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INFLUENCE OF TEMPERATURE-HUMIDITY RELATIONS DURING YEARS ON MILK PRODUCTION AND QUALITY

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Abstract

TOUŠOVÁ RENÁTA, DUCHÁČEK JAROMÍR, STÁDNÍK LUDĚK, PTÁČEK MARTIN, POKORNÁ SYLVANA. 2017. Influence of Temperature-Humidity Relations During Years on Milk Production and Quality. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 65(1): 0211–0218.

The aim of this study was to evaluate influence of climatic conditions represented by daily air temperature and relative air humidity on indicators of Holstein cows' milk quality and production. The first dataset represented individual milk production in day of milk performance recording (milk kg, fat %, protein %, and somatic cells count thous.*ml^{-1}). The second dataset represented total daily milk characteristics of herd (milk kg, fat %, protein % and somatic cells count thous.*ml^{-1}). A total of 654 Holstein cows were observed and evaluated. Both datasets were evaluated in relation to selected external influences (year, month, average daily air temperature, and average daily relatively air humidity). Statistical analysis was performed using SAS 9.3, and UNIVARIATE, REG and GLM procedure. Three groups of daily air temeperature (< 4.4 °C; 4.4 – 13.2 °C; > 13.2 °C), and daily relative air humidity (< 65.3 %; 65.3–80.4 %; > 80.4 %) were conducted for evaluation. Significant ($P < 0.05$) linear regressions were computed among daily air temperature and all milk production indicators, except of somatic cells count attribute. The highest individual daily milk production (35.94 kg, $P < 0.01$), and protein content (3.41 %, $P < 0.01$) were achieved with the highest average daily air temperature. Opposite results were observed for milk yield of herd as well as protein content. Average daily relative air humidity had lower influence on individual and bulk milk samples. The better results were achieved for both datasets (individual and bulk samples) in groups (65.3–80.4 %; > 80.4 %) of average daily relative air humidity. Obtained results point out importance of outdoor climatic parameters monitoring and preventive measures of climatic conditions in the stable.

Keywords: climatic condition, milk yield, fat content, protein content, somatic cell count

INTRODUCTION

The effective barn microclimate management is needed for ensuring animal welfare (Velecká *et al.*, 2014) and attainment maximal milk production. Crucial elements influencing barn microclimate are daily air temperature (TEM) and daily relative air humidity (HUM) (Bílek *et al.*, 2002; Němečková *et al.*, 2013). High TEM in combination with inadequate HUM influenced negatively feed intake (Silanikove, 2000), reproduction (Wolfenson *et al.*, 2000), health and cow's milk production and welfare (Erbez *et al.*, 2012; Dikmen *et al.*, 2013). Thermo neutral zone for cows' ranges from −5 °C to +24 °C, when maximal TEM of +21 °C should not be exceeded in high production cows (Gregoriadesová and Doležal, 2000, Vokřálová *et al.*, 2010). European cattle breed usually tolerate lower TEM than higher (Novák *et al.*, 2000). Angrecka and Herbut (2015) observed only small decrease (1 to 2 kg) of daily milk production during cold stress (frost days). Also Večeřa et. al. (2014) observed fluctuation of milk production depending on barn in-side temperature. This opinion is confirmed by differences in milk production of cows calved from autumn to spring compared to cows calved in summer time (Kučera *et al.*, 1999). However, Doležal and Černá (2003) added, that lower TEM concurrently leads to increase requirements on quantity and quality of feed ration. Increased TEM in combination with inappropriate HUM induces temperature stress dairy cows (Brouček *et al.*, 2006), which is manifested by immediately milk production decrease as well as gradual decline after several days of exposure (West *et al.*, 2003). Milk production and chemical composition changes of milk evoked by heat stress was confirmed also Bouraoui *et al.* (2002), Tapki and Sahin (2006), and Joksimović-Todorović *et al.* (2011). The toleration to temperature stress is influenced by lactation phase, when this ability is the lowest in cows after calving and in the first part of lactation (Brouček *et al.* 2009).

Somatic cells count (SCC) in milk is quality indicator reflecting also health status of milk gland or total cows' health status (Seydlová, 2010). According to Dolejš *et al.* (2005) increase of environment TEM over 25 °C decreased milk production by 10–20 %, increased SCC, and influenced milk composition (fat and protein content). Therefore it is needed to eliminate heat stress by active cooling of cows (Mitlöhner *et al.*, 2001). However, according Broučka *et al.* (2008) air cooling by fogging can obstruct animal perspiration and indirectly increase body temperature.

Based on literature review we can pronounce assumption, that TEM, respectively HUM and their change in barn and in outdoor during year can influence milk production, content of basic components and milk quality. The aim of this work was to evaluat effect of outdoor TEM and HUM on milk production, proportion of basic components, and SCC as indicator of milk quality. These changes should be detected on individual base as well as on base of total daily milk characteristics of herd.

MATERIALS AND METHODS

Characteristic of observed breed

Dataset contained information from 654 Holstein cows bred in selected commercial farm. This farm is located in potato-growing region with altitude 435 m.a.m. The average milk production was 10,705 kg, 3.5 % of fat (F) content, and 3,3, % of protein (P) content in evaluated herd. Animal were housed in free cubical stall for 420 cows. Straw box stable was divided into 6 sections, each of them for 70 animals. Ventilation of stable was provided by two lines ventilators and evaporation-fogging installed above the feed corridor, when the TEM exceeding 20 °C. The feeding alley with double sided feeding table was located in the middle of stable. Cows' feed ration in different phases of lactation is specified in Tab. I. in detail. Feed ration composition during calving interval differed especially in quantity of concentrated feed, which corresponded with phase of lactation and cow's reproduction cycle. The frequency of feeding was 3× per day with ongoing gathering 9× per day. Cows in each section had access to drinking haul. Milking was carried out in herringbone (fishbone) parlour 2 × 14 unit, three times a day (4:00 a.m., 12:00 p.m., 8:00 p.m.).

Data collection

Two datasets were evalutated in presented study. First dataset represented individual cow's production in concrete day of milk recording (kg milk, fat %, protein %, somatic cell count thous.* ml^{-1}). This dataset included information about 7622 individual cow's milk samples. Second dataset contained totally daily milk production for the whole herd (kg), fat % content (F), protein % content (P), and somatic cell count (SCC) (thous.* ml^{-1}). F % and P % for total herd milk yield

I: *Composition of feed ratio during calving interval by observed cows*

components/ phase of reprod. cycle	increase milk production period*	lactation **	dry cows	transition period***
haylage (kg)	8.5	10	12	7
pea (kg)	4	5		7
corn (kg)	18.8	22	10	14
CCM (kg)	2.1	2.5		
draff (kg)	4	5	5	2
straw (kg)	0.5	0.6	4	2.5
molasses (kg)	0.7	0.8		0.4
lactation mix (kg)	7.7	9		
dry stand mix (kg)			1.5	
calving mix (kg)				2
propylenglykol (kg)				0.15
dextrofat (kg)	0.25			0.2

*from two week of lactation to 100 days of lactation
**from 101 days to end of lactation, live weight 650 kg and average daily production 34 l milk, 3,7 % F, and 3,3 % P
***from two week before calving to two week of lactation

were analysed always eight times in month in the bulk samples. SCC ware recorded 2 to 3 times in month according standard procedures in dairy sector. Dataset contained 731 informations about totally daily milk yield production.

Both datasets were added by information about average daily air temperature (TEM) and average daily relative air humidity (HUM) for relevant days in observed calendar month (January the 1st to December the 31st) and years (2012 and 2013). Information about TEM and HUM were provided by Czech Hydrometeorological Institute, branch office in distance ca. 5 km from stable. The developments of TEM and HUM in observed months during 2012 and 2013 are given in Fig. 1.

Statistical evaluation

The evaluation of dataset was carried out using SAS 9.3 (SAS Institute Inc., 2011), UNIVARIATE, REG and GLM procedures. Procedure UNIVARIATE were used for determination datasets basic parameters. Relationship between selected indicators was assessed with linear regression, which were computed by REG procedure. To select relevant model for evaluation of indicators procedure REG, method STEPWISE was use. The groups of TEM and HUM were created using arithmetic means and standard deviation ($< x - 1/2s$; $x - 1/2s$ to $x + 1/2s$; $> x + 1/2s$). The Tukey-Kramer method was used for evaluation of differences between least square means. The model equation used for the evaluation was as follows:

$$y_{ijklmn} = \mu + a_i + b_j + c_k + d_l + f_m + b^*(DR) + e_{ijklmn}$$

where:

y_{ijklmn} – value of dependent variable (individual milk production in milk recording day kg, F %, P %, SCC thous.*ml^{-1}, total herd daily milk yield kg, F and P % content, respectively SCC thous.*ml^{-1} in bulk samples),

μ – general value of dependent variable;

a_i – fixed effect of year (i = 2012, n = 2418 individual samples/366 bulk samples; i = 2013, n = 5204 individual samples/365 bulk samples);

b_j – fixed effect calendar month (j = January, n = 402 individual samples/62 bulk samples; j = February, n = 463/57; j = March, n = 513/62; j = April, n = 561/60; j = May, n = 576/62; j = June, n = 594/60; j = July, n = 615/62; j = August, n = 645/62; j=September, n = 757/60; j = October, n = 804/62; j = November, n = 839/60; j = December, n = 853/62);

c_k – fixed effect group of average TEM (k = 1 < 4.4 °C, n = 2479 individual samples/215 bulk samples; k = 2 – 4.4 to 13.2 °C, n = 1834/215; k = 3 > 13.2 °C , n = 2341/240);

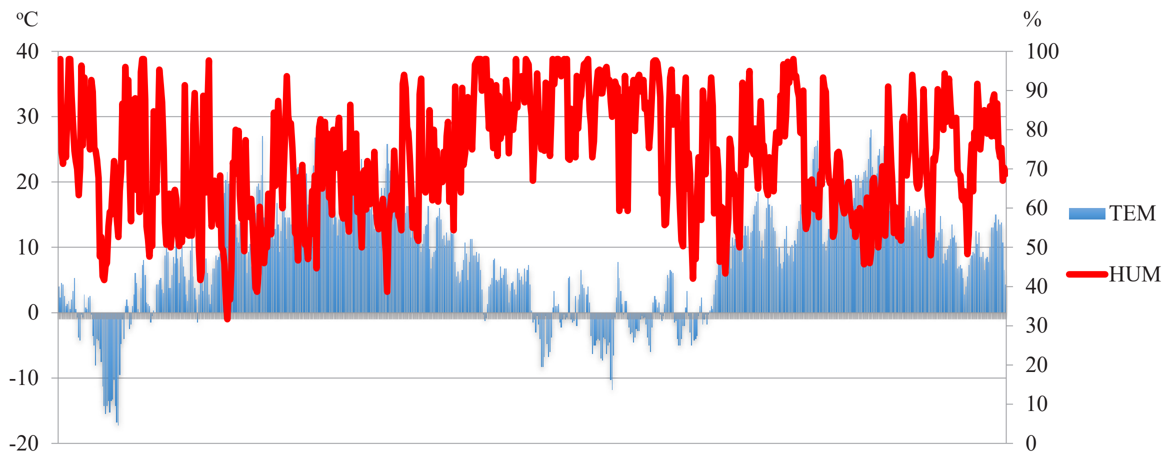
d_l – fixed effect group of average HUM (l = 1 < 65.3 %, n = 1859 individual samples/234 bulk samples; l = 2 – 65.3 to 80.4 %, n = 1141/206; l = 3 > 80.4 % , n = 3654/230);

f_m – fixed effect of parity (m = 1st, n = 2151; m = 2nd, n = 2157; m = 3rd and subsequent, n = 3314) – only using model for evaluation of individual animal production;

$b^*(DR)$ – regression on order of control within milk recording - only using model for evaluation of individual animal production;

e_{ijklmn} – random residual error.

Significance levels $P < 0.05$, and $P < 0.01$ were used to evaluate the differences among groups.



1: *Development of average daily air temperature (TEM) and average daily relative air humidity (HUM) in observed period*

II: *Linear regression between indicators milk production, resp. quality and average daily air temperature (TEM)*

		Regression equation on TEM	r^2
Individual cow milk yield	**kg milk**	$y = 34.868 + 0.043\,x^{**}$	0.001
	% F	$y = 3.640 - 0.012\,x^{**}$	0.025
	% P	$y = 3.448 - 0.012\,x^{**}$	0.078
	SCC (thous.*ml.$^{-1}$)	$y = 334.573 + 1.997\,x$	0.000
Total herd milk yield	**kg milk**	$y = 18655 - 47.229\,x^{**}$	0.258
	% F	$y = 3.775 - 0.011\,x^{**}$	0.474
	% P	$y = 3.358 - 0.005\,x^{**}$	0.483
	SCC (thous.*ml.$^{-1}$)	$y = 278.828 + 1.538\,x^{*}$	0.091

F – fat %; P – protein %; SCC – somatic cells count thous.*ml^{-1}; * significant level P < 0.05; ** significant level P < 0.01

RESULTS

Basic statistics

The average TEM during the observed period was 8.8 °C and the average daily relatively air humidity (HUM) was 72.8 %. There were only 12 days, when TEM in day milk recording exceed 25 °C (Fig. 1) during the observation.

Regression analysis

Linear regression between TEM and evaluated milk characteristics are presented in Tab. II. Significant (P < 0.05) linear relationships were computed for all indicators in individual cow milk yield, except of SCC. Neverthless, these relationships explained only a small variability of evaluated indicators (from 0.1 % in milk production to 7.8 % in P %). Increase of 1 °C TEM (in range −11.25 to 23.5 °C) was associated with 0.043 kg increase of average cows milk production. In the contrary increase of 1 °C TEM (in range −11.25 to 23.5 °C) was followed by 0.012 % decrease of F content and 0.012 % decrease of P content.

Similar results were observed in relation to TEM on total herd milk yield and milk quality. Significant (P < 0.05) linear regressions for all the evaluated indicators explained from 9.1 % (SCC) to 48.3 % (P %) of their variability. Increase of 1 °C of TEM (in range −11.3 to 23.5 °C) was associated with 47.229 kg increasing of total herd milk yield. Increase of 1 °C of TEM (in range −11.3 to 23.5 °C) was followed by 0.011 % decrease of F content in milk and 0.005 % decrease of P content. Finally, 1.538 thous.*ml^{-1} increase of SCC was connected with increasing of 1 °C of TEM.

Linear regression among HUM and milk production and quality indicators on individual level as well as on total herd milk characteristics were non-significant. Therefore, these results are not presented in detail.

Model description

Results presented in Tab. III. were performed by ANOVA method using GLM procedure. The model equations for evaluation of individual as well as total herd milk characteristics were significant (P < 0.01) and they explained from 5 % to 79 % variability of evaluated indicators. Factors in model equations were mostly significant (P < 0.05). Detailed evaluation for groups of TEM and groups of HUM for individual milk and total herd characteristics is presented in Tab. III.

Average daily air temperature (TEM)

Increased milk production (+2.98 to +4.16 kg; P < 0.01) and P % (+0.06 to +0.13 %; P < 0.01) occurred with higher TEM group in individual evaluation of production. Oppositely, significantly highest F % (3.80 %) was described in group of TEM 4.4–13.2 °C. Numerically highest value of SCC on individual level was computed in group of TEM 4.4–13.2 °C; however, non-significantly.

In the contrary, opposite tendencies were observed on the level of total herd milk yield. Decrease of total herd milk yield (−86 to −141 kg; P > 0.05) as well as decrease of P % (−0.02 to −0.06 %; P < 0.01) was detected when TEM increased (from group TEM < 4.4 °C to group TEM > 13.2 °C). Contrary, increase SCC (+10.46 thous.*ml.$^{-1}$ to +25.94 thous.*ml.$^{-1}$) occurred with higher TEM group. Only F % content did not change in relation to TEM groups. In terms of total herd milk characteristics, the best results were observed in group TEM < 4.4 °C.

Average daily relative air humidity (HUM)

Highest values of milk production for the individual milk samples were estimated in the lowest (< 65.3 %) and the highest (> 80.4 %) group of HUM (P < 0.01). Similar tendency was described in P % attribute. Significantly highest F % (3.87 %; P < 0.01) as well as non-significantly SCC were estimated in HUM 65.3–80.4 %.

The HUM had only minor influence on milk production and composition on total herd milk characteristics. Non-significantly increase of total herd milk yield (+ 57 to + 124 kg) as well as SCC (+ 9.46 to + 9.60 thous.*ml.$^{-1}$) was detected when HUM increased (from group HUM < 65.3 % to group HUM > 80.4 °C). Contrary, decrease of F % (– 0.01 to – 0.03) was detected with higher HUM group. HUM had only minor, but significant (P < 0.05), influence on P %.

III: *Evaluation of indicators milk production and quality for individual animals and for herd in relation on average daily air temperature (TEM) and average daily relative air humidity (HUM)*

Samples	effect	level	milk kg	F (%)	P (%)	SCC (thous.*ml^{-1})
			LSM ± SE	LSM ± SE	LSM ± SE	LSM ± SE
Individual	Grups of TEM	< 4.4 °C	$31.78 \pm 0.62^{A,B}$	3.50 ± 0.05^{A}	3.28 ± 0.02^{A}	346.01 ± 66.41
		4.4 – 13.2 °C	34.76 ± 0.37^{A}	$3.80 \pm 0.03^{A,B}$	3.34 ± 0.01^{B}	482.78 ± 40.11
		> 13.2 °C	35.94 ± 0.53^{B}	3.66 ± 0.04^{B}	$3.41 \pm 0.02^{A,B}$	373.91 ± 57.29
	Grups of HUM	< 65.3 %	35.53 ± 0.24^{A}	3.62 ± 0.02^{A}	3.37 ± 0.01^{a}	385.67 ± 25.51
		65.3 – 80.4 %	$31.09 \pm 0.68^{A,B}$	3.87 ± 0.05^{A}	3.30 ± 0.02^{a}	484.11 ± 73.65
		> 80.4 %	35.86 ± 0.23^{B}	3.47 ± 0.02^{A}	3.35 ± 0.01	332.91 ± 24.32
Bulk	Grups of TEM	< 4.4 °C	18339 ± 60.67	3.68 ± 0.02	3.35 ± 0.01^{A}	275.85 ± 13.86
		4.4 – 13.2 °C	18253 ± 44.21	3.68 ± 0.01	3.33 ± 0.01^{B}	286.28 ± 8.96
		> 13.2 °C	18198 ± 59.83	3.68 ± 0.02	$3.29 \pm 0.01^{A,B}$	301.79 ± 12.95
	Grups of HUM	< 65.3 %	18203 ± 42.99	3.69 ± 0.01	3.33 ± 0.01^{a}	281.62 ± 8.80
		65.3 – 80.4 %	18260 ± 40.14	3.68 ± 0.01	3.32 ± 0.01^{a}	291.08 ± 8.49
		> 80.4 %	18327 ± 39.28	3.66 ± 0.01	3.33 ± 0.01	291.22 ± 8.59

F – fat %; P – protein %; SCC – somatic cells count (thous.*ml^{-1}); same letters in columns means statistical significance A, B … $P < 0.01$; a, b … $P < 0.05$.

DISCUSSION

Most recent studies were focused on cows heat stress in summer period (Bouraoui *et al.*, 2002; Brouček *et al.*, 2006; Dikmen *et al.*, 2013). Neverthelles, some of the studies, for example Večeřa *et al.* (2012) or Javorová *et al.* (2014), have demonstrated influence of in-side barn TEM on behaviour as well as milk production of cows. Our work differed from others by detailed evaluation of year-round period performed in 2012 and 2013 and influence of outdoor temperature.

Individual milk production and SCC positively correlated with increased TEM, while content of fixed components in milk had opposite tendency. Evaluation of total herd milk characteristics differed only in opposite tendency in milk production. These results were supposed by Brűgemann *et al.* (2012) who described similar trends to ours, however expressed by THI index. In contrast Kurihara and Shioya (2003) observed opposite results, when he observed decrease of daily milk production by 1 kg per cow with increase of TEM by 1 °C. This is also in accordance with results of Koukal (2001) performed in heat TEM summer period. SCC increase in milk is a natural reaction of organism on heat stress (Šoch *et al.*, 2005). Fryč (2002) added that higher TEM had negative influence on total cow's health and mastitis occurrence. Increase of individual milk production per cow with increase TEM indicate that cows were not exposed to heat stress and they have created optimal climatic condition. Optimal climatic condition is one of critical assumption for attainment stabile results in cow's herd (Novák and Rožňovský, 2008). Higher TEM decreased milk production, F %, and P % in total herd milk characteristics. Oppositely, higher TEM increased SCC in milk in individual production on cow as well as by total herd milk characteristics. These results indicated that higher TEM was connected with more incidences of mastitis and therefore with decrease of total number of cows, which participates on total milk production to dairies.

Model used in our study was similar to Joksimović-Todorović *et al.* (2011). Brouček *et al.* (2008), respectively Doležal *et al.* (2002) confirmed effect of year and calendar month. These authors in accordance to our results observed highest average milk production during cooler months (January, April, May, September, and October–December). However higher energy requirement during low TEM period are necessary (Doležal and Černá, 2003), which can negatively affect economy of production. Year seasonality are manifested also in SCC as in individual milk production, so in total herd milk characteristics. These facts are in accordance with Bečvář (2008), who observed increase of SCC in summer period. Higher SCC is according to this author probably caused by larger infection pressure from environment and decrease cows' immunity.

Influence of TEM on milk production was manifested with increasing milk production and P content on individual level. Increasing of individual milk production can be caused by evaporation system, which is in observed breed actived when outdoor TEM exceeding the 21 °C. Brouček *et al.* (2008) also confirmed increasing milk production using evaporation. Nevertheless, the using of evaporation system only reduced heat stress, but did not eliminate it completely.

Decreased milk production and P % with higher TEM group was observed on level of total herd milk characteristics. This fact confirmed a general assertion that TEM belongs among most important factors influencing temperature status of animal organism (Bílek *et al.*, 2002). Cattle belongs to livestock with very good thermoregulation ability, however they are more tolerant to low TEM (Doležal *et al.*, 2002).

The HUM did not influence milk production, milk composition and SCC on the individual level as well as on the total herd milk characteristics. Higher HUM was the most appropriate with respect on milk production. Oppositely, rather average to lower HUM was the most appropriate from the viewpoint of basic milk components and SCC. Despite this fact combination of inappropriately TEM and inappropriately HUM can cause negatively. Doležal *et al.* (2002), also found decreased toleratnce limit of cows during high HUM in combination with high TEM. They also determinated the TEM of 28 °C and 80 % HUM as strictly stressor factor. Nevertheless, relative HUM had negative effect on cow's organism especially in combination with extreme TEM (above 30 °C). The recommended value of HUM is in range 50–70 %, or 80 % in winter period in combination with lower TEM (Přikryl, 1997). Oppositely our study indicated that average HUM was most appropriate only from viewpoint of F content in milk. Nevertheless, based on our results, it is difficult to recommend optimal range for HUM in stable.

Heat temperature stress is manifested by inappropriate combination of TEM and HUM which is remaining for longer time period (Brouček *et al.*, 1998). However these results are demonstrated only on 5 days in summer period when HUM was above 70 % and TEM exceeds 20 °C (Fig. 1). But only 5 isolated days in our study could not probably negatively influence milk production.

CONCLUSION

Results of presented study demonstrated variability of milk production characteristics on individual and herd level in relation with TEM. However, only minor influence of HUM on milk production characteristics were detected. These results were confirmed by regression analysis and ANOVA method. Colder period of year had none positive influence on change of milk production. On the other hand, production traits were significantly influenced by increase of outdoor TEM and therefore potential heat stress. Generally better results of milk production were observed during average to lower HUM rather then during extremely high values, however without significance. Obtained results point out importance of preventive measures of outdoor climatic parameters monitoring, as well as preventive measures of climatic conditions in the stable. Therefore, breeders should include observation of these parameters to basic daily work tasks.

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REFERENCES

ANGRECKA, S. and HERBUT, P. 2015. Conditions for cold stress development in dairy cattle kept in free stall barn during severe frosts. *Czech J. Anim. Sci.*, 60(2): 81–87.

BEČVÁŘ, O. 2008. The causes of the increase and control of somatic cells count [in Czech: Příčiny zvýšení a kontrola počtu somatických buněk]. *Náš chov*, 68(12): 55–58.

BÍLEK, M., DOLEŽAL, O., DOLEJŠ, O. and TOUFAR, O. 2002. *Welfare in a stable for cattle* [in Czech: *Welfare ve stáji pro skot*]. Praha: ÚZPI.

BOURAOUI, R., LAHMAR, M., MAJDOUB, A., DJEMALI, M. and BELYEA, R. 2002. The relationship of temeperature-humidity index with milk production of dairy cows in a Mediterranean climate. *Anim. Res.*, 51(6): 479–491.

BROUČEK, J., MIHINA, Š., RYBA, Š., TONGEĽ, P., KIŠAS, P., UHRINČAŤ, M. and HANUS, A. 2006. Effects of high air temperatures on milk efficiency in dairy cows. *Czech J. Anim. Sci.*, 51(3): 93–101.

BROUČEK, J., BOTTO, L. and ŠOCH, M. 2008. *Protection of cattle, pigs and poultry to high temperatures* [in Czech: *Ochrana skotu, prasat a drůbeže proti vysokým teplotám*]. Certifikovaná metodika pro zemědělskou praxi. České Budějovice: Jihočeská univerzita v Českých Budějovicích.

BROUČEK, J., NOVÁK, P., VOKŘÁLOVÁ, J., ŠOCH, M., KIŠAC, P. and UHRINČAŤ, M. 2009. Effect of high temperature on milk production of cows from free-stall housing with natural ventilation. *Slovak J. Anim. Sci.*, 42(4): 167–173.

BRŰGEMANN, K., GERNAND, E., KŐNIG VON BORSTEL, U. and KŐNIG, S. 2012. Defining and evaluating heat stress thersholds in different dairy cow production systems. *Arch. Anim. Breed., Arch. Tier.*, 55(1): 13–24.
DIKMEN, S., COLE, J. B., NULL, D. J. and HANSEN, P. J. 2013. Genome-wide association mapping for identification of quantitative trait loci for rectal temperature during heat stress in Holstein cattle. *PLoS ONE*, 8(7): 1–7.
DOLEJŠ, J., NĚMEČKOVÁ, J., TOUFAR, O. and KNÍŽEK, J. 2005. The effect of high temperatures on the cattle physiological characteristics [in Czech: Vliv vysokých teplot na fyziologické ukazatele skotu]. In: *Bioklimatologie současnosti a budoucnosti*. Křtiny, 12–14 September. Brno: Česká bioklimatologická společnost.
DOLEŽAL, O., BÍLEK, M., ČERNÁ, D., DOLEJŠ, J., GREGORIDESOVÁ, J., KNÍŽEK, I., KUNC, P. and TOUFAR, O. 2002. *Comfortable housing of high-yield dairy cows* [in Czech: *Komfortní ustájení vysokoprodukčních dojnic*]. Praha: VÚŽV-Uhříněves.
DOLEŽAL, O. and ČERNÁ, D. 2003. The influence of stable cubature and area on quality of breeding environment [in Czech : Vliv stájové kubatury a plochy na kvalitu chovného prostředí]. *Agro měsíčník*, 2.
ERBEZ, M., BØE, K. E., FALTA, D. and CHLÁDEK, G. 2012. Crowding of dairy cows in a cubicle barn during hot summer months. *Arch. Anim. Breed., Arch. Tier.*, 55(4): 325–331.
FRYČ, J. 2002. Ventilation in buildings for dairy cows [in Czech: Větrání v objektech pro dojnice]. *Farmář*, 8(3): 76–77.
GREGORIADESOVÁ, J. and DOLEŽAL, O. 2000. *The influence of high environment temperature on cattle* [in Czech: *Vliv vysokých teplot prostředí na skot*]. Praha: VÚŽV Uhříněves.
JAVOROVÁ, J., VELECKÁ, M., FALTA, D., VEČEŘA, M., ANDRÝSEK, J., STUDENÝ, S. and CHLÁDEK, G. 2014. The effect of air temperature and time of day on distribution of Czech Fleckvieh cows within the barn. *Acta Univ. Agric. et Silvic. Mendel. Brun.*, 62(1): 117–124.
JOKSIMOVIĆ-TODOROVIĆ, M., DAVIDOVIĆ, V., HRISTOV, S. and STANKOVIĆ, B. 2011. Effect of heat stress on milk production in dairy cows. *Biotechnol. Anim. Husb.*, 27(3): 1017–1023.
KOUKAL, P. 2001. Nutrition of dairy cows in hot weather, according to experience summer 2000 [in Czech: Výživa dojnic v teplém počasí podle zkušeností z léta 2000]. *Farmář*, 7(9): 75–76.
KUČERA, J., HYÁNEK, J., MIKŠÍK, J. and ČERMÁK, V. 1999. The influence of the season of parturition on milk performance in the Czech Pied cattle. *Czech J. Anim. Sci.*, 44(8): 343–350.
KURIHARA, M. and SHIOYA, S. 2003. *Dairy Cattle Management in a Hot Environment*. Food and Fertilizer Technology Center. [Online]. Available at: http://en.fftc.org.tw/htmlarea_file/library/20110801153254/eb529.pdf. [Accessed: 2015, July 15].
MITLÖHNER, F. M., MORROW-TESCH, J. L., DAILEY, J. W., WILSON, S. C., GALYEAN, M. L., MILLER, M. F. and MCGLONE, J. J. 2001. Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. *J. Anim. Sci.*, 79(9): 2327–2335.
NĚMEČKOVÁ, D., KNÍŽKOVÁ, I., KUNC, P. and STÁDNÍK, L. 2013. The effect of the design of housing systems for calves on the microclimatic conditions of the rearing environment. *Arch. Anim. Breed., Arch. Tier.*, 56(49): 509–517.
NOVÁK, P., ZABLOUDIL, F., ŠOCH, M. and LENGLOVSKÝ, J. 2000. Stable environment-significant factor for the welfare and productivity of cows. In: *Proceedings of the 10th International congress on animal hygiene*. Maastricht, 2–6 July 2000, the Netherland. 1019–1024.
NOVÁK, P. and ROŽŇOVSKÝ, J. 2008. The influence of climatic changes to the organism of farm animals [in Czech : Vliv klimatických změn na organismus hospodářských zvířat]. In: *Výživa a zdraví skotu s ohledem na kvalitu mléka. Technologie chovu hospodářských zvířat se zaměřením na pohodu a jatečnou kondici*. BVV, 7–10 April. Brno: VFU Brno, 18–20.
PŘIKRYL, M. 1997. *Technological equipment of livestock production buildings* [in Czech: *Technologická zařízení staveb živočišné výroby*]. Praha: Tempo Press.
SAS Institute Inc. 2011. *SAS/STAT® 9.3 User's Guide*. Cary, NC: SAS Institute Inc.
SEYDLOVÁ, R. 2010. Can be solved udder health during dry period? [in Czech: Lze řešit zdravotní stav mléčné žlázy v období zaprahování?] *Náš chov*, 70(3): 72–74.
SILANIKOVE, N. 2000. Effect of heat stress on the welfare of extensively managed domestic ruminants. *Livest. Sci.*, 67(1–2): 1–18.
ŠOCH, M. 2005. *The influence of environment on selected indicators of cattle welfare* [in Czech: *Vliv prostředí na vybrané ukazatele pohody skotu*]. České Budějovice: Zemědělská fakulta Jihočeská univerzita v Českých Budějovicích.
TAPKI, I. and SAHIN, A. 2006. Comparison of the thermoregulatory behaviours of low and high producing dairy cows in a hot environment. *Appl. Anim. Beh. Sci.*, 99(1–2): 1–11.
VEČEŘA, M., FALTA, D., CHLÁDEK, G. and MÁCHAL, L. 2012. The effect of low and high barn temperatures on behaviour and performance of Holstein dairy cows. *Acta Univ. Agric. et Silvic. Mendel. Brun.*, 60(6): 343–350.

VELECKÁ, M., JAVOROVÁ, J., FALTA, D., VEČEŘA, M., ANDRÝSEK, J. and CHLÁDEK, G. 2014. The effect of temperature and time of day on welfare indices in loose-housed Holstein cows. *Acta Univ. Agric. et Silvic. Mendel. Brun.*, 62(3): 565–570.
VOKŘÁLOVÁ, J., NOVÁK, P., ILLEK, J., BRIX, M., ODEHNALOVÁ, S. and IHNÁT, O. 2007. Influence of climate on milk production [in Czech: Vliv klimatu na mléčnou produkci]. *Náš chov*, 67(6): 66–68.
WEST, J. W., MULLINIX, B. G. and BERNARD, J. K. 2003. Effects of hot, humid weather on milk temperature, dry matter intake, and milk yield of lactating dairy cows. *J. Dairy Sci.*, 86(1): 232–242.
WOLFENSON, D., ROTH, Z. and MEIDAN, R. 2000. Impaired reproduction in heat-stressed cattle: basic and applied aspects. *Anim. Reprod. Sci.*, 60–61: 535–547.

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