IMPACT OF TEMPERATURE-HUMIDITY INDEX ON MILK COMPOSITION AND SOMATIC CELL COUNT OF HOLSTEIN COWS IN CONTINENTAL CLIMATES IN TÜRKIYE

TUTKUN, M.

Department of Animal Science, Faculty of Agriculture, Dicle University, 21280 Diyarbakır, Türkiye
(e-mail: muhittin.tutkun@dicle.edu.tr; phone: +90-53-2668-7313; fax: +90-41-2241-1048)

(Received 29th Apr 2025; accepted 30th Jul 2025)

Abstract. The aim of the study is to examine the seasonal variation of the Temperature-Humidity Index (THI) and its relationship with milk yield, fat content, solids-not-fat (SNF), and somatic cell count (SCC) in Holstein cows raised under continental climatic conditions in Diyarbakır, Türkiye. Meteorological data and milk yield parameters were collected during the year 2024. THI values were calculated using ambient temperature and relative humidity and classified. The results showed that average THI values in spring (56.92), autumn (60.57), and winter (41.99) remained within the no-stress comfort zone. In summer, the average THI reached 73.11, approaching the upper threshold of thermal comfort (THI ≤ 74), with maximum daily THI slightly exceeding this limit (74.57), suggesting potential short-term moderate heat stress events. Correspondingly, milk yield was lowest in summer (15.84 kg/day) and highest in autumn (19.33 kg/day), indicating seasonal sensitivity to heat. Although correlation analyses between THI and milk traits (yield, fat, SNF, SCC) revealed meaningful trends, no statistically significant associations were found.
Keywords: *dairy cow, welfare, seasonal climate, lactation, bioclimatic stress*

Introduction

The most significant climatic factors that can be considered sources of stress are air temperature and relative humidity, as the interaction between these two components has varying effects on cattle. The higher the humidity in the air, the more challenging it becomes to regulate body temperature. The adverse effects of environmental conditions are particularly significant under intensive production systems, especially in high-yield animals.

The efficiency and sustainability of dairy production are, however, challenged by a wide range of factors, including climatic changes, which have gained increasing attention due to their profound effects on livestock health and productivity (Guzman-Luna et al., 2022).

The combined effect of factors causing an increase in the normal body temperature of dairy cattle is referred to as "Heat Stress." Heat stress primarily affects reproductive performance, milk yield, and functional traits (Hansen, 2007; Smith et al., 2013; Rhodas et al., 2009).

Understanding the dynamics of these changes and their underlying mechanisms is essential for developing strategies to maintain milk quality and enhance the overall sustainability of dairy production. Milk quality principally concerns levels of milk fat, protein, and solids-not-fat (SNF). Any undesirable changes in these components result in reduced milk quality (Khastayeva et al., 2021).

Several environmental variables, including temperature, relative humidity, solar radiation, air circulation, and precipitation, contribute to heat stress in animals. Recent studies on heat stress in livestock have primarily emphasized the effects of temperature and relative humidity (Igono et al., 1985; Igono and Johnson, 1990; Ravagnolo and Misztal, 1999; Bouraoui et al., 2002).

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_89878998

The combination of high temperatures and elevated relative humidity exacerbates the severity of heat stress (Armstrong, 1994). Among various bioclimatic indices, the temperature-humidity index (THI) is extensively utilized to evaluate heat stress in animals (Hahn et al., 2003). THI serves as a key metric for gauging the stress levels caused by elevated ambient temperature and humidity. By analyzing THI values, researchers can classify animals into comfort or stress zones (Bohmanova et al., 2007).

The primary response of dairy cattle to heat exposure is a decline in feed intake, leading to a decrease in both milk production and its components (Habeeb, 2020).

The hypothalamus region that regulates hunger receives inhibitory nerve impulses from peripheral heat receptors when the ambient temperature is high in the summer. By decreasing feed intake, the animals' heat load is decreased (Habeeb, 2022).

The primary issue in cattle affected by heat stress is maintaining the balance between heat production in the body and the dissipation of this heat. Basal heat production, which refers to the body's fundamental heat production, depends on factors such as species, breed, body weight, color, production status, diet, air temperature, and humidity. The temperature range within which cattle can maintain their normal body temperature has been determined to be between 4.5°C and 26.5°C. Within this range, basal heat production is 825 kcal per hour. When the air temperature exceeds 26.5°C, heat production in the body decreases by one-third. This reduction is due to animals moving less and consuming less feed. Decreased feed intake is one of the main reasons for reduced productivity (Chase and Soiffen, 1988; West, 2003).

The primary aim of this study is to investigate the seasonal variation of the Temperature-Humidity Index (THI) and its influence on milk yield, milk composition (fat and solids-not-fat), and somatic cell count (SCC) in Holstein dairy cows raised under continental climatic conditions in Türkiye.

Materials and methods

Study area

The study was carried out on private dairy farm (*Fig. 1*) in Diyarbakır Province, Turkey (37°85'00 N and 40°66'91 E, 535 m asl). Diyarbakır province is located in the continental climate zone, specifically within the climate characteristics of southeastern Turkey. Temperatures often rise significantly with little to no rainfall during in summer. Most of the annual rainfall occurs during the winter. Transitional seasons are relatively short and characterized by milder temperatures and occasional rainfall.

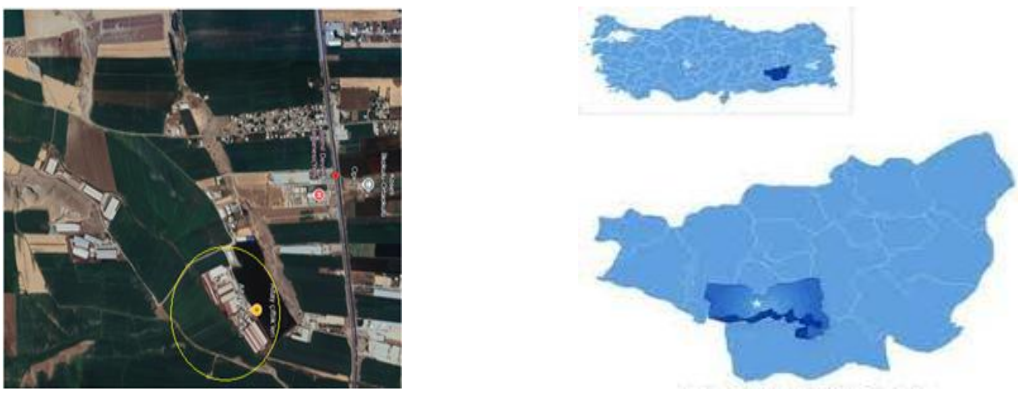

Figure 1. *The location of the study area*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_89878998

Experimental design and data collection

Milk yield data were collected from a private dairy farm in Diyarbakır, involving 210 Holstein cows: 49 in spring, 56 in summer, 49 in autumn, and 56 in winter. All animals were housed in semi-open stalls typical for the region. Although in-barn microclimate measurements were not available. The cows were kept under consistent management and feeding protocols throughout the year. Minor seasonal adjustments were made to the feed to match forage availability and environmental needs such as higher energy feeds and vitamin-mineral supplements. Milking was performed twice daily (07:00 and 17:00). The dataset included cows from four different parities, with one lactation record (non-repeated observation) collected per cow. Complete and valid records were used in the analysis only. Cows with missing or incomplete data were excluded. Additionally, each cow was represented by a single lactation record, which reduced the effect of repeated measures and individual variation.

Feed rations

The ration content used of lactating cows was adjusted according to the changing energy and nutritional needs throughout the lactation period (*Table 1*).

Table 1. *The seasonal ration content for lactating cows*

Season	Energy (MJ/kg)	Protein (%)	Fat (%)	Fiber (%)	Key feeds and adjustments
Winter	11-13	16-18	3.5-4.5	18-22	High-quality roughage energy-boosting feeds, vitamins, and mineral supplementation
Spring	10-12	15-17	3-4	17-21	Fresh grass
Summer	9-11	14-16	2.5-3.5	16-20	Quality fresh grass and low-fat feeds
Autumn	10-12	15-17	3-4	17-21	Dried hay and silage, balanced protein and energy

Chemical analyses

The somatic cell count in the raw milk samples was determined using the Somatos Mini device with a direct measurement technique and milk composition analyses (fat, SNF) were performed using the Milk Analyzer (Milkotester Master Classic). in the Animal Breeding Laboratory of the Department of Animal Science. Each milk sample was analyzed in duplicate to ensure measurement reliability.

Calculation of temperature-humidity index (THI)

Weather data included daily maximum, minimum and average temperature, and humidity were obtained from the public weather station located in Diyarbakir that belongs to the Turkish State Meteorological Service for the year 2024.
The formula proposed by Mader et al. (2006) is highly correlated with the panting score. For this reason, the formula given below (*Eq. 1*) was used for THI calculations in this study.

$$THI = (0.8 \times AT°) + [(\%RH / 100) \times (AT° - 14.4)] + 46.4 \qquad (Eq.1)$$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_89878998

where THI = Temperature humidity index; AT = Ambient temperature (°C); RH = Relative humidity (%).

The values of THI: divided into 4 ranges, according to Hahn et al. (2003) classification. The intensity of heat stress was evaluated as follows: normal, moderate, severe and very severe (emergency) stress, which corresponds to the following values: THI ≤ 74, 75–78, 79–83 and THI ≥ 84, respectively.

Data analysis

SPSS version 26 was used to analyze interaction between milk yield and weather parameters. One-way ANOVA (Analysis of Variance) to compare the means of each variable across the four seasons. Post-hoc test (like Tukey's HSD or Duncan's multiple range test) to determine which specific seasons differed significantly from each other.

Results

The seasonal variation during the experimental period

The seasonal variations in temperature (T), relative humidity (RH) and the Temperature-Humidity Index (THI) were shown in *Table 2*.

Table 2. *Seasonal variations in temperature (T), relative humidity (RH), and temperature-humidity index (THI)*

Parameters	Seasons			
	Spring	Summer	Autumn	Winter
Average daily T, (°C)	13.2	29.06	17.26	3.73
Standard deviation, (°C)	2.88	2.001	5.48	0.76
T, minimum (°C)	3.1	18	4.7	-1.4
T, maximum (°C)	25.2	37.8	32.4	9.6
Average daily RH, (%)	58	24.6	43.3	69
Standard deviation, (%)	4.41	3.26	11.32	0.7
RH, minimum (%)	51	22	27	68
RH, maximum (%)	63	30	59	70
Average daily THI	56.92	73.11	60.57	41.99
Standard deviation	19.86	17.8	24.84	9.9
THI, minimum	50.02	70.39	51.21	40.04
THI, maximum	63.85	74.57	69.3	43.14

Mean, standard deviation, minimum, and maximum values of daily temperature (°C), relative humidity (%), and temperature-humidity index (THI) across different seasons

Analysis of the climatic data during the study period revealed that summer had the highest average temperature (29.06°C), with values ranging from 18°C to 37.8°C. In contrast, winter recorded the lowest average temperature (3.73°C), with a minimum as low as -1.4°C. Relative humidity (RH) was highest in winter (69%) and lowest in summer (24.6%), indicating a hot and dry summer season that may increase the risk of heat stress in dairy cattle.

Regarding the Temperature-Humidity Index (THI), spring (56.92), autumn (60.57), and winter (41.99) remained well within the thermal comfort zone (THI ≤ 74). However,

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_89878998

in summer, the average THI reached 73.11, approaching the upper threshold of thermal comfort. The maximum daily THI value of 74.57 slightly exceeded this limit, suggesting the potential for short-term moderate heat stress events during peak summer days. Additionally, autumn showed the greatest THI variability (standard deviation = 24.84), indicating fluctuating environmental conditions during this season.

These findings confirm that summer poses the greatest thermal challenge for dairy cows in the studied region and underscore the need for effective heat stress mitigation strategies such as cooling systems and environmental management during this period.

Figure 2 illustrates the seasonal trends of average temperature (°C), relative humidity (%), and temperature-humidity index (THI), which are key climatic factors influencing dairy cow performance. During summer, the average temperature reached its peak (~29°C), while relative humidity dropped to its lowest level (~25%). Consequently, the average THI also peaked at 73.11, approaching the upper thermal comfort threshold (THI ≤ 74). This pattern indicates a high risk of heat stress during summer, even in the presence of low humidity. An estimation of the frequency of heat stress was made based on the seasonal THI values. The average THI in summer was 73.11, with maximum values reaching 74.57 and minimum values at 70.39. This suggests that a substantial proportion of days during the summer season exceeded the commonly accepted heat stress threshold (THI > 72) for dairy cows. Based on the range and average, it is estimated that approximately 60% to 80% of summer days were associated with moderate heat stress conditions. In contrast, spring and autumn showed moderate temperature and humidity levels, with THI values (56.92 and 60.57, respectively) remaining within the no-stress comfort zone. Winter exhibited the lowest average temperature (~3.7°C) and THI (~41.99), but the highest relative humidity (~69%). These findings demonstrate that summer poses the most thermally stressful period for dairy cows, whereas spring, autumn, and winter offer relatively favorable environmental conditions from a THI perspective.

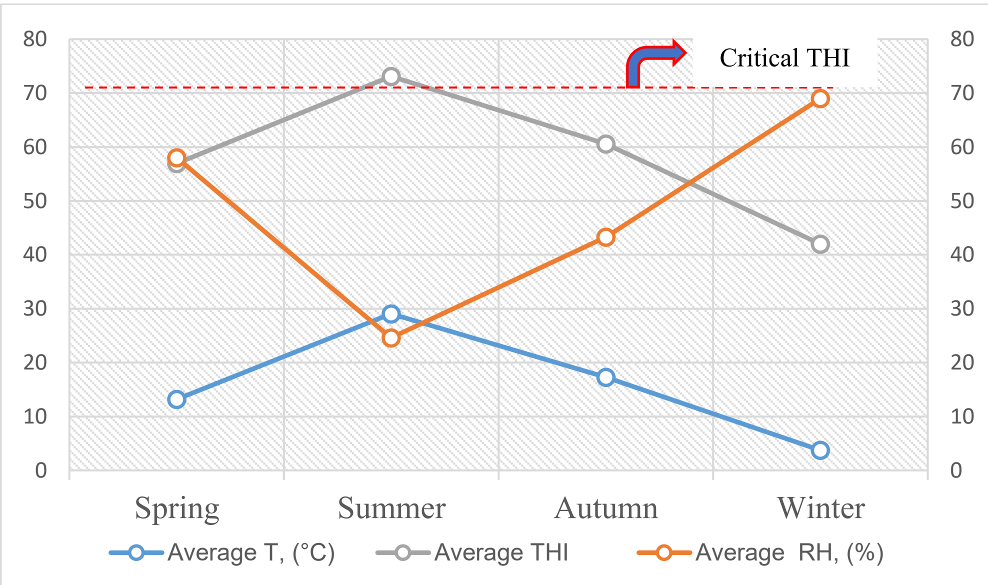

Figure 2. *Seasonal heat stress levels based on the THI*

Although the THI values in winter were substantially below the threshold for heat stress, its calculation was retained to provide a full seasonal comparison. This allowed for

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_89878998

a clearer interpretation of thermal comfort levels year-round and emphasized that winter posed no heat-related risk to dairy cows in the study region.

The graphical data reinforce the importance of implementing targeted heat stress mitigation strategies during summer to sustain milk productivity and animal welfare.

Seasonal variation in milk yield, composition, and somatic cell count

The seasonal variation in Temperature-Humidity Index (THI), milk yield, milk composition (fat and solids-not-fat), and somatic cell count (SCC) in Holstein cows is presented in *Table 3*.

Table 3. *Seasonal variation*

Season	THI	Milk Yield	Fat	SNF	SCC
Spring	56.92 ± 4.01^{a}	16.82 ± 0.23^{b}	3.77 ± 0.34^{a}	9.08 ± 23.52a	212.19 ± 31.78^{ab}
Summer	73.11 ± 1.36^{b}	15.84 ± 0.23^{b}	3.72 ± 0.38^{a}	9.08 ± 24.02a	219.51 ± 31.53^{a}
Autumn	60.57 ± 5.23^{b}	19.33 ± 0.38^{a}	3.35 ± 0.23^{b}	9.13 ± 26.43a	207.36 ± 29.84^{ab}
Winter	44.68 ± 3.51^{c}	18.49 ± 0.38^{a}	3.60 ± 0.28^{a}	9.11 ± 27.73a	203.56 ± 27.94^{b}
p	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**0.048**

Means followed by different superscript letters within columns differ significantly according to Tukey's test ($p < 0.05$). THI: Temperature-Humidity Index, SNF: Solids-Not-Fat, SCC: Somatic Cell Count

All parameters demonstrated statistically significant differences across seasons ($p < 0.05$). The highest average THI was recorded in summer (73.11 ± 1.36), significantly exceeding the values observed in spring (56.92 ± 4.01), autumn (60.57 ± 5.23), and winter (44.68 ± 3.51) ($p < 0.001$). Corresponding to this thermal variation, milk yield was significantly lower in summer (15.84 ± 0.23 kg/day) compared to autumn (19.33 ± 0.38 kg/day) and winter (18.49 ± 0.38 kg/day) ($p < 0.001$), suggesting that elevated THI may negatively influence lactational performance.

Milk fat content varied significantly among seasons ($p < 0.001$), with the lowest value observed in autumn (3.35 ± 0.23%) and higher values maintained in spring (3.77 ± 0.34%), summer (3.72 ± 0.38%), and winter (3.60 ± 0.28%). This pattern may reflect seasonal shifts in diet or physiological responses unrelated to THI alone. Solids-not-fat (SNF) values remained relatively stable across seasons (ranging from 9.08 to 9.13%), though the differences were statistically significant ($p < 0.001$), the biological relevance of these small variations may be limited.

Somatic cell count (SCC), an indicator of udder health, was highest in summer ($219.51 \pm 31.53 \times 10^3$ cells/mL) and lowest in winter ($203.56 \pm 27.94 \times 10^3$ cells/mL), with significant seasonal variation ($p = 0.048$). The elevated SCC during summer may suggest increased susceptibility to subclinical mastitis or immune challenges under heat stress conditions. Overall, the findings support the hypothesis that elevated THI during the summer period adversely affects both milk yield and udder health.

Between Temperature-Humidity Index (THI), Milk Yield, Fat Percentage, and Somatic Cell Count (SCC) in Dairy Cows was shown in *Figure 3* as well.

Correlation between THI and other variables

The analysis examined the relationship between the Temperature-Humidity Index (THI) and other variables was shown in *Table 4*.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_89878998

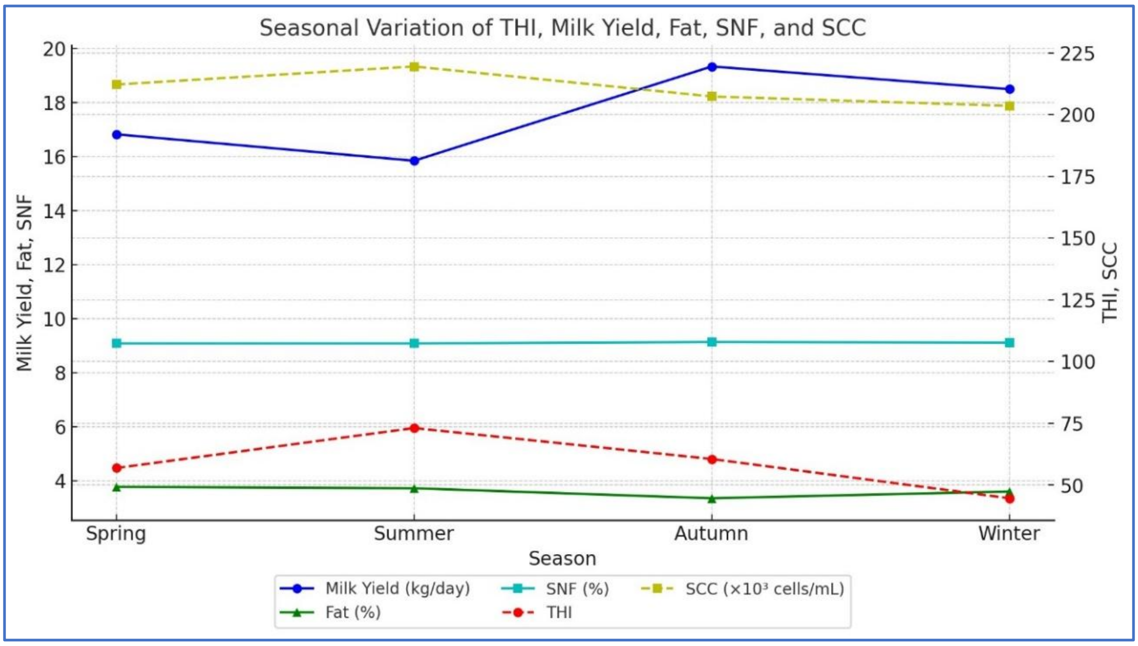

***Figure 3.** Seasonal relationships between temperature-humidity index (THI), milk yield, fat percentage, and somatic cell count (SCC) in dairy cows. The figure illustrates how environmental stress (measured by THI) varies across the seasons and corresponds to changes in milk yield (kg/day), fat content (%), solids-not-fat (SNF, %), and somatic cell count ($\times 10^3$ cells/mL). THI peaks in summer, coinciding with the lowest milk yield and highest SCC, indicating potential heat stress effects. Milk composition, particularly fat and SNF also shows seasonal fluctuations*

***Table 4.** The correlation matrix with r-values (correlation coefficients) and p-values*

Parameter		THI	Milk yield	Fat	SNF	SCC
THI	r p	**1.000**	-0.586 0.414	0.136 0.864	-0.386 0.614	0.898 0.102
Milk yield	r p	-0.586 0.414	**1.000**	-0.875 0.125	0.961 0.039 (*)	-0.882 0.118
Fat	r p	0.136 0.864	-0.875 0.125	**1.000**	-0.966 0.034 (*)	0.557 0.443
SNF	r p	-0.386 0.614	0.961 0.039 (*)	-0.966 0.034 (*)	**1.000**	-0.750 0.250
SCC	r p	0.898 0.102	-0.882 0.118	0.557 0.443)	-0.750 0.250)	**1.000**

(*) Significant correlation at $p < 0.05$; THI and SCC (0.898, $p = 0.102$): High positive correlation (not statistically significant at $p < 0.05$), higher THI tends to increase SCC

A strong negative correlation was found between THI and milk yield ($r = -0.993$, $p < 0.001$), indicating that as environmental heat stress increases, milk yield decreases significantly. Similarly, fat percentage was moderately and negatively correlated with THI ($r = -0.846$, $p = 0.001$), suggesting heat stress also affects milk composition. A weaker negative correlation was observed between THI and solids-not-fat (SNF) ($r = -0.419$), but this was not statistically significant ($p = 0.227$), indicating limited evidence

http://www.aloki.hu • ISSN 1589 1623 (Print) • ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_89878998

of THI influence on SNF levels. The correlation between THI and SCC ($r = 0.898$, $p = 0.102$) was not statistically significant and no firm conclusions can be drawn from this result. Specifically, the correlations between THI and milk yield ($r = –0.993$, $p < 0.001$) and THI and fat content ($r = –0.846$, $p = 0.001$) were statistically significant and biologically relevant, confirming the adverse impact of heat stress on both productivity and milk composition. Overall, the results highlight that milk yield and fat content are the most sensitive parameters to seasonal heat stress, while SNF and SCC appear less consistently affected in this dataset.

Discussion

The lack of statistically significant correlations between THI and certain milk traits, such as SCC and SNF, may be attributed to several factors. First, individual cow variability, including genetic differences in heat tolerance, immune response, and lactation stage, may buffer or obscure environmental effects. Second, the study used seasonal average values, which can reduce the sensitivity to detect short-term fluctuations or acute stress responses that occur over shorter time scales (e.g., daily or hourly THI changes). Third, the semi-open barn structure and uniform management conditions may have helped mitigate some of the heat stress impacts, especially for SCC, which is also influenced by infection status, hygiene, and other non-climatic factors. Finally, the relatively moderate intensity and short duration of heat stress events in this continental climate may have been insufficient to produce strong physiological responses in all traits measured.

The findings of this study confirm that summer is the most critical season for heat stress in dairy cows, aligning with previous research conducted in different European regions. The observed THI value of 73.11 ± 1.36 in summer exceeds the commonly accepted threshold for heat stress (THI > 72) indicating that cows were exposed to potentially harmful thermal conditions. Similar results have been reported in the Mediterranean region (Bouraoui et al., 2002), where prolonged periods of heat stress were observed during summer. However, the severity of heat stress in Mediterranean regions appears to be greater, as Bouraoui et al. (2002) reported that 96% of summer days had THI values exceeding 72 suggesting a more extreme thermal burden compared to our findings.

Milk yield was significantly affected by seasonal changes, with the lowest yield recorded in summer (15.84 ± 0.23 kg) and the highest in autumn (19.33 ± 0.38 kg). Compared to autumn, milk yield decreased by 18.1% in summer and 13.6% in spring. Similar seasonal impacts on yield and composition were reported by Benedet et al. (2021) in tropical Holsteins.

This study demonstrated that milk yield was strongly influenced by THI levels, with higher THI values leading to a significant decline in milk production. These findings align with those of Reyad et al. (2016), da Silva et al. (2022), and Polsky et al. (2021), who also observed reduced milk yield under elevated THI conditions. The physiological mechanism involves a reduction in feed intake and increased maintenance energy expenditure under thermal stress (Chen et al., 2021; Trevisi et al., 2020).

Milk yield was significantly affected by seasonal changes with the lowest yield recorded in summer (15.84 ± 0.23 kg) and the highest in autumn (19.33 ± 0.38 kg). Compared to autumn, milk yield decreased by 18.1% in summer and 13.6% in spring. The lowest THI in winter corresponded to a yield of 18.49 ± 0.38 kg, indicating a 4.3%

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_89878998

decrease compared to autumn but a 16.7% increase compared to summer. A study reported that heat stress led to a reduction in milk yield ranging from 4.16% to 14.42% across different THI groups. The highest daily milk yield was observed in the THI range of 61–66 (7.40 L) while the lowest yield occurred in the THI range of 79–81 (6.33 L) (Ekine et al., 2020). These findings are consistent with the present study.

Seasonal differences in THI patterns were also evident in spring and autumn. Unlike Gantner et al. (2010) in Croatia who found that spring THI exceeded 72, the present study recorded a significantly lower spring THI value (56.92 ± 4.01) indicating that heat stress was not a concern during this season. This result is consistent with studies conducted in Italy (Bertocchi et al., 2014) and Mediterranean climates (Bouraoui et al., 2002), where no heat stress conditions were reported in spring. Similarly, autumn THI in the current study (60.57 ± 5.23) remained below the critical heat stress threshold, further supporting the absence of thermal stress during this season and aligning with previous research findings.

Winter conditions were characterized by the lowest THI value (44.68 ± 3.51), confirming the absence of heat stress risks. This result is consistent with findings from Gantner et al. (2010), Bertocchi et al. (2014), and Bouraoui et al. (2002), all of which reported that winter does not pose any significant thermal challenges for dairy cows.

The study found that milk components, including milk fat and SNF% increased as temperature and humidity decreased from winter to summer. Hot and humid conditions negatively impact milk yield and quality, with fat and solids-not-fat (SNF) percentages declining by 39.7% and 18.9%, respectively as reported by Kadzere (2002). Several studies (Hammami, 2013; Bernabucci, 2014) have also documented significant reductions in milk fat yield under heat stress conditions.

In this study, seasonal variations in somatic cell count (SCC) were observed. The highest mean SCC was recorded in summer (219.51×10^3 cells/mL), while the lowest was in winter (203.56×10^3 cells/mL); however, these differences were only marginally statistically significant ($p = 0.048$). The limited seasonal variation in SCC suggests that heat stress was not a dominant factor influencing udder health under the study conditions. These findings are partially consistent with studies by Bouraoui et al. (2002) and Do Amaral et al. (2009), which showed that heat stress could impair immune function and elevate SCC. However, studies such as Leitner et al. (2001) and Hammami et al. (2013) emphasize that SCC is a multifactorial trait, affected not only by ambient temperature but also by hygiene, mastitis status, milking practices, and housing systems.

In this study, the cows were housed in semi-open barns under standard management and milking routines, which may have helped buffer seasonal stress effects. Moreover, based on THI data observed in summer, the intensity and duration of heat stress appeared to be moderate and may not have been sufficient to trigger a strong inflammatory response in the udder. This could explain the lack of a strong or consistent correlation between THI and SCC, suggesting that SCC interpretation based solely on environmental indices may have limitations.

As summer THI levels neared the moderate heat stress threshold, it becomes crucial to adopt appropriate mitigation strategies to safeguard both productivity and animal well-being. According to Kumar et al. (2022), a variety of interventions such as improved airflow through ventilation, the use of evaporative cooling systems, and dietary modifications can be particularly effective in semi-open barn environments common in continental regions. These measures play a vital role in minimizing heat load and maintaining consistent milk performance.

Given that the Temperature-Humidity Index (THI) values in summer approached or slightly exceeded the threshold for moderate heat stress, implementing effective mitigation strategies is essential to maintain animal welfare and productivity. One of the most practical approaches is to improve ventilation in semi-open barns by using fans or tunnel ventilation systems, which enhance airflow and reduce heat accumulation. Additionally, evaporative cooling systems, such as sprinklers combined with fans, can significantly lower the microclimate temperature around animals and have been shown to improve milk yield under thermal stress. Providing shade structures and minimizing direct sun exposure, particularly during peak temperature hours, is also crucial in outdoor areas. From a nutritional standpoint, adjusting feed formulations during hot months by increasing the energy density of the diet, using rumen-protected fats, and ensuring a consistent water supply can help support metabolic demands and reduce heat load. Lastly, scheduling milking and feeding during cooler times of the day (early morning or evening) can reduce animal discomfort and optimize performance. These strategies, tailored to local farm infrastructure and economic feasibility, are essential to minimize the impact of heat stress in regions with continental climates.

While the analysis revealed trends indicating potential associations between THI and milk yield, fat, SNF and SCC, none of these correlations reached statistical significance within this dataset. This suggests that in present study, the observed variations in THI did not demonstrate a statistically reliable relationship with the measured milk performance variables. Further research with larger datasets is needed to confirm or refute these trends.

Conclusion

This study examined the seasonal variation of the Temperature-Humidity Index (THI) and its association with milk yield, milk composition (fat and solids-not-fat), and somatic cell count (SCC) in Holstein cows raised under continental climatic conditions in Diyarbakır, Türkiye. The results indicated that average THI values remained within thermal comfort levels in spring, autumn, and winter, while approaching the moderate heat stress threshold during summer. Although summer was associated with lower milk yield and higher SCC compared to other seasons. No statistically significant correlations were found between THI and the examined milk traits, including fat, SNF, and SCC.

These findings suggest a possible seasonal sensitivity in dairy performance, particularly during warmer periods. However, due to the lack of strong statistical associations, the results should be interpreted cautiously and not considered indicative of a direct causal relationship. Further research with larger datasets, continuous climate monitoring, and controlled on-farm trials is needed to clarify the complex interactions between environmental stress and milk quality traits. This work highlights the importance of monitoring environmental conditions and considering adaptive management strategies during periods of elevated THI, even when stress indicators fall near subclinical thresholds.

Conflict of interests. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

[1] Armstrong, D. V. (1994): Heat stress interaction with shade and cooling. – J. Dairy Sci. 77: 2044-2050.
[2] Bartussek, H., Leeb., C. H., Held, S. (2000): Animal needs index for cattle, ANI 35 L/ 2000-cattle. – Federal Research Institute for Agriculture in Alpine Regions (BAL), Gumpenstein.
[3] Benedet, A., Dallago, G. M., Bittante, G. (2021): Heat stress effects on milk yield and composition of Holstein cows in tropical regions. – Tropical Animal Health and Production 53(1): 19-20. https://doi.org/10.1007/s11250-020-02468-4.
[4] Bernabucci, U., Biffani, S., Buggiotti, L., Vitali, A., Lacetera, N., Nardone, A. (2014): The effects of heat stress in Italian Holstein dairy cattle. – Journal of Dairy Science 97(1): 471-486. https://doi.org/10.3168/jds.2013-661.
[5] Bertocchi, L., Vitali, A., Lacetera, N., Nardone, A., Varisco, G., Bernabucci, U (2014): Seasonal variations in the composition of Holstein cow's milk and temperature–humidity index relationship. – Animal 8(4): 667-674. https://doi.org/10.1017/S1751731114000032.
[6] Bohmanova, J., Misztal, I., Cole, J. B. (2007): Temperature-humidity indices as indicators of milk production losses due to heat stress. – J. Dairy Sci. 90(4): 1947-1956. https://doi.org/10.3168/jds.2006-513.
[7] Bouraoui, R., Lahmar, M., Majdoub, A., Djemali, M., Belyea, R. (2002): The relationship of the temperature-humidity index with milk production of dairy cows in a Mediterranean climate. – Anim. Res. (51): 479-491.
[8] Chase, L. E., Soiffen, C. J. (1988): Feeding and managing dairy cows during hot weather. – Tropical Animal Health Production 17: 209-215.
[9] Chen, Y., Wang, X., Zhao, Y. (2021): Effects of temperature-humidity index on dairy cow production and physiology. – Frontiers in Veterinary Science 8: 746299. https://doi.org/10.3389/fvets.2021.746299.
[10] Do Amaral, B. C., Connor, E. E., Tao, S., Hayen, J., Bubolz, J., Dahl, G. E. (2009): Heat-stress abatement during the dry period: Does cooling improve transition into lactation? – The Journal of Dairy Science. 92(12): 5988-5999. https://doi.org/10.3168/jds.2009-2343.
[11] Ekine-Dzivenu, C. C., Mrode, R., Oyieng, E (2020): Evaluating the impact of heat stress as measured by temperature-humidity index (THI) on test day milk yield of small holder dairy cattle in a sub-Sahara African climate. – Livestock Science 242: 104314. https://doi.org /10.1016/j.livsci.2020.104314.
[12] Gantner, V., Mijić, P., Kuterovac, K., Solić, D., Gantner, R. (2011): Temperature-humidity index values and their significance on the daily production of dairy cattle. – Daily Production of Dairy Cattle 61(1): 56-63.
[13] Guzmán-Luna, P., Mauricio-Iglesias, M., Flysjö, A., Hospido, A (2022): Analysing the interaction between the dairy sector and climate change from a life cycle perspective. A review. – Trends Food Science Technology. 126: 168-179. https://doi.org/10.1016/j.tifs.2021.09.001.
[14] Habeeb, A. M. (2020): Impact of climate change in relation to temperature-humidity index on productive and reproductive efficiency of dairy cattle. – Boffin Access Limited. International Journal of Veterinary and Animal Medicine 3(1): 124-133. https://doi.org//10.31021/ijnam.20203124.
[15] Habeeb, A. M. (2022): Side effects of high environmental temperature on reproductive efficiency of ruminants. – IASR Journal of Agriculture and Life Sciences 2(1): 15-18. https://doi.org/10.1007/s11250-023-03805-y.
[16] Hahn, G., Mader, T. L., Eigenberg, R. A. (2003): Perspective on the development of thermal indices for animal studies and management. – EAAP Technical Series 7: 31-44.
[17] Hammami, H., Bormann, J., M'hamdi, N. H., Montaldo, H., Gengler, N. (2013): Gendler N: evaluation of heat stress effects on production traits and somatic cell scores of Holsteins

in a temperate environment. – Journal of Dairy Science 96: 1844-1855. https://doi.org/10.3168/jds.2012-5947.
[18] Hansen, J. (2007): Exploitation of genetic and physiological determinants of embryonic resis-tance to elevated temperature to improve embryonic survival in dairy cattle during heat stress. – Theriogenology 68: S242-S249. https://doi.org/10.1016/j.theriogenology.2007.04.008.
[19] Igono, M. O., Johnson, H. D. (1990): Physiologic stress index of lactating dairy cows based on diurnal pattern of rectal temperature. – J. Interdiscipl. Cycle Res. 21: 303-320.
[20] Igono, M. O., Steevens, B. J., Shanklin, M. D., Jhonson, H. D. (1985): Spray cooling effects on milk production, milk, and rectal temperatures of cows during a moderate temperate summer season. – J. Dairy Sci. 68: 979-985.
[21] Khastayeva, A. Z., Zhamurova, V. S., Mamayeva, L. A., Kozhabergenov, A. T., Karimov, N. Z., Muratbekova, K. M. (2021): Qualitative indicators of milk of Simmental and Holstein cows in different seasons of lactation. – Vet. World 14: 956-963. https://doi.org / 10.14202/vetworld.2021.956-963.
[22] Kumar, A., Verma, D. N., Upadhyay, R. C. (2022): Mitigation strategies to combat heat stress in dairy cattle—a review. – Livestock Science 259: 104930. https://doi.org/10.1016/j.livsci.2022.104930.
[23] McDowell, R. E. (1972): Improvement of Livestock Production in Warm Climates. – Freeman, San Francisco, pp. 410-449.
[24] Misztal, I. (1999): Model to study genetic component of heat stress in dairy cattle using national data. – J. Dairy Sci. 82: 32. https://doi.org/10.3168/jds.S0022-0302(00)75095-8.
[25] Polsky, L., von Keyserlingk, M. A. G. (2021): Invited review: effects of heat stress on dairy cattle welfare. – Journal of Dairy Science 104(5): 5312-5333. https://doi.org/10.3168/jds.2020-20029.
[26] Ravagnolo, O., Misztal, I. (2000): Genetic component of heat stress in dairy cattle, parameter estimation. – J. Dairy Sci. 83: 2126-2130. https://doi.org/10.3168/jds.S0022-0302(00)75094-6.
[27] Reyad, M. A., Sarker, M. A. H., Uddin, M. E., Habib, R., Rashid, R. (2016): Effect of heat stress on milk production and its composition of Holstein Friesian crossbred dairy cows. – Asian Journal of Medical and Biological Research 2(2): 190-195. https://doi.org/10.3329/ajmbr.v2i2.29060.
[28] Rhodas, M. L., Rhodas, R. P., VanBaale, M. J., Weber, W. J., Croker, B. A., Baumgard, L. H. (2009): Effects of heat stress and plane of nutrition on lactating Holstein cows: I. Production, metabolism, and aspects of circulating somatotropin. – J. Dairy Sci. 92: 1986-1997. https://doi.org/10.3168/jds.2008-1641.
[29] Silva, R. G., de Almeida, G. L. P., Santos, P. M. (2022): Effects of heat stress on milk yield and milk composition in Holstein cows. – Animal Feed Science and Technology 285: 115221. https://doi.org/10.1016/j.anifeedsci.2021.115221.
[30] Smith, D. L., Smith, T., Rude, B. J., Ward, S. H. (2013): Short communication: comparison of the effects of heat stress on milk and component yields and somatic cell score in Holstein and Jersey cows. – J. Dairy Sci. 96(5) 3028-3033. https://doi.org/10.3168/jds.2012-5737.
[31] Thom, E. C. (1959): The discomfort index. – Weather Wise 12: 57-60.
[32] Trevisi, E., Minuti, A., Bertoni, G. (2020): Immunological and metabolic responses to heat stress and its impact on somatic cell count. – Animal 14(2): 370-380. https://doi.org/10.1017/S1751731119002075.
[33] West, J. W. (2003): Effects of heat-stress on production in dairy cattle. – Journal of Dairy Science 86: 2131-2144. https://doi.org/10.3168/jds.S0022-0302(03)73803-X.