EFFECT OF ENVIRONMENTAL TEMPERATURE ON HEAT PRODUCTION AND ITS ENERGY COST FOR THERMOREGULATION IN DAIRY HEIFERS

B. P. Purwanto[1], M. Harada and S. Yamamoto

Department of Animal Science, Hiroshima University,
Higashihiroshima 724, Japan

Summary

A study was conducted using four dairy heifers to determine the effect of 10, 20 and 30℃ environmental temperatures on the physiological responses and heat production, at a fixed level of TDN intake (60.5 g/kg$^{0.75}$ d). The analysis showed significant affects of environmental temperature on respiration rate (RR), mean body temperature (Tb), changes in body heat storage (S) and heat production (HP). The HP at 20℃ was almost the same as at 10℃, but the HP at 30℃ was 11% higher than at 10℃. A tendency for an elongation of standing time (ST) with the increase in environmental temperature was also observed. These results suggest that the increase in HP at 30℃ compared with 10℃ could be associated, in part, with the 104 min increase in energy cost of elongation of ST (9.2 kJ/kg$^{0.75}$ d) and 1.3℃ increase in Tb (17.3 kJ/kg$^{0.75}$ d).
(Key Words : Environmental Temperature, Heat Production, Standing Time, Mean Body Temperature, Dairy Heifer)

Introduction

When cattle are kept under hot environmental conditions, there is a change in their heat loss (HL) pathway from sensible (sHL) to evaporative heat loss (eHL) (Blaxter and Wainman, 1961; McLean and Calvert, 1972). Thus, the increases in respiration rate and rectal temperature (McLean and Calvert, 1972; Shibata and Mukai, 1977) and skin surface temperature (McLean et al., 1983) under hot environmental conditions may be a physiological mechanism to increase eHL from respiratory passage and skin surface.

The increase in rectal temperature and skin surface temperature at high environmental temperature may also help to increase sHL. It means that sHL at high environmental conditions may be an active process, which is still important for the animals to keep and maintain their heat balance. On the other hand, Purwanto et al. (1993) showed that at the same level of feed intake, the increase in heat production (HP) under hot conditions was associated with the active sHL and the increase in eHL. However, the relationship between body thermoregulation and HP under hot environmental conditions are limited and not yet fully understood.

The present study was carried out to observe the involvement of the energy costs of standing time, maintenance of body temperature and other thermoregulatory responses on HP in dairy heifers.

Materials and Methods

Animals

Four Holstein dairy heifers with an average initial body weight of 180.9 ± 12.6 kg (8 months old) were used in this experiment. They were kept in individual pens (120 × 190, cm) in a climatic chamber and offered with about 3.0 kg of mixed concentrate pellet and 2.0 kg of bahiagrass hay (*Paspalum notatum*) for two 2-hour periods at 09:00 and 17:00. During the experiment, all of feeds were consumed by the animals. Water was freely available during these periods.

The animals were exposed to temperature of 10, 20 and 30℃ in the climatic chamber for 6-day periods. The first 4 days of each period were used for adjustment to the experimental situation and the last 2 days for data collection. The body weight were measured at the end of each exposure period.

Measurements

Environmental temperatures (dry and wet bulb

[1]Address reprint requests to Dr. B. P. Purwanto, Lab. Ternak Perah, Fakultas Peternakan IPB, Gunung Gede, Bogor 16151, Indonesia.
Received June 14, 1993
Accepted November 17, 1993

temperatures) were measured using thermocouples and a data trend logger (Advantest, TR 2723).

The measured physiological responses were heat production (HP), heart rate (HR), respiration rate (RR), rectal temperature (RT), skin surface temperature (Ts) and standing time (ST).

The HP and HR were measured continuously by head cage and radiotelemetry methods, respectively, as described previously by Purwanto et al. (1990). The head cage, 79 (W) × 64 (D) × 128 (H) cm, was equipped with devices for feeding and drinking. The ventilation rate of the hood was about 350 l/min. During the measurement of HP, the animal's posture was measured by a switch (National, AM1701) which stretched above the animal using a cord.

The RR, RT and Ts were measured at 08:00, 12:00, 16:30, 20:00 and 22:30. The RR was measured by counting flank movements using a heart girth carbon pick up (Nihon Kohden, TR-601T) and a bioelectric amplifier (Nihon Kohden, AB-621G), which then recorded on the polygraph recorder (Nihon Kohden, WT-645G). At the same time, the RT was measured with a thermocouple, and recorded on the data trend logger (Advantest, TR 2723).

The Ts was measured (after McLean et al., 1983) at upper trunk (a), lower trunk (b), upper front leg (c) and lower front leg (d) by a digital surface contact thermometer (Anritsu, HL-206). Mean skin surface temperature (MST) was calculated as MST = 0.25 (a + b) + 0.32 c + 0.18 d, and mean body temperature (Tb) was then calculated as Tb = 0.86 RT + 0.14 MST. Changes in body heat storage (△HS) was calculated in terms of mean body temperature using (McLean et al., 1983):

$\triangle HS = c \times m \times \triangle Tb$,

where c = mean specific heat of body tissue (3.47 kJ/kg ℃), m = body weight (kg) and △Tb is the difference in mean body temperature at 10 and 20 or 30℃ environmental temperature (℃).

Data analysis

The mean value of each physiological response at each temperature was calculated using individual mean data obtained from a single 24 h measurement from 11:00 (n = 4). The HP, HR, RR, Ts, △HS and ST data, and comparisons among temperature treatments were analyzed using Student's t-test procedures (Steel and Torrie, 1984).

Results

Mean values of environmental temperatures, feed intake, daily weight gain, HP and △HS are shown in table 1. The TDN intake per metabolic body size was the same at all environmental temperature regimes, but the animals gained weight at 1.1, 0.8 and 0.5 kg per day at the environmental temperatures of 10, 20 and 30℃ respectively.

The HP increased with environmental temperature, being 74 $kJ/kg^{0.75}$ d higher at 30℃ ($p < 0.05$) than at 10℃; but HP at 20℃ was not significantly different from HP at 10 or 30℃.

TABLE 1. FEED INTAKE, HEAT PRODUCTION (HP), CHANGES IN BODY HEAT STORAGE (△HS) AND DAILY WEIGHT GAIN OF DAIRY HEIFERS AT 10, 20 AND 30℃ ENVIRONMENTAL TEMPERATURE (MEAN ± S.D.)

	Environmental temperature (℃)		
	10	20	30
Chamber temperature (℃):			
Dry bulb temperature	11.2 ± 0.1	21.0 ± 0.1	30.5 ± 0.2
Wet bulb temperature	9.7 ± 0.2	17.9 ± 1.5	24.9 ± 0.9
TDN intake, $g/kg^{0.75}$ d	60.4 ± 0.3	60.2 ± 0.3	60.5 ± 0.6
HP, $kJ/kg^{0.75}$ d	670 ± 16^{a}	688 ± 24^{ab}	744 ± 44^{b}
△HS, $kJ/kg^{0.75}$	0	8.6 ± 1.8	17.3 ± 7.7
Daily weight gain, kg/d	1.1 ± 0.6	0.8 ± 0.5	0.5 ± 0.2

^{ab} Mean within a same row with different supercripts differs significantly ($p < 0.05$).

The differences between standing and lying HP at 10, 20 and 30℃ environmental temperatures during day time (07:00-19:00) were 6.04, 6.11 and 5.73 kJ/kg$^{0.75}$ h, respectively. The some differences during the night time (19:00-07:00) were 5.33, 4.03 and 4.35. Mean value of the difference was 5.3 kJ/kg$^{0.75}$ h. So, the HP increased by 0.088 kJ/kg$^{0.75}$ for each minute of elongation ST.

The △HS increased with the environmental temperature. The △HS at 20 and 30℃ increased by 8.6 kJ/kg$^{0.75}$ and 17.3 kJ/kg$^{0.75}$, respectively compared with the △HS at 10℃ of environmental temperature.

Mean values of RR, RT, MST, Tb, HR and ST are shown in table 2. The mean values of RR, RT, MST and Tb increased ($p < 0.05$) with the environmental temperature. A significant difference in mean value of HR between 20℃ (80 ± 5 beats/min) and 30℃ (81 ± 5 beats/min) was not observed. The mean HR at 10℃, 72 ± 5 beats/min was lower ($p < 0.05$) than at 20 and 30℃.

Although there was a tendency for elongation of ST with the increase in environmental temperature, the observed trends were not statistically significant.

TABLE 2. EFFECT OF ENVIRONMENTAL TEMPERATURE ON THERMOREGULATORY RESPONSES AND STANDING TIME OF DAIRY HEIFERS (MEAN ± S.D.)

	Environmental temperature (℃)		
	10	20	30
Respiration rate (/min)	20 ± 1^a	50 ± 4^b	85 ± 16^c
Rectal temperature (℃)	38.8 ± 0.2^a	39.0 ± 0.1^b	39.6 ± 0.5^c
Mean skin temperature (℃)	31.9 ± 0.7^a	35.8 ± 0.4^b	36.9 ± 0.2^c
Mean body temperature (℃)	37.9 ± 0.2^a	38.6 ± 0.1^b	39.2 ± 0.4^c
Heart rate (beats/min)	72 ± 5^a	80 ± 5^b	81 ± 5^b
Standing time (min/d)	543 ± 92	594 ± 92	647 ± 85

^{a,b,c} Mean within a same row with different supercripts differs significantly ($p < 0.05$).

Discussion

The increases in RR and Tb with the elevation of environmental temperature in the present study are comparable with the studies by Shibata and Mukai (1977) and McLean et al. (1983). The increase in RR with the elevation of environmental temperature was expected and it was an indicator of increase in eHL from respiratory passage. The increase in Tb with environmental temperature elevation is of benefit for the initiation of eHL.

The increase in the HP with environmental temperature in the present study is comparable with previous studies by Kurihara et al. (1991) and may be associated with the change in HL pathway from sHL to eHL. Blaxter and Wainman (1961) and McLean (1963) showed that at environmental temperature of 24-28℃, 50% of HL was dissipated by evaporation. This suggests that elongation of ST and increase in Tb at environmental temperature of 30℃ may be effective behavioral and physiological mechanisms to support the increase in eHL.

In the present study, the difference in HP, ST and Tb between 10 and 30℃ is 74 kJ/kg$^{0.75}$ d, 104 min/d and 1.3℃, respectively. From these results, it could be estimated that the increase in energy cost of the elongation of ST and increase in Tb at environmental temperature of 30℃ compared with 10℃ are 9.2 kJ/kg$^{0.75}$ d and 17.3 kJ/kg$^{0.75}$ d, respectively. We suggest that the remaining (47.5 kJ/kg$^{0.75}$ d) is the energy costs for the maintenance of high Tb and the increase in other thermoregulatory activities to support eHL, such as an increase in RR due to the thermoregulatory "failure".

Daily standing and lying HP patterns (figure 1) showed that although total HP differed significantly between temperature regimes, all regimes had similar daily patterns for standing and lying HP. The effect of evironmental temperature on standing or lying HP during the day time (07:00-19:00) was unclear. However, during the night time, after feeding in the afternoon until 03:00 A.M., this effect was clearly observed; the standing and lying HP at 30℃ were higher than at 10 or 20℃ of environmental temperature. These results are comparable with those of the previous study (Purwanto et al., 1993).

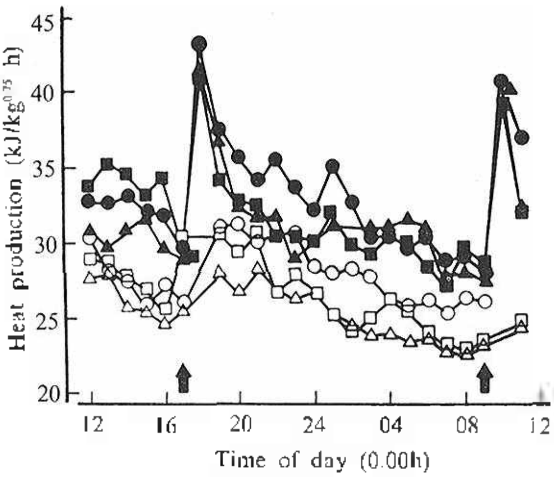

Figure 1. Daily lying (open points) and standing (closed points) heat production at 10 (△, ▲) 20 (□, ■) and 30℃ (○, ●) of environmental temperature. The arrows indicate the time of feeding.

The HP during the night time at high environmental temperature (30℃) was higher than that of at 10 and 20℃. This condition may be due to the difference in resting conditions. It probably means that during the night time, the animals can not fully take a rest because they do more autonomic effort to dissipate excess body heat accumulated during the day (Scott et al., 1983).

From these results, it was concluded that the increase in HP at high environmental temperature was associated with the increase in energy cost of the elongation of ST and increase in Tb; and the animals do more physiological activities or autonomic efforts for the increase in HL during the night time.

Acknowledgements

We are grateful to Dr. J. A. McLean (Scotland) for critical reading of the manuscript.

Literature Cited

Blaxter, K. L. and F. W. Wainman. 1961. Environmental temperature and the energy metabolism and heat emission of steers. J. Agric. Sci. 56:81-90

Kurihara, M., S. Kume, S. Takahashi and T. Aii. 1991. The effect of roughage type and environmental temperature on the energy metabolism of dry dairy cows at maintenance level of feeding. Anim. Sci. Technol. (Jpn) 62:375 382.

McLean, J. A. 1963. The partition of insensible losses of body weight and heat from cattle under various climatic conditions. J. Physiol. (London) 167: 427-447.

McLean, J. A., A. J. Downie, C. D. R. Jones, D. P. Stombaugh and C. A. Glasbey. 1983. Thermal adjustments of steers (*Bos taurus*) to abrupt changes in environmental temperature. J. Agric. Sci. Camb., 100:305-314.

McLean, J. A. and D. T. Calvert. 1972. Influence of air humidity on the partition of heat exchanges of cattle. J. Agric. Sci. Camb. 78:303-307.

Purwanto, B. P., Y. Abo, R. Sakamoto, F. Furumoto and S. Yamamoto. 1990. Diurnal patterns of heat production and heart rate under thermoneutral conditions in Holstein Friesian cows differing in milk production. J. Agric Sci. Camb. 114:139-142.

Purwanto, B. P., F. Nakamasu and S. Yamamoto. 1993. Effect of environmental temperatures on heat production in dairy heifers differing in feed intake level. AJAS 6:275-279.

Scott, I. M., H. D. Johnson and G. L. Hahn. 1983. Effect of programmed diurnal temperature cycles base on plasma thyroxine level, body temperature, and feed intake of Holstein dairy cows. Int. J. Biometeorol. 27:47-62.

Shibata, M. and A. Mukai. 1977. The effect of environmental temperature and level of hay intake on the heat production and some physiological responses of dry cows. Jap. J. Zootech. Sci. 48:509-514.

Steel, R. G. D. and J. H. Torrie. 1984. Principles and Procedures of Statistics: A Biometrical Approach. 2nd Edn. McGraw-Hill International Book Company, Tokyo.