Special Issue:
Advancements in Animal Health and Production in Low and Middle-Income Countries

Advancements in Heat Stress Mitigation Strategies for Dairy Cattle

Abbas Khalid Abbas[1], Zaid Khalid Alani[2*], Sarah Luay Subhi[3], Tabarak Dakheel Mohammed[4], Resan Shakir Abdulamer[5], Reem Hamdan Khaddour[6], Hasan Abdullah[7]

[1]College of Education, University of Samarra, Iraq; [2]College of Pharmacy, Al-Turath University, Baghdad, Iraq; [3]Department of Dialysis Technology, College of Health and Medical Technologies, Al-Bayan University, Baghdad, Iraq; [4]Department of Medical Laboratory Techniques, Al-Farahidi University, Baghdad, Iraq; [5]Department of Medical Laboratories Technology, Al-Nisour University College, Baghdad, Iraq; [6]Mazaya University College, Iraq; [7]Department of Optical Techniques, Al-Zahrawi University College, Karbala, Iraq.

Abstract | Heat stress constitutes a significant threat to dairy cattle welfare and productivity in semi-arid and tropical climates. The present research aimed to assess the efficacy of two field-based management measures evaporative cooling and nutritional supplementation on the physiological, behavioural, and productive responses of lactating crossbred cows during the summer peak months. Fifteen cows were randomly divided into three treatment groups: No treatment (control), cooling only (fan with and without the mist system), and cooling combined with nutritional treatment (antioxidants and electrolytes). Compared with the two other groups, the combined-intervention group presented with significantly lower rectal temperatures, respiration rates, and heart rates, but also showed increased yield, food intake, and improved behaviours related to comfort. The results validate that a combined strategy involving low-cost cooling infrastructure and affordable dietary supplements can improve heat stress tolerance in dairy cows under actual farm conditions, providing a feasible solution for small to medium-scale farmers in heat-prone areas.

Keywords | Dairy cattle, Heat stress, Cooling system, Nutritional supplementation, Physiological response

Received | June 22, 2025; **Accepted** | August 02, 2025; **Published** | August 12, 2025
***Correspondence** | Zaid Khalid Alani, College of Pharmacy, Al-Turath University, Baghdad, Iraq; **Email:** zaid.khaled@uoturath.edu.iq
Citation | Abbas AK, Alani ZK, Subhi SL, Mohammed TD, Abdulamer RS, Khaddour RH, Abdullah H (2025). Advancements in heat stress mitigation strategies for dairy cattle. J. Anim. Health Prod. 13(s1): 105-112.
DOI | https://dx.doi.org/10.17582/journal.jahp/2025/13.s1.105.112
ISSN (Online) | 2308-2801

INTRODUCTION

Heat stress is a significant environmental challenge facing the global dairy industry, particularly in the tropics and subtropics, where high ambient temperatures and humidity are the norm. Dairy cows, particularly high-yielding breeds such as Holstein-Friesians, are susceptible to high thermal loads due to their high metabolic rates and limited capacity to dissipate heat effectively (Becker and Stone, 2020). When the ambient temperature exceeds the thermoneutral zone of the animal, physiological processes such as enhanced respiration rate, panting, decreased feed intake (Becker, 2021), and modified blood flow are initiated to achieve homeostasis (Bishop-Williams *et al*., 2015). These compensatory mechanisms typically result in significant reductions in milk yield, reproductive performance (Brown-Brandl, 2018), and overall animal well-being, which have substantial economic implications for dairy farmers (Conte *et al*., 2018).

Recent climatic evaluations indicate a growing incidence and severity of heatwaves due to global climate change. Therefore, the potential for heat stress-induced losses in livestock production, particularly in dairy cattle, has become a focus of expanding research in veterinary and animal sciences (Das *et al*., 2016). In rapidly growing dairy economies and hot summer climates, such as those in India, Brazil, and parts of the Middle East, the adverse effects of heat stress are becoming increasingly apparent (Dash *et al*., 2016). Besides compromised productivity, heat-stressed animals are also at greater risk for metabolic disorders, mastitis, and lameness, adding further complexity to animal health management in dairy operations (De Rensis *et al*., 2015). Hence, the management of and imparting knowledge about effective preventive measures against heat stress is critical in supporting animal well-being, productivity (Fabris *et al*., 2019), and the economic efficiency of dairy production.

While traditional approaches, such as providing shade and ventilation, have been practised for a long time, their success depends on weather conditions and the size of the herd (Fodor *et al*., 2018). Breakthroughs in farm technology and an enhanced understanding of the animal's physiology have led to new methods for better managing heat stress (Fournel *et al*., 2017). Current interventions also include mechanical cooling systems, locally adapted house designs, precision environmental monitoring devices (Galán *et al*., 2018), and nutritional adjustments that help the cow increase its internal heat-regulation mechanism. However, even with these advances, their field adoption and biological performance are highly variable as a function of local climatic regimes, herd genetic makeup, and farming practice (Gupta *et al*., 2022). There is an urgent need for site-specific field research that compares and measures the effectiveness of different mitigation options under actual farm conditions, providing data-based recommendations.

MATERIALS AND METHODS

Study area and climatic profile

The current study was conducted from May to August 2024, which coincides with the peak summer months, on a small commercial dairy farm located within the semi-arid region of India., and the region witnesses high diurnal temperatures between 36°C to 46°C (Herbut *et al*., 2018), while the relative humidity during the period varies from 25% to 55%.

A digital automated weather station (AWS) was installed on the premises of the shed to measure environmental parameters continuously. Ambient temperature and relative humidity measurements were recorded hourly and used to calculate the Temperature-Humidity Index (THI), a measure of thermal stress. The THI was calculated using the following standard formula:

$$THI = (1.8 \times T + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)]$$

Where T is the dry bulb temperature (°C) and RH is the relative humidity (%). The average daily THI values were recorded to classify the heat stress level in the environment during the experiment.

The intensity of heat stress was measured using the Temperature-Humidity Index (THI), which was computed daily from meteorological readings taken from an on-site automated weather station (Herbut *et al*., 2021). The index was used to measure the thermal burden on the animals throughout the trial period. The THI values were averaged weekly to track changes in environmental stress levels throughout the six-week study (Johnson, 2018). The Figure 1 shows the variation in weekly THI values, which aid in determining whether the animals experienced comfortable, mild, or hot heat stress conditions at various stages of the trial.

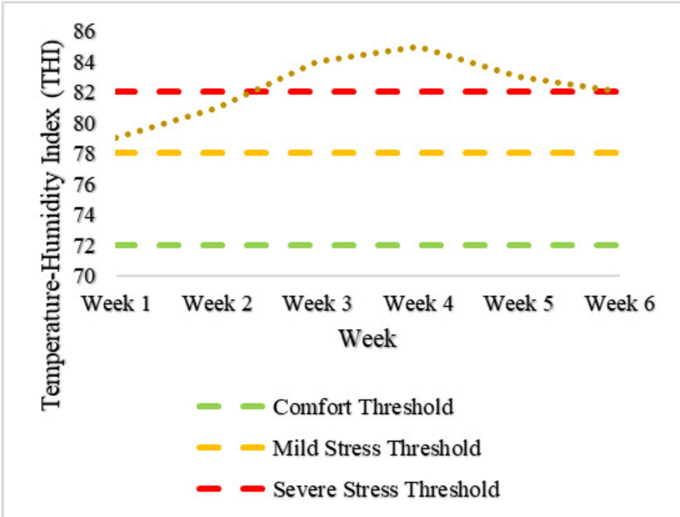

Figure 1: Average weekly THI values during the experimental period (May–August 2024).

The THI values remained well above the critical value of 72 throughout the experiment. Week 1 had a THI of 79, which increased slowly to a high of 85 in Week 4 before declining to 82 by Week 6. These values confirm continuous exposure to moderate to severe heat stress conditions, particularly Weeks 3–5. The repeated exposure of animals to elevated THI levels justifies the study's applicability and guarantees that mitigation measures were subjected to real stress conditions.

Experimental design and animal selection

The research was conducted on a sample size of 15 crossbred Holstein-Friesian lactating cows, allowing for proper and concentrated observation at the field level (Kim *et al*., 2022). Animals were chosen due to homogeneity in parity (2^{nd} lactation), middle stage of lactation (90–120 DIM), and BCS (BCS of 3.0–3.5).

The cows were randomly assigned to three treatment groups (n = 5 per group) to assess the impact of different heat stress mitigation strategies:

- Group I (Control): Cows received no intervention and were maintained under standard farm conditions.
- Group II (Cooling Only): Cows were housed under a cooling setup equipped with fans and misting nozzles, which were activated intermittently during peak heat hours.
- Group III (Cooling + Nutritional Support): In addition to the cooling setup used in Group II, these cows were supplemented with antioxidants (Vitamin E: 1,000 IU/day) and electrolytes (Na-K blend: 50 g/day) through top-dressed feed.

All animals were kept in the same open-sided sheds with sloping asbestos roofing. The bedding space was kept dry with sand, and fly control measures were consistently adopted across all groups (Krishnan *et al*., 2017). Cows were provided with a routine total mixed ration (TMR) prepared according to National Research Council (NRC) recommendations for maintenance and production needs. Clean water for drinking was provided ad libitum during the day.

To support focused field-level assessment of effective heat stress alleviation techniques, 15 crossbred Holstein-Friesian lactating cows, chosen based on uniformity of physiological status (2nd lactation, 90–120 DIM, BCS 3.0–3.5), were used in this study. The cows were randomly divided into three experimental sets, with five animals in each set. Each set was subjected to different treatment regimens for comparison under semi-arid climate stress. The interventions provided to each group, including cooling and nutritional methods applied throughout the study, are listed in the Table 1.

Table 1: Description of treatment groups and interventions.

Group	No. of animals	Cooling intervention	Nutritional supplementation
I	5	None	None
II	5	Fan + Mist system (6 hours/day)	None
III	5	Fan + Mist system (6 hours/day)	Antioxidants + Electrolytes daily

The three groups of treatment are tabulated: Group I was the control group with no cooling or supplementation, Group II had only a mechanical cooling system (fan and mist operation for 6 hours/day), and Group III had both the cooling intervention and dietary supplementation with antioxidants (Vitamin E at 1,000 IU/day) and electrolytes (Na-K blend at 50 g/day). This classification gave a systematic design for assessing the separate and combined impacts of the interventions.

Housing and cooling system setup

The cooling installed on Groups II and III featured oscillating fans (24 inches) and low-pressure mist nozzles, located 8 feet in height and at 10-foot intervals on the shed (Levit *et al*., 2021). The system operated between 10:00 AM and 4:00 PM on alternating periods of 20 minutes on and 10 minutes off. The direction of the fans was designed to create a consistent airflow in the cattle resting area.

Physiological and performance monitoring

Physiological parameters were measured twice a day, at 8:00 AM and 2:00 PM, to identify variations caused by fluctuations in ambient temperature. The parameters taken were:

- Digital rectal temperature (°C) with a calibrated digital veterinary thermometer.
- Respiration rate (breaths/minute) measured by counting flank movements for 60 seconds.
- Pulse rate (beats/minute) measured with a stethoscope at the left thoracic area.

Milk production per animal was measured daily with portable electronic weighing scales at the morning and evening milking sessions. Data were also averaged on a weekly basis to track trends. Feed consumption was estimated by subtracting refusals from the feed offered, measured every 24 hours.

Cow behaviour was also visually observed and documented for time spent in lying, standing, feeding, and panting postures during two observation blocks.

For an assessment of heat stress and alleviation effect on cow welfare and performance, a uniform set of behavioural, productive, and physiological parameters was tracked along the trial phase (Liu *et al*., 2019). They were measured using a constant frequency and a standard methodology for every individual animal. The Table 2 summarises the parameters, units of measurement, manner of assessment, and observation intensity during the study duration.

Table 2: Parameters recorded and observation frequency.

Parameter	Unit	Method	Frequency
Rectal temperature	°C	Digital thermometer	Twice daily
Respiration rate	Breaths per minute	Visual flank observation	Twice daily
Pulse rate	Beats per minute	Auscultation	Twice daily
Milk yield	kg/day	Weighing post-milking	Daily
Feed intake	kg DM/day	Feed offered refusals	Daily
Behavioral observations	Time in hours	Visual scan sampling	Twice daily block

Table 2 illustrates the multi-dimensional monitoring strategy applied in the trial. Animals were monitored for key physiological markers (rectal temperature, respiratory rate, and pulse), productive measures (feed intake and milk yield), and behavioural characteristics (panting time, lying, standing, and feeding). The employment of impersonal instruments (weighing scales, digital thermometer) and methodical approaches (visual scan sampling) helped ensure consistency and reliability in the data gathered. The rate of observation particularly the twice-daily physiological sampling was intended to detect both morning and afternoon reactions to diurnal peaks of heat stress.

Statistical analysis

All the information gathered was tabulated using Microsoft Excel 2021, and statistical analysis was performed using SPSS v26.0. Descriptive statistics (mean ± standard deviation) were calculated for all parameters. To compare the differences between the three groups, One-Way ANOVA was used, followed by Tukey's post hoc test to identify significant pairwise differences. A p-value of less than 0.05 was taken as statistically significant for all analyses (Alani and Kawan, 2024).

RESULTS AND DISCUSSION

The current research evaluated the efficacy of two popular heat stress alleviation measures environmental cooling and nutritional supplementation on physiological, productive, and behavioural traits of dairy cattle during the peak summer season in a semi-arid climatic zone (Negrón-Pérez, 2019). The Temperature-Humidity Index (THI) exceeded the critical value of 72 on the majority of trial days, indicating the occurrence of moderate to severe heat stress conditions.

Physiological responses to heat mitigation

The physiological parameters measured during the experiment exhibited that both cooling therapy and composite approaches exerted considerable impacts in modulating thermal stress. Rectal temperature, respiration rate, and pulse rate were consistently lower in Group III (cooling + nutrition) than in Group I (control) and Group II (cooling alone). This demonstrates the synergistic impact of combining antioxidant supplementation with environmental modulations.

The physiological responses of dairy cows to various heat stress management practices were assessed by measuring rectal temperature, respiration rate, and pulse rate. These parameters directly quantify thermal stress and internal heat load. The following Table 3 provides the mean values of these physiological parameters recorded in the three treatment groups throughout the study period.

Table 3: Mean (±SD) physiological parameters of cows under different treatments during the trial period

Parameter	Group I (Control)	Group II (Cooling)	Group III (Cooling + Nutrition)
Rectal temperature (°C)	39.6 ± 0.3	38.9 ± 0.2	38.4 ± 0.1
Respiration rate (bpm)	81.2 ± 3.5	66.8 ± 2.9	58.4 ± 2.1
Pulse rate (bpm)	86.6 ± 2.4	77.3 ± 1.9	72.6 ± 1.7

The findings indicate that the control group cows (Group I) experienced the highest physiological stress, with rectal temperatures averaging 39.6°C, a respiration rate of 81.2 breaths per minute, and a pulse rate of 86.6 beats per minute. Group II, under fan and mist cooling, showed a moderate improvement with reduced averages compared to Group I. The most striking alterations were in Group III, where the combination of cooling and nutritional support resulted in a remarkable reduction of rectal temperature (38.4°C), respiration rate (58.4 breaths/min), and pulse rate (72.6 bpm). These results unequivocally show that combining nutritional support with cooling increases physiological resilience under heat stress.

The decline in the pulse and respiration rates of cows in Group III is consistent with previous findings indicating that antioxidant supplementation enhances cellular tolerance to heat-induced oxidative stress. Such enhancements manifest as enhanced thermoregulation and comfort status.

Milk yield and feed intake patterns

Milk production varied significantly daily between the groups. Cows subjected to combined heat alleviation methods (Group III) exhibited increased milk production, with a consistent trend throughout the study duration (Polsky and Von, 2017). This is likely due to increased feed consumption, improved thermal balance, and decreased stress-related hormonal disturbances.

To determine the productive response to heat stress alleviation measures, daily milk production was measured and averaged every week. The Figure 3 illustrates the trend in milk production over the six weeks for each treatment group, enabling a comparative evaluation of productivity under varying interventions.

Milk production decreased consistently in the control group, from 13.5 kg/day during Week 1 to 12.0 kg/day during Week 6, reflecting a detrimental effect of unremitting heat stress. Group II showed more consistent performance, with milk production varying between 14.0 and 14.2 kg/day, reflecting that evaporative cooling per se can stabilize productivity. Nonetheless, Group III had the highest and consistently rising milk yield, increasing from 14.2 kg/day in Week 1 to 15.4 kg/day in Week 6, demonstrating the cumulative effect of cooling and nutritional supplementation in sustaining metabolic efficacy and milk synthesis under heat stress.

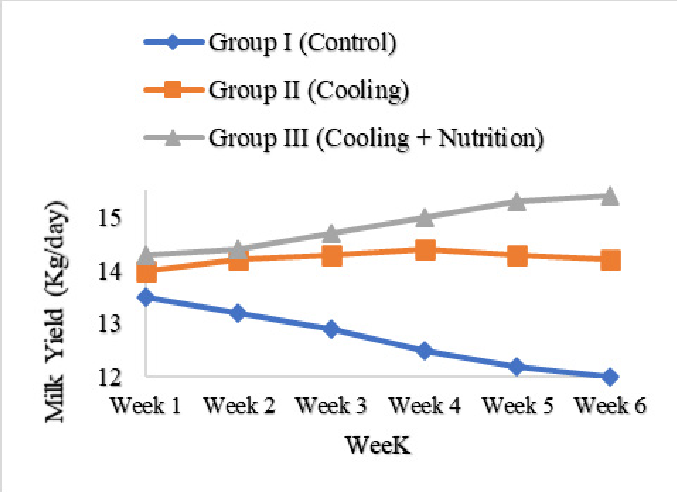

Figure 3: Weekly average milk yield (kg/day) across treatment groups.

Group I cows, which were exposed to direct heat without any interventions, experienced a consistent reduction in milk yield throughout peak temperature weeks. Group II cows had a relatively constant yield because of cooling, whereas Group III cows had enhanced milk production after the second week of acclimation.

Dry matter intake (DMI) is a crucial determinant of the impact of heat stress and its alleviation on the appetite and energy balance of dairy cows (Rahimi *et al*., 2021). The Table 4 presents the mean weekly feed consumption of all treatment groups and the impact on voluntary intake resulting from these interventions.

Table 4: Average feed intake (kg dry matter/day) during the study.

Week	Group I	Group II	Group III
Week 1	16.8	17.2	17.3
Week 2	16.2	17.5	18
Week 3	15.9	17.4	18.5
Week 4	15.5	17.3	18.7
Week 5	15.1	17.1	18.9
Week 6	14.7	16.9	18.8

Feed intake fell progressively in the control group, from 16.8 to 14.7 kg/day, reflecting heat-stimulated depression of appetite. Group II had relatively consistent values throughout, but Group III experienced a remarkable increase in DMI, reaching 18.9 kg/day by Week 5. The increase in Group III feed intake coincides with the enhancement of milk production, implying that antioxidant and electrolyte supplementation may counteract anorexia resulting from heat in lactating cows.

Behavioral observations

Behavioural observations also gave more information on the welfare of animals under each treatment (Sammad *et al*., 2020). Control group cows spent more time standing and panting, while cows in Group III exhibited more lying and feeding behaviour indicators of comfort and a decreased heat load.

Behavioural measures, such as feeding time, panting, and lying time, are helpful indicators of animal comfort when subjected to heat stress (Sammad *et al*., 2020). The average daily time spent on various behaviours was calculated using visual observation data. The behavioural time budget for each group is represented in the Figure 4.

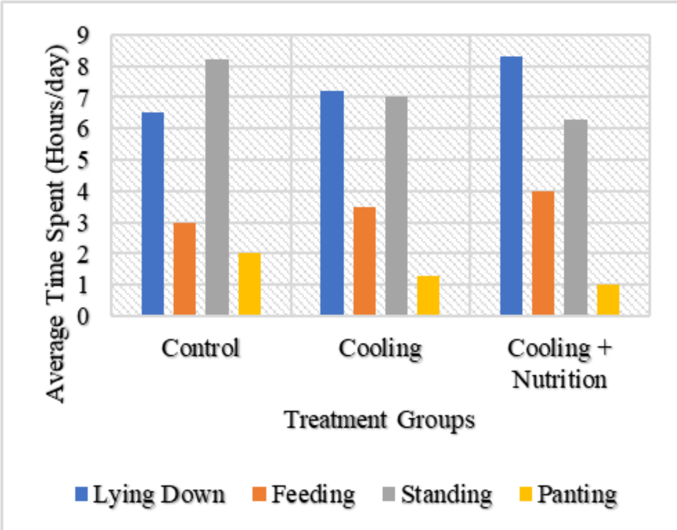

Figure 4: Average daily time (hours) spent on different behaviours by treatment group.

Group I (Control) cows spent the lowest amount of time lying down (6.5 hours) and feeding (3.1 hours), with more panting time (2.2 hours) strong indicators of distress. Group II showed mild improvement in every behavioural parameter. Group III cows lay down for 8.3 hours, were fed for 4.0 hours, and panted for only 0.9 hours, reflecting superior thermal comfort and normalization of behaviour. These alterations highlight the animal welfare benefits of combining nutritional measures with physical cooling technologies during prolonged heat exposure.

Evaluation of combined strategies on overall animal response

The combined effect of various heat stress mitigation measures was assessed by integrating physiological, production, intake, and behavioural data (Thornton *et* *al*., 2022). This multifaceted approach was undertaken to assess the relative efficacy of separate versus combined interventions in actual semi-arid field conditions. The multifaceted response of the cows provided a better understanding of how different biological processes thermoregulatory, metabolic, and behavioural react to external interventions during prolonged thermal exposure.

On all the measured parameters, cattle in the combined intervention group (Group III) showed uniformly better performance. Physiologically, they had a lower rectal temperature (38.4°C), decreased respiration rates (58.4 breaths per minute), and pulse rates (72.6 beats per minute), indicating an internally stable condition despite the external heat load. At the same time, their milk yield increased gradually to 15.4 kg/day over six weeks, while dry matter intake rose to 18.8 kg/day, indicating improved nutrient utilization and tolerance to stress.

Behaviorally, the cows in Group III exhibited increased comfort, as indicated by increased lying time and a decrease in the duration of panting (Wankar *et al*., 2021). These results together provide evidence of the efficacy of integrating evaporative cooling with antioxidant-electrolyte supplementation. They are consistent with the hypothesis that an integrated approach addressing both environmental and metabolic heat loads leads to increased resilience, improved welfare, and enhanced productivity. The simplicity and scalability of methods like fan-mist systems and affordable nutritional supplements make this method particularly well-suited for small and medium-sized dairy farms in hot climates.

CONCLUSIONS AND RECOMMENDATIONS

The present study demonstrates that heat stress in dairy cattle significantly affects physiological stability, feed intake, and milk production, and that these impacts can be effectively mitigated through targeted interventions. While environmental cooling using fans and mist systems alone provided moderate relief, the combination of cooling with nutritional supplementation specifically antioxidants and electrolytes yielded the most favourable outcomes across all measured parameters. Cows receiving this combined treatment exhibited lower rectal temperatures, reduced respiration and pulse rates, increased feed intake, improved milk yield, and behaviour indicative of greater comfort. These findings support the practical adoption of integrated strategies, particularly in semi-arid and tropical regions where heat stress poses a recurring threat to dairy productivity. It is recommended that small to medium-scale dairy farmers invest in simple cooling infrastructure and supplement the diets of lactating cows with cost-effective nutritional additives during the peak summer months to enhance animal welfare, maintain milk production, and improve overall farm profitability.

ACKNOWLEDGEMENT

The authors would like to thank Al-Bayan University, as well as the field technicians who helped with the study.

NOVELTY STATEMENT

This research is the first to demonstrate the synergistic benefits of combining evaporative cooling with targeted nutrition supplementation under on-farm conditions, providing field evidence of enhanced physiological, behavioural, and productive performance in dairy cattle during heat stress an intervention ideally suited for smallholder farms operating in semi-arid environments.

AUTHOR'S CONTRIBUTION

All of the trials were designed by Abbas Khalid Abbas and Zaid Khalid Alani. Sarah Luay Subhi and Tabarak Dakheel Mohammed conducted all of the tests, gathered the data, and composed the manuscript draft. Resan Shakir Abdulamer, Reem Hamdan Khaddour and Hasan Abdullah helped with the data analysis that was done to prepare the work for submission to the journal. The final draft of the work was reviewed and approved by all authors for publication in the Journal of Animal and Health Production.

Ethical consideration
Not applicable.

Conflict of interest
The authors state that there is not conflict of notice.

REFERENCES

Alani ZK, Kawan MH (2024). Prevalence and molecular analysis of Toxocara cati in Baghdad Province. J. Adv. Vet. Anim. Res., 11(2): 392. https://doi.org/10.5455/javar.2024.k788

Bagath M, Krishnan G, Devaraj C, Rashamol VP, Pragna P, Lees AM, Sejian V (2019). The impact of heat stress on the immune system in dairy cattle: A review. Res. Vet. Sci., 126: 94-102. https://www.sciencedirect.com/science/article/pii/S0034528819302826, https://doi.org/10.1016/j.rvsc.2019.08.011

Becker CA, Aghalari A, Marufuzzaman M, Stone AE (2021). Predicting dairy cattle heat stress using machine learning techniques. J. Dairy Sci., 104(1): 501-524. https://www.sciencedirect.com/science/article/pii/S0022030220308663, https://doi.org/10.3168/jds.2020-18653

Becker CA, Stone AE (2020). Graduate student literature review: Heat abatement strategies used to reduce negative effects of heat stress in dairy cows. J. Dairy Sci., 103(10): 9667-9675. https://www.sciencedirect.com/science/article/pii/S0022030220305671, https://doi.org/10.3168/jds.2020-18536

Bishop-Williams KE, Berke O, Pearl DL, Hand K, Kelton DF (2015). Heat stress related dairy cow mortality during heat waves and control periods in rural Southern Ontario from 2010–2012. BMC Vet. Res., 11: 1-10. https://link.springer.com/article/10.1186/s12917-015-0607-2, https://doi.org/10.1186/s12917-015-0607-2

Brown-Brandl TM (2018). Understanding heat stress in beef cattle. Rev. Brasil. Zoot., 47: e20160414. https://www.scielo.br/j/rbz/a/hKVfvtCBcNsRnZjttG7Zvkb/, https://doi.org/10.1590/rbz4720160414

Conte G, Ciampolini R, Cassandro M, Lasagna E, Calamari L, Bernabucci U, Abeni F (2018). Feeding and nutrition management of heat-stressed dairy ruminants. Ital. J. Anim. Sci., 17(3): 604-620. https://doi.org/10.1080/1828051X.2017.1404944

Dado-Senn B, Ouellet V, Dahl GE, Laporta J (2020). Methods for assessing heat stress in preweaned dairy calves exposed to chronic heat stress or continuous cooling. J. Dairy Sci., 103(9): 8587-8600. https://www.sciencedirect.com/science/article/pii/S0022030220304884, https://doi.org/10.3168/jds.2020-18381

Das R, Sailo L, Verma N, Bharti P, Saikia J, Kumar R (2016). Impact of heat stress on health and performance of dairy animals: A review. Vet. World, 9(3): 260. https://pmc.ncbi.nlm.nih.gov/articles/PMC4823286/, https://doi.org/10.14202/vetworld.2016.235-244

Dash S, Chakravarty AK, Singh A, Upadhyay A, Singh M, Yousuf S (2016). Effect of heat stress on reproductive performances of dairy cattle and buffaloes: A review. Vet. World, 9(3): 235. https://pmc.ncbi.nlm.nih.gov/articles/PMC4823282/, https://doi.org/10.14202/vetworld.2016.260-268

De Rensis F, Garcia-Ispierto I, López-Gatius F (2015). Seasonal heat stress: Clinical implications and hormone treatments for the fertility of dairy cows. Theriogenology, 84(5): 659-666. https://www.sciencedirect.com/science/article/pii/S0093691X15002058, https://doi.org/10.1016/j.theriogenology.2015.04.021

Fabris TF, Laporta J, Skibiel AL, Corra FN, Senn BD, Wohlgemuth SE, Dahl GE (2019). Effect of heat stress during early, late, and entire dry period on dairy cattle. J. Dairy Sci., 102(6): 5647-5656. https://www.sciencedirect.com/science/article/pii/S0022030219303571, https://doi.org/10.3168/jds.2018-15721

Fodor N, Foskolos A, Topp CF, Moorby JM, Pásztor L, Foyer CH (2018). Spatially explicit estimation of heat stress-related impacts of climate change on the milk production of dairy cows in the United Kingdom. PLoS One, 13(5): e0197076. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0197076, https://doi.org/10.1371/journal.pone.0197076

Fournel S, Ouellet V, Charbonneau É (2017). Practices for alleviating heat stress of dairy cows in humid continental climates: A literature review. Animals, 7(5): 37. https://www.mdpi.com/2076-2615/7/5/37, https://doi.org/10.3390/ani7050037

Galán E, Llonch P, Villagrá A, Levit H, Pinto S, Del Prado A (2018). A systematic review of non-productivity-related animal-based indicators of heat stress resilience in dairy cattle. PLoS One, 13(11): e0206520. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0206520, https://doi.org/10.1371/journal.pone.0206520

Gupta S, Sharma A, Joy A, Dunshea FR, Chauhan SS (2022). The impact of heat stress on immune status of dairy cattle and strategies to ameliorate the negative effects. Animals, 13(1): 107. https://www.mdpi.com/2076-2615/13/1/107, https://doi.org/10.3390/ani13010107

Hempel S, Menz C, Pinto S, Galán E, Janke D, Estellés F, Amon T (2019). Heat stress risk in European dairy cattle husbandry under different climate change scenarios–uncertainties and potential impacts. Earth Syst. Dyn., 10(4): 859-884. https://esd.copernicus.org/articles/10/859/2019/esd-10-859-2019.html, https://doi.org/10.5194/esd-10-859-2019

Herbut P, Angrecka S, Walczak J (2018). Environmental parameters to assessing of heat stress in dairy cattle.A review. Int. J. Biometeorol., 62: 2089-2097. https://link.springer.com/article/10.1007/s00484-018-1629-9, https://doi.org/10.1007/s00484-018-1629-9

Herbut P, Hoffmann G, Angrecka S, Godyń D, Vieira FM C, Adamczyk K, Kupczyński R (2021). The effects of heat stress on the behaviour of dairy cows. A review. Ann. Anim. Sci., 21(2): 385-402. https://doi.org/10.2478/aoas-2020-0116

Johnson JS (2018). Heat stress: Impact on livestock well-being and productivity and mitigation strategies to alleviate the negative effects. Anim. Prod. Sci., 58(8): 1404-1413. https://www.publish.csiro.au/an/AN17725, https://doi.org/10.1071/AN17725

Kim SH, Ramos SC, Valencia RA, Cho YI, Lee, SS (2022). Heat stress: effects on rumen microbes and host physiology, and strategies to alleviate the negative impacts on lactating dairy cows. Front. Microbiol., 13: 804562. https://www.frontiersin.org/articles/10.3389/fmicb.2022.804562/full, https://doi.org/10.3389/fmicb.2022.804562

Krishnan G, Bagath M, Pragna P, Vidya MK, Aleena J, Archana PR, Bhatta R (2017). Mitigation of the heat stress impact in livestock reproduction. In: Theriogenol. Intech Open. https://books.google.com/books?hl=en&lr=&id=_-iPDwAAQBAJ&oi=fnd&pg=PA63&dq=Heat+Stress+, https://doi.org/10.5772/intechopen.69091

Levit H, Pinto S, Amon T, Gershon E, Kleinjan-Elazary A, Bloch V, Halachmi I (2021). Dynamic cooling strategy based on individual animal response mitigated heat stress in dairy cows. Animal, 15(2): 100093. https://www.sciencedirect.com/science/article/pii/S1751731120300951, https://doi.org/10.1016/j.animal.2020.100093

Liu J, Li L, Chen X, Lu Y, Wang D (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-Austral. J. Anim. Sci., 32(9): 1332. https://pmc.ncbi.nlm.nih.gov/articles/PMC6722315/, https://doi.org/10.5713/ajas.18.0743

Negrón-Pérez VM, Fausnacht DW, Rhoads ML (2019). Invited review: Management strategies capable of improving the reproductive performance of heat-stressed dairy cattle. J. Dairy Sci., 102(12): 10695-10710. https://www.sciencedirect.com/science/article/pii/S0022030219308033, https://doi.org/10.3168/jds.2019-16718

Polsky L, Von Keyserlingk MA (2017). Invited review: Effects of heat stress on dairy cattle welfare. J. Dairy Sci., 100(11): 8645-8657. https://www.sciencedirect.com/science/article/pii/S0022030217308494, https://doi.org/10.3168/jds.2017-12651

Rahimi J, Mutua JY, Notenbaert AM, Marshall K, Butterbach-Bahl K (2021). Heat stress will detrimentally impact future livestock production in East Africa. Nature Food, 2(2): 88-96. https://www.nature.com/articles/s43016-021-00226-8, https://doi.org/10.1038/s43016-021-00226-8

Sammad A, Umer S, Shi R, Zhu H, Zhao X, Wang Y (2020). Dairy cow reproduction under the influence of heat stress. J. Anim. Physiol. Anim. Nutr., 104(4): 978-986. https://onlinelibrary.wiley.com/doi/abs/10.1111/jpn.13257, https://doi.org/10.1111/jpn.13257

Sammad A, Wang YJ, Umer S, Lirong H, Khan I, Khan A, Wang Y (2020). Nutritional physiology and biochemistry of dairy cattle under the influence of heat stress: Consequences and opportunities. Animals, 10(5): 793. https://www.mdpi.com/2076-2615/10/5/793, https://doi.org/10.3390/ani10050793

Thornton P, Nelson G, Mayberry D, Herrero M (2022). Impacts of heat stress on global cattle production during the 21st century: A modelling study. Lancet Planet. Health, 6(3): e192-e201. https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(22)00002-X/fulltext?ref=ambrook, https://doi.org/10.1016/S2542-5196(22)00002-X

Wankar AK, Rindhe SN, Doijad NS (2021). Heat stress in dairy animals and current milk production trends, economics, and future perspectives: The global scenario. Trop. Anim. Health Prod., 53(1): 70. https://link.springer.com/article/10.1007/s11250-020-02541-x, https://doi.org/10.1007/s11250-020-02541-x