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Influence of the daily milk yield level on some physiological parameters of dairy cows reared under the same temperature and humidity conditions

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Abstract

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The present study examines the relationship between the level of daily milk yield and some physiological parameters of dairy cows of the Holstein cattle breed under the same temperature and humidity conditions. The tests were carried out in the course of one year in three cattle-breeding farms with a different capacity. The farms are located in the central part of Southern Bulgaria in the region around Plovdiv. The conditions in the rearing premises in the farms examined range from mild to moderate heat stress during the summer and partially- during the spring. When they are compared to the cows with low milk yield of up to 30 kg, the cows with high daily milk yield – over 40 kg show higher values in all physiological indicators even under conditions of temperature comfort (THI up to 72). The cows with lower milk yield – up to 40 kg react with an increased rectal temperature upon THI values above 72. The cows with low milk yield (up to 30 kg) react with an increase in the skin temperature at higher THI values – over 80. All milk-yield groups indicate quickened pulse rate upon increase of the THI values. The pulse rate quickening upon THI of up to 72 and over 80 is by 26, 23.2 and 29.8% respectively for the three cow groups based on their milk yield group. The pulse rate of the cows with daily milk yield of up to 30 kg is considerably quickened upon THI increase over 80, while the pulse rate of the cows with a milk yield between 30 and 40 kg quickens by 19% upon THI values from 72 to 80. The breathing intensity significantly increases (from 26 to 30%) in all three milk – yield groups upon increase of the THI values: from conditions of comfort (up to 72) to reaching the conditions of a moderate stress (above 80).

Keywords: dairy cows; THI; daily milk yield; physiological parameters

Introduction

The environmental conditions are major stress factors affecting the animals and leading to serious changes in their physiological and hematological indicators (Mazzullo et al., 2014) The increasing interest towards the heat comfort of the agricultural animals is well-founded not only with reference to countries located in tropical zones but also with reference to such which are in the temperate zones where the high environmental temperatures are becoming a problem (Segnalini et al., 2013).

The temperature which is considered to be the upper limit for the dairy cows to maintain their homeothermy or stable rectal temperature is 25-26°C (Berman et al., 1985). The increase of the ambient temperature does not have the same effect on the physiological indicators of the cows with different productivity. According to Morrison (2000), upon temperature increase from 18 to 29°C, the high-yielding cows increase their body temperature with 1.4°C and decrease their daily milk yield with 4 kg, while the low-yielding cows increase their temperature with only 0.7°C and decrease their daily milk yield with 2 kg. Collier et al. (2017) add that the decreased milk yield is a result of the increased body temperature which leads to a reduced food intake and change in the energy metabolism. The heat stress is a result of an imbalance between the heat flow and its release from the body under high-temperature conditions. The heat stress is triggered by the high temperature of the air in combination with high or, the opposite, very low humidity. The comfort zone for the local cattle breeds is within the temperature range from +4 to +20°C, and for the high-yield ones – from +9 up to +16°C. Each temperature increase above the optimum levels leads to the activation of mechanisms connected with energy consumption and decrease in the adaptive capacities effectiveness (Brown-Brandl, 2018). In the context of globally changing climate conditions, the heat stress is becoming a serious problem for the dairy cattle farming.

The temperature-humidity index indicates the combined effect of the temperature and the relative humidity of the air on the physiological, productive and other indicators in cows. Multiple studies show that the THI may be used as a heat stress indicator for the dairy cows (Dikmen & Hansen, 2009; Hristev et al., 2020).

Dairy cows respond to heat stress in several ways: decrease of the feed and increase of the water intake, change in the metabolism speed, increase of the water loss from evaporation, increase of the respiration rate, changes in the blood hormones concentration, and increase of the body temperature (Knížková & Kunc, 2002). The high-yield and older cows are more susceptible to heat stress (Bucklin et al., 1991).

Taking the above mentioned into account, we set ourselves the goal to examine whether, and to what extent, there is a connection between the milk productivity and some physiological indicators of Holstein cows reared under the same temperature-humidity conditions in the region of Plovdiv.

Materials and Methods

The studies were performed in the course of one year in three cattle-rearing farms with a different capacity. The three farms are located in the central part of Southern Bulgaria, in the region around Plovdiv. The region is characterized by temperate-continental climate with high temperatures during the summer and moderately cold temperatures during the winter.

The cow-rearing technology in two of the farms was free in groups with individual boxes for resting, and in the third one- free in groups living on deep litter bedding. The buildings of the first farm were semi-open and each cow was provided with space of 9.4 m². The open spaces of the building had an area of 170 m². The mechanical ventilation was controlled automatically. The buildings of the second farm were reinforced concrete constructions with concrete wall and roof panels. Each cow was ensured space of 11.5 m². During the winter period the windows and the skylights were covered with polyethylene sheets. The cows in the third farm were reared on a deep litter bedding in a semi-open building with brick walls. Each animal was provided space of 8.06 m². The cleaning of manure was performed twice a year along with a periodic addition of hay. The feeding of the cows in all three farms was unlimited with a total mixed ration and a permanent access to water.

The study includes 18 black and white cows with the same period of calving. The first reporting of both the milk yield and the physiological indexes coincided with the spring when the cows examined were in their Ist lactation period (day 60-80). The same cows were in their IInd lactation period (day 180-200) during the summer, and in the winter they were at the end of their lactation. The reporting of the micro-climatic indexes (temperature and relative humidity of the air) and the monitoring of the physiological indicators (rectal and skin temperature, pulse rate and breathing intensity) were performed during the three seasons (spring, summer and winter). The cows were in a different lactation- from second to third. The examination of the physiological indexes was carried out on the same animals throughout all seasons, with the exception of two, which fell out due to different reasons and were replaced by animals which were analogous with them in terms of period of lactation, milk yield and age. The daily milk yield of the cows part of the study was taken by the official milk productivity control systems of the respective farm. The micro-climatic indicators reported were about the three seasons – spring, summer and winter. The micro-climatic indicators (temperature, relative humidity of the air and THI) values for the seasons spring and autumn were similar and therefore only those regarding the spring are displayed. The temperature and the relative humidity were measured in the premises on the level of the animals at 2 o'clock pm by means of an aspiration psychrometer by Assmann. The physiological indicators of each cow- rectal and skin temperature, pulse rate and breathing intensity were measured at the same time. The skin temperature was taken with a manual multi-functional Compact infrared thermometer 105518 with a scope from 50 to + 550°C and a resolution of 0.1°C, and the rectal temperature – with a Kerbl digital thermometer 2130 in degrees Celsius. The skin temperature is displayed as the average of the head, stomach and back temperature. The breathing intensity was measured visually by observing and reporting the movement of the chest per minute under the methodology of Zimbelman et al. (2009). The pulse rate was measured in the zone of the tail vein with a chronometer.

The calculation of the temperature-humidity index was performed under the following formula (Kelly & Bond, 1971):

$$THI = T - (0.55 - 0.0055 \text{ x } RH) \times (T - 58),$$

where T is the temperature measured in °F

RH – relative humidity, %.

For the purpose of a better approximation during the analysis of variance, the two factors examined – daily milk yield and THI are displayed in classes as follows:

Daily milk yield, respectively – up to 30 kg, from 30 to 40 kg and over 40 kg, and THI – up to 72, from 73 to 80 and above 80 (Armstrong, 1994).

The basic statistical processing of the data was performed via MS Excel, and the statistical indexes of the analysis of variance were processed with the use of the respective modules of StatSoft STATISTICA (Copyright 1990-1995 Microsoft Corp.).

The following model was used for the assessment of the influence of the factors on the values of the physiological indicators examined:

$$Y_{ijkl} = \mu + DM_i + THI_j + DM{*}THI_k + e_{ijkl},$$

where Y_{ijkl} is a dependable variable (physiological indicator); μ is the model average; DM_i is the effect of the daily milk yield (classes), THI_j is the effect of the temperature-humidity index (classes), $DM{*}THI_k$ is the cluster effect of the daily milk yield and the THI, and e_{ijkl} is the effect of the non-controlled factors (error).

The average of the least square mean (LSM) per the model by classes of fixed factors was established by means of the analysis of variance (ANOVA).

Results and Discussion

Table 1 displays the average values of the daily milk yield of the cows included in the study and its variation by seasons and farms. The milk yield was reported on the day of taking the physiological parameters and the temperature and relative humidity of the air in the premises. The highest average daily milk yield was exhibited by the cows in farm 3- between 34.33 kg and 50.17 kg. Similar, however, lower was the milk yield of the cows in farm 1 – from 34.03 kg to 43.37 kg, and the lowest milk yield was that of the cows in farm 2 – from 19.83 to 22.05 kg. The first reporting of both the milk yield and the physiological parameters was performed in compliance with the scheme of the study during the spring when the cows examined were in their I[st] lactation period. During the summer the same cows were in their II[nd] period of lactation and in the winter they were at the end of their lactation. Thus, the highest daily milk yield was reported during the spring, followed by the summer and the winter, which correlates with the changes in the milk yield during the lactation.

The temperature-humidity index, representing the combined influence of the temperature and the relative humidity of the air shows that there were periods with unwanted

Table 1. Average values and variations of the daily milk yield and the THI by farms and seasons of reporting of the physiological indicators

Season	Number	Daily milk yield. kg				THI values
		x ± SE	SD	min	max	
Farm 1						
Spring	6	43.37 ± 1.31	3.20	38.4	47.6	69.8
Summer	6	37.65 ± 1.44	3.52	33.8	43.5	78.3
Winter	6	34.03 ± 0.75	1.85	31.2	36.5	43.9
Farm 2						
Spring	6	22.05 ± 0.27	0.66	21.3	22.8	71.0
Summer	6	20.95 ± 0.34	0.82	20.2	22.3	82.4
Winter	6	19.83 ± 0.15	0.37	19.2	20.3	46.3
Farm 3						
Spring	6	50.17 ± 3.59	8.79	43.0	67.0	71.4
Summer	6	43.83 ± 2.48	6.08	37.0	53.0	85.0
Winter	6	34.33 ± 0.71	1.75	32.0	37.0	48.6

Note: The THI values were reported upon the reporting of the physiological indicators micro-climate, especially during the summer and part of the spring. In the summer this index reached 85 in farm 3, followed by farm 2 – 82.4. According to the classification of Armstrong (1994) these are values setting conditions for temperate heat stress in the dairy cows. During the summer the average THI values were below 72 (from 69.8 to 71.4), and in the winter they fell below 50 i.e. these THI values provided conditions for temperature comfort of the animals. The higher THI values in the cows zone in farm 3 during the summer were probably due to the type of building and the deep litter bedding which were the reasons for both the higher temperatures and the increased relative humidity in the premises. This is also proved by the fact that the THI values in the three seasons studied were higher than those in the other two farms examined. The approximately lowest average values were reported during the spring and the summer in farm 1 where in the animals premises there were fans which were automatically turned on upon temperatures of above 25°C.

Normally, the index is divided into classes which show different levels of heat stress. Nevertheless, the definitions and the scope of these levels are quite variable according to the different authors. Armstrong (1994) considers an index of below 71 to be a comfort zone, index 72-79 – a mild stress zone, index of 80-89 – a moderate stress zone, and values above 90 to be a severe heat stress zone. Huhnke at al. (2001) subdivide THI into 2 categories: upon $79 \leq THI \leq 83$ – dangerous situation and upon $THI \geq 84$ – an emergency one. Segnalini et al. (2013) consider even a lower threshold to be a heat stress limit – THI of 68-72 (mild discomfort). These differences in the different authors' classification of the THI values might be due to the examination of different cattle breeds, milk yield levels and other factors. The cattle of different breeds and production types react differently to the THI levels. Furthermore, the cattle sensitivity to heat stress increases when the milk yield goes up, (Berman, 2005). This stems from the fact that the metabolic heat released increases along with the productivity of the cows. The author adds that upon milk yield increase from 35 to 45 kg per day, the temperature threshold for heat stress decreases by 5°C.

Consequently, the values from 69.8 to 71.4 reported by us for the spring can also be considered a prerequisite for disruptions in the temperature homeostasis of the dairy cows organisms (mild discomfort). Other studies also point to prerequisites for conditions of different degrees of heat stress in the dairy cows in Bulgaria. During a one-year study of the climatic conditions in Southern Bulgaria, Dimov (2017) ascertained that values of THI setting conditions for heat stress in dairy cows reared in buildings of semi-open type were reported during the summer- average daily values of above 75. The author established that there was also a certain risk of such conditions during the spring upon average THI daily values of above 69. Such results are indicated by Hristev et al. (2020), too.

A model for assessment of the effect of the daily milk yield and the THI (by classes) on the physiological indicators of the cows was applied on the basis of their reported values (Table 2). The analysis of variance performed displayed a significant effect of the daily milk yield levels only on the pulse of the cows ($p < 0.01$), while the THI values had a significant effect on the three physiological parameters- skin temperature, pulse and breathing intensity ($p < 0.001$). The daily milk yield levels under different THI values also had a significant effect on these three physiological parameters ($p < 0.01$) and ($p < 0.001$)No significant effect of the milk yield and the THI was indicated only with reference to the rectal temperature.

Figures 1-4 display the LS means with reference to the effect of the daily milk yield under different THI levels.

Figure 1 displays the LS means of the rectal temperature of the cows with different milk yield levels and THI values. With reference to the cows with milk yield of above 40 kg, there was a tendency for a rectal temperature increase (from 38.4 to 38.6°C) upon all THI levels. The main prerequisite for the higher rectal temperature was the intense milk production. Purwanto et al. (1990) indicate that upon milk yield between 18.5 and 31.6 kg, the heat production is respectively 27.3% and 48.5% higher than that of the non-lactating cows.

Under THI values over the temperature comfort zone (THI 72), the rectal temperature of of the cows in the groups with daily milk yield of up to 30 kg and from 30 to 40 kg in-

Table 2. Analysis of variance for the influence of the daily milk yield and THI on the physiological parameters

Parameters	Total for the model		Daily milk yield		THI		Daily milk yield/THI		Error
	MS	F P	MS	F P	MS	F P	MS	F P	MS
Rectal temperature C°	11.06	0.61-	3.60	0.19 -	7.92	0.43	5.97	0.33	18.07
Skin temperature C°	18.84	24.69***	0.38	0.50-	26.23	34.37***	13.43	17.60***	0.76
Pulse n/min	299.42	20.29 ***	97.1	6.58**	835.6	56.63***	73.2	4.28**	14.8
Breath n/min	86.58	16.56 ***	8.09	1.55 -	208.7	39.91***	30.32	5.79***	5.23

Note: * – significance upon $p < 0.05$; ** – significance upon $p < 0.01$; *** – significance upon $p < 0.001$; – no significant effect creased from 37.6 to 38.4°C (almost 1°C). All reported values, however, remained within the physiological norms. The temperature increase was probably a reaction of the organism in an attempt to restore its thermal balance. Upon thermal load not only are the pulse (Avendono-Reyes et al., 2012) and breathing accelerated but the food intake is decreased, and the water intake is increased. (Bernabucci et al., 2010). The body temperature, however, is a variable. Throughout the day its values vary in connection with the metabolic processes and the organism thermoregulation capacity.

The cows with high daily milk yield (above 40 kg) maintained a higher rectal temperature (over 38°C) upon all THI values when compared with those with daily milk yield lower than 40 kg regarding which the rectal temperature started to increase when the THI values exceeded 72.

Just like the human body, that of the animal can be subdivided into a central part, where the temperature is subject to minor fluctuations, and peripheral (skin) whose temperature constantly changes depending on the changes of the ambient temperature. The heat exchange between these two parts is performed by the blood circulation.

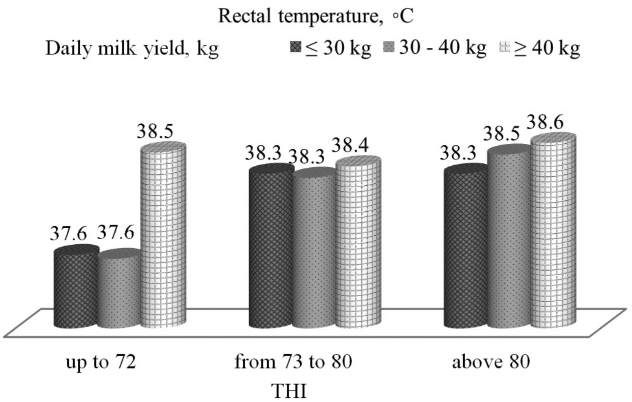

Fig. 1. Rectal temperature LS means depending on THI and the daily milk yield

Figure 2 displays the skin temperature LS means depending on the daily milk yield and the THI values. The cows with low milk yield (up to 30 kg) reacted by increasing their skin temperature upon THI values of over 80, while the cows with milk yield from 30 to 40 kg increased their skin temperature upon THI from 72 to 80 and retained it higher even upon THI of over 80. Upon THI from 72 and above 80, the cows with high daily milk yield (above 40 kg) had a higher skin temperature than the cows form the other groups. These results are also supported by the studies of Collier et al. (2007) who have calculated that each THI increase by one unit results in a skin temperature increase with 0.38°C. The correlation between the milk yield, THI, body and skin temperature ascertained requires introduction or correction of the existing methods for cooling of the cows before the critically hot periods.

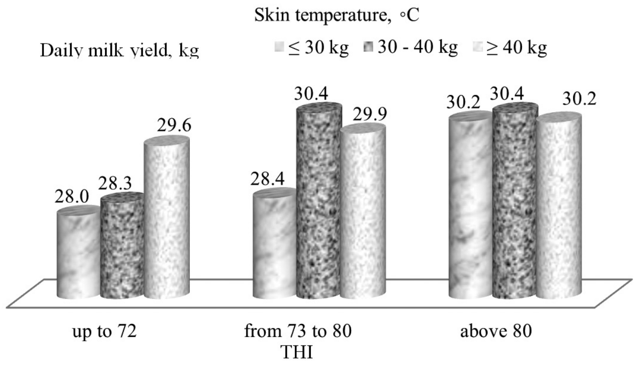

Fig. 2. Skin temperature LS means depending on THI and daily milk yield

The physiological effects based on THI are currently underestimated as a heat stress indicator but could be used in the milk yield prediction especially with reference to the highly productive cows.

Figure 3 displays the pulse LS means (beats per minute) of the cows with different levels of milk yield and THI values. The increase of the THI values resulted in a faster pulse of the animals in all milk yield groups.

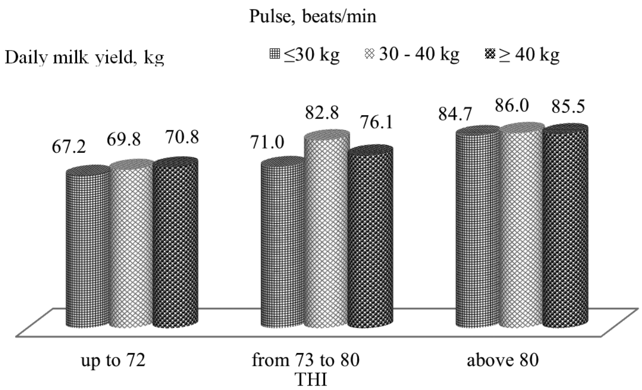

Fig. 3. Pulse LS means depending on THI and the daily milk yield

The pulse quickening upon THI from 72 and above 80 was respectively by 26, 23.2 and 29.8% in the three milk yield groups. The pulse of the cows with daily milk yield of up to 30 kg was significantly quickened upon THI values of above 80, while with reference to the cows with daily milk yield from 30 to 40 kg, it increased by 19% upon THI values from 72 to 80.

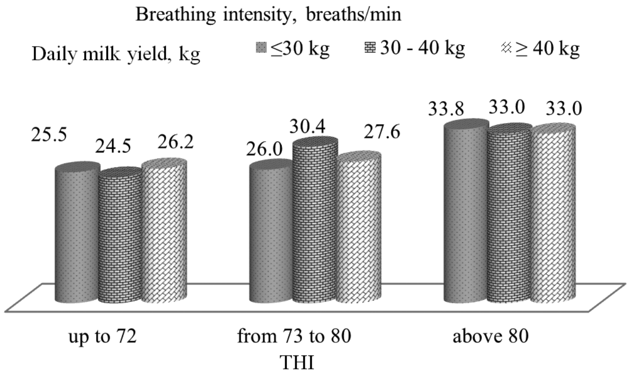

Fig. 4. Breathing intensity LS means depending on THI and the daily milk yield

According to Atkins et al. (2018), the breathing movements can also be considered a criterion for measuring the heat stress. This parameter may vary widely depending on whether the cow is in upright or lying position, what is its productivity as well as other factors. The momentary reporting, however, may not be always regarded reliable due to the fact that the cows might be stressed by the manipulation itself.

The results of our study indicate respiration intensification (Figure 4) upon THI values of above 80 (moderate heat stress conditions) with average values of 33 breaths per minute instead the reference ones 10-30. The breathing intensity increased significantly in the three milk yield groups upon THI increase from comfort conditions (THI 72) to moderate stress conditions (THI above 80). The respiratory intensity increase was almost the same in the three milk yield groups- from 26 to 30%.

The data obtained show the process of the air temperature and relative humidity effect on the physiological parameters of the dairy cows. Regardless of the relatively high summer temperatures measured in the buildings during the day, the THI values did not exceed the moderate heat stress zone- 80-90 (Armstrong, 1994). Along with the negative results of the heat stress related to the milk yield decrease, many authors add changes in the behavior, increased water and decreased food intake, limited social contacts, diminished survival rate, changes in the physiology and the biochemical processes (Marchesini et al., 2018).

The higher values of most of the physiological parameters ascertained regarding the cows with high milk yield-above 40 kg, when compared to the lower-milk-yield groups, point that it is high time newer concepts for THI reference values with reference to the highly productive dairy cows were adopted.

According to Collier et al. (2012) the existing THI threshold standard is 72. This threshold is identical with the assessment of Bernabucci et al. (2014) with the information being about the daily productivity of the Italian black and white cows. Nevertheless, Zimbelman et al. (2009) recalculate the THI threshold of 72 validity and recommend the more realistic value of 68 with reference to highly productive Holstein cows. This also concurs with the evaluations considered thresholds for the latter breed in Central Europe.

Conclusion

The conditions in the three farms subject to our study were within the slight to moderate heat stress zone during the summer and partially during the spring.

The cows with high daily milk yield – above 40 kg had higher values of all physiological parameters examined even under the conditions of temperature comfort (THI up to 72) when compared to the cows with low milk yield of up to 30 kg. The cows with lower milk yield – below 40 kg reacted with an increased rectal temperature upon THI values of above 72. The cows with low milk yield (up to 30 kg) reacted with a skin temperature increase when the THI values were higher – above 80.

Pulse quickening was reported in all milk yield groups upon THI values increase – from THI of up to 72 and THI above 80, the increase was respectively by 26, 23.2 and 29.8% in the three milk yield groups. The pulse of the cows with a daily milk yield of up to 30 kg was significantly increased upon THI values of above 80, while it increased by 19% for the cows with daily milk yield from 30 to 40 kg upon values from 72 to 80.

The breathing intensity increased significantly in the three milk yield groups upon THI values elevation from comfort conditions (up to 72) to reaching moderate stress conditions (above 80) with average values of over 33 breaths per minute with reference to all milk yield groups. The breathing intensity increase was almost the same in the three milk yield groups – 26 to 30% when the conditions changed from temperature comfort to mild heat stress ones.

All mentioned above, provides grounds to recommend the farms, especially those rearing more highly productive dairy cows, to provide different adequate cooling methods in the premises and for the cows inside for the purpose of decreasing the consequences of the heat stress during the warm months of the year.

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