-parametric ANOVA was used to estimate P value

The average amounts of water used for a single cow/h for 0.5, 1.25 and 2.0 L/min rates were 5, 12.5 and 20 L, respectively (Table 2). Milk yield, physiological and behavioural responses of cows exposed to the 1.25 L/min flow rate was similar to the cows exposed to the 2.0 L/min rate, while using 37.5% less water. These results agree with those of Chen *et al.* (2015), who reported that rates of 1.3 and 4.5 L/min provided similar heat abatement on lactating Holstein cows. The effects of heat load on cattle subjected to water sprayed at 1.3 and 4.9 L/min were similar despite the 73% difference in water use (Chen *et al.*, 2016).

Sprinkler flow rates >0.5 L/min were effective in cooling Holstein cows in an environment in which the THI approached 90 during the afternoon. A rate greater than 1.25 L/min was deemed unnecessary. The current findings can be applied at Holstein dairy farms under subtropical summer conditions.

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Authors' Contributions

MQS and MB conceived the study idea, collected the data, did the statistical analysis, and drafted the manuscript. KJ and TNP assisted in data curation and reviewed the manuscript for final submission.

Conflict of Interest Declaration

The authors declare there is no conflict of interest.

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