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Effects of induced heat stress on temperature response and biochemistry: alteration of biochemical constituents in Holstein calves by heat stress

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Abstract

The aim of the present study was to evaluate the effect of the induced heat stress on physiological response and serum biochemical parameters involving glucose, cholesterol, blood urea nitrogen (BUN), non-esterified fatty acids (NEFA), and cortisol in Holstein calves. Ten calves were kept in a climate controlled room (air temperature 37°C and 90% humidity from 09:00 to 19:00) for three days. Those animals were given a one-day adaptation period. During the treatment period, we measured the skin temperature six times. Following the treatment periods, blood samples were collected before the experiment began (09:00) and at the end of the stress period (19:00). To aid analysis of the biochemical parameters, also we monitored the rectal temperature. The results, exhibited that both rectal and skin temperature showed increase in the heat stress-induced animals as compared with un-stressed animals. Moreover, we noticed that the levels of BUN and NEFA increased in the blood serum of heat stress induced animals when compared with un-stressed ones. From these results, we concluded that the physiological and biochemical changes in the calves were induced by heat stress. Hence, the present study findings could be employed as base line data for development of stress reduction techniques in the dairy industry.

Keywords: biochemical constituents, calves, heat stress

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Introduction

In tropical regions, physiological factors, such as solar radiation, air temperature, relative humidity, and wind speed can cause heat stress in dairy cattle (West et al., 2003; Spiers et al., 2004; Tapki and Sahin, 2006). Global warming can also negatively influence the heat exchange between dairy cows and their environment (Baumgard and Rhoads, 2012). Unfavorable temperatures can be considered a chronic stress (Shehab-El-Deen et al., 2010). During heat stress, dairy cows use more energy for circulatory adjustments to increase the respiratory rate, sweating, and panting (Srikandakumar and Johnson, 2004). Moreover, heat stress is associated with a lower food intake and increased negative energy balance (Igono et al., 1992; Chaiyabutr et al., 2008, Shehab-El-Deen et al., 2010; Choi, 2018). Cortisol is a physiological and stress-associated hormone and is an appropriate biological marker for investigating the hypothalamic-pituitary-adrenal (HPA) axis, and the exogenous administration of adrenocorticotropic hormone can be used to study the HPA axis activity (Negrao et al., 2004, 2010). The HPA axis is the primary neuroendocrine system involved in stress response. The HPA axis secretes adrenocorticotropic hormone. However, there are few scientific reports regarding the relationship between heat stress and biochemical parameters in calves. To the best of our knowledge, this is the first evaluation of the biochemical constituent profile in Holstein calves after heat stress.

Materials and methods

Animals and experimental design

The selected animals and the experimental protocol were approved by the Institutional Animal Ethical Committee of the National Institute of Animal Science (NIAS), South Korea. The animals registered in the national database originated from the standard breeding program described in the NIAS guidelines. Animals were fed a formulated diet to meet nutrient requirements according to the NRC (1987). These requirements include 68% total digestible nutrients (TDN), 15% crude protein, and hay. During the heat stress treatment, water and fresh hay were provided *ad libitum*. Ten calves, weighing an average of 126 ± 5 kg, aged 4 - 6 months, were housed for 3 consecutive days in a climatic room. The animals were given a 1-day adaptation period to adapt to the environmental conditions, then the animals were placed in an open barn for 3 days without restrictions on hay consumption. During the experimental period, the behavior of individual animals was monitored. After medical checks for registered diseases and of the respiratory systems, the animals were placed in an environmentally controlled building at NIAS.

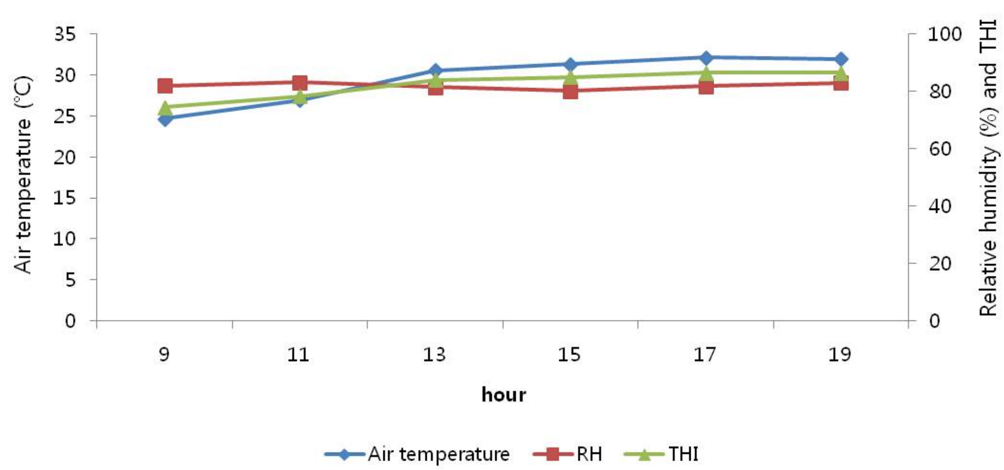

Fig. 1. Air temperature, relative humidity (RH), and temperature and humidity index (THI) during heat stress.

Heat stress treatment

Calves were exposed to high air temperatures and humidity in a climatic room for 3 consecutive days. We maintained the air temperature at 37°C and the humidity at 90% from 09:00 to 19:00 (10 h). Following the experimental period, the air temperature and humidity were reduced gradually to 20℃ over 14 h. The ambient air temperature and relative humidity were recorded using a data logger and the temperature and humidity index (THI) was calculated (Fig. 1).

Sample collection

Throughout each experimental period, the skin temperature was monitored every 1.5 h using a temp-gun (Hitachi, USA) on the left side of the shoulder and neck for a total of three measurements, with a distance of approximately 60 cm between the humans and animals to prevent any human influence on the skin temperature. The rectal temperature was measured before and after heat stress (BHS and AHS). Blood samples were collected before the experiment began (09:00) and at the end of the experimental period (19:00). The collected blood samples were centrifuged at 3,000 rpm for 15 min at 4℃ to obtain plasma. The obtained plasma was stored at - 80℃ until further analysis. Plasma concentrations were analyzed photometrically (Abx Pentra 400, Horiba, Kyoto, Japan) using a kit from Wako Chemicals (Neuss, Germany).

Statistical analyses

The collected data were subjected to a generalized linear model procedure (PROC-GLM) of the Statistical Analysis System (SAS Institute, Cary, USA). Differences among treatment means were determined using Duncan's multiple range tests. Statistical significance was established at $p < 0.05$.

Results

Experimental cows were kept in a free stall under heat stress for 3 days. During the experimental period, the air temperature ranged from 24.7℃ to 32.1℃ with a mean of 29.6 ± 3.1℃. The relative humidity had a mean of 82.0 ± 1.1% and the THI was above 72 (Fig. 1). The rectal temperature (RT) and skin temperature (ST) values were significantly lower ($p < 0.05$) at 09:00 than at 19:00 h (Table 1). During the experimental periods, the skin temperature of the calves increased from time 09:00 to 19:00. Calves showed higher temperatures AHS than BHS. In addition, the blood constituents reflected the nutritional and physiological status of the heat stress induced in the animals. Table 2 shows the changes in the biochemical parameters before and after heat stress. No significant changes were observed in the levels of albumin, Ca, blood glucose, aspartate transaminase (AST), alanine transferase (ALT), Mg, P, total protein, cholesterol, and cortisol in the calves with heat stress. However, the serum levels of blood urea nitrogen (BUN) and non-esterified fatty acid (NEFA) were significantly ($p < 0.05$) higher AHS than BHS.

Table 1. Means and standard error (SEM) of the rectal temperature (RT) and skin temperature (ST) measured in the experimental calves under heat stress.

Time sampling data	Mean ± SEM					
	09:00 h	11:00 h	13:00 h	15:00 h	17:00 h	19:00 h
RT (°C)	37.13b ± 1.18	-	-	-	-	39.90a ± 0.11
ST (°C)	32.54d ± 0.12	34.49c ± 0.16	35.33bc ± 0.11	36.54ab ± 0.14	35.92ab ± 1.12	36.94a ± 0.14

a - d: Values within a row with differing superscripts denote significant differences ($p < 0.05$) between periods.

Table 2. Biochemical values (mean ± SEM) in the calves.

Parameter	Before heat stress	After heat stress
Albumin (g/dL)	3.9 ± 0.2	3.9 ± 0.1
Ca (mg/dL)	10.6 ± 0.5	10.7 ± 0.5
Glucose (mg/dL)	84.2 ± 6.5	87.6 ± 9.5
ALT (IU/L)	20.4 ± 2.3	20.4 ± 2.4
Mg (mg/dL)	2.3 ± 0.2	2.3 ± 0.2
P (mg/dL)	8.3 ± 0.7	8.1 ± 0.6
Cholesterol (mg/dL)	75.9 ± 9.1	77.0 ± 9.8
Total protein (g/dL)	6.5 ± 0.2	6.6 ± 0.3
BUN (mg/dL)	18.7 ± 2.4*	16.7 ± 3.4*
NEFA (uEq/L)	167.4 ± 107.5*	88.7 ± 44.6*
Cortisol (ug/mL)	0.6 ± 0.6	0.8 ± 0.6

AST, aspartate transaminase; ALT, alanine transferase; BUN, blood urea nitrogen; NEFA, non-esterified fatty acids.
* $p < 0.05$.

Discussion

Heat stress in dairy cows is a result of all the high temperature-related forces that can induce alterations at the sub-cellular level to assist the cows in avoiding physiological dysfunction and remaining healthy (Kadzere et al., 2002). The present study examined the effect of heat stress on the temperature and biochemical changes in calves.

Cattle are homeotherms and maintain a constant body temperature at a particular level. Normal body temperature for cattle ranges from 36.0℃ to 38.4℃ (Hansen et al., 1992). The rectal temperature is an indicator of thermal balance and may be used to assess the adversity of the thermal environment, which can affect dairy cows' growth, lactation, and reproduction (Johnson, 1980a). A rise of less than 1℃ in the rectal temperature is enough to reduce performance in most livestock species (McDowell et al., 1976). Thus, the body temperature is a sensitive indicator of the physiological response to heat stress in cows, as it is usually constant under normal conditions. A rise in body temperature of only 4.4℃ above normal is often quickly fatal, and most mammals die at a core temperature of 42 - 45℃ (Brody, 1948; Silanikove, 2000). Table 1 shows that the calves exposed to heat stress had higher temperatures compared with BHS. The same trend has been observed in Friesian cows (Muller and Botha, 1993). Therefore, changing the body temperature patterns may provide an opportunity to characterize physiological actions that may be related to adaptations for heat stress.

We found that heat stress did not increase plasma NEFA levels in the calves; these results agreed with the results from other heat-stressed ruminant models (Sano et al., 1983; Itoh et al., 1998; Ronchi et al., 1999; Rhoads et al., 2009; Shwartz et al., 2009). The lack of an elevated NEFA response is especially surprising as acute heat stress causes a marked increase in circulating cortisol, norepinephrine, and epinephrine levels (Collier et al., 2005), which are catabolic signals that normally stimulate lipolysis and adipose mobilization. The calculated energy balance (EBAL) is known to be closely associated with circulating NEFA levels. The fact that heat-stressed cows fail to enlist this 'shift' in post-absorptive energy metabolism (despite inadequate nutrient intake) may indicate that heat stress directly affects the energetics and is not just mediated by the feed intake.

Cortisol is a stress-related hormone; plasma cortisol concentrations have been used as physiological markers of stress. Hormonal responses to heat stress include a rise in plasma cortisol with short-term exposure to heat, maybe because of the 'stress' reaction. Cortisol does not consistently increase when animals are exposed to moderate heat (Johnson, 1980b). In the present study, a small increase in the cortisol levels was observed AHS. Acute heat stress has been shown to significantly increase the cortisol concentration (Abilay et al., 1975), whereas prolonged heat stress was accompanied by slight decreases in the plasma levels of cortisol (Marplc et al., 1972; Alvarez and Johnson, 1973; Rhynes and Ewing, 1973; Vanjonack and Johnson, 1975; Ingraham et al., 1979; Adeyemo et al., 1981). Urea is a good indicator of dehydration, but the concentration of urea may be affected by additional factors, mainly nutritional factors. In the present study, heat stress decreased blood urea nitrogen concentrations (18.7 $\pm$ 2.4 vs. 16.7 $\pm$ 3.4 mg/dL). This study confirmed the findings of Elmasry et al. (1989) and Ronchi et al. (1995) that chronic heat exposure in cattle and buffaloes results in decreased urea levels.

Conclusion

Heat stress is a cause of great concern among livestock owners. Under the climate change scenario, elevated temperature and relative humidity will impose heat stress on all the species of livestock, and will adversely affect their productive and reproductive potential especially in dairy cattle. The immediate need for livestock researchers aiming to counter heat stress impacts on livestock is an understanding of the biology of the hat stress responses. This will proved researchers with a basis for predicting when an animal is under stress.

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References

Abilay TA, Mitra R, Johnson HD. 1975. Plasma cortisol and total progestin levels in Holstein steers during acute exposure to high environmental temperature (42 degrees Celsius) conditions. Journal of Animal Science 41:113-117.

Adeyemo O, Heath E, Adadevoh BK, Steinbach J. 1981. Plasma cortisol in *Bos taurus* and *Bos indicus* heifers in seasonal tropical climate. Journal of Dairy Science 64:1586-1592.

Alvarez MB, Johnson HD. 1973. Environmental heat exposure on cattle plasma catecholamine and glucocorticoids. Journal of Dairy Science 56:189-194.

Baumgard LH, Rhoads RP. 2012. Ruminant production and metabolic responses to heat stress. Journal of Animal Science 90:1855-1865.

Brody S. 1948. I, Physiological backgrounds. Missouri Agricultural Experiment Station 423:1-43.

Chaiyabutr N, Chanpongsang S, Suadsong S. 2008. Effects of evaporative cooling on the regulation of body water and milk production in crossbred Holstein cattle in a tropical environment. International Journal of Biometeorology 52:575-585.

Choi CW. 2018. Nutrient requirement for maintenance and nutritional changes of the Hanwoo steers in early-fattening stage under heat stress. Korean Journal of Agricultural Science. 45:74-83. [in Korean]

Collier RJ, Baumgard LH, Lock AL, Bauman DE. 2005. Physiological limitations, nutrient partitioning. In yield of farmed species. Constraints and opportunities in the 21st Century (ed. Sylvester-Bradley R and Wiseman J). pp. 351-377. Nottingham University Press, Nottingham, UK.

Elmasry KA, Kamal TH, Abouulnga AI, Marai IF. 1989. Daily body weight gain, total body solids and biochemical responses of Friesian calves to mineral mixture and urea during heat stress. pp. 641-648. In the 3rd Egyptian – British Conference on Animal, Fish and Poultry Production. 7-10 October, Alexandria, Egypt.

Hansen PJ, Thatcher WW, Ealy AD. 1992. Methods for reducing effects of heat stress on pregnancy, In Van Horn, Wilcox CJ (eds): Large Dairy Herd Management. pp. 116-125. American Dairy Science Association, Champaign, USA.

Igono MO, Bjotvedt G, Sanford-Crane HT. 1992. Environmental profile and critical temperature effects on milk production of Holstein cows in desert climate. International Journal of Biometeorology 36:77-87.

Ingraham RH, Stanley RW, Wagner WW. 1979. Seasonal effects of tropical climate on shaded and nonshaded cows as measured by rectal temperature, adrenal cortex hormones, thyroid hormone, and milk production. American Journal of Veterinary Research 40:1792-1797.

Itoh F, Obara Y, Rose MT, Fuse H, Hashimoto H. 1998. Insulin and glucagons secretion in lactating cows during heat exposure. Journal of Animal Science 76:2182-2189.

Johnson HD. 1980a. Depressed chemical thermogenesis and hormonal functions in heat. In Environmental Physiology: Aging, Heat, and Altitude. pp. 3-9. Elsevier, New York, USA.

Johnson HD. 1980b. Environmental heat effects depressed chemical thermogenesis and hormonal functions of cattle. Page 311 in Life, Heat and Altitude. Horvath SM and Yousef MK (Eds). Elsevier, New York, USA.

Kadzere CT, Murphy MR, Silanikove N, Maltz E. 2002. Heat stress in lactating dairy cows: A review. Livestock Production Science 77:59-91.

Marplc DN, Arbele ED, Forrest JD, Oiake WH, Judge MD. 1972. Effects of humidity and T on porcine plasma adrenal corticoids, ACTH and growth hormone levels. Journal of Animal Science 34:809-812.

McDowell RE, Hooven NW, Camoens JK. 1976. Effects of climate on performance of Holsteins in first lactation. Journal of Dairy Science 59:956-973.

Muller CJC, Botha JA. 1993. Effect of summer climatic conditions on different heat tolerance indicators in primiparous Friesian and Jersey cows. South African Journal of Animal Science 23:98-103.

Negrao JA, Porcionato MAF, de Pasille AM, Rushen J. 2004. Cortisol in saliva and plasma of cattle after ACTH administration and milking. Journal of Dairy Science 87:1713-1718.

Negrao JA, Porcionato MAF, de Passille AM, Rushen J. 2010. Behavioural responses of heifers to ACTH injections. Applied Animal Behaviour Science 128:18-22.

NRC (National Research Council). 1987. Nutrient requirements of dairy cattle. National Academy Press, Washington, D.C., USA.

Rhoads ML, Rhoads RP, VanBaale MJ, Collier RJ, Sanders SR, Weber WJ, Crooker BA, Baumgard LH. 2009. Effects of heat stress and plane of nutrition on lactating Holstein cows: I. production, metabolism and aspects of circulating somatotropin. Journal of Dairy Science 92:1986-1997.

Rhynes WE, Ewing LL. 1973. Plasma corticosteroids in Hereford bulls exposed to high ambient temperature. Journal of Animal Science 36:369-373.

Ronchi B, Bernabucci U, Lacetera NG, Nardone A, Bertoni G. 1995. Effects of heat stress on metabolic status of Friesian heifer calves. Zootenica E Nutrizione Animale 21:209-221.

Ronchi B, Bernabucci U, Lacetera N, Verini Supplizi A, Nardone A. 1999. Distinct and common effects of heat stress and restricted feeding on metabolic status in Holstein heifers. Zootecnica E Nutrizione Animale 25:71-80.

Sano H, Takahashi K, Ambo K, Tsuda T. 1983. Turnover and oxidation rates of blood glucose and heat production in sheep exposed to heat. Journal of Dairy Science 66:856-861.

Shehab-El-Deen MAMM, Fadel MS, Soom AV, Saleh SY, Maes D, Leroy JLMR. 2010. Circadian rhythm of metabolic changes associated with summer heat stress in high-producing dairy cattle. Tropical Animal Health and Production 42:1119-1125.

Shwartz G, Rhoads ML, VanBaale MJ, Rhoads RP, Baumgard LH. 2009. Effects of a supplemental yeast culture on heat-stressed lactating Holstein cows. Journal of Dairy Science 92:935-942.

Silanikove N. 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. Livestock Production Science 67:1-18.

Spiers DE, Vogt DW, Johnson HD, Garner GB, Murphy CN. 2004. Use of physiological parameters to predict milk yield and feed in take in heat-stressed dairy cows. Journal of Thermal Biology 29:759-764.

Srikandakumar A, Johnson EH. 2004. Effect of heat stress on milk production, rectal temperature, respiratory rate and blood chemistry in Holstein, Jersey and Australian Milking Zebu cows. Tropical Animal Health and Production 36:685-692.

Tapki I, Sahin A. 2006. Comparison of the thermoregulatory behaviours of low and high producing dairy cows in a hot environment. Applied Animal Behaviour Science 99:1-11.

Vanjonack WJ, Johnson HD. 1975. Effect of moderate heat and milk yield on plasma thyroxine levels in cattle. Journal of Dairy Science 58:507-511.

West J, Mullinix BG, Bermand JK. 2003. Effects of hot, humid weather on milk temperature, dry matter intake, and milk yield of lactating dairy cows. Journal of Animal Science 86:232-242.