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Research Article

Temporal and Spatial Variations of Temperature-Humidity Index Related to Heat Stress in High-Altitude Dairy Cattle Farms

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ABSTRACT

Heat stress is a significant concern in dairy cattle production, even in high-altitude areas typically associated with cooler climates. This study investigated the temporal and spatial variations of the Temperature-Humidity Index (THI), air temperature, and relative humidity at a high-altitude dairy farm during the rainy season in West Sumatra, Indonesia. Environmental data were collected bi-hourly from 08:00 to 16:00 at three different locations: outside the pen, inside a pen equipped with fan ventilation, and inside a pen without fan ventilation. ANOVA and Tukey post-hoc tests revealed significant differences across both time and location. The highest THI levels were recorded outside the pen during midday (12:00–14:00), with a mean of 80.18 ± 3.76, compared to 76.17 ± 1.96 in the fan-ventilated pen and 74.96 ± 1.88 in the non-ventilated pen. Notably, there were no significant differences in THI between the two indoor environments, indicating that fan ventilation had limited effectiveness. All indoor THI values reflected moderate heat stress. Additionally, Pearson correlation analysis revealed a strong negative correlation between temperature and humidity across all locations ($r = -0.88$ to -0.97; $p < 0.05$). These findings highlight the limitations of current ventilation systems and emphasize the urgent need for improved microclimate management strategies in high-altitude dairy farming.

Keywords: dairy cattle, heat stress, temperature-humidity index, fan ventilation, microclimate, West Sumatra

INTRODUCTION

Heat stress has become a significant challenge for the dairy farming industry in recent years, particularly impacting high-altitude dairy cattle operations. As climate change exacerbates extreme weather conditions, including rising temperatures and variable humidity levels, the effects on dairy cattle productivity and welfare are profound. The Temperature-Humidity Index (THI) is a crucial metric for assessing heat stress, as it evaluates the combined effects of temperature and humidity on cattle physiology and productivity. Elevated THI values are associated with reduced feed intake, diminished milk yield, and a heightened risk of health issues, including increased disease incidence and mortality among dairy cows (Liu et al., 2019; Nzeyimana et al., 2023; Tariq et al., 2024).

Traditionally, high-altitude environments have been viewed as relatively adapted to heat stress due to their lower ambient temperatures. However, recent studies have revealed that these regions are not free from heat-related challenges, particularly during midday hours when solar radiation is at its peak, which can lead to cumulative stress responses in cattle (Bedada et

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al., 2021). Consequently, the growing incidence of heat stress cases in high-altitude dairy farms highlights an urgent need for comprehensive research into the environmental variables that affect dairy cattle welfare.

Dairy cattle are especially vulnerable to heat stress due to their high metabolic demands and physiological responses to rising temperatures (Habimana et al., 2023a). The significant adverse effects include a marked decline in reproductive performance, as heat stress disrupts both ovulatory functions and gestational outcomes (Cartwright et al., 2023; Nielsen & Wredle, 2023). Studies have demonstrated that heat stress can lead to specific physiological changes, including increased rectal temperatures, alterations in metabolic profiles, and heightened stress hormone levels, which can culminate in various health challenges (Dahl et al., 2020; Joo et al., 2021; Sesay, 2023).

Given the distinct climatic condition's characteristic of high-altitude dairy farms, particularly during the rainy season, a thorough understanding of microclimatic factors is essential. This study aims to comprehensively assess the temporal and spatial variations of the Temperature-Humidity Index (THI), ambient temperature, and relative humidity across three distinct locations within a high-altitude dairy farm in West Sumatra, Indonesia. By systematically investigating environmental stressors in both ventilated and non-ventilated indoor settings, this research aims to clarify the microclimatic challenges these animals face and inform effective management strategies. Furthermore, the insights gained from this study may contribute to enhanced animal welfare measures and improve productivity outcomes for dairy farmers operating in comparable climatic regions.

MATERIAL AND METHODS

Study Area and Period

The study was conducted at a high-altitude dairy farm in West Sumatra, Indonesia, situated approximately 850 meters above sea level. This location was characterized by specific microclimatic conditions that can differ significantly from those found in lower-altitude dairy farming environments. Data collection took place over several consecutive days during the rainy season 2024.

Experimental Design and Sampling Locations

To assess microclimatic variations within the farm, a structured experimental design was implemented, focusing on three distinct locations selected for their differing environmental interventions:

1. Outside the Pen (Outside Pen): This site reflects the typical ambient conditions of the farm's external environment and serves as a baseline for comparative analysis with the more controlled indoor settings.
2. Inside the Pen with Fan Ventilation (Inside Pen with Fan): This location features mechanical fan ventilation to enhance air circulation. The goal of this intervention is to create a more stable microclimate, which may help to alleviate thermal stress experienced by the cattle.
3. Inside the Pen without Fan Ventilation (Inside Pen without Fan): In this setting, there is no active air movement, offering a controlled environment to examine the effects of stagnant air on temperature and humidity levels.

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Data Collection

The study concentrated on three crucial environmental parameters essential for understanding the welfare implications of heat stress in dairy cattle:

1. Air Temperature (°C, °F): Measured as a direct indicator of the thermal environment experienced by the cattle. Temperature data were converted from Celsius to Fahrenheit using the formula $F = [(C \times (9/5)] + 32$.
2. Relative Humidity (RH, %): Measured to evaluate the moisture content in the air, which significantly impacts thermal comfort and respiratory health in cattle.
3. Temperature-Humidity Index (THI): Calculated to provide a comprehensive evaluation of heat stress levels, incorporating both air temperature and relative humidity. The formula for THI calculation is as follows: $THI = (1.8 \times T + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)]$. In this equation, T represents the air temperature in degrees Celsius, and RH signifies the relative humidity as a percentage. This calculation combines temperature and humidity data to reflect the potential thermal stress experienced by the cattle.

Data collection was conducted systematically every two hours, from 08:00 to 16:00, allowing for capturing environmental variations throughout the day. To ensure accuracy in reflecting the microenvironments experienced by the animals, calibrated digital thermo-hygrometers were strategically positioned at a height of 1.5 meters from the ground, aligning with the typical position of cattle's respiratory tracts.

Statistical Analysis

Descriptive statistics, including means and standard deviations, were calculated for each environmental variable. A One-way Analysis of Variance (ANOVA) was conducted to identify significant differences in recorded values among the three sampling locations. To strengthen the robustness of the observed differences, Tukey's Honestly Significant Difference (HSD) test was utilized for pairwise comparisons. Additionally, Pearson correlation analysis was performed to examine the relationship between air temperature and relative humidity. Throughout the statistical assessments, a significance level of $p < 0.05$ was maintained to ensure the reliability of the findings.

RESULTS AND DISCUSSION

The research on temperature, relative humidity (RH), and Temperature-Humidity Index (THI) at a high-altitude dairy farm during the rainy season in 2024 delineates critical insights into the environmental challenges dairy cattle face, particularly concerning heat stress. The study reported on Table 1 that significant temperature fluctuations, with peak external temperatures reaching 30.46°C (86.83°F) and a maximum THI of 80.18 ± 3.76 occurring from noon to 14:00. These conditions indicate a severe heat stress risk for the cattle, corroborating existing literature that highlights the detrimental effects of high ambient temperatures on livestock health and production (Cardoso et al., 2018; Cartwright et al., 2022).

Inside the barns, despite lower temperatures, the observed THI values (ranging from 70.81 to 76.17) suggest that moderate heat stress conditions persisted. This finding is significant, as higher indoor relative humidity, frequently exceeding 70%, can hinder the animals' ability to dissipate heat via evaporative cooling mechanisms (Cartwright et al., 2022; Santoso et al., 2023). The limited effectiveness of fan ventilation, which did not lead to a statistically significant reduction in THI ($p > 0.05$), indicates challenges associated with fan capacity and placement, along with the impacts of high humidity (Santoso et al., 2023; Jung et al., 2023). Previous studies

have demonstrated that inadequate ventilation strategies can significantly contribute to thermal discomfort in cattle, underscoring the need for optimized microclimate management approaches to alleviate heat stress (Küçüktopçu et al., 2022; Jung et al., 2023).

The emphasis on the need for enhanced environmental management practices is critical. Current passive cooling methods, such as fan ventilation, are insufficient in severe humidity conditions, leading to calls for the implementation of active cooling techniques like misting systems. Research indicates that misting systems can effectively enhance thermal comfort by utilizing evaporative cooling principles, which may lower ambient temperatures substantially (Delgado et al., 2020; Wang et al., 2024). For instance, studies have revealed that well-designed misting systems can contribute to better physiological responses in cattle by managing THI and reducing heat stress (Horr et al., 2019; Santoso et al., 2023; Wang et al., 2024). It was initially found that significant variations existed among the measured parameters across different locations and times of day.

Correlation between Temperature and Relative Humidity

Pearson correlation analysis revealed a significant negative correlation between temperature and relative humidity across all sampling locations: outside pen ($r = -0.88$), inside pen with fan ($r = -0.97$), and inside pen without fan ($r = -0.95$, $p < 0.05$). Established research indicates that as ambient temperatures rise alongside increased humidity, the ability of dairy cows to dissipate heat diminishes, leading to adverse physiological and production outcomes (Fontoura et al., 2022; Cartwright et al., 2022; Habimana et al., 2023a).

The relationship between temperature, relative humidity, and dairy cattle health and productivity is underscored by studies identifying specific THI thresholds above which significant physiological distress occurs. When THI exceeds values around 70, signs of heat stress become evident, including increased respiration rates and elevated rectal temperatures (Rolando et al., 2022). These stress responses not only impact immediate welfare but also contribute to long-term effects such as reduced feed intake, lower milk yield, and decreased fertility (Polsky & Keyserlingk, 2017; Habimana et al., 2023b; Tariq et al., 2024).

Implications for Dairy Cattle Welfare

The data (Figure 1) emphasized that despite residing in a high-altitude area, dairy cattle were subjected to moderate to severe heat stress, especially during midday. Recent studies highlight that many current ventilation and cooling practices on dairy farms are insufficient in counteracting such thermal stress, prompting a need for innovative agricultural practices to protect animal welfare (Mogre et al., 2021; Comin et al., 2022; Habimana et al., 2023a). Potential interventions could involve optimizing ventilation strategies, exploring passive cooling designs, and integrating alternative cooling methodologies, such as misting systems and better thermal mass structures. The implications of heat stress extend beyond immediate discomfort; they can lead to long-term economic and productivity losses, thereby challenging the sustainability of dairy operations, even in regions typically perceived as cooler (Leliveld & Provolo, 2020; Comin et al., 2022).

Adaptation strategies for dairy farming must encompass management practices and genetic improvement approaches. Breeds exhibiting heat tolerance could offer enhanced resilience against heat stress, and integrating such breeds into genetic improvement programs is crucial for productivity, especially in changing climatic conditions (Chawala et al., 2021; Habimana et al.,

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2023a). By focusing on immediate and long-term strategies to mitigate heat stress, the dairy industry can enhance cattle welfare and thus promote the economic viability of dairy operations.

Table 1. Average of Temperature (°C and °F), Relative Humidity (RH in %), and Temperature-Humdity Index (THI) at Various Times and Locations

Location	Hour	Temperature (°C)					Temperature (°F)				
		Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
Outside Pen	8	25.34	25.70	23.60	27.20	1.44	77.61	78.26	74.48	80.96	2.60
	10	27.90	28.10	24.60	31.30	2.39	82.22	82.58	76.28	88.34	4.31
	12	30.46	31.20	24.90	33.00	3.20	86.83	88.16	76.82	91.40	5.76
	14	29.40	30.10	25.00	31.90	2.59	84.92	86.18	77.00	89.42	4.66
	16	27.70	28.40	26.30	29.00	1.26	81.86	83.12	79.34	84.20	2.26
		RH (%)					THI				
		Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
	8	69.20	69.00	67.00	72.00	1.92	74.29	75.14	71.67	76.92	2.20
	10	61.40	58.00	56.00	70.00	6.23	76.98	76.81	73.26	81.00	2.74
	12	59.20	57.00	48.00	72.00	8.93	80.18	81.88	73.92	83.32	3.76
	14	61.40	59.00	51.00	71.00	7.80	79.07	79.83	73.97	80.95	2.90
	16	60.80	57.00	56.00	68.00	6.14	76.66	77.04	75.47	78.00	1.05
		Temperature (°C)					Temperature (°F)				
		Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
Inside Pen with Fan	8	22.42	22.00	21.60	24.30	1.09	72.36	71.60	70.88	75.74	1.97
	10	23.46	22.80	22.40	25.80	1.42	74.23	73.04	72.32	78.44	2.56
	12	25.74	26.40	22.90	27.10	1.65	78.33	79.52	73.22	80.78	2.98
	14	24.98	25.30	21.80	26.90	1.90	76.96	77.54	71.24	80.42	3.41
	16	24.56	24.50	23.50	25.50	0.93	76.21	76.10	74.30	77.90	1.68
		RH (%)					THI				
		Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
	8	80.60	80.00	78.00	85.00	2.61	70.81	70.10	69.78	73.59	1.60
	10	76.00	78.00	66.00	81.00	6.04	72.02	71.22	70.74	74.62	1.61
	12	70.60	69.00	64.00	82.00	6.77	74.96	75.88	71.71	76.27	1.88
	14	70.40	70.00	62.00	83.00	7.77	73.77	74.32	70.00	76.35	2.32
	16	72.00	70.00	67.00	79.00	5.66	73.36	73.11	72.24	74.29	0.90
		Temperature (oC)					Temperature (°F)				
		Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
Inside Pen without Fan	8	23.42	23.20	22.00	25.40	1.24	74.16	73.76	71.60	77.72	2.24
	10	24.28	24.10	22.70	26.70	1.47	75.70	75.38	72.86	80.06	2.65
	12	26.84	27.20	23.80	28.10	1.76	80.31	80.96	74.84	82.58	3.17
	14	26.46	26.80	23.80	28.10	1.59	79.63	80.24	74.84	82.58	2.86
	16	25.88	25.90	24.70	26.90	1.03	78.58	78.62	76.46	80.42	1.85
		RH (%)					THI				
		Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
	8	79.20	80.00	68.00	86.00	6.72	72.26	72.21	70.10	74.25	1.49
	10	72.60	75.00	63.00	79.00	6.07	72.97	72.99	71.14	75.57	1.64
	12	67.00	63.00	62.00	78.00	7.00	76.17	77.02	72.80	77.58	1.96
	14	68.40	70.00	58.00	81.00	8.68	75.77	76.57	73.08	76.90	1.57
	16	68.60	65.00	62.00	78.00	7.80	74.97	74.70	74.02	75.73	0.75

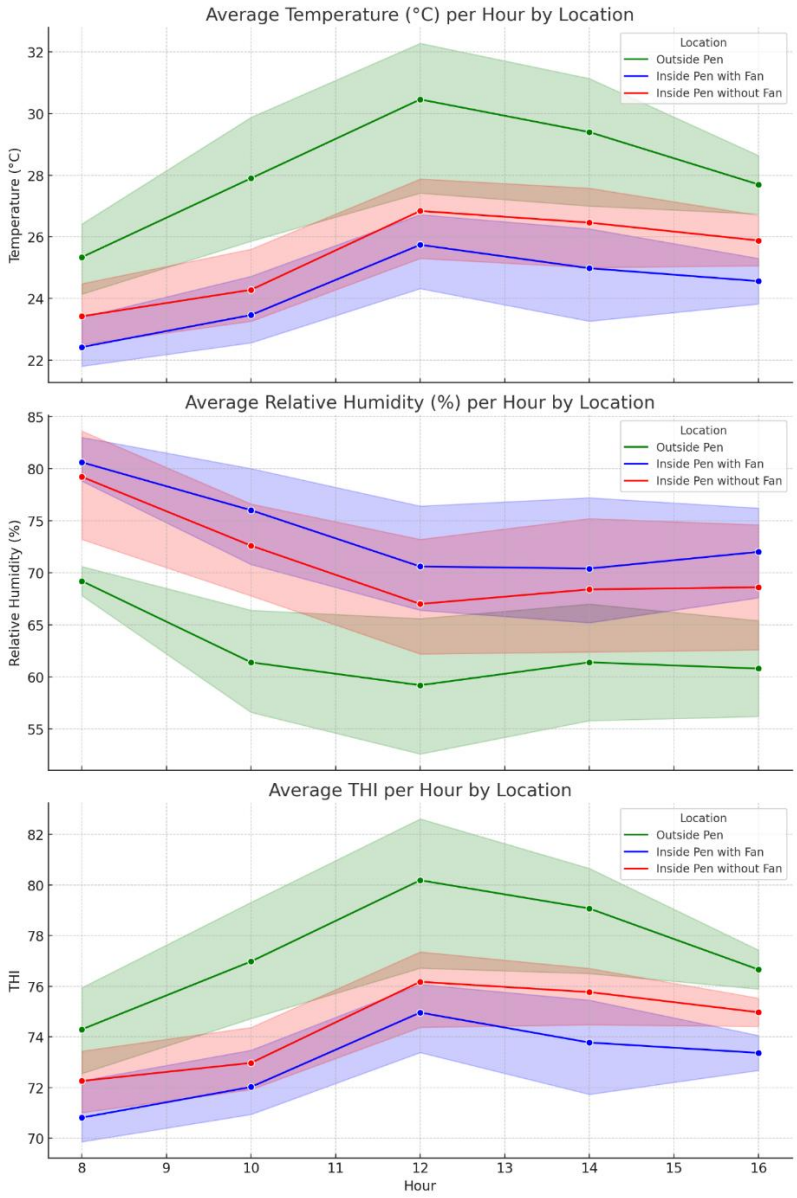


Figure 1. Average of Temperatures, RH, and THI per Hour by Location

Table 2 presents the mean and standard deviation (SD) of the Temperature-Humidity Index (THI) measured at three locations—outside the pen, inside the pen with fan ventilation, and inside the pen without fan ventilation—across five time points between 08:00 and 16:00.

Table 2. Temperature-Humidity Index (THI) Analysis by Location and Hour

Hour	Outside Pen (Mean ± SD)	Inside Pen with Fan (Mean ± SD)	Inside Pen without Fan (Mean ± SD)
8	74.29 ± 2.20^{a}	72.26 ± 1.49^{b}	70.81 ± 1.60^{c}
10	76.98 ± 2.74^{a}	72.97 ± 1.64^{b}	72.02 ± 1.61^{b}
12	80.18 ± 3.76^{a}	76.17 ± 1.96^{b}	74.96 ± 1.88^{c}
14	79.07 ± 2.90^{a}	75.77 ± 1.57^{b}	73.77 ± 2.32^{c}
16	76.66 ± 1.05^{a}	74.97 ± 0.75^{b}	73.36 ± 0.90^{b}

Note: Superscript letters indicate significant differences among locations for each hour ($p<0.05$). Locations sharing the same letter are not significantly different.

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Interestingly, the superscript letters denote significant differences among locations. At 8:00, 12:00, and 14:00, there is a clear distinction among all three locations, with each showing significantly different THI values (a ≠ b ≠ c). However, at 10:00 and 16:00, the THI values inside the pen with and without fan ventilation share the same superscript letter 'b', indicating no significant difference between these two indoor conditions at these times. This suggests that fan ventilation may only have a limited or time-dependent impact on reducing heat stress within the pen.

The temporal specificity and varying impact of fan ventilation on THI necessitate reevaluating current management practices in dairy operations. As these insights illustrate the complexity of livestock thermal environments, integrating additional cooling interventions, such as misting systems or improved airflow designs, may prove beneficial in mitigating heat stress more effectively (Yano et al., 2018). Research increasingly indicates that a multi-faceted approach addressing environmental management can significantly enhance dairy cow welfare and productivity under challenging climatic conditions.

This issue is particularly significant in Indonesia, a tropical country where ambient temperatures can reach 34°C and relative humidity frequently hovers between 70% and 90%. Most of the dairy cattle population—over 98%—is located on Java Island and primarily consists of Friesian Holstein (FH) cattle, which were initially bred for temperate climates. These environmental conditions render FH cattle especially susceptible to heat stress, which has emerged as one of the primary factors limiting dairy productivity (Asmarasari et al., 2023).

CONCLUSION

Dairy cattle in high-altitude areas are still susceptible to heat stress during the rainy season. Current ventilation strategies are inadequate in mitigating heat stress, particularly under high humidity. Integrating alternative cooling systems and revising barn designs are essential to improve cattle welfare and farm productivity. Further research is needed to evaluate physiological responses and milk yield under various microclimate interventions.

REFERENCES

Asmarasari, S., Azizah, N., Sutikno, S., Puastuti, W., Amir, A., Praharani, L., ... & Hayanti, S. (2023). A review of dairy cattle heat stress mitigation in Indonesia. *Veterinary World*, 1098–1108. https://doi.org/10.14202/vetworld.2023.1098-1108

Bedada, K., Kechero, Y., & Janssens, G. (2021). Seasonal and agro-ecological associations with feed resource use and milk production of ranging dairy cows in the southern Ethiopian Rift Valley. *Tropical Animal Health and Production, 53*(4). https://doi.org/10.1007/s11250-021-02867-0

Cardoso, C., Keyserlingk, M., Hötzel, M., Robbins, J., & Weary, D. (2018). Hot and bothered: Public attitudes towards heat stress and outdoor access for dairy cows. *PLoS One, 13*(10), e0205352. https://doi.org/10.1371/journal.pone.0205352

Cartwright, S., Schmied, J., Livernois, A., & Mallard, B. (2022). Physiological response to heat stress in immune phenotyped Canadian Holstein dairy cattle in free-stall and tie-stall management systems. *Frontiers in Animal Science, 3*. https://doi.org/10.3389/fanim.2022.852958

Cartwright, S., Schmied, J., Karrow, N., & Mallard, B. (2023). Impact of heat stress on dairy cattle and selection strategies for thermotolerance: a review. *Frontiers in Veterinary Science, 10*. https://doi.org/10.3389/fvets.2023.1198697

Chawala, A., Sánchez-Molano, E., Dewhurst, R., Peters, A., Chagunda, M., & Banos, G. (2021). Breeding strategies for improving smallholder dairy cattle productivity in Sub-saharan Africa. *Journal of Animal Breeding and Genetics, 138*(6), 668-687. https://doi.org/10.1111/jbg.12556

Comin, V., Karsburg, H., Souza, B., Almeida, H., Neira, L., & Rossi, G. (2022). Perception of animal welfare and its certification system by Brazilian consumers and dairy farmers. *Journal of Dairy Research, 89*(1), 53-56. https://doi.org/10.1017/s0022029922000024

Dahl, G., Tao, S., & Laporta, J. (2020). Heat stress impacts immune status in cows across the life cycle. *Frontiers in Veterinary Science, 7*. https://doi.org/10.3389/fvets.2020.00116

Delgado, M., Ramos, J., Domínguez, S., Ulloa, F., & Ríos, J. (2020). Evaporative mist cooling as heat dissipation technique: Experimental assessment and modelling. *Applied Sciences, 10*(17), 6026. https://doi.org/10.3390/app10176026

Fontoura, A., Javaid, A., Maza-Escolà, V., Salandy, N., Fubini, S., Grilli, E., … & McFadden, J. (2022). Heat stress develops with increased total-tract gut permeability, and dietary organic acid and pure botanical supplementation partly restores lactation performance in Holstein dairy cows. *Journal of Dairy Science, 105*(9), 7842-7860. https://doi.org/10.3168/jds.2022-21820

Habimana, V., Ekine-Dzivenu, C., Nguluma, A., Nziku, Z., Morota, G., Chenyambuga, S., … & Mrode, R. (2023a). Genes and models for estimating genetic parameters for heat tolerance in dairy cattle. *Frontiers in Genetics, 14*. https://doi.org/10.3389/fgene.2023.1127175

Habimana, V., Nguluma, A., Nziku, Z., Ekine-Dzivenu, C., Morota, G., Mrode, R., … & Chenyambuga, S. (2023b). Heat stress effects on milk yield traits and metabolites and mitigation strategies for dairy cattle breeds reared in tropical and sub-tropical countries. *Frontiers in Veterinary Science, 10*. https://doi.org/10.3389/fvets.2023.1121499

Horr, Y., Tashtoush, B., Chilengwe, N., & Musthafa, M. (2019). Performance assessment of a hybrid vapor compression and evaporative cooling fresh-air-handling unit operating in hot climates. *Processes, 7*(12), 872. https://doi.org/10.3390/pr7120872

Joo, S., Lee, S., Park, D., Kim, D., Gu, B., Park, Y., … & Kim, E. (2021). Changes in blood metabolites and immune cells in holstein and jersey dairy cows by heat stress. *Animals, 11*(4), 974. https://doi.org/10.3390/ani11040974

Jung, S., Chung, H., & Choi, C. (2023). Assessment of airflow patterns induced by a retractable baffle to mitigate heat stress in a large-scale mechanically ventilated barn. *Agriculture, 13*(10), 1910. https://doi.org/10.3390/agriculture13101910

Küçüktopçu, E., Seyfi, S., Mustaqimah, M., & Cemek, B. (2022). Computational fluid dynamics modeling of environmental conditions in a naturally ventilated free-stall dairy barn. *Journal of Agricultural Faculty of Gaziosmanpasa University*. https://doi.org/10.55507/gopzfd.1181753

Leliveld, L. and Provolo, G. (2020). A review of welfare indicators of indoor-housed dairy cow as a basis for integrated automatic welfare assessment systems. *Animals, 10*(8), 1430. https://doi.org/10.3390/ani10081430

 DOI: 10.25077/alive.v2.n1.p98-106.2025

Liu, J., Li, L., Chen, X., Lu, Y., & Dong, W. (2019). Effects of heat stress on body temperature, milk production, and reproduction in dairy cows: a novel idea for monitoring and evaluation of heat stress — a review. *Asian-Australasian Journal of Animal Sciences, 32*(9), 1332-1339. https://doi.org/10.5713/ajas.18.0743

Mogre, J., Adzitey, F., & Teye, G. (2021). Assessment of cattle welfare on ghanaian farms. *Asia Pacific Journal of Sustainable Agriculture Food and Energy, 9*(2), 1-9. https://doi.org/10.36782/apjsafe.v9i2.113

Nielsen, P. and Wredle, E. (2023). How does the provision of shade during grazing affect heat stress experienced by dairy cows in Sweden?. *Animals, 13*(24), 3823. https://doi.org/10.3390/ani13243823

Nzeyimana, J., Fan, C., Zhao, Z., Butore, J., & Cheng, J. (2023). Heat stress effects on the lactation performance, reproduction, and alleviating nutritional strategies in dairy cattle, a review. *Journal of Animal Behaviour and Biometeorology, 11*(3), 2023018. https://doi.org/10.31893/jabb.23018

Polsky, L. and Keyserlingk, M. (2017). Invited review: effects of heat stress on dairy cattle welfare. *Journal of Dairy Science, 100*(11), 8645-8657. https://doi.org/10.3168/jds.2017-12651

Rolando, P., Sandoval-Monzón, R., Montenegro, M., & Ruiz-García, L. (2022). Temperature-humidity index and reproductive performance of dairy cattle farms in Lima, Peru. *Open Veterinary Journal, 12*(3), 399. https://doi.org/10.5455/ovj.2022.v12.i3.14

Santoso, K., Audona, R., Komariah, K., Seminar, K., & Ulum, M. (2023). Innovative barn cattle for microclimate management through the misting system. *Buletin Peternakan, 47*(4), 207. https://doi.org/10.21059/buletinpeternak.v47i4.79464

Sesay, A. (2023). Effect of heat stress on dairy cow production, reproduction, health, and potential mitigation strategies. *Journal of Applied and Advanced Research*, 13-25. https://doi.org/10.21839/jaar.2023.v8.8371

Tariq, M., Khan, M., Manzoor, H., Asghar, M., Nazeer, H., Sadiq, A., … & Rehman, M. (2024). Effect of heat stress on ovaries evolution of repeat breeders in dairy cattle, specifically Holstein Friesian. *Biological and Clinical Sciences Research Journal*, (1), 737. https://doi.org/10.54112/bcsrj.v2024i1.737

Wang, P., Lu, S., Wu, X., Tian, J., & Li, N. (2024). Mist spraying as an outdoor cooling spot in hot-humid areas: Effect of ambient environment and impact on short-term thermal perception. *Buildings, 14*(2), 336. https://doi.org/10.3390/buildings14020336

Yano, A., & Widayati, D. (2018). Application of a tunnel-ventilated barn on the physiological responses, milk yield, and dry matter intake of dairy cows in tropical area during the wet season. *Journal of Animal Behaviour and Biometeorology, 6*(4), 97–101. https://doi.org/10.31893/2318-1265jabb.v6n4p97-101