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Effect of temperature-humidity index on physiological and haematological indicators in dairy cows

Vliv teplotně-vlhkostního indexu na fyziologické a hematologické ukazatele dojnic

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ABSTRACT

Heat stress in cows is commonly assessed using the temperature and humidity index (THI), a combination of ambient temperature and relative humidity. In this study, the influence of the THI on haematological and other physiological indicators in cows was evaluated. A significant difference was found in respiratory rate; when THI increased above 70 breaths/min, respiratory rate increased from 19.8 to 34.4 breaths/min. When THI increased above 80 breaths/min, there was a sharp increase in respiratory rate to 128.8 breaths/min. This was observed between 3 and 4 clocks in the afternoon when the highest thermal stress was assumed in dairy cows. The correlation coefficient between THI and body temperature was 0.38, but when weighted averages of minimum temperatures for three days were used, the correlation coefficient increased to 0.48. Based on these results, it is more reasonable to use the minimum THI over several days. At critical temperatures, haemoglobin decreased to 115.45 ± 23.12 g/l, compared with values measured in dairy cows under optimal conditions. However, these values did not fall below 125 g/l. A similar trend was observed for hematocrit under optimal conditions it was 34.42 ± 1.03%, and under stress, it was 37.5-39.12%. The number of erythrocytes was the lowest (6.51 ± 0.137 × 1012/l) in the most heat-stressed dairy cow group.

Keywords: dairy cows, heat stress, temperature-humidity index, body temperature respiratory rate, haematological indicators

ABSTRAKT

Byl hodnocen vliv teplotně-vlhkostního indexu (THI) na fyziologické a hematologické ukazatele krav. Zřetelný statisticky průkazný rozdíl byl nalezen u frekvence dechu, kdy při zvýšení THI nad 69,8 došlo k vzestupu frekvence dechu z 19,8 na 34,4 dechů za minutu. Při dalším vzestupu THI o 10, došlo prudkému nárůstu frekvence dechu až na hodnotu 128,8 dechů/min. Tato hodnota byla zaznamenána mezi 15–16 hodinou, kdy se předpokládalo nejvyšší tepelné zatížení dojnic. Korelační koeficient mezi THI a tělesnou teplotou byl 0,38. Pokud se ale do sledování zahrnuly vážené průměry minimálních teplot za 3 dny, došlo ke zvýšení koeficientu korelace na hodnotu 0,48. U maximálních hodnot to pak bylo 0,44. Z dosaženého výsledku je patrné, že o dopadu tepelného stresu je vhodnější využívat hodnot denního minima, se zahrnutím několikadenních hodnot. U hemoglobinu došlo v době kritických teplot k jeho poklesu na hodnotu 115,45 ± 23,12 g/l, oproti hodnotám, které byly zaznamenány u dojnic v optimálních podmínkách. U těchto nedošlo k poklesu pod 125 g/l. Podobně tomu bylo u hematokritu s hodnotou 34,42 ± 1,03% oproti ostatním s průměrem 37,5 do 39,12%. U počtu erytrocytů byl zjištěn statisticky nejnižší průměr (6,51 ± 0,137 x 1012/l) u tepelně namáhané skupiny dojnic.

Klíčová slova: dojnice, tepelný stres, index tepelného stresu, tělesná teplota, frekvence dechu, hematologické ukazatele

INTRODUCTION

Heat stress is becoming increasingly important, as increases in milk yield are associated with decreases in heat tolerance (Berman et al., 1985; West, 2003; Jensen et al., 2022). Although suitable cooling systems exist, their efficiency is lower in humid climates than in dry climates, and these systems are often unable to maintain normal body temperature. Ongoing genetic selection to improve dry matter intake and milk yield will result in cows that are less tolerant of heat. Combined with the unknowns associated with future global warming, heat stress is expected to worsen for dairy products in the future (West, 2003; Carabano, 2016; Tao et al., 2020). Heat stress in cows is commonly assessed using the temperature and humidity index (THI), a combination of ambient temperature and relative humidity (Schueller et al., 2013).

Generally, animals are considered to be in thermoneutral conditions when THI values are below 72 units, or when no stressful conditions are assumed to exist. Mild stress was assumed when the THI value was between 72 and 79. Moderate stress was observed when the THI value was 80–89. Severe stress occurs when the THI value is between 90 and 99 (Veissier et al., 2018; Dimov et al., 2020). In recent studies on Holstein cattle in Central Europe, low THI thresholds for milk yield of 60 were found in German Holsteins and 62 in the Holstein population in Luxembourg (Gorniak et al., 2014; Lambertz et al., 2014; Hammami et al., 2013).

Respiratory rate is an early indicator of heat stress that can be measured noninvasively (Gaughan and Mader, 2014; Galán et al., 2019). The normal respiratory rate in cattle ranges from 20 to 60 breaths per minute (Jelínek and Koudela, 2003), with a respiratory rate of 50-60 breaths per minute observed in animals maintained at 25-26 °C (Berman et al., 1985). The number of breaths ranging from 80 to 120 breaths per minute indicates moderate heat stress (Koubková et al., 2002; Gaughan et al., 2000), while 120 breaths/min is exceeded in severe heat stress. Based on the results of the effect of THI on respiratory rate, they recommended that the cooling of dairy cows should begin when THI reaches 65° to 66 degrees (Yan et al., 2021). From the thresholds for rectal temperature and respiratory rate in cows with high milk yield, the THI was 68.0 and 64.7, respectively. Rectal temperature is commonly used to assess calf well-being and is important for achieving thermal equilibrium (West, 1999; Zábranský et al., 2022). Xue et al. (2010) showed that rectal temperature increased from 37.8 °C to 38.5 °C when THI increased from 45 to 72.

Changes in erythropoiesis are one of the body's adaptations to heat stress. The process usually takes at least four mitoses and their maturation period is approximately 4-5 days in cattle (Trhall, 2007). Omar et al. (1996) reported a decrease in the number of red blood cells and hematocrit during the cooling process in animals, whereas the number of white blood cells increased. Blood haematology includes immune factors such as WBC, LYM, MON, and GRA, which are expected to be suppressed by stress and an increase in cortisol because they are unfavourably related (Bagath et al., 2019). In contrast, Abd-El-Samee and Ibrahim (1992) reported significantly higher haemoglobin concentrations and hematocrit. Amadori et al. (1997) considered the evaluation of clinical and haematological indicators as basic indicators for the evaluation of animal welfare. The ratio of neutrophil granulocytes to lymphocytes is also considered an index for the evaluation of heat stress. This increased ratio can induce stress in animals.

The aim of this study was to investigate the relationship between heat stress, as measured by the temperature-humidity index (THI), and physiological and haematological parameters in dairy cows. Specifically, this study aimed to assess the effect of heat stress on body temperature, respiratory rate, and blood parameters, such as haemoglobin, hematocrit, red blood cell count, white blood cell count, total blood protein, and glucose levels. It was hypothesized that as the THI increases, dairy cows will exhibit elevated body temperature and respiratory rate, indicating heat stress. Furthermore, it was expected that heat stress would affect blood parameters, leading to changes in haemoglobin, hematocrit, red blood cell count, white blood cell count, total blood protein, and glucose levels.

MATERIAL AND METHODS

Animal observations were made at the University Training Farm in Žabčice (Czech Republic; geographic coordinates 49°04″ N and 16°36’ E; elevation 179 m) during the six warmest months of 2021 (July 1, 2021, to August 31, 2021). The measurement results were obtained from evaluated and subsequently analyzed data from a barn with 308 dairy cows. The barn is equipped with concrete stalls and divided into four separate sections according to the different lactation stages, with 77 lying boxes available in each section. The Holstein breed is bred here, with a proportion of dairy cows in the second to eighth lactations. The microclimate (temperature and relative humidity) was measured using the comet data logger S3120 at 10-minute intervals. The following equation was used to calculate THI:

$$THI = 0.72 \times (T_{db} + T_{wb}) + 40.6$$

where T_{db} is the dry-bulb temperature and T_{wb} is the wet-bulb temperature in °C.

Fifteen healthy Holstein dairy cows, 2–3 months after calving, with an average daily milk yield of 35.83kg (2nd to 3rd lactation) were used for the experiment. For the haematological, biochemical, and acid-base analyses, blood was drawn from the dairy cows at approximately bi-monthly intervals, starting at 16:00, using the HEMOS® collection system. Blood samples were stabilized with ethylenediaminetetraacetic acid (EDTA) and stored in a cool box at 4 °C until further processing. For haematological and biochemical indicators, blood was collected from 22 animals. The basic haematological parameters of red blood count (total number of erythrocytes, haemoglobin content, hematocrit value, mean erythrocyte volume (MCV), erythrocyte haemoglobin (MCH), mean haemoglobin concentration in erythrocytes (MCHC)), and white blood count (total number of leukocytes) were determined using a haematological analyzer MEDONIC CA 620 from Boule Medical AB. Immediately after collection, blood plasma was separated and stored at 4 °C for further laboratory analysis. In the laboratory, biochemical spectrophotometric analysis was performed with an XT 20 I automatic analyzer, using commercially available equipment from Biovendor-Laboratorní medicína, statistical analysis was performed using the test NOVA, and the mean and standard error of the mean were calculated. A comparative evaluation of the groups for each characteristic was performed using Tukey’s test.

RESULTS AND DISCUSION

The relationship between stall THI in the barn and body temperature and respiratory ratio, expressed by the number of breaths/minute, was assessed in 15 dairy cows during ambulatory measurements (Table 1). Significantly higher values of these two measured physiological indicators were found at a THI of 80 and a significantly higher number of breaths at a THI of 70 than at a lower THI. This occurred on the day preceded by several days of mild heat stress, with a maximum THI value of 70. The highest respiratory rate at a THI of 80 was 138 breaths/min, with an average of 128.8 breaths/min. This value was measured between 3 and 4 p.m., when environmental stress to the animals was the greatest. A significant increase in the number of breaths was observed at the THI of 70. Hahn (1999) reported an increased respiratory rate when the ambient temperature was > 21 °C. When the ambient temperature was below 20 °C, the total LHL (skin + respiration) accounted for approximately 50% of the total heat loss, whereas when the ambient temperature was above 28 °C, the LHL accounted for more than 70% of the total heat loss. Respiratory heat loss increased by 34 and 24% for short and long exposures, respectively, when the ambient temperature increased from 16 °C to 32 °C (Zhou et al., 2022).

The THIs obtained during the indoor measurements are listed in Table 1. Our results show the dependence of these physiological indicators on the THI. Respiratory rate can be considered a basic indicator for the detection of heat stress in dairy cows. It increased by almost two-fold when the THI was close to the heat stress level.

Table 1. The relationship between temperature-humidity index, body temperature and respiratory rate in dairy cows

	THI - Maximum and minimum for the previous 5 days				*P*-value
	34.2-61.1	48.6-65.2	52.3-71.3	57.4-85.4	
Actual THI	54.4	58.3	69.8	79.8	
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	
Body temp. (°C)	38.56±0.21^{b}	38.42±0.19 ^{b}	38.81±0.21 ^{a}	39.56±0.10 ^{a}	0.0051
Respiratory rate/min)	19.8±3.14 ^{b}	21.4±2.81 ^{b}	34.4±3.82 ^{a}	128.8±16.4 ^{a}	0.0011

Means with different superscripts (a) within a row are significantly different at ($P \le 0.05$)

Hall and Hall (2020) considered this to be a normal response to changing environmental conditions, in an effort to ensure heat loss through higher evaporation. At the same time, they pointed out that the response to changes in temperature, relative humidity, and heat stress index can occur within minutes or hours, as these are compensatory mechanisms that interfere with the metabolism of water and minerals in the animal body, as well as affecting vascular self-regulatory functions and blood pressure. Robertshaw (2006) considered not only the respiratory rate but also body temperature, the rise of which is associated with increased sweating and salivation, as a basis for assessing thermal well-being. When the body temperature of cows maintained at THI 80 was evaluated, it increased to 40.16 °C in the afternoon, with a respiratory rate of 128 breaths/min. Calamari et al. (2007) indicated a very strong dependence or correlation coefficient between respiratory rate and THI value, with the highest correlation found mainly in the first wave of high temperatures. At later high ambient temperatures, he explained the milder response, and thus the lower respiratory rate, by the probably more effective activation of the thermoregulatory center and some degree of acclimation. Hurst et al. (2022) and Perera et al. (1986) added that dairy cows in the middle of lactation with the highest milk production responded with the highest increase in respiratory rate. Abeni et al. (2007) arrived at a similar conclusion. In addition, they observed the most rapid increase under mild heat stress conditions. In the present case, this increase was similar.

Under normal conditions, body temperature ranges from 38.3 to 38.7 °C, while elevated values indicate heat stress or thermoregulatory disorders (Calamari et al., 2007), in which there are various responses that include restricted feed intake, increased evaporation from the body surface, but also increased respiratory rate and other mechanisms that involve changes in the endocrine system (Armstrong, 1994; Hahn, 1999). For the evaluation of body temperature, we selected days when the degree of heat stress could be characterized not only from the point of view of maximum but also average and minimum values, which exceeded the limit of moderate stress during the day and even at night, while their effects are presented in Table 1. Our results show increased body temperature under THI 80 conditions when body temperature approached 40 °C, with a group average of 39.56 ± 0.11 °C. The results are presented in Table 1. A body temperature of 39.5 °C was also measured by Dikmen and Hansen (2009), who found a rectal temperature of 39 °C at an ambient temperature of 29.7 °C and a rectal temperature of 39 °C at an ambient temperature of 31.4 °C. They found a correlation coefficient of r = 0.41 between ambient temperature and body temperature. In a separate analysis of relative humidity, the correlation coefficient for body temperature was only 0.29. Bohmanova et al. (2007), who examined the relationship between relative humidity and milk production, noted the need for long-term monitoring of relative humidity. They pointed out the importance of this microclimatic variable and emphasized that, for example, in the state of Georgia.

Table 2. Influence of temperature-humidity index on biochemical and haematological parameters of dairy cows

	THI				*P*-value
	34.2-61.1	48.6-65.2	52.3-71.3	57.4-85.4	
Actual THI	54.4	58.3	69.8	79.8	
Hb (g/l)	125.14±23.14 ^{b}	125.29±20.19 ^{b}	129.62±28.21 ^{b}	115.45±23.16 ^{a}	0.0001
HCT (%)	37.50±2.88 ^{b}	37.67±1.87 ^{b}	39.12±2.76 ^{b}	34.42±1.02 ^{a}	0.0001
RBC (10^{12}/l)	6.75±0,17 ^{b}	6.66±0.16	6.68±0.14	6.51±0.13 ^{a}	0,0001
WBC (10^{9}/l)	7.12±0.28	7.21±0.30	8.15±0.31	7.72±0.32	0.0614
Total blood protein (g/l)	2.42±0.08 ^{b}	2.45±0.14 ^{b}	2.37±0.09 ^{a}	2.35±0.17 ^{a}	0,0001
Albumin (g/l)	31.37±0.23	31.47±0.23	31.35±0.23	31.61±0.49	0.0454
Glucose (mmol/l)	3.85±0.07 ^{b}	3.68±0.07 ^{b}	3.87±0.07 ^{b}	3.65±0.15 ^{a}	0.0001

Means with different superscripts (a) within a row are significantly different at ($P \leq 0.05$).

CONCLUSION

In this study, we used the temperature–humidity index (THI) as an indicator to investigate the effects of heat stress on dairy cows. Our research encompassed a range of THI values, from 34.2 to 85.4, to understand the physiological and haematological changes in these animals.

Notably, we observed a significant correlation between THI and respiratory rate. As the THI surpassed 70, the respiratory rate doubled. Moreover, as THI further increases, reaching a value of 10 breaths/min, the respiratory rate sharply escalates to a staggering 128.8 breaths/min. This pattern is mirrored in haematological indicators such as Hb, HCT, and RBC.

Furthermore, our evaluation of the correlation coefficients between THI and body temperature indicates that assessing the impact of heat stress on dairy cows is best accomplished by considering multiple days with minimal THI values. By incorporating this approach, we can gain a more comprehensive understanding of the effects of heat stress in these animals.

These findings shed light on the intricate relationship between heat stress, THI, and the physiological and haematological well-being of dairy cows. Such insights are invaluable for developing effective strategies to mitigate the adverse consequences of heat stress in these animals, thereby promoting their overall welfare and productivity.

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