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Temperature-humidity index values and their significance on the daily production of dairy cattle

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Summary

The objectives of this study were to determine the microclimatic conditions in stables in three climactic regions (East, Mediterranean, and Central) of Croatia as well as to evaluate the effect of temperature-humidity index (THI) values on the daily production of dairy cattle. With that purpose, 1675686 test-day records collected from January 2005 until April 2010 were extracted from HPA (Croatian Agricultural Agency) database. For estimation of the effect of THI on daily production of dairy cows fixed-effect model that took into account the effects of lactation stage, breed, calving season, measuring season, and THI group (T_1 - THI≤72; T_2 - THI>72) was used. Model was applied to each class of parity (P_1, P_2, P_3, P_4 and P_5) and region. During the analysed period, the highest monthly averages of ambient temperature were determined in Mediterranean region, the highest monthly averages of relative humidity were observed in Central region, while the highest monthly mean values of temperature-humidity index (THI) were determined in Mediterranean region. Heat stress conditions indicated with mean daily values of THI>72 were determined during spring and summer season in all analysed regions. Absence of heat stress conditions during autumn and winter season also characterised all three regions. Highly significant (P<0.01) decrease of daily milk yield as well as of daily fat and protein content due to enhanced THI was observed in all cows regardless the parity class and in all three climatic regions. Furthermore, the most deteriorate effect of heat stress was observed in East region. During heat stress period, with the aim of minimization of the effects of heat stress, it is necessary to regulate management strategies in the dairy herd.

Key words: dairy cattle; daily production; temperature-humidity index

Introduction

Heat stress could be reason of the significant increase of production cost in the dairy industry. Armstrong (1994) noticed that the relative daily cows' production is constant when temperatures are low and medium, while after passing a threshold, starts to decrease. The rate of decline increases with rising temperatures. Exposition of dairy cattle to high ambient temperatures (Ta), high relative humidity (RH) and solar radiation for extended periods decrease the ability of the lactating dairy cow to disperse heat. At the same time, lactating dairy cows create a large quantity of metabolic heat. So, accumulated and produced heat joined with decreased cooling capability induced by environmental conditions, causes heat stress in the animals. Finally, heat stress induces increase of body temperature. Johnson (1980) observed that when the body temperature is significantly elevated, feed intake, metabolism, body weight and milk yields decrease to help alleviate the heat imbalance. Johnson et al. (1962) determined that with the termination of the hot season, in high-producing cows, the productivity does

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not completely return to normal since the energy deficit cannot be fully compensated. The permanent drop in the current lactation is proportional to the length of the heat stress. The temperature-humidity index (THI) could be used to determine the influence of heat stress on productivity of dairy cows. Milk production is affected by heat stress when THI values are higher than 72, which corresponds to 22 °C at 100 % humidity, 25 °C at 50 % humidity, or 28 °C at 20 % humidity (Du Preez et al., 1990a). Johnson (1980) reported that, when THI reaches 72, milk production as well as feed intake begins to decrease. The amount of milk yield decrease during the summer period in comparison with the winter period for Holstein cows about 10 % to 40 % (Du Preez et al., 1990b). Under Mediterranean climatic conditions, milk yield drops by 0.41 kg per cow per day for each point increase in the value of THI above 69 (Bouraoui et al., 2002). Beside changes in milk yield, heat stress could also cause changes in milk composition, somatic cell counts (SCC) and mastitis frequencies (Rodriguez et al., 1985, Du Preez et al., 1990b).

The objectives of this study were to determine the microclimatic conditions in stables in three climactic regions of Croatia as well as to evaluate the effect of temperature-humidity index values on the daily production of dairy cattle.

Material and methods

Datasets

For analysis of variability of microclimatic conditions in the stable as well as their significance on the daily production of dairy cattle in Croatia, 1675686 test-day records collected from January 2005 until April 2010 on 8273 dairy farms all around Croatia were extracted from HPA (Croatian Agricultural Agency) database. Milk recording in Croatia occurs according to the alternative milk recording method every four weeks when, depending of the particularly farm, the HPA control assistant (A) or the farmer (B) measures morning or evening milk yield, notes initial time of control milking and initial time of previous milking, and, for analysis of milk composition, takes milk sample from each lactating cow. For analysis of milk fat, protein and lactose content MilkoScan 133 B was used. The interval between successive milking, required for projection of daily values, was computed as the time from the beginning of previous milking to the beginning of control milking. Daily production of milk yield and components was projected using projection parameters estimated in authors' earlier research (Gantner, 2008). Logical control of production data was performed according to ICAR standards (2003). The yields recorded after the 500th lactation day was deleted from the dataset.

According to the parity, cows were divided into five classes that are heifers (P_1), cows in second lactation (P_2), cows in third lactation (P_3), cows in fourth lactation (P_4), and cows in fifth and higher lactations (P_5). Variability of analyzed traits in regard to parity classes is shown in Table 1.

According to the test date, four measuring season subgroups were created (S_1 - spring - including the period from April till June; S_2 - summer - including the period from July till September; S_3 - autumn - including the period from October till December; and S_4 - winter - including the period from January till March). Cows were divided in two calving season subgroups regarding the calving date (C_1 and C_2 that include animals calved in spring/summer and autumn/winter season). In accordance to the geographical and climatic characteristics of Croatia three different regions were formed, namely East, Mediterranean, and Central region where 2795, 1980, and 3500 respectively dairy farms were included in research.

Table 1. Description of dataset used for analysis (n = 1675686)

Parameter	Parity				
	P_1	P_2	P_3	P_4	P_5
Daily milk yield, kg	16.62±6.69	17.73±7.84	17.89±7.93	17.34±7.54	15.93±6.79
Daily fat content, %	4.23±0.91	4.25±0.95	4.22±0.95	4.17±0.94	4.09±0.92
Daily protein content, %	3.47±0.48	3.50±0.49	3.47±0.48	3.45±0.47	3.44±0.46

The temperature and the relative humidity in stable were recorded at each milking. The daily temperature-humidity index (THI) values were calculated using the equation by Kibler (1964):

$$THI = 1.8Ta - (1 - RH)(Ta - 14.3) + 32 \quad (1)$$

where:

Ta - measured ambient temperature in °C, RH - relative humidity as a fraction of the unit. According to the value of the temperature-humidity index (THI), two THI subgroups were created (T_1 where THI≤72; and T_2 where THI>72).

For estimation of the effect of temperature-humidity index (THI) on daily production of dairy cows following fixed - effect model was used:

$$y_{ijkl} = \mu + b_1 (d / 305) + b_2 (d / 305)^2 + b_3 \ln(305 / d) + b_4 \ln^2 (305 / d) + B_i + C_j + S_k + T_l + e_{ijkl} \quad (2)$$

where:

y_{ijkl} = predicted daily performance (yield or content),

μ = intercept.

b_i = regression coefficients of Ali and Schaeffer lactation curve (1987),

d = lactation stage (days),

B_i = effect of breed (i = Holstein; Simmental),

C_j = effect of calving season (j = 1 - spring/summer; 2 - autumn/winter),

S_k = effect of measuring season (k = 1 - spring; 2 - summer; 3 - autumn; 4 - winter),

T_l = effect of THI group (l = 1 - THI≤72; 2 - THI>72),

e_{ijkl} = residual.

The significance of differences between the means of the daily milk yield, as well as between the means of the daily fat and protein content within the THI classes in regard to parity classes by climatic regions was tested with Scheffe test. For the statistical analysis and the figures drawing the SAS/STAT package was used (SAS Institute Inc., 2000).

Results and discussion

Variations in the ambient temperature (Ta, °C), relative humidity (RH, %), and the temperature-humidity index (THI) in the stable noted during the measuring months for analysed regions (East, Mediterranean, Central) are reported in Table 2.

Comparing the monthly averages of microclimatic parameters in analysed regions, highest ambient temperatures were determined in Mediterranean, while highest relative humidity were observed

Table 2. Microclimate conditions in the stables during measuring months in accordance to the regions (East, Mediterranean, and Central)

Month/Season	Region/Parameter								
	East			Mediterranean			Central		
	Ta, °C	RH, %	THI	Ta, °C	RH, %	THI	Ta, °C	RH, %	THI
I./S_4	7.5±4.3	69.5±9.8	47.5±6.6	10.3±4.7	70.7±9.6	51.7±7.1	9.6±4.5	73.8±8.7	50.5±6.9
II./S_4	8.1±4.6	67.5±9.7	48.4±7.0	11.2±4.9	68.6±9.7	53.1±7.2	10.3±4.5	71.9±8.7	51.6±6.9
III./S_4	10.2±4.7	67.1±9.9	51.6±7.4	13.3±5.1	66.6±9.9	56.2±7.3	12.1±4.8	69.4±9.1	54.4±7.2
IV./S_1	13.8±5.2	66.4±9.3	56.9±7.8	17.0±5.1	64.0±9.4	61.5±7.2	16.1±4.8	66.9±4.8	60.3±7.0
V./S_1	17.6±5.8	65.5±9.8	62.5±8.5	20.4±5.1	65.5±9.7	66.6±7.4	19.8±5.1	67.5±9.5	65.8±7.5
VI./S_1	20.4±6.1	67.4±9.7	66.7±9.0	23.3±5.2	67.7±9.2	70.9±7.8	22.5±5.1	68.9±9.5	69.8±7.6
VII./S_2	23.1±6.1	66.1±9.9	70.6±8.8	24.9±4.7	68.6±9.5	73.5±6.9	23.9±4.9	68.7±9.8	71.9±7.3
VIII./S_2	21.7±5.8	66.2±9.9	68.6±8.3	23.5±4.7	68.6±9.6	71.4±7.1	22.9±4.5	69.6±9.1	70.7±6.9
IX./S_2	18.8±5.6	66.6±9.8	64.3±8.0	20.3±4.7	69.8±9.3	66.7±7.1	19.5±4.7	70.9±8.8	65.5±7.1
X./S_3	14.6±5.4	69.6±9.7	58.1±8.1	17.0±4.9	70.1±9.0	61.8±7.3	15.9±4.7	71.9±8.5	60.1±7.2
XI./S_3	10.9±5.1	69.9±9.4	52.2±7.8	13.2±4.9	70.5±9.8	56.1±7.4	12.5±4.5	72.6±9.0	55.0±6.9
XII./S_3	8.4±4.8	70.5±9.8	48.7±7.4	11.2±4.7	72.1±9.6	53.1±7.1	10.3±4.6	74.1±8.6	51.6±7.0

Ta - ambient temperature (°C); RH - relative humidity (%); THI - temperature-humidity index

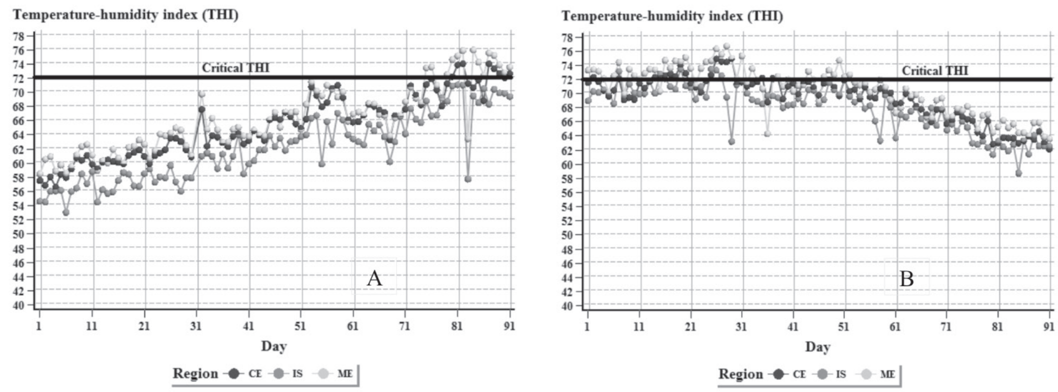

Figure 1. Average temperature-humidity indexes during the spring (A) and the summer (B) season

in Central region. In Mediterranean region were also determined the highest values of temperature-humidity index (THI). The severity of heat stress is correlated to both ambient temperature and humidity level. The bovine thermal comfort zone is -13 °C to +25 °C. Within this temperature range, the animal comfort is optimal, with a body temperature between 38.4 °C and 39.1 °C (Lefebvre and Plamondon, 2003). Above 25 °C, and even 20 °C for some authors, the cow suffers from heat stress: its health status and production performance are affected. Berman (1968) determined that for lactating dairy cows the ambient temperatures above 25 °C are associated with lower feed intake, drops in milk production and reduced metabolic rate. Berman et al. (1985) noticed that the upper limit of ambient temperatures at which Holstein cattle may maintain a stable body temperature is 25 to 26 °C, and that above 25 °C practices should be instituted to minimize the rise in body temperature. Bianca (1965) determined decrease in daily milk yield of Holstein, Jersey and Brown Swiss cows in amount of 3, 7 and 2 % of normal at a temperature of 29 °C and 40 % relative humidity. Increase of relative humidity to 90 % induces additional decrease of milk yield for 31, 25, and 17 % of normal yield. Use of a temperature-humidity index is a one way to measure the combined effect of temperature and humidity. A mean daily THI in value of 72 is considered to be the critical point at which milk yield is reduced (Johnson, 1987). Increasing THI in the range of 71 to 81 reduced the milk yield and intake of feed and water for dairy cows (Johnson et al., 1963). The effect was greatest when THI exceeded 76. Du Preez et al. (1990b) stated that milk production is affected by heat stress when THI values are higher than 72, which corresponds to 22 °C at 100 % humidity, 25 °C at 50 % humidity, or 28 °C at 20 % humidity.

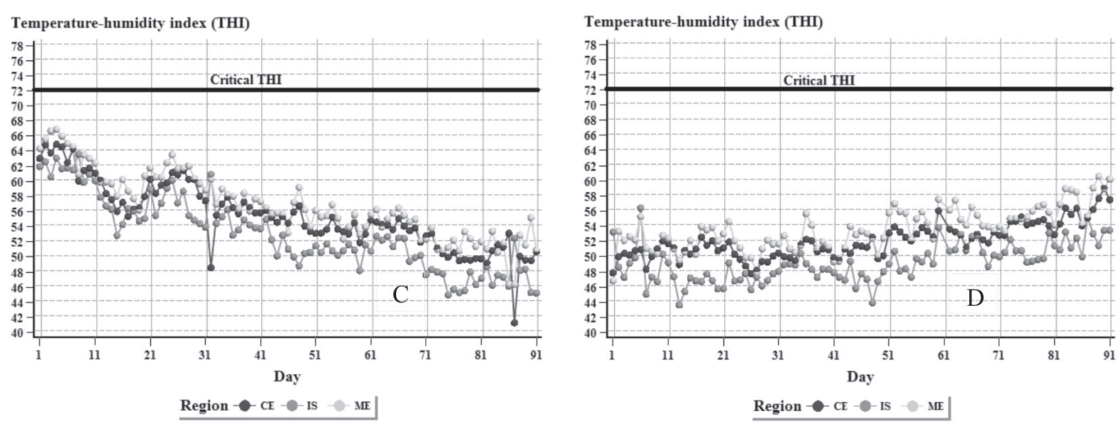

Figure 2. Average temperature-humidity indexes during the autumn (C) and the winter (D) season

Table 3. Lsmeans of production parameters for THI groups (T_1, T_2) in relation to parity classes (P_1, P_2, P_3, P_4, P_5) and regions (East, Mediterranean, Central)

Parity	Parameter	Region/THI group					
		East		Mediterranean		Central	
		T_1	T_2	T_1	T_2	T_1	T_2
P_1	Daily milk yield, kg	17.734^A	16.814^B	17.264^A	16.497^A	15.809^A	15.452^B
	Daily fat content, %	4.110^A	4.061^B	4.246^A	4.196^B	4.279^A	4.208^B
	Daily protein content, %	3.445^A	3.401^B	3.452^A	3.395^B	3.447^A	3.389^B
P_2	Daily milk yield, kg	19.076^A	18.038^B	18.322^A	17.842^B	16.910^A	16.605^B
	Daily fat content, %	4.128^A	4.057^B	4.281^A	4.241^B	4.293^A	4.208^B
	Daily protein content, %	3.474^A	3.414^B	3.514^A	3.470^B	3.502^A	3.440^B
P_3	Daily milk yield, kg	19.173^A	18.597^B	18.564^A	18.091^A	17.187^A	16.826^B
	Daily fat content, %	4.107^A	4.049^B	4.229^A	4.199^B	4.256^A	4.196^B
	Daily protein content, %	3.443^A	3.380^B	3.470^A	3.429^B	3.466^A	3.409^B
P_4	Daily milk yield, kg	18.605^A	18.312^B	18.053^A	17.518^B	16.687^A	16.291^B
	Daily fat content, %	4.075^A	4.023^B	4.189^A	4.134^B	4.195^A	4.167^B
	Daily protein content, %	3.432^A	3.375^B	3.451^A	3.416^B	3.449^A	3.398^B
P_5	Daily milk yield, kg	16.947^A	16.269^B	16.762^A	16.398^B	15.445^A	15.161^B
	Daily fat content, %	4.020^A	3.941^B	4.102^A	4.054^B	4.099^A	4.049^B
	Daily protein content, %	3.411^A	3.358^B	3.447^A	3.387^B	3.433^A	3.376^B

*the values within the classes of parity and regions marked with the different letters differ highly significant ($P>0.01$)

Mean daily THI values during spring (Figure 1A) and summer (Figure 1B) season were highest in Mediterranean region were, during 15 days in spring and 38 days in summer, mean daily THI value exceeded critical (72) indicating heat stress conditions. Lowest frequency of days with heat stress conditions were observed in Eastern region. Absence of heat stress conditions ($THI<72$) during autumn and winter season characterised all three regions (Figure 2C and 2D).

Effect of exceeded THI on daily milk yield and components in relation to parity classes and climatic regions are shown in table 3. Highly significant ($P<0.01$) decrease of daily milk yield due to enhanced THI was observed in heifers in all three regions. The highest amount of daily loss (>0.9 kg/day) was determined in heifers breed in East region. Regarding the effect of THI value above critical on daily fat and protein content in heifer cows, highly significant ($P<0.01$) decrease was observed in all analysed regions. Furthermore, in cows in second lactation highly significant ($P<0.01$) decrease of daily milk yield as well as of daily fat and protein content induced by heat stress conditions were observed in all regions. Highly significant ($P<0.01$) decrease of analysed productive parameters were also determined in older cows in all climatic regions, while the most deteriorate effect of heat stress was observed in East region.

Deteriorate effect of exceeded THI on daily milk yields and components were also observed in other studies. Ingraham (1979) estimated that milk yield reduction was 0.32 kg per unit increase in THI. Schneider et al. (1988) observed that heat stressed dairy cows in one chamber experiments consumed less feed (13.6 vs. 19.4 kg/day), more water (86.0 vs. 81.9 l/day) and produced less milk (16.5 vs. 20.0 kg/day) than cows in a thermal neutral environment. McDowell (1976) suggested that milk production is reduced by 15% accompanied by a 35 % decrease in the efficiency of energy utilization for productive purposes, when a lactating Holstein cow is transferred from an air temperature of 18 to 30 °C. Johnson et al. (1963) reported that the milk yield and the DMI (dry matter intake) exhibited significant declines (by 1.8 and 1.4 kg for each 0.55 °C increase in rectal temperature) when maximum THI reached 77. A significant negative correlation between THI and DMI was determined for cows in the south-eastern U.S. (Holter et al., 1996; 1997). Same authors presume that the effect of THI is probably mediated through the effects of increasing body temperature on cow performance. Umphrey et al. (2001) reported that the partial correlation between milk yield and rectal temperature for cows in Alabama was -0.135. Ravagnolo et al. (2000) determined that milk yield declined by 0.2 kg per unit increase in THI when THI exceeded 72. Bouraoui et al. (2002) observed that the daily THI was negatively correlated to milk yield (r = -0.76) and feed intake (r = -0.24). Same authors also determined that milk yield decreased by 0.41 kg per cow per day for each point increase in the THI>69. The reduction in milk production during heat stress may be due to decreased nutrient intake and decreased nutrient uptake by the portal drained viscera of the cow. Blood flow shifted to peripheral tissues for cooling purposes may alter nutrient metabolism and contribute to lower milk yield during hot weather. West et al. (2002) reported that, during hot weather, the mean THI two days earlier had the greatest effect on milk yield, while DMI was most sensitive to the mean air temperature two days earlier. Milk yield for Holsteins declined 0.88 kg per THI unit increase for the 2-d lag of mean THI, while DMI declined 0.85 kg for each degree (°C) increase in the mean air temperature. The authors presume that the delayed impact of climatic variables on production could be related to altered feed intake, delay between intake and utilization of consumed nutrients, or changes in the endocrine status of the cow.

Milk fat and milk protein percentage also decreases due to heat stress. Bouraoui et al. (2002) determined decrease of daily fat (3.24 vs. 3.58 %) and protein (2.88 vs. 2.96 %) content, as well as decrease of daily fat (0.68 vs. 0.48) and protein (0.56 vs. 0.43) yields during summer in regard to spring period. The depressions in milk fat and protein percentages associated with heat stress environments were also determined by Rodrigez et al. (1985). On the other hand, Knapp and Grummer (1991) found no significant decrease in fat percentage for cows under heat stress. The difference between results obtained in this research and those reported by Knapp and Grummer (1991) could be caused by use of total mixed rations (TMR) which probably alleviate milk fat depression commonly associated with heat stress by maintaining the intended forage to concentrate intake and, ensuring adequate fibre for proper rumen fermentation. In the same study Knapp and Grummer (1991) observed decrease of milk protein with increase of maximum daily temperature. The reduction in milk protein is probably caused by a decreased DMI and energy intake. Emery (1978) quoted that decreased levels of food intake during lactation are usually associated with decreased protein content.

Conclusions

Based on analysis of microclimatic conditions in stables in climactic regions of Croatia and evaluation of the effect of temperature-humidity index values on the daily production of dairy cattle following conclusions could be emphasised:

The highest monthly averages of ambient temperature during analysed period were determined in Mediterranean region, the highest monthly averages of relative humidity during analysed period were observed in Central region, while the highest monthly mean values of temperature-humidity index (THI) were determined in Mediterranean region.

Heat stress conditions indicated with mean daily values of THI>72 were determined during spring and summer season in all analysed regions. The highest incidence of exceeded THI was observed in Mediterranean region (15 days in spring and 38 days in summer period). Absence of heat stress conditions during autumn and winter season characterised all three regions.

Highly significant (P<0.01) decrease of daily milk yield due to enhanced THI was observed in all cows regardless the parity class and in all three climatic regions. Regarding the effect of THI value above critical on daily fat and protein content, highly significant (P<0.01) decrease was observed in all cows and in all analysed regions. Furthermore, the most deteriorate effect of heat stress was observed in East region. During heat stress period, with the aim of minimization of the effects of heat stress, it is necessary to regulate management strategies in the dairy herd. There are many tools available to help the dairy farmer combat heat stress. For instance, environmental cooling can maintain feed intake and nutrient density of feed can optimize nutrient intake to maintain milk production.

Utjecaj vrijednosti temperaturno-humidnog indeksa na dnevnu proizvodnju mliječnih goveda

Sažetak

Ciljevi su provedenoga istraživanja bili utvrditi mikroklimatske uvjete u proizvodnim objektima u tri klimatske regije Hrvatske (istočna, mediteranska te centralna) te evaluirati utjecaj vrijednosti temperatutno-humidnog indeksa (THI) na dnevnu proizvodnju mliječnih goveda. U tom je cilju iz baze podataka HPA (Hrvatske poljoprivredne agencije) ekstrahirano 1675686 dnevnih zapisa prikupljenih u razdoblju od siječnja 2005. do travnja 2010. godine. Za procjenu utjecaja THI na dnevnu proizvodnju mliječnih goveda korišten je model fiksnih utjecaja u kojem su uvaženi utjecaji stadija laktacije, pasmine, sezone telenja, sezone mjerenja, te THI grupe (T_1 - THI≤72; T_2 - THI>72). Model je apliciran zasebno po razredima redoslijeda laktacije (P_1, P_2, P_3, P_4 i P_5) te regije. Tijekom analiziranog razdoblja, najviše prosječne mjesečne vrijednosti ambijentalne temperature utvrđene su u mediteranskoj, najviše prosječne mjesečne vrijednosti relativne vlage utvrđene su u centralnoj, dok su najviše prosječne mjesečne vrijednosti temperaturno-humidnog indeksa (THI) utvrđene u mediteranskoj regiji. Toplinsko stresni uvjeti indicirani prosječnom dnevnom vrijednošću THI>72 utvrđeni su tijekom proljetne i ljetne sezone u svim analiziranim regijama. Odsustvo toplinsko stresnih uvjeta tijekom jesenske i zimske sezone karakteriziralo je sve tri regije. Visoko signifikantan (P<0.01) pad dnevne količine mlijeka te dnevnog sadržaja mliječne masti i bjelančevina uzrokovan povišenom vrijednošću THI utvrđen je u svih grla neovisno o redoslijedu laktacije te u svim klimatskim regijama. Nadalje, najizraženiji negativni utjecaj toplinskog stresa utvrđen je u istočnoj regiji. Tijekom razdoblja toplinskog stresa, s ciljem minimalizacije utjecaja istog, neophodna je prilagodba managementa u stadu mliječnih grla. Uzgajivačima su na raspolaganju različiti alati za borbu protiv toplinskog stresa. Na primjer, hlađenje okoliša omogućuje unos dostatne količine krmiva dok prikladan sastav obroka osigurava dostatan unos hranjiva. Navedeno omogućava održavanje optimalne proizvodnje mlijeka.

Ključne riječi: mliječna goveda; dnevna proizvodnja; temperaturno-humidni indeks

References

1. Ali, T.E., Schaeffer, L.R. (1987): Accounting for covariances among test day milk yields in dairy cows. *Can. J. Anim. Sci. 67*, 637-644.
2. Armstrong, D.V. (1994): Heat stress interaction with shade and cooling. *J. Dairy Sci. 7*, 2044-2050.
3. Berman, A. (1968): Nychthemeral and seasonal patterns of thermoregulation in cattle. *Aust. J. Agric. Res. 19*, 181-189.
4. Berman, A., Folman, Y., Kaim, M., Mamen, M., Herz, Z., Wolfenson, D., Arieli, A., Graber, Y. (1985): Upper critical temperatures and forced ventilation effects for high yielding dairy cows in a subtropical climate. *J. Dairy Sci. 68*, 1488-1495.
5. Bianca, W. (1965): Reviews of the progress of dairy science. Section A. Physiology. Cattle in a hot environment. *J. Dairy Res. 32*, 291-345.
6. Bouraoui, R., Lahmar, M., Majdoub, A., Djemali, M., Belyea, R. (2002): The relationship of temperature-humidity index with milk production of dairy cows in a Mediterranean climate. *Anim. Res. 51*, 479-491.
7. Du Preez, J.H., Giesecke, W.H., Hattingh, P.J. (1990a): Heat stress in dairy cattle and other livestock under Southern African conditions. I. Temperature-humidity index mean values during the four main seasons. *Onderstepoort J. Vet. Res. 57*, 77-86.
8. Du Preez, J.H., Hatting, P.J., Giesecke, W.H., Eisenberg, B.E. (1990b): Heat stress in dairy cattle and other livestock under Southern African conditions. III. Monthly temperature-humidity index mean values and their significance in the performance of dairy cattle. *Onderstepoort J. Vet. Res. 57*, 243-248.
9. Emery R.S. (1978): Feeding for increased milk protein. *J. Dairy Sci. 61*, 825-828.
10. Gantner, V. (2008): Točnost procjene dnevne količine i sastava mlijeka krava po alternativnoj shemi kontrole mliječnosti, Ph.D. Diss., University of J.J. Strossmayer, Osijek, Croatia.
11. Holter, J.B., West, J.W., Mcgilliard, M.L., (1997). Predicting ad libitum dry matter intake and yield of Holstein cows. *J. Dairy Sci. 80*, 2188-2199.
12. Holter, J.B., West, J.W., Mcgilliard, M.L., Pell, A.N. (1996): Predicting ad libitum dry matter intake and yields of Jersey cows. *J. Dairy Sci. 79*, 912-921.
13. Ingraham R.H., Stanley, R.W., Wagner, W.C. (1979): Seasonal effect of the tropical climate on shaded and non shaded cows as measured by rectal temperature, adrenal cortex hormones, thyroid hormone, and milk production. *Am. J. Vet. Res. 40*, 1792-1797.

14. ICAR - International Committee for Animal Recording (2003). Guidelines approved by the General Assembly held in Interlaken, Switzerland, on 30 May 2002, Roma, 19-39.
15. Johnson, H.D. (1980): Environmental management of cattle to minimize the stress of climate changes. *Int. J. Biometeor. 24* (Suppl. 7, Part 2), 65-78.
16. Johnson, H.D. (1987): Bioclimates and livestock. Bioclimatology and the Adaptation of Livestock. World Animal Science. (H. D. Johnson, ed.) Elsevier Science Publ. Co., New York.
17. Johnson, H.D., Ragsdale, A.C., Berry, I.L., Shanklin, M.D. (1962): Effect of various temperature humidity combinations on milk production of Holstein cattle. Res. Bull. Missouri Agric. Exp. Station, 791.
18. Johnson, H.D., Ragsdale, A.C., Berry, I.L., Shanklin, M.D. (1963): Temperature-humidity effects including influence of acclimation in feed and water consumption of Holstein cattle. Missouri Agr. Exp. Sta. Res. Bul. 846.
19. Kibler, H.H. (1964): Environmental physiology and shelter engineering. LXVII. Thermal effects of various temperature-humidity combinations on Holstein cattle as measured by eight physiological responses. Res. Bull. Missouri Agric. Exp. Station. 862.
20. Knapp, D.M., Grummer, R.R. (1991): Response of lactating dairy cows to fat supplementation during heat stress. *J. Dairy Sci. 74*, 2573-2579.
21. Lefebvre, D., Plamondon, P. (2003): Le Producteur De Lait Québécois, Juin 2003.
22. Mcdowell, L.R. (1976): Mineral deficienties and toxicities and their effect on beef production in developing countries, Symposium: Beef cattle production in developing countries, University of Edinburgh, Scotland 216-241.
23. Rodriguez, L.W., Mekonnen, G., Wilcox, C.J., Martin, F.G., Krienk, W.A. (1985): Effects of relative humidity, maximum and minimum temperature, pregnancy and stage of lactation on milk composition and yield. *J. Dairy Sci. 68*, 973-978.
24. SAS/STAT User's Guide (2000): Version 8. Cary, NC, SAS Institute Inc.
25. Schneider, P.L., Beede, D.K., Wilcox, C.J. (1988): Nycterohemeral patterns of acid-base status, mineral cncentrations and digestive function of lactating cows in natural or chamber heat stress environments. *J. Anim. Sci. 66*,112-125.
26. Umphrey, J.E., Moss, B.R., Wilcox, C.J., Van Horn, H.H. (2001): Interrelationships in lactating Holsteins of rectal and skin temperatures, milk yield and composition, dry matter intake, body weight, and feed efficiency in summer in Alabama. *J. Dairy Sci. 84*, 2680-2685.