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Original Research Article

Impact of Heat Stress on Milk Production and Reproductive Performance in Dairy Cattle

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Abstract: *Heat stress is a major environmental constraint affecting dairy cattle productivity, particularly in regions with high ambient temperature and humidity. Elevated Temperature-Humidity Index (THI) may reduce milk production and impair reproductive efficiency.* ***Objective:*** *To determine the effect of heat stress on milk yield and reproductive performance of lactating dairy cows during summer using the Temperature-Humidity Index.* ***Methods:*** *This observational study was conducted during the summer season among 120 lactating dairy cows in a dairy farm setting. Cows were categorized into four groups according to THI: normal, mild, moderate, and severe heat stress. Productive parameters included milk yield, milk fat percentage, and milk protein percentage, while reproductive parameters included estrus expression, days to first estrus, conception status, services per conception, and days open. Data were analyzed using SPSS. Descriptive statistics were calculated, one-way ANOVA was applied for comparison of continuous variables, chi-square test was used for categorical variables, Pearson correlation assessed the relationship between THI and outcome variables, and linear regression was performed to determine the predictive effect of THI on milk yield.* ***Results:*** *Increasing THI was significantly associated with reduced milk yield, milk fat percentage, and milk protein percentage (p<0.001). Reproductive performance was also adversely affected, with cows under severe heat stress showing weaker estrus expression, delayed first estrus, lower conception rate, higher number of services per conception, and prolonged days open compared with cows maintained under normal thermal conditions. Pearson correlation showed a strong negative association between THI and milk production traits, while THI was positively correlated with indicators of reproductive inefficiency. Linear regression further confirmed THI as a significant predictor of reduced milk yield.* ***Conclusion:*** *Heat stress significantly compromises milk production and reproductive performance in dairy cows. Regular monitoring of THI, along with heat-abatement strategies and improved environmental management, may help sustain productivity and fertility during hot and humid seasons.*

Keywords: Cattle; Heat Stress Disorders; Humidity; Lactation; Milk; Reproduction; Temperature

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Introduction

The practice of raising livestock for milk and dairy products is integral to food security and agricultural economies worldwide. The profitability and sustainability of dairy production systems are primarily determined by productive and reproductive efficiency (1). Environmental stressors, particularly heat stress, are among the main factors reducing dairy cattle performance worldwide. Heat stress is a condition in which the animal's heat load exceeds its ability to dissipate heat, leading to physiological and metabolic imbalances. High milk production metabolic activity makes dairy cattle very sensitive to high environmental temperatures (2). The adverse effects of heat stress are becoming increasingly significant as the climate deteriorates, global temperatures rise, and frequent heat waves occur, particularly in cattle-producing tropical and subtropical regions, due to chronic exposure of dairy animals to acidic environmental conditions (3).Heat stress negatively affects numerous physiological functions in dairy cattle, including decreased feed intake, altered endocrine activity, immune dysfunction, and increased maintenance energy requirements. The two major downsides of heat stress are reduced milk yield and reduced milk quality (4). The production of milk by the mammary gland is negatively affected by reduced dry matter intake and changes in nutrient metabolism of lactating cows under high THI environments. In addition to productive losses, heat stress affects reproduction by disrupting hormonal balance, follicular development, estrus expression, conception rate, and embryonic survival (5). Thermal stress can contribute to prolonged days open, delayed estrous response, and increased services per conception. These reproductive issues combined have a significant economic impact on dairy herds through compromised reproduction and additional herd management costs (6).
Therefore, the temperature-humidity index (THI) is widely used internationally as an effective indicator of heat stress severity in livestock. By monitoring the THI, researchers and farm managers can analyze environmental conditions and animal performance. Knowledge of the effects of heat stress on production and reproduction is necessary to

design adequate management systems that not only enhance animal welfare but also result in an economically sustainable dairy farm. Numerous studies have reported the effects of thermal stress on dairy cattle; however, due to the diversity of breeds, management, and environmental conditions across various production systems, further investigation is required. Accordingly, this study was conducted to assess the influence of heat stress on productive, reproductive, and environmental indicators in commercial dairy cattle across different levels of the temperature-humidity index (THI) (4, 7).

Methodology

The experiment was conducted on dairy cattle kept under semi-industrial conditions in a subtropical climate. The range consisted of fluctuations in ambient temperature and relative humidity during high environmental temperatures. The evaluation of the influence of thermal stress on the productive and reproductive performance of dairy cattle was conducted under both normal and heat-stress conditions.

A cross-sectional observational design was used to evaluate whether heat stress at the individual-animal level is associated with dairy performance. Animals were classified into multiple heat-stress groups based on the temperature-humidity index (THI). The productive and reproductive parameters were compared to determine the effect of increased heat-stress severity among these groups.

A total of 120 lactating dairy cows were used in this study. The selected animals were of the dairy breeds Holstein Friesian, Jersey, and Sahiwal. We included only clinically healthy cows in our study (animals with signs of systemic illness, metabolic disturbances, or reproductive abnormalities were excluded). All the cows were kept under regular farm management, feeding, and housing conditions.

Animals were sorted into quartiles based on their temperature-humidity index (THI) values. THI values between 68 and 72 were considered normal for cows. Animals were partitioned into mild heat-stress (THI: 73 and 78) and moderate heat-stressed (THI: 79 and 84). Severe heat stress was defined as exposure to THI values above 85 and below 90. There were 30 lactating dairy cows per group.

Ambient temperature and relative humidity were monitored with standard environmental monitoring instruments in the animal housing areas. The temperature-humidity index (THI), an indicator of exposure to heat stress, was calculated. THI has been divided into normal heat stress, mild heat stress, moderate heat stress and severe heat stress for animals.

Milk production was assessed based on daily milk yield and milk composition. Litter daily milk yield per cow. For this, standard milk analysis methods were performed to obtain composite parameters of milk as far as fat and protein are concerned. The extent of heat stress on milk yield and quality was estimated using these parameters.

Composite reproductive performance which includes expression of estrus, days from calving to first estrus, conception, services per conception and days open. Estrus expression was evaluated through direct observations and farm reproductive records. Days to first estrus comprised the number of days from calving to the first estrus. Conception status was determined after the breeding and reproductive management records were used to extract services per conception and days open.

Data on the environmental conditions, milk production, milk composition, and reproductive performance were collected on a structured recording sheet. The data was checked for completeness and checked for consistency between and within different data sources prior to analysis. Data were entered in the Microsoft Excel, sorted according to animal identification, breed, parity, lactation stage, heat-stress group, productive traits and reproductive traits.

Statistical analysis was performed using SPSS software. For all continuous variables, descriptive statistics were calculated and reported as mean (SD). Milk production and reproductive performance parameters were compared between groups exposed to varying temperatures using one-way analysis of variance. Multiple comparisons between groups were performed using Tukey's post hoc test. The association between the heat-stress groups and categorical reproductive parameters (estrus expression and conception status) was evaluated using chi-square tests. Pearson's correlation analysis was used to examine the associations between temperature-humidity index (THI) values and continuous productive and reproductive variables. Using linear regression analysis, the effect of the THI on milk yield was studied. Statistical significance was set at $p < 0.05$.

Results

In dairy cattle, heat stress significantly affected milk production performance. Milk production decreased with increasing heat-stress severity (Table 1). The highest average milk yield was observed in cows kept in a normal THI environment, and the lowest yield was recorded in cows under severe heat stress. A more direct representation of this decreasing trend is shown in Figure 1. Increasing THI levels also affected milk composition. Heat stress severity was also positively correlated with fat and protein, both of which declined with increasing heat stress severity. The normal THI group showed the highest levels of fat and protein, whereas the severe heat-stress group showed the lowest. Figure 2 provide a visual summary of these changes.

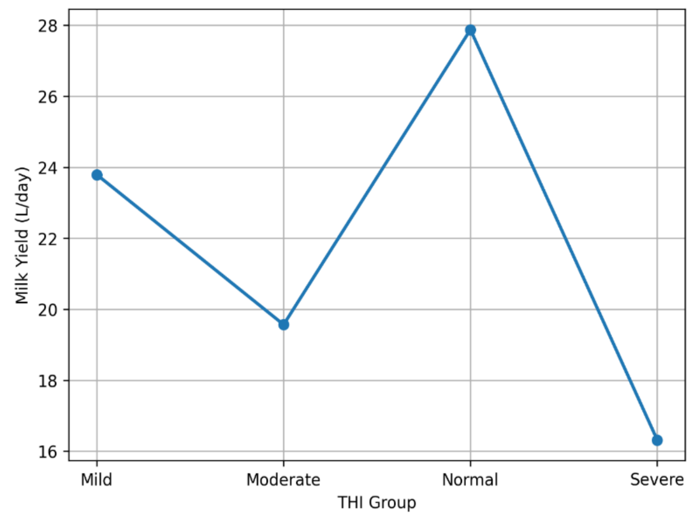

Figure 1: Effect of heat stress on daily milk yield in dairy cattle.

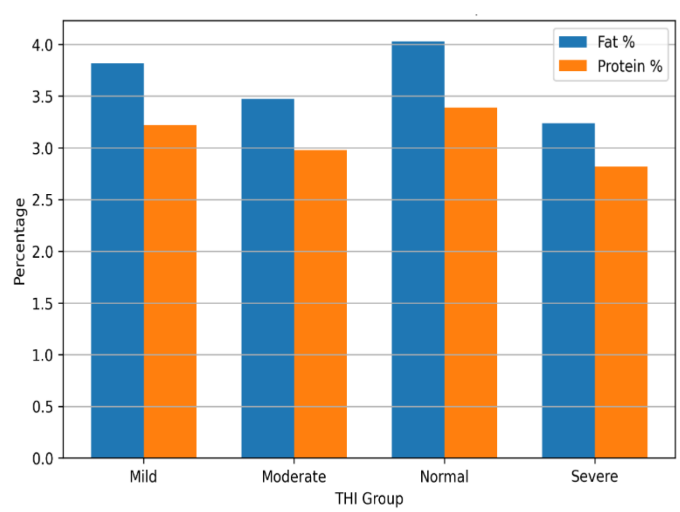

Figure 2: Effect of heat stress on milk fat and protein percentages in dairy cattle.

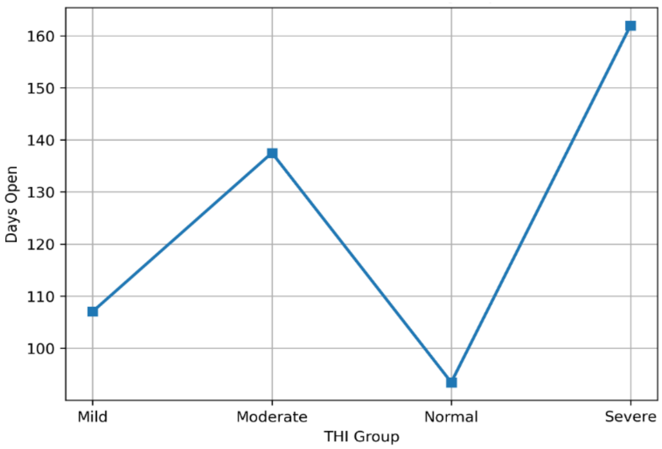

Figure 3: Effect of heat stress on days open in dairy cattle.

Heat stress affected reproductive performance in dairy cattle. The days for the first estrus were longer with higher THI, as shown in Table 2. Under normal environmental conditions, the interval to the first estrus was shorter in cows than in the group of cows affected by severe heat stress. Thus, providing more evidence of deferred post-calving reproductive activity under a more thermally stressful event. The increasing severity of heat stress also increased the number of services per conception. The normal THI group had the fewest services per conception, and the heat-stress group had the greatest value, according to the heat-insulation group. In addition, the days open increased markedly according to heat stress severity. Figure 3 shows the increase in days open, and Figure 4 shows the increase in services per conception.

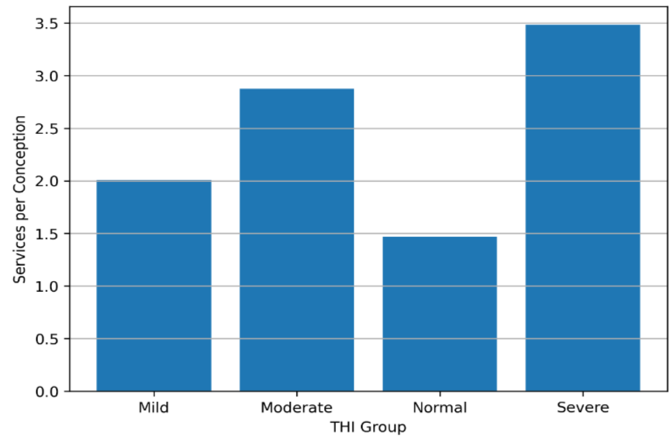

Figure 4: Effect of heat stress on services per conception in dairy cattle.

Table 1: Effect of Heat Stress on Milk Production and Milk Composition Parameters in Dairy Cattle

THI Group	Milk Yield (L/day) Mean ± SD	Fat (%) Mean ± SD	Protein (%) Mean ± SD
Normal	27.9 ± 2.1	4.01 ± 0.18	3.41 ± 0.09
Mild Heat Stress	24.2 ± 1.9	3.79 ± 0.20	3.21 ± 0.10
Moderate Heat Stress	20.1 ± 2.2	3.48 ± 0.19	3.01 ± 0.11
Severe Heat Stress	15.9 ± 2.0	3.18 ± 0.21	2.81 ± 0.10
p-value	<0.001	<0.001	<0.001

Table 2: Effect of Heat Stress on Reproductive Performance Parameters in Dairy Cattle

THI Group	Days to First Estrus Mean ± SD	Services per Conception Mean ± SD	Days Open Mean ± SD
Normal	44.6 ± 5.2	1.5 ± 0.3	89.8 ± 9.7
Mild Heat Stress	55.2 ± 6.1	2.0 ± 0.4	110.4 ± 11.8
Moderate Heat Stress	67.8 ± 7.9	2.8 ± 0.5	135.1 ± 14.6
Severe Heat Stress	81.9 ± 9.8	3.5 ± 0.6	160.3 ± 17.5
p-value	<0.001	<0.001	<0.001

Estrus expression was significantly reduced with increasing heat stress severity. The estrus observation percentage was higher in cows under normal THI conditions and lower in cows under severe heat stress (Table 3). There was a significant association between the THI group and estrus expression, as revealed by the chi-square test.

Table 3: Association Between THI Groups and Estrus Expression in Dairy Cattle

THI Group	Estrus Observed (%)	Estrus Not Observed (%)
Normal	86.7	13.3
Mild Heat Stress	73.3	26.7
Moderate Heat Stress	53.3	46.7
Severe Heat Stress	33.3	66.7
p-value	<0.001	

Heat stress also affected conception status. The pregnancy rate decreased gradually as heat stress severity increased (Table 4). The conception rate was highest in the normal THI group, followed by the mild and moderate heat-stress groups, which had closely similar rates, and the lowest was observed in the severe group. The THI group was significantly associated with conception status.

Table 4: Association Between THI Groups and Conception Status in Dairy Cattle

THI Group	Pregnant (%)	Not Pregnant (%)
Normal	80.0	20.0
Mild Heat Stress	63.3	36.7
Moderate Heat Stress	43.3	56.7
Severe Heat Stress	26.7	73.3
p-value	<0.001	

A high correlation was observed between THI and productive and reproductive traits using Pearson's correlation analysis. THI in Table 5 was negatively associated with milk yield, fat percentage, and protein percentage. This suggests that higher THI levels have adverse effects on milk production and milk quality. On the other hand, THI had positive associations with days to first estrus, services per conception, and days open.

In a linear regression analysis, THI was indicated as a significant predictor of milk yield. As shown in Table 6, the beta coefficient for THI was negative, indicating that each unit increase in THI was associated with a decrease in milk yield. The current findings are consistent with the observed reduction in milk yield in heat-stress groups.

Table 5: Pearson Correlation Between THI and Productive and Reproductive Parameters in Dairy Cattle

Variable	Correlation Coefficient (r)	p-value
Milk Yield	-0.87	<0.001
Fat Percentage	-0.81	<0.001
Protein Percentage	-0.84	<0.001
Days to First Estrus	0.88	<0.001
Services per Conception	0.85	<0.001
Days Open	0.91	<0.001

Table 6: Linear Regression Analysis Showing the Effect of THI on Milk Yield in Dairy Cattle

Predictor Variable	Beta Coefficient	Standard Error	t-value	p-value
THI Value	-0.68	0.05	-13.42	<0.001

Discussion

Heat stress (HS) has an important adverse effect on milk production and reproductive performance in dairy cows, as reported in the present study. Milk yield, milk fat %, and milk protein % decreased progressively with increasing Temperature-Humidity Index (THI). The results demonstrate that exposure to higher environmental temperatures associated with climate change negatively influences the production efficiency of dairy cows (8). The reduction in milk production under moderate to severe heat stress conditions is likely to have resulted from loss of feed intake, endocrine dysfunction, and increased metabolic workload for thermoregulation. Dairy cattle allocate energy to maintaining body temperature rather than continuously sustaining milk synthesis under heat stress, leading to reduced productivity (9).
The decrease in milk composition observed in the current study also supports the negative effect of thermal stress on both mammary gland activity and nutrient utilization. The results indicate that the percentages of fat and protein decreased linearly with increasing THI, suggesting possible impaired ruminal fermentation and changes in nutrient partitioning under environmental stress (10). In various available dairy studies, the same results were reported: under higher thermal stress, milk quality traits decreased due to reduced dry matter intake and metabolic disorders. The strong negative correlation between THI and milk production parameters observed in this study underscores that lactating dairy cattle are sensitive to climatic stressors (11). Heat stress also significantly impairs reproductive performance. The current results revealed a longer time to the first estrus, greater services per conception, and longer days open in cows exposed to higher THI levels (12). Furthermore, severe heat stress decreased estrus and conception rates. These effects can be attributed to high body temperature (13), which can disrupt ovarian function and can resulted as a hormonal imbalance that leads to impaired follicular development. Heat stress decreases fertility in dairy cattle by negatively affecting reproductive endocrinology, including: (1) reducing secretion of luteinizing hormone (2) decreasing oocyte quality and (3) increasing embryonic mortality (6). The high correlation coefficient between THI and reproductive performance observed in this study indicates that reproductive efficiency is affected by environmental stress. These studies demonstrated that heat stressed cows exhibited reduced estrus detection and conception rates than herds maintained in ambient environmental conditions (14). The positive correlations of THI with indicators of reproductive inefficiency support the concept that a higher THI is related to increased environmental stress that delays reproductive recovery, elongates response interval, and ultimately leads to decreased breeding efficiency. These results coincide with reports of pronounced fertility depression under heat stress and impaired physiological and behavioral reproductive response (15). Thus, this study's findings highlight the need for robust heat-stress management strategies in dairy production systems. The introduction of cooling systems, improved house ventilation, sufficient access to drinking water, and dietary adjustments can help mitigate thermal stress in dairy cattle. THI at high environmental temperatures can be monitored at critical times to identify heat-stress conditions and assist farmers in adopting preventive management practices to minimize deviations from optimal productive and reproductive performance in dairy herds.

Conclusion

The present study revealed that heat stress has a substantial impact on milk production and reproductive performance in dairy animals. Higher levels of the temperature-humidity index (THI) were significantly associated with sequential reductions in milk yield, fat content, and protein content, indicating the adverse influence of higher environmental temperature on dairy performance. Moderate to severe heat stress negatively affected reproductive efficiency in cows, including increased days to estrus, increased services per conception, increased days open, reduced estrus expression, and increased conception rates. The significant correlations found among THI and productive and reproductive traits strongly establish heat stress as the major environmental factor negatively affecting dairy herd performance. This indicates that thermal stress adversely affects normal physiological, metabolic, and endocrine functions, ultimately reducing the overall productivity of dairy cattle. However, with the well-documented detrimental effects of heat stress on productivity and fertility, the fact is that effective strategies, including increasing ventilation in housing, installing cooling systems, and maintaining nutritional support. Consequently, heat-stress conditions can be anticipated and prevented, and ultimately leads to positive economic, reproductive and welfare outcomes, especially in monitoring dairy livestock sections.

Declarations

Consent for publication
Approved

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Conflict of interest

The authors declared the absence of a conflict of interest.

Author Contribution

MJK, S, IH
Contributed to study design, data collection and initial manuscript drafting
Assisted in data acquisition, literature review and manuscript editing
Performed statistical analysis and contributed to interpretation of results
IAC, MMS, BA
Helped in methodology development, data organization and manuscript formatting
Contributed to patient recruitment, data entry and results compilation
Assisted in referencing, proofreading and final revisions of the manuscript
AUR, SKAS, SQ, GK
Provided guidance in study execution and critically reviewed the manuscript
Supervised the research, coordinated among authors, finalized the manuscript and approved the final version

All authors reviewed the results and approved the final version of the manuscript. They are also accountable for the integrity of the study.

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