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THERMAL STRESS INFLUENCE ON THE PRODUCTIVE AND ECONOMIC EFFECTIVENESS OF HOLSTEIN-FRIESIAN DAIRY COWS IN TEMPERATE CLIMATE

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Abstract

The aim of this study was to evaluate the heat stress influence on milk production from primiparous and multiparous Holstein-Friesian cows and to estimate economic losses associated with the decrease in the farm's milk yield. The cows selected for the study were in the middle phase of the 1st, 2nd, and 3rd lactation and were characterized by similar daily milk production. Additionally, the animals were kept in the same conditions and fed with the same feeds throughout the season. The analysis covered two 30-day periods – "cold" (April), in which no days with THI >70 were noted, and "hot" (July), in which THI was above 70 for 90% of the days (74.4 on average). The average daily drop in milk production noted in the hot period was 1.25 kg/cow for multiparous cows and 2.78 kg/cow for primiparous cows. The average daily financial loss resulting from a drop in milk production was €0.55/day/cow in primiparous and €0.46/day/cow in multiparous animals. The calculated daily loss in the profit on production of 1 kg of milk was €0.27/day/kg for primiparous and €0.24/day/kg for multiparous animals. Based on test results, economic losses were simulated depending on the daily milk yield and the size of the primary cattle herd. For the multiparous cows, the estimated losses ranged from €6.07/day (farm sizes 25 cows and average daily milk yield 25 kg) to nearly €219/day (900 cows/ 25 kg). In larger facilities (900 cows) with an average daily milk yield of 55 kg, the daily loss will be about €481. The obtained results confirmed the assumptions made that with a change in microclimate conditions in the barn, a decrease in the daily production and changes in the milk chemical composition were noted, and the economic efficiency of the studied activity decreased.

Key words: dairy cattle, economic efficiency, milk production, heat stress, climate change

Until recently, the influence of high ambient temperatures on livestock was considered to be limited to tropical regions. Today, it has spread to the northern latitudes in response to the rising global temperature (Renaudeau et al., 2012; Fournel et al., 2017). As a consequence of climate changes that we have been observing recently, heat stress (HS) occurrence in dairy cows has become an increasingly important issue. Additionally, some regions of the world will experience more marked and faster changes than others (Meehl et al., 2004). And what is worse, due to climatic changes, livestock animals' HS episodes are expected to become more frequent. Effects of climate changes are observed in several Polish regions (Kundzewicz et al., 2018). Some authors observed a significant rising trend based on the temperature observations in Poland. In their article, Graczyk et al. (2017) reported that in Poland, the number of hot days and tropical nights per year are increasing and hot summer period is lengthening. According to the study by Hempel et al. (2019), it was estimated that by the end of the century, in Europe, over 30% of days in the year will be critical in terms of heat stress conditions, and this may cause an additional drop in milk yield of 2.8% compared to the current conditions.

Global warming puts dairy cattle at risk of HS, which may influence physiological processes and in consequence, reduce cows' production potential (Seerapu et al., 2015). Importantly, metabolic heat production increases with the improvement in dairy cows' production capacity (West et al., 2003). During lactation, cows disperse more heat from metabolic processes when compared to dry cows. Production and accumulation of large quantities of heat with a limited possibility of cooling lead to the reduced consumption of nutrients needed for milk synthesis. Such a situation may result in a decrease in the quantity of produced milk (Cowley et al., 2015; Novak et al., 2009) and the deterioration of its chemical composition in terms of the protein (Bernabucci et al., 2015) and fat (Reyad et al., 2016) contents. Considering the above, milk producers face a challenge of the seasonal drop in cows' productivity and the deteriorated milk composition caused by HS, and this translates into financial losses (Negri and Cobuci, 2021).

The aim of every agricultural producer is to obtain an income adequate to expectations. High economic efficiency can be achieved by maximizing profits and minimizing costs. A decrease in milk yield leads to a decrease in the economic efficiency of production and profit.

Based on a meta-analysis conducted by Vriezen et al. (2021), it was observed that the number of studies concerning an economic analysis of HS in dairy cattle is scarce. The range of losses in milk production conditions is difficult to estimate, as consequences of HS are usually masked by other factors, such as lactation, breed or age of animals (Mayer et al., 1999); furthermore, production systems, climate conditions, and market requirements differ. Taking into account the dynamics of the climate changes, the economic analysis of the HS influence on the production yield of dairy cows appears valuable, especially for farms with large-scale production, where potential financial losses may be significant (Chetroiu et al., 2022). Thus, the aim of this study was to evaluate heat stress influence on milk production from primiparous and multiparous Holstein-Friesian cows and to estimate economic losses associated with the decrease in the farm's milk yield.

Material and methods

Experimental design

The experiment was conducted in 2021 in two periods: spring (without HS – April), and in the summer moist and hot period (with HS – July). The facility under study was located in northwest Poland. In terms of the climate, this area is the warmest in Poland, with an average annual rainfall and temperature of about 600 mm and 8.5°C, respectively. The climate of the region is significantly influenced by polar marine and polar continental air masses and by tropical marine air masses in the summer. On average, the wind states represent winds predominantly from the west side. The area is characterized by a relatively small contribution of windless periods. The study was conducted in a free-stall barn of an open type (a curtain barn). The main ventilation system was based on natural ventilation, with air supply and transverse ventilation through partly open side walls and air exhaust through a ridge exhaust duct. In the barn, the area per cow was 7.55 m^2 (about 3 m^2 of the bedding surface area).

Animals and feeding

The study was performed on 117 dairy cows of the Polish Holstein-Friesian breed from a herd of 390 animals. In the spring, 41 primiparous and 26 multiparous cows were selected for the study. In the summer, 35 primiparous and 15 multiparous cows were selected, which spent 30 days in each of the selected months. The average daily milk production during April and July was 36.94±1.56 (primiparous) and 46.23±2.29 kg (multiparous – parity 2.5±0.5). Both groups of cows were exposed to the same conditions and the same farm handling and housing conditions. Table 1 shows the characteristics of cows used in both experiment periods.

Table 1. The experiment diagram

	Primiparous		Multiparous	
	April	July	April	July
No. of cows	41	35	26	15
No. of records	1230	1050	780	450
No. of test days/cow	30	30	30	30
No. of lactation	1	1	2–3	2–3

The animals were fed with the complete feed in the total mixed ration system (TMR), and the feed ration composition corresponded to living and production needs (Tables 2 and 3). The animals had free access to feed 24 hours a day, excluding the milking time. Cows were milked three times a day.

Table 2. Assumptions regarding the feed ration for dairy cows

Item	Value
BW kg	650.0
BCS (1–5)	3.0
DMY (kg/day)	40.0
CP (%)	3.3
Fat (%)	4.0

Abbreviations: BW = body weight; BCS = body condition score; DMY = daily milk yield; CP = crude protein.

Table 3. Ingredient composition and feed costs of the total mixed ration used for dairy cows

Ingredient	Forage (kg/day)	DM (%)	DM (kg/day)	Forage price (EUR/kg)[1]	Real forage cost (EUR/cow)[1]
Maize silage	28.5	31.5	9.00	0.04	1.07
Alfalfa silage	9.0	42.0	3.80	0.04	0.32
Wheat straw	0.7	92.0	0.60	0.04	0.03
Brewers' grain	7.0	23.0	1.61	0.05	0.36
Barley and wheat middlings	5.8	88.2	5.12	0.16	0.95
Rapeseed meal	2.3	90.2	2.07	0.28	0.64
Soybean meal	0.8	90.0	0.72	0.74	0.59
Megalac	0.5	97.0	0.49	1.10	0.55
Molasses	0.8	75.0	0.60	0.13	0.10
Complementary mix for dairy cows[2]	2.4	92.0	2.21	0.37	0.89
Total	57.8		26.21		5.50

[1]EUR 1 = 4.2693 PLN according to the Regulation of the Council of Ministers of 19 December 2019 on an average exchange rate of PLN to EUR, used to calculate the value of the public procurement (Regulation of the Prime Minister, 2019).

[2]Composition % share: crude protein 24%, crude fibre 6.5%, crude fat 3.0%, crude ash 6.4%, energy 6.99 MJ/kg.

Environmental measures

The ambient temperature (Ta°C) and relative humidity (RH%) were registered every 60 minutes on all days of the experiment, using data recorders Comet S-3121 (Comet System Ltd., Rožnov pod Radhoštěm, Czech Republic). The THI was calculated according to the following formula by the National Research Council (1971):

$$THI = (0.8 \times Ta) + \left[\frac{RH}{100} \times (Ta - 14.4) \right] + 46.4$$

where: *Ta* – ambient temperature (°C); *RH* – relative humidity (%).

For each day, minimum, mean, and maximum *THI* was calculated. In our analysis, we used the maximum daily *THI*.

Milk production and composition

In both periods, the daily yield and the percentage of fat and protein content in milk were analysed as characteristics of the milk performance. Measurements of the daily milk yield (DMY) and the percentage fat and protein content for each cow were recorded by the herd management system AfiFarm 5.4 A-DU (2021; Afimilk, Israel) on each day of the experiment.

Economic efficiency of milk production

One of the most popular definitions of economic efficiency expresses a time-bound relationship between the results obtained and the expenditures necessary to achieve them.

In general, the essence of measuring the understood effectiveness is the relationship between effects and inputs. The study also evaluated the economic efficiency of the milk production depending on existing microclimate conditions, being a basis for the THI calculation. The economic analysis of the milk production in the studied cattle herd was conducted in 2021 in two periods – spring (April) and summer (July). The analysis covered income and costs (classified as direct and indirect production costs) and obtained results in the form of the produced milk. The basic measure for the evaluation of economic effects was the level of income on activities. The calculated production value covered: the value of milk produced, the value of a poorly performing cow, and livestock increase (weaned calves). The costs were analysed and divided into direct and indirect, depending on the place where they arose (a way in which they were connected with the activities). The main indicator of the economic evaluation of the farm was profit understood as the difference between total revenues from milk production and direct and indirect costs incurred for this production.

Direct costs of the milk production included: own concentrate feeds and roughage, purchased feeds (Table 3), direct costs of forage crops, costs of dairy cows herd renewal, and other direct costs (i.e., insemination, veterinary care, and those that can be directly allocated to this activity). Direct milk production costs accounted for 76.91% (April) and 78.34% (July) of total costs. The study mainly focused on analysing direct costs of animal production, which reflect the production effectiveness of the conducted activities. The indirect costs burden the entire farm in terms of its functioning; therefore, they are not an indicator of the production effectiveness of kept animals. In the calculations, the currency exchange rates were established based on: for EUR – the Regulation of the Council of Ministers of 19 December 2019 on an average exchange rate of PLN to EUR, used to calculate the value of the public procurement (Regulation of the Prime Minister, 2019) for other currencies used in the study, according to the Table of average exchange rates of the National Bank of Poland No. 245/A/NBP/2019 of 19/12/2019 (http://rss.nbp.pl/kursy/TabRss.aspx?n=2021/a/21a245).

Statistical analysis

Individual cows were treated as experimental specimens and repeatable measurements. The one-way analysis of variance (ANOVA) was used to test the effect of the experimental factor (April and July) on the DMY, fat and protein content in milk.

The one-way ANOVA had a general form as follows:

$$Yij = \mu + \alpha i + \varepsilon ij$$

where: *Yij* is the measured dependent variable; μ is the overall mean; αi is the effect of the period (n=2; 1 April, 2 July); εij is the random error. For statistical analysis data are presented as mean and standard deviation (SD) of the individual values and standard error of the mean (SEM). The correlation procedure was used to determine Pearson correlation coefficient between THI and milk production parameters were assessed.

When the correlation among variables was significant, the study would continue to find the linear regression. Linear regression equation was developed and formulated as: $y = a + bx + \epsilon$, where y (DMY) is the value of the dependent variable; x (THI) is the explanatory of the independent variable. The slope or the beta coefficient of the line is "b", while "a" is the intercept (the value of y when x=0). The data were considered significant for $P \leq 0.05$. All analyses were conducted using the Statistica package (13.0. StatSoft, Poland).

The tabulated results on economic efficiency of milk production are presented as means for the entire studied set of the selected cows. In the study, methods of descriptive and comparative analyses were used; the basis was an analysis of relations and a comparison of horizontal correlations between production results. The selected research methods enabled the evaluation of the milk production profitability depending on microclimate conditions.

Results

The mean, maximum and minimum temperatures and humidity and the calculated THI for 60 days of the experimental period are presented in Table 4.

Table 4. Environmental conditions during the experimental periods

Parameters	Season	
	April	July
Average temperature (°C)	9.99±2.26	23.36±1.98
Temp max (°C)	14.11	27.32
Temp min (°C)	5.94	19.71
Average RH (%)	60.72±8.14	71.29±9.07
RH max	74.60	88.67
RH min	42.20	51.40
Average daily THI	57.55±4.21	74.74±2.94
% days daily THI >70	0.00	90.32

Mean±SD.

The "cold" period was selected because no HS occurred at that time. In this period, no days with THI above 70 were noted (57.55 on average). In the "hot" period, this index was above 70 for 90% of the days, and this implies that cows probably suffered from HS (Carabaño et al., 2014).

Upon examination of Figure 1, it can be determined that the THI index exceeded 70 after the 2nd of July (the "hot" period) and displayed an upward trend in the following days. The maximum (THI 80.74) was reached mid-July. During this period, a decrease in milk production was observed, indicating the occurrence of heat stress.

The results of the average DMY confirmed the strong influence of HS on production results (Table 5). In July, a significant drop in milk production was noted, both in primiparous (P<0.001) and in multiparous (P<0.05) cows, by 7.3% and 2.6%, respectively, versus April.

Table 5. Average daily milk yield and milk composition during selected periods of the experiment

Items	Parity	Season		SEM	P-value
		April	July		
DMY (kg)	Primiparous	38.33±1.86 a	35.55±1.25 b	0.268	<0.001
	Multiparous	46.85±2.50 a	45.60±2.07 b	0.305	0.020
Fat (%)	Primiparous	3.71±0.11 a	3.47±0.10 b	0.020	<0.001
	Multiparous	3.61±0.17 a	3.29±0.21 b	0.316	<0.001
Protein (%)	Primiparous	3.17±0.76 b	3.45±0.14 a	0.023	<0.001
	Multiparous	3.32±0.10 b	3.57±0.10 a	0.020	<0.001

Mean ± SD.
a, b – means within columns with no common letters differ significantly (P≤0.05).

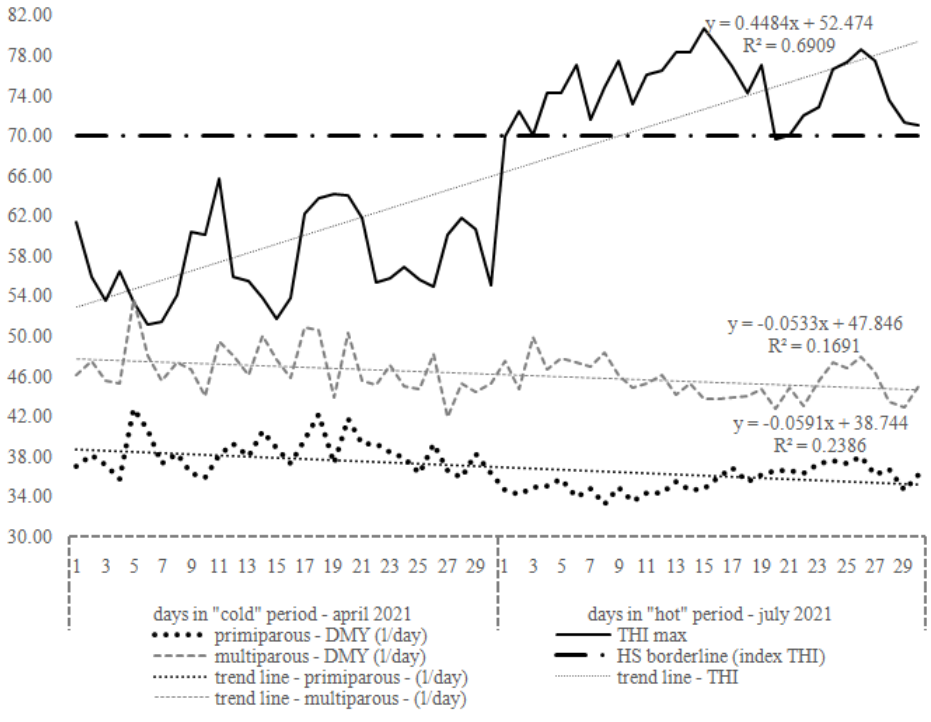


Figure 1. Daily milk yield and daily THI during the experimental periods

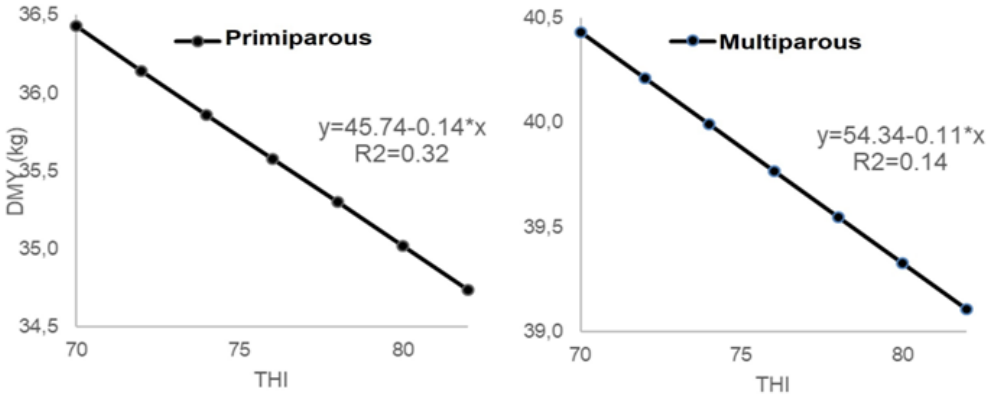


Figure 2. Relation of average daily milk yield to average THI in primiparous and multiparous cows

In milk obtained from studied cows, the protein content was highly significantly higher in the summer ("hot") period when compared to the spring ("cold") period. In the summer period, cows were characterized by a higher protein content of 0.28 g for primiparous cows and 0.25 g for multiparous cows per 100 g of milk (Table 5).

The variance analysis showed that following heat stress, the percentage fat content in milk also dropped significantly in primiparous (by 0.2 pp) and multiparous (by 0.3 pp) cows, at $P<0.001$.

Based on obtained results shown in Table 6, the proposed hypothesis that with the increase in THI, the dairy cows' productivity decreases and the composition of milk changes is confirmed. Taking into account the relation between THI and the cows' production characteristics, a significant correlation was found ($P<0.01$) (Table 6). The DMY and the percentage fat content in milk were negatively correlated with THI (r=-0.32 to -0.67). For DMY, the observed correlation was higher in primiparous (r=-0.61) than in multiparous (r=-0.32) cows. In the case of a relation between THI and the protein percentage in milk, the correlation was strongly positive in both technological groups (r=0.73).

Table 6. Correlation analysis of THI and DMY, fat, protein

	Parity	DMY	Fat	Protein
THI	Primiparous	-0.61*	-0.67*	0.73*
	Multiparous	-0.32*	-0.62*	0.73*

Means correlation analysis between THI and DMY, fat and protein levels. Coefficients of correlation significant at *($P<0.05$).

Table 7. The economic efficiency of milk production in a primiparous cow's herd depending on microclimate conditions in a barn

Item	Unit	Primiparous*	
Research period	month	April	July
No. of cows in the herd	number	41	35
Average milk price**	EUR/kg	0.370	0.365
Average total cost***	EUR/kg	0.262	0.264
Per day			
average daily milk production per cow	kg/day	38.33	35.55
average daily decrease in milk production	kg/day/cow		2.78
average daily financial loss	EUR/day/cow		0.55
average daily lost profit per 1 kg of milk	EUR/day/kg		0.27
Per month			
monthly milk production	kg/month	1150.04	1066.52
difference between April and July in milk production per 1 cow	kg/month/cow		83.53
average monthly profit per cow	EUR/month/cow	123.91	107.42
difference – monthly financial loss	EUR/month/cow		16.49
Average % decrease in milk production (as compared to April to July, where April=100%)	%		7.26

*Primiparous – dairy cows in their 1st lactation. 1 EUR = 4.2693 PLN according to the Regulation of the President of the Cabinet of 19/12/2019 on an average exchange rate of the PLN to EUR, used as a basis for calculation of public procurements value (Regulation of the Prime Minister, 2019).

**Average milk price – April – 1.58 PLN/kg; July – 1.56 PLN/kg.

***Average total cost – April – 1.12 PLN/kg; July – 1.13 PLN/kg.

Table 8. The economic efficiency of milk production in a multiparous cow's herd depending on microclimate conditions in a barn

Item	Unit	Multiparous*	
Research period	month	April	July
No. of cows in the herd	number	26	15
Average milk price**	EUR/kg	0.370	0.365
Average total cost***	EUR/kg	0.262	0.264
Per day			
average daily milk production per cow	kg/day	46.85	45.60
average daily decrease in milk production	kg/day/cow		1.25
average daily financial loss	EUR/day/cow		0.46
average daily lost profit per 1 kg of milk	EUR/day/kg		0.24
Per month			
monthly milk production	kg/month	1405.41	1367.87
difference between April and July in milk production per 1 cow	kg/month/cow		37.53
average monthly profit per cow	EUR/month/cow	151.43	137.77
difference – monthly financial loss	EUR/month/cow		13.66
Average % decrease in milk production (as compared to April to July, where April=100%)	%		2.67

*Multiparous – dairy cows in their 2nd and 3rd lactation. 1 EUR = 4.2693 PLN according to the Regulation of the President of the Cabinet of 19/12/2019 on an average exchange rate of the PLN to EUR, used as a basis for calculation of public procurements value (Regulation of the Prime Minister, 2019).
**Average milk price – April – 1.58 PLN/kg; July – 1.56 PLN/kg.
***Average total cost – April – 1.12 PLN/kg; July – 1.13 PLN/kg.

Table 9. The estimated daily financial loss depending on the milk yield and the size of the basic herd of multiparous cows (as EUR)

Daily milk yield	No. of cows					
	25	40	60	99	250	900
46.85*	11.38	18.21	27.31	45.07	113.80	409.68
25.0	6.07	9.72	14.58	24.05	60.73	218.63
30.0	7.29	11.66	17.49	28.86	72.88	262.36
35.0	8.50	13.60	20.41	33.67	85.02	306.08
40.0	9.72	15.55	23.32	38.48	97.17	349.81
45.0	10.93	17.49	26.24	43.29	109.31	393.53
55.0	13.36	21.38	32.07	52.91	133.61	480.98

*The average daily milk yield in the studied herd.

The regression equation calculated for THI is shown in Figure 2. The results indicate that with the increase in the THI unit, the DMY decreases by 0.14 kg (primiparous) and by 0.11 kg (multiparous) at $P<0.05$. However, the value of this relation for predictive purposes is relatively low, which is reflected in the R^2 value of 0.32 and 0.14 for primiparous and multiparous cows, respectively.

July, characterized by a large number of hot days compared to cold April, caused significant differences in cows' milk yield. In the summer, the calculated mean THI amounted to 74.74 and was 29.9% higher than in the spring. This situation resulted in the drop in the productivity of primiparous cows by 2.78 kg of milk a day (Table 7), while in multiparous animals, that decrease amounted to 1.25 kg of milk a day from one cow (Table 8). In the case of multiparous cows, that difference was lower compared to cows after the first calving. This translated directly into the financial performance of the cattle herd. Then, the daily financial loss amounted to 0.46 EUR/day/cow in multiparous cows and 0.55 EUR/day/cow in primiparous animals. In the analysed herd, in multiparous cows the average profit loss on production of 1 kg of milk, resulting from HS, amounted to €0.24/kg (Table 8). The loss in EUR calculated per kilogram of milk was lower by 12.5% than in primiparous cows.

Despite the significantly lower difference in the milk yield obtained from one cow between April and July in multiparous cows versus primiparous cows, both the average daily financial loss and the lost profit on the milk production were lower. This results from the milk production scale per one cow. In the case of primiparous cows, the average milk yield was lower by over 20% when compared to the multiparous cows, and this translated into the higher lost profit on production when calculated per 1 kg of milk produced by the herd. The studies show that the milk production profitability is determined by the scale of its production by a farm.

Table 10. The estimated daily financial loss depending on the milk yield and the size of the basic herd of primiparous cows (as EUR)

Daily milk yield	No. of cows					
	25	40	60	99	250	900
38.33*	13.75	21.99	32.99	54.43	137.45	494.83
25.0	8.96	14.34	21.51	35.50	89.64	322.70
30.0	10.76	17.21	25.82	42.60	107.57	387.24
35.0	12.55	20.08	30.12	49.70	125.49	451.78
40.0	14.34	22.95	34.42	56.80	143.42	516.32
45.0	16.14	25.82	38.72	63.89	161.35	580.86
55.0	19.72	31.55	47.33	78.09	197.21	709.94

*The average daily milk yield in the studied herd.

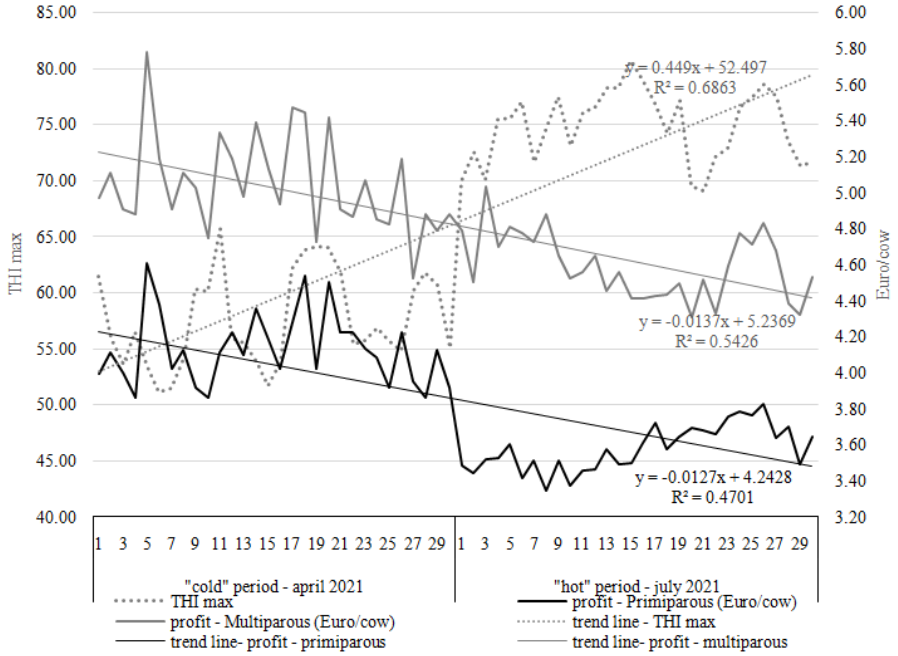


Figure 3. A relationship between profit on the milk production and THI value in the herd of primiparous and multiparous cows in analysed periods of time ("cold" and "hot")

Tables 9 and 10 present the estimated daily financial loss depending on milk yield and the size of the basic herd for cows during HS. In analysed groups, with the increase in the daily yield of cows and their number on a farm, the financial loss also increased significantly. Depending on the HS length, a specific, measurable loss can be estimated. In multiparous cows, losses resulting from lowest producing cows ranged from 6.07 EUR/day to nearly 219 EUR/day (Table 9). In larger facilities (900 cows) with an average daily milk yield of 55 kg, the daily loss will amount to about €481. Similarly, in the primiparous group, this loss will be higher by 47.61% due to the lower individual milk yield of cows (Table 10), which determines the economic efficiency of milk production.

Figure 3 shows the relationship between profit on milk production in primiparous and multiparous cows and THI value. Both groups of cows demonstrated similar relations, i.e., with an increase in THI, the animal productivity decreased, and this translated into the amount of income on milk production calculated per one cow. In the thermally optimal period, the average income was €4.13 (primiparous cows) and €5.05 (multiparous cows). For comparison, in the period of thermal discomfort, income calculated per one cow was lower and amounted to €3.58 and €4.59 for primiparous and multiparous cows, respectively.

The obtained profit on activities per one cow was strongly correlated with the period in which it was generated, and this is proven by the calculated coefficient, r=0.7366 for multiparous cows and r=0.6856 for primiparous cows. Furthermore, as the determination coefficient shows, these variations were explained in 54% and 47%, respectively.

Discussion

Apart from genetic conditions, the milk yield of cows is also influenced by environmental factors, including

the high temperature in the summer and air humidity and movement. As highly productive Holstein-Friesian cows are susceptible to HS, effective management of a dairy cattle herd is particularly important because it can reduce the HS influence on the milk yield and thus contribute to its profitability. The conducted studies represent a comprehensive analysis of a relation between HS and its influence on the economic efficiency of milk production. The quantitative analysis of the temperature influence on economic factors is very rare.

According to Bernabucci et al. (2014), in Italian Holstein cows, the value of the heat stress burden is THI = 72. Pinto et al. (2020) state that highly productive Holstein-Friesian cows experience HS when the average daily THI exceeds 65 in lying cows or 70 in standing cows, whereas according to Habeeb et al. (2018), the thermal environment index assumes values of 64, 72 and 76 as a minimum, mean, and maximum HS, accordingly.

Analysing the results of Bernabucci et al. (2014), Pinto et al. (2020), Habeeb et al. (2018) also the authors of the present study obtained similar results establishing the strong effect of heat stress on HF cows above 70 THI in the month of July.

Consistent results were obtained in an experiment conducted on the Holstein-Friesian cows, in which it was noted that in the summer, an increase in THI by one unit resulted in the milk yield decrease by 0.11 kg (Imrich et al., 2021). The obtained results were confirmed by studies of Ravagnolo et al. (2000), who analysed, among others, relations between overall milk yield and heat tolerance in Holstein-Friesian cattle. Their results demonstrated a decrease of 0.2 kg of milk per one unit of THI increase above 72, assuming that THI consisted of the maximum temperature and the minimum humidity. This is also consistent with other studies showing that THI is a more reliable indicator of conditions that may cause heat stress in dairy cattle (Pinto et al., 2020; De Rensis et al., 2015).

The level of heat stress illustrated in the study translated into lower production performance of cows. This is confirmed by a study by Herbut et al. (2018) reporting that in the summer months, the thermal burden deteriorates cow productivity and is an economic burden for the dairy sector. Furthermore, in our study, primiparous animals were more susceptible to the thermal load, and this is consistent with the study by Castro-Montoya and Corea (2021).

Studies conducted by Chanda et al. (2017) and Castro-Montoya and Corea (2021) demonstrated that the DMY differs significantly between periods with and without HS. A mechanism of the milk productivity deterioration in the period of HS is related to the decreased supply of nutrients, although according to Rhoads et al. (2009), the reduced feed intake in periods of thermal burden is responsible only for about 35% of the decrease in milk production. These authors noted, as did the authors of the present paper, that temperature fluctuations have a significant impact on the milk yield of cows during "cool" as well as "warm" periods.

In the context of the technological quality of milk, the protein content, especially of casein, is an important aspect (Barłowska et al., 2006).

In our experiment, the protein content of milk was higher during the summer similar to the study of Anzures et al. (2015), which observed the higher protein content in milk of Holstein cows in the summer versus the winter ($P<0,05$). Similar result has been obtained by Corazzin et al. (2020) and established that HS caused an increase of the protein ($P<0.10$) and fat ($P<0.10$) content. Sobotka et al. (2011) in research carried out in Polish Holstein-Friesian cows, reported that the milk in the summer season (July) was characterized by higher protein content than in spring season (April). The obtained results are not consistent with other data available in the literature on this subject (Seerapu et al., 2015; Rhoads et al., 2009). The authors of the above studies noted lower protein content in milk of cows kept in conditions of HS when compared to cows kept in thermally comfortable conditions. Mechanisms controlling the synthesis of milk proteins in the HS conditions are not thoroughly known, but according to Gao et al. (2017), they are associated with changes in several biological systems. Corazzin et al. (2020) have reported that the tendency to increase percentage of protein in the milk of cows kept in conditions of HS is caused by the reduction in milk yield and subsequent concentration of protein in addition to possibly greater non-protein nitrogen contents in the milk from heat-stressed cows than cows kept in a thermal comfort zone. On the other hand, Tao et al. (2018) concluded that it is possible that there are differential associations by HS with milk protein percentage, such as dietary composition, stage of lactation, length of treatments and experimental model used. In the present study cows were comparable with respect to these factors, however, variances in milk composition result not only from management and feeding, but also from genetic factors.

In the experiment, there was a decrease in milk fat content during the period of thermal discomfort. This may be due to more concentrated milk yields that can occur where milk production is reduced and fat synthesis stays constant (Hill and Wall, 2015).

In a study published by M'Hamdi et al. (2021) it was observed that the average fat content decreased by 0.1 pp ($P<0.001$) when THI exceeded the value of 72, when compared to the milk of cows kept in a thermal comfort zone ($68<THI<72$). Beside the microbiological cleanliness and somatic cells content, the fat content in milk is one of determinants of milk price. For milk processors, it is extremely important that purchased raw material is characterized by the qualitative and quantitative composition that remains as uniform as possible throughout a year. Similar observations were made by Imrich et al. (2021), who noted a negative correlation between THI and the milk yield ($r=-0.64$) and the fat content ($r=-0.24$).

Long-term economic consequences of HS affecting the economic efficiency of milk production have not been studied thoroughly. The available reports on estimating

economic losses resulting from the influence of changes in thermal air conditions on the summer economic efficiency of cows in the temperate climate are scarce (Ferreira et al, 2016; Vasilenko and Milostiviy, 2018; Ouellet et al., 2020).

A percentage loss in the milk yield of cows similar to that calculated in our study was also estimated by Hempel et al. (2019). It was about 2.8% when compared to the optimum THI. Similar relations were demonstrated in the study by Ogundeji et al. (2021), who analysed the financial consequences of HS for small-scale milk producers in various regions of the Republic of South Africa. They established that at the THI threshold of 70, the total average loss in milk production is 0.35 litre per cow a day, corresponding to 1.27 ZAR (0.076 EUR) per cow a day. Unfortunately, the authors (Ogundeji et el., 2021) did not inform about the costs of milk production because this was beyond the scope of the study and were not considered in the calculation of economic losses. They estimated losses in milk production only based on revenue, therefore the losses were possibly even higher.

When comparing the effect of HS on dairy cows according to subsequent lactation in the present study, there was a decrease in milk yield in both cases. More sensitive to heat discomfort were primiparous cows.

Similar conclusions were reached by Castro-Montoya and Corea (2021) when studying the HS influence and alleviation on primiparous and multiparous cows. This was tested on crossbred cows (3/4 Holstein × 1/4 Brahman) in a tropical climate. The authors established that primiparous cows were more susceptible to HS. In primiparous cows, cooling alleviated HS more efficiently, increasing the feed intake and the milk yield. The increase in the milk yield amounted to 1.40 kg/day (from 14.40 kg/day during HS to 15.80 kg/day after cooling) in primiparous versus 1.10 kg/day (from 16.90 kg/day during HS to 18.00 kg/day after cooling) in multiparous cows. Bernabucci et al. (2014) found that multiparous cows are less resistant to heat, and the drop in the milk yield alone can reach even 1 kg of milk a day.

Studies conducted indicate that the profitability of milk production is significantly dependent on its size. This is determined, among other things, by the size and individual yield of cows. The financial losses determined by HS estimated in the study ranged from a few to several hundred euros per day per herd.

St-Pierre et al. (2003) reported that the total economic losses differ depending on the level of HS but also on the milk production yield in a given region. In one of the studies conducted in Ontario, it was estimated that the average heat wave of three days might cost farmers from USD 253 to USD 337 (€227.18 to €302.61) when the average milk price is 0.75/L USD (€0.67/L) and the dairy cattle herd of 75 animals. Estimates provided by Ferreira et al. (2016) for annual costs were affected by HS calculated per one cow in the United States, ranging from USD 87 to USD 383 (€78.12–€343.91). Vasilenko and Milostiviy (2018) reported that THI exceeding the "comfort" level due to high temperatures in Ukraine in the hot season of 2017 caused financial losses for a dairy cattle herd of EUR 37.5 thousand, i.e., 39.5 EUR/cow. Furthermore, results of studies conducted by Ouellet et al. (2020) show that economic losses resulting from decreased protein and fat content in milk caused by heat stress in cows in Canada may range from CAD 5.03 to CAD 7.07 per hL^{-1} (€3.44–€4.84), depending on an amplitude of future changes in the temperature and humidity. In one of the studies conducted in Europe, a loss of 5.4% of the farm's monthly income was foreseen in a month in which mild HS occurred (Hempel et al., 2019).

Conclusion

The milk yield evaluation showed that a decrease in the daily yield and changes in milk chemical composition were noted depending on the THI value, and this significantly translated into the profitability of the analysed herd. The production profitability in cows during their 1st lactation was lower compared to cows in the 2nd or 3rd lactation, which translated into a higher lost profit on production of 1 kg of milk. The studies confirm that the scale of its production determines the milk production profitability of a farm.

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