REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

Biological Variables Contributing to Heat Stress in Dairy Cattle: Comprehensive Analysis

Dr. Kumud Saxena[1]*, A Rengarajan[2], Rakesh Kumar Yadav[3]
*[1]Professor and HOD, Department of Computer Science & Engineering, Noida Institute of Engineering and Technology, Greater Noida, Uttar Pradesh, India, Email Id- kumud.saxena@niet.co.in, Orcid Id-000-0002-2571-3192
[2]Professor, Department of Computer Sceince and Information Technology, Jain (Deemed to be University), Bangalore, India, Email Id- a.rengarajan@jainuniversity.ac.in, Orcid Id- 0000-0002-4168-3333
[3]Associate Professor, Maharishi School of Engineering & Technology, Maharishi University of Information Technology, Uttar Pradesh, India, Email Id- rakesh.yadav@muit.in, Orcid Id- 0000-0002-0151-4981

Abstract

Heat stress (HS) is an imminent threat to the production well-being and sustainability of dairy farms. Recognizing the complex biological factors driving HS in dairy cattle is crucial for developing effective mitigation techniques as global temperature increases.The well-being of animals can be significantly impacted when dairy cattle are subjected to HSdue to the conditions. As the population of high milk-yielding production animals with increased metabolic activity continues to grow, the challenges in managing HS have reached unprecedented levels.The aim of this research was to examine the variations in the biological characteristics of dairy cows and determine which biological markers exhibit more reliability when it comes to verifying HS.Moreover, the research gathered the biological variables, which included heart rate (HR), respiration rate (RR), rectal temperature (RT), andserum hormones concentrations from 110 dairy cows and analyzed them for 30 Days.It is crucial to have a grasp of the biological variables that cause HS in dairy cattle to create management strategies that protect the animals, increase their productivity, and guarantee that dairy farming can continue even when the environment changes.Statistical analysis was used to analyze the data, the MIXED technique was used for mixed form equations to infer fixed and random effects. Exploring HS in dairy cattle's complex biological variables improves our understanding of physiological responses to elevated temperatures and enables the development of targeted interventions and precision management strategies to improve dairy herd resilience and well-being under changing climates.Since respiratory rate is the most adapted biological metric to HS, it is the greatest predictor of HS in dairy cattle.

Keywords: Dairy cattle, cows, heat stress (HS), biological variables, temperature.

INTRODUCTION

A dairy cows' output depends on several factors, including cows environment, genetics, and the quality of cows feed, as well as the use of trained animals.One of the key things restricting dairy cattle productivity is heat stress(HS). It influences the overall health, reproductive capabilities, well-being, and productivity of dairy cows. Among these effects, the well-recognized one is a reduction in milk production (1).Temperate regions are the ancestral homes of modern dairy cattle. Their susceptibility to shifting weather patterns has diminished as a result of selective breeding for maximum production of milk (2). Dairy cows suffer huge losses in output when they experience environmental-induced heat. HScauses noticeable changes in diet and digestion, which ultimately leads to decreased productivity and health (3). Particularly in animals with high genetic merit, HS hurts dairy output and composition in dairy cows. To mitigate output decreases, it is important to investigate the biological processes of HS for decreased animal production (4). To secure and improve dairy production, this basic information can help suggest biological, managerial, nutritional, and related preventative mitigation techniques (5).Cattle houses in subtropical and tropical climates, where they are exposed to extreme outside temperatures or moisture levels for extended periods, can suffer significant health and production losses under hot environmental conditions (6). In the field of research, the discomfort that animals experience as a consequence of hot weather is known as an HS. Livestock under extended heat stress have lower feed intake and lower dairy yields (7).An animal experiences HS when it creates more heat than expel, which is a general biological reaction to a hot environment. Among dairy cattle, the Hamburg breed is the most widely used worldwide. This breed's reduced capacity to disperse heat via skin evaporation during the summer inhibits the production of dairy products (8). The study of biological variables, including body temperature, respiratory rate, and hormone concentrations, has been used to quantify the alterations in homeostasis that HS induces. The crucial values of these qualities for crossbred cows remain small understood, despite the mentioned and well-known breed variations and their responses to HS (9).Management interventions are possible in these cases, but they are difficult and expensive to implement, particularly on cattle that have not adapted to their surroundings for the first time(10). Cattle that are acclimated to their environment and productive can be selected and bred without the need for any management interventions, which is the most effective way to mitigate the impacts of stressful circumstances on animal welfare and production (11).The goalof this research is to investigate the change in the biological variables of dairy cattle, figure out crucial threshold values, and identify biological indicators that exhibit greater reliability for verifying HS in dairy cows.

The purpose of the research (12) was to examine how HS affected the physiological parameters and productivity of Holstein cows. Four farms in Tunisia were the sites of two 6-week trials: one in the summer under HS circumstances and another in the fall under thermo-neutral conditions. The experimental periods were marked by the measurement of RR, skin temperature (ST), RT, and dairy production. Dairy samples were taken twice weekly throughout this time. To determine the temperature-humidity index (THI), the barn's interior heat and relative wetness were recorded.The research (13) examined that HS impacted performance in the late afternoon and throughout dry weather. A 45-day lead time was given to the cows before they were cleaned out and chosen based on their mature-equivalent milk production. Cows were segregated based on parity, past 305-day olderthe same milk output, and body weight. They were randomized to either HS condition.The research(14) employed an HS scoring system to assess dairy cow heat sensitivity utilizing various heat reduction methods. The methods used THI, rate of respiration, time of lying, lying battles, whole phases, salivating, sweating, shading, somatic cells rating, reticulorumen heat, hygiene physical state score, dairy products yield, Dairy fat and protein percent, and the quantity of milk produced to calculatethe accuracy of the organization.

The goal of the paper (15) was to research on HS in dairy cattle by taking inspiration from classicsemployed on human biometeorology, specifically the apparent heat scale. It was emphasized how important it was to have an understanding of heat transfer and thermoregulation from a mechanistic perspective. A structure for recognizing and describing circumstances that can result in HSwas built using a model from the literature. The purpose of the research (16) was to investigate the impact that HS has on the performance of dairy cattle as well as the expression of certain DNAs that are involved in the metabolism of dairy proteins. After being housed in settings that were thermo-neutral for eight days, eight cows were kept in conditions,- that were mildly HS for an additional eight days. During the last three days of the control and HS time, the RT, feed intake, and dairy production were measured.The research (17) was aimed to examine the dairy production, blood biochemical variables, and composition of milk from dairy cows subjected to three different degrees of HS: none, mild, and moderate. The goal was to determine the function of oxygen metabolism in overall cow health. Because HS reduces oxygen metabolism and transfer, it has a deleterious effect on dairy cows' health and their ability to lactate.The study (18)aimed to measure how HS affected female fertility, production, and health characteristics at various times. In this sense, longitudinal cow characteristics from electronic recording systems were integrated with temperature and relative humidity data obtained from on-farm observations to create THI.The research (19) evaluated the future danger of HS in such dairy cow husbandry systems using a numerical modeling technique. In three reference barns located in central Europe and the Mediterranean area, the interior climate was observed. Using data from official meteorological weather stations, an artificial neural network was qualified to correlate the recorded inside microclimate with the outside weather.The study (20) proposed an affordable embedded imaging system that can track dairy cows' drinking habits while concurrently recording the

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

outside temperature and humidity using integrated sensor modules. An experimental dairy farm served as the testing ground for the embedded imaging system, with imaging modules placed above the drinking troughs to record video feeds.

MATERIALS AND METHODS

Mechanism of heat stress (HS)

Animals gather and evaluate both inside and outside data for homeostatic operations. Various species have different methods, but a steady internal environment is crucial for development and production. Temperature, humidity, sun radiation, and heat waves impact animal homothetic reactions. Animals suffer HS syndrome when they cannot remove metabolic heat by heat transfer, conduction, exposure to radiation, or evaporation.Animals have a greater tolerance for cold than HS within quantifiable limits. Figure (1) illustrates the HS and normal cows.

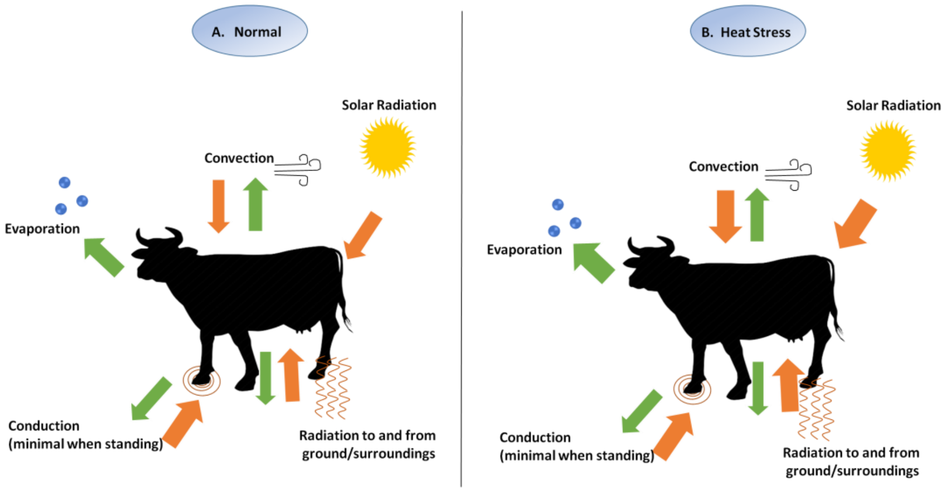

Figure (1). Normal and Heat stress on cow (Source:https://www.researchgate.net/profile/Sukanta-Mondal/publication/323622368/figure/fig2/AS:1178534844338177@1657996011082/mpact-of-heat-stress-on-dairy-cow.jpg)

The hormonal system, the brain, and the nervous system in the periphery all work together to regulate how the organism responds to HS.The stress reaction differs depending on factors such as the intensity and length of the stimulus, the animal's breed, its preconditioning, its stage of development, its pregnancy, its age, any illnesses it can have, and its gender. It is unusual to see acclimatory reactions in natural settings. When animals experience several stresses, a process known as an acclimatization reaction occurs.HS can be broken down into two subcategories: acute and chronic. Acute reactions, which can last anywhere from a few minutes to a few days, are synergistically mediated by glucocorticoids and catecholamines.

Biological variables

The most important ways of dealing with a temperature environment that is not ideal are the biological and behavioral responses. Acclimatization and adaptation are terms that explain the methods by which animals deal with HS. When subjected to severe temperature circumstances, these responses can vary from normal to impaired levels, and this change is proportional to both the intensity and length of the conditions.Each animal was confined in a darkened holding enclosure while the following biological variables were recorded: heart rate HR, RR, and RT. All cows had their RTmonitored every ten minutes using reticulorumen injections. For the optical observation of RR, the duration of ten full breaths was timed in seconds, and the flank movements were monitored. The respiration in every minute was calculated by dividing this number by sixty.An early warning

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

indication of the beginning of HS is the RR. Panting is a useful strategy to cool the brain when it is under HS, according to reports. The cow's body can raise its respiratory rate to disperse extra heat. Drinking water, which lowers the temperature of the body's internal environment via the process of conductive cooling of the water, can end up in a large decrease in RR. It is common practice to use eye detection to measure RR. Figure (2) illustrates the biological variables of cattle.

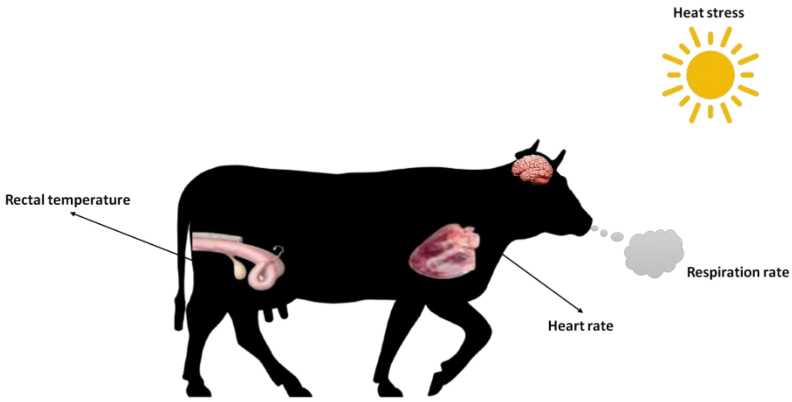

Figure (2). Biological variables (Source:https://www.researchgate.net/profile/Bagath-Madiajagan/publication/326597449/figure/fig1/AS:652285436776448@1532528375500/Alterations-in-various-physiological-variables-in-heat-stressed-cattle.png)

Either by human observation or through the scanning of video records at regular intervals, it is possible to monitor the frequency of breathing.The HR can be recorded on the farm, and it has been used in the past to determine the amount of metabolic energy that is expended by ruminants when they are subjected to HS or other situations. Because, of the increased expenditure of energy required to keep the body at a constant temperature, the amount of energy that is preserved for activities connected to production can decrease. HR can serve as an intermediate predictor of heat tolerance. The designs of the HR monitors that are in use, these are based on electrocardiograph analysis. These devices communicate the data remotely, which reduces the amount of human presence near the animals.There is a strong correlation between production performance and RT, which is a measure of core body temperature. While RT remains relatively unchanged in the thermal neutral zone (TNZ), it tends to rise when the temperature of the surrounding environment rises.The serum hormone concentrations are a measurement of the various hormone levels that are present in the circulation. These concentrations are represented in nanograms per milliliter. Physiological processes cannot occur without the presence of these hormones, which include cortisol, progesterone, and Isoprostane. Healthcare practitioners can diagnose disorders, keep track of endocrine function, and guide treatment by employing blood tests to quantify these quantities.

Heat stress in dairy cattle

HS occurs in dairy cattle when they are focused to temperatures higher than their thermo-neutral zone. Draught milk yield, milk quality, growth, feed conversion efficiency, reproductive performance, and DMI are negatively impacted by rising heat stress levels. Thyroid hypo function, brought by HS, leads to decreased metabolic heat output. As a result, as temperatures rise, the body has an adaptation mechanism to lower its metabolic heat output, which manifests as a decrease in thyroid hormone concentration.There are several negative health effects of HS on cattle, which is a reduced immunological response. Vaccinating calves when they are under HS can prevent them from an optimal immunological reaction, which can render the vaccine useless.In addition to lowering an animal's natural defenses against germs, HS can affect endotoxin levels, which could have unintended consequences for vaccinations that include complete bacterial cells. Figure (3)demonstrates the impacts of HS.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

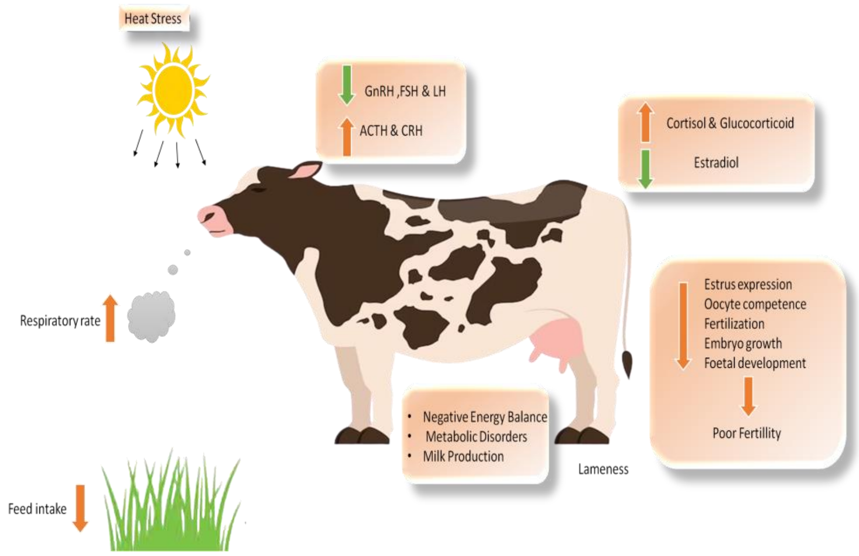

Figure (3). Impacts of HS (Source:https://www.researchgate.net/profile/Sukanta-Mondal/publication/323622368/figure/fig2/AS:1178534844338177@1657996011082/mpact-of-heat-stress-on-dairy-cow.jpg)

Animals have a drop in productivity due to an HS reduction in metabolic heat output, which is necessary for homoeothermic maintenance. This is mainly because mammary glands do not have enough synthesis precursors, which causes HS to reduce dairy production and dairy protein in dairy cattle. Casein is the primary protein in milk, and it is made from a combination of amino acids and glucose. The majority of the amino acids that reach the mammary glands come from rumen Microbial Protein. This means that under HS, a drop in milk protein levels is strongly associated with a drop in dry matter intake (DMI).

Statistical analysis

The application SAS University Edition was used for the analysis of the data that was obtained. In this context, we employed the MIXED technique to deduce both fixed and random effects by utilizing mixed form equations. This was done for the repeated measurements that were performed for each characteristic. The following equation (1) was the statistical structure:

$$Z_{jilknm} = \mu + KR_j + E_i + THI_l + T_J + B_n + f_{jilknm} \quad (1)$$

The following variables were used in the given data: Z_{jilknm}, which represented the $jilknm$ hematological, cow's production, biological, and chromosomereaction ($\Delta Ct\ value$)qualities; μ, the generally mean effect; KR_j, the unchangingoutcome for the j^{th}feeding stage class; E_i, the secure effect for the i^{th} farm; THI_l, the setoutcome for the l^{th} THI1to7 class for production, blood-related, and biological behavior; and the test day THI, for chromosomereaction, as recommended for such data. There was a fixed effect for the k^{th}season called T_J, an unpredictable outcome for two consecutive measurementsof m^{th} animal called B_n, and a random residual effect called f_{jilknm}.

RESULT

Dataset

In this section, the research gathered 110cows that were randomly selected in the dairy cattle.There were treatments implemented, and the data collecting period lasted 30 days, from June 5, 2019, to July 4, 2019. Due to receiving an HS obtainthreesets of 10 days for consecutive measurements, as described in the methods section, it was calculated how cows are reacting normally and HS by dividing the three biological variables such as RR, HR, and RT are calculated by how the cows are reacted in morning, evening, and the serum hormones concentrations of the cows.

Rectal temperature (RT)

A portable IR thermometer assessed skin and udder surface temperatures when dry, while a rectal temperature probe monitored RT. A temperature logger in a soft plastic anchor was also put into the vagina to record vaginal temperature every minute.The average daily, morning, and evening RTs presented in Table (1) exhibited a linear increase with elevating chamber temperatures. Even a modest loss in RT was associated with diminished routine in cattle. This underscores the sensitivity of body temperature as an indicative measure of the biological response to HS in cows, given its stability under typical conditions. The first ten days in the morningRTs at the heat zone parts 38.2°C the next ten days at 37.4°C and another ten days RT is 38.5°C. Increases in evening RT,39.2°C, 38.9°C, and 39.5°C, during the morning time were exposed HS, respectively. Figure (4) depictsthe comparisons of rectal temperature for 30 days.

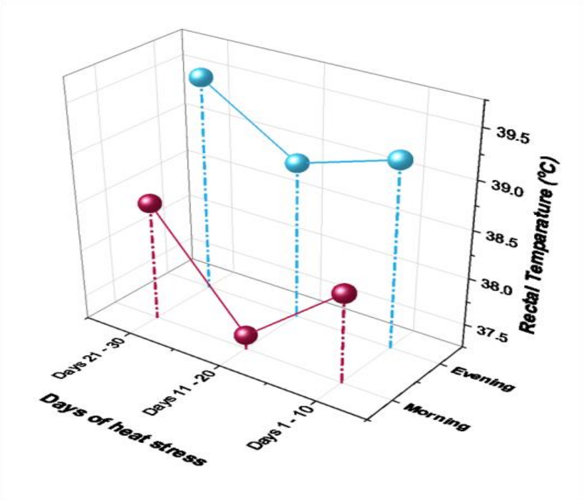

Figure (4). Comparisons of rectal temperature (Source: Author)

Table (1). Numerical Outcomes of rectal temperature(Source: Author)

Days of heat stress	Rectal Temperature (°C)	
	Morning	Evening
Days 1 - 10	38.2	39.2
Days 11 - 20	37.4	38.9
Days 21 - 30	38.5	39.5

Respiratory rate (RR)

An appropriate indication for determining whether or not animals are under climate stress is the rate of respiration. An increased RR in animals during times of temperature stress is indicative of the activation of respiratory evaporative cooling. To offer the reason for the identification of movements that are caused by breathing, a measurement of the scale of motion that can be detected is examined. It is possible to see respiration from a distance; hence, it is very probable that the amplitude of the motions is more than one millimeter. The amplitude of a neck motion is one millimeter, and the RR is sixty breaths per minute.The RR of dairy cattle under HS was observed in the morning and evening. In the first 10 days, when temperatures were high, morning respiration was 38.2 breaths per minute and evening respiration was 39.2. In the next 10 days, the morning RR dropped to 37.4 breaths per minute, but the evening rate rose to 38.9. In particular, between days 21–30 of HS, the morning respiration rate rose to 38.5 breaths per minute and the evening rate to 39.5. These data show that dairy cattle's respiratory responses under extended HS are dynamic, emphasizing the need for time-specific considerations in understanding environmental stressors' effects on biological parameters.Figure (5) and Table (2) showthe RR of cattle.

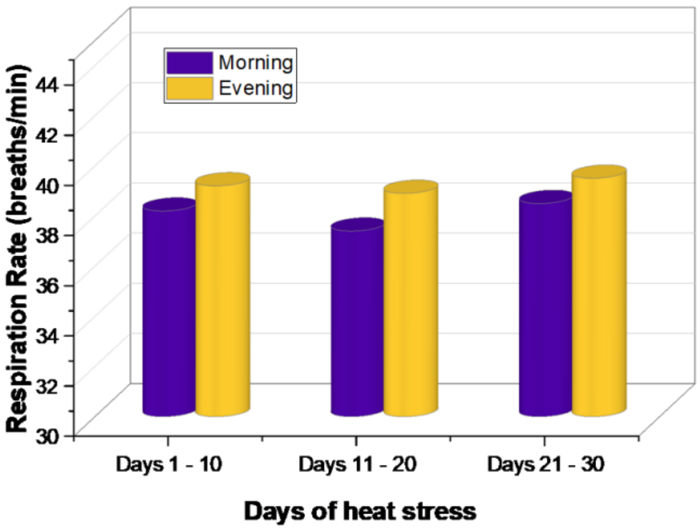

Figure (5). Comparisons of respiration rate (Source: Author)

Table (2). Numerical Outcomes of respiration rate(Source: Author)

Days of heat stress	Respiration Rate (breaths/min)	
	Morning	Evening
Days 1 - 10	38.2	39.2
Days 11 - 20	37.4	38.9
Days 21 - 30	38.5	39.5

Heart rate (HR)

In dairy cattle, HS can have a major influence on their well-being and their output. If cattle are subjected to HS, their biological responses, particularly their heart rate, can undergo modifications. The degree of HS in dairy cattle can be evaluated in several methods, which is monitoring their HR.Figure (6) and Table (3) show that dairy cattle's heart rate varies under HS. For the first 10 days of HS, morning and evening heart rates rose to 61.6 and 90.12 BPM, respectively. Thereafter, heart rates dropped to 53.5 BPM in the morning and 81.6 BPM in the evening for 10 days. In the next 10 days (21-30), heart rates rebounded to 57.4 BPM in the morning and 89.17 BPM in the evening. The cardiovascular response of dairy calves to sustained heat stress shows a complex temporal pattern, suggesting adaption mechanisms or acclimatization stages that need further study. Dairy cattle's biological reactions during protracted HS periods are dynamic, thus complete monitoring is necessary.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No. 3 (2023)
http://www.veterinaria.org
Article Received: 10 September 2023; Revised: 20 October 2023; Accepted: 09 November 2023

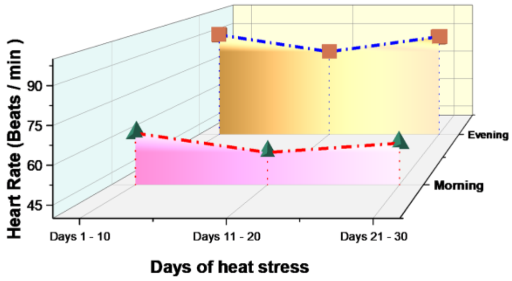

Figure (6). Comparisons of heart rate(Source: Author)

Table (3). Numerical Outcomes of Heart Rate (Source: Author)

Days of heat stress	Heart Rate (Beats/ min)	
	Morning	Evening
Days 1 - 10	61.6	90.12
Days 11 - 20	53.5	81.6
Days 21 - 30	57.4	89.17

Serum hormone concentrations

Serum hormone concentrations are a measure of the different hormone levels in the bloodstream, expressed in ng/ml. These hormones, which include cortisol, progesterone, and Isoprostane, are essential to physiological functions. By using blood tests to measure these amounts, medical professionals can identify diseases, monitor endocrine function, and direct therapy.Figure (7) and Table (4)show substantial changes in blood hormone concentrations between normal and heat-stressed dairy cattle. HS lowered progesterone levels from 64 ng/ml to 46 ng/ml, which can affect reproduction. Cortisol, a stress hormone, increased from 34 ng/ml to 68 ng/ml under heat stress, showing the physiological reaction to high temperatures. In HS, Isoprostane, a measure of oxidative stress, rises from 55 ng/ml to 85 ng/ml, highlighting dairy cattle's increased oxidative load. These results demonstrate the complex hormonal and metabolic changes that occur during HS, offering useful insights for future management methods to reduce the negative impacts on dairy cow reproductive and general health.

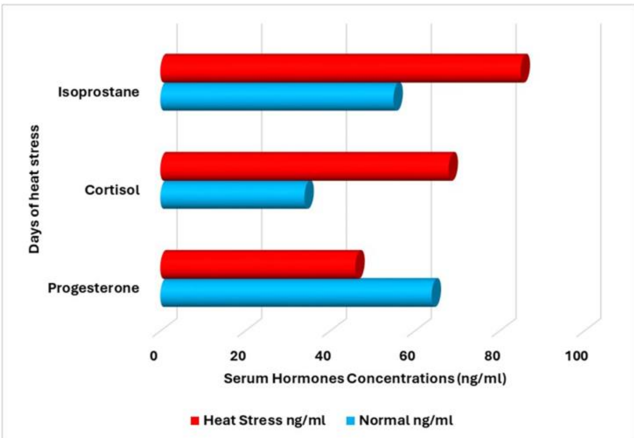

Figure (7). Comparisons of serum hormones concentrations(Source: Author)

Table (4). Numerical Outcomes of serum hormones concentrations(Source: Author)

Serum Hormones Concentrations	Normal(ng/ml)	Heat Stress(ng/ml)
Progesterone	64	46
Cortisol	34	68
Isoprostane	55	85

CONCLUSION

The aim of theresearch was to perform an exhaustive analysis of the physiological parameters of dairy cows, to find critical indicators that can consistently signal HS. An in-depth investigation of biological variables, such as HR, RR, RT, and serum hormone concentrations, was carried out in a panel of 110 dairy cows over thirtydays for the research. The research used a wide range of monitoring methods to evaluate the effects of HS on dairy cattle. These techniques included infrared thermometry, assessments of respiratory and heart rates, and analysis of serum hormone concentrations. The findings of this research provide important details for the advance of biological variables on dairy cattle tailored management plans to reduce the harmful effects of HS on the reproductive health of dairy cattle.HS can affect milk output, reproductive function, and illness susceptibility in dairy cattle. Cows' heat dissipation issues affect their health. Temperatures reduce feed intake, lowering nutrients.Innovative technology and management approaches can help dairy cattle with HS. Animal welfare, productivity, and climate change mitigation will improve dairy production with sustainable solutions.

REFERENCES

[1] Brito, L. F., Oliveira, H. R., Houlahan, K., Fonseca, P. A., Lam, S., Butty, A. M., ... &Schenkel, F. S. (2020). Genetic mechanisms underlying feed utilization and implementation of genomic selection for improved feed efficiency in dairy cattle. Canadian journal of animal science, 100(4), 587-604.Doi: 10.1139/cjas-2019-0193
[2] Sammad, A., Wang, Y. J., 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. Doi: 10.3390/ani10050793
[3] Worku, D., Hussen, J., De Matteis, G., Schusser, B., &Alhussien, M. N. (2023). Candidate genes associated with heat stress and breeding strategies to relieve its effects in dairy cattle: a deeper insight into the genetic architecture and immune response to heat stress. Frontiers in Veterinary Science, 10. Doi: 10.3389%2Ffvets.2023.1151241
[4] Idris, M., Uddin, J., Sullivan, M., McNeill, D. M., & Phillips, C. J. (2021). Non-invasive physiological indicators of heat stress in cattle. Animals, 11(1), 71. Doi:10.3390/ani11010071
[5] 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-Australasian journal of animal sciences, 32(9), 1332. Doi:10.5713%2Fajas.18.0743
[6] Lees, A. M., Sejian, V., Wallage, A. L., Steel, C. C., Mader, T. L., Lees, J. C., &Gaughan, J. B. (2019). The impact of heat load on cattle. Animals, 9(6), 322. Doi:10.3390/ani9060322
[7] Islam, M. A., Lomax, S., Doughty, A., Islam, M. R., Jay, O., Thomson, P., & Clark, C. (2021). Automated monitoring of cattle heat stress and its mitigation. Frontiers in Animal Science, 2, 60.Doi:10.3389/fanim.2021.737213
[8] Vieira, R., Louvandini, H., Barcellos, J., Martins, C. F., & McManus, C. (2022). Path and logistic analysis for heat tolerance in adapted breeds of cattle in Brazil. Livestock Science, 258, 104888. Doi:10.1016/j.livsci.2022.104888
[9] Habimana, V., Nguluma, A. S., Nziku, Z. C., Ekine-Dzivenu, C. C., Morota, G., Mrode, R., &Chenyambuga, S. W. (2023). 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. Doi:10.3389%2Ffvets.2023.1121499
[10] Kondruchina, S. G., Semenov, V. G., Tyurin, V. G., Kuznetsov, A. F., Leontyev, L. B., Larionov, G. A., ... &Ivanova, E. N. (2021, December). Effect of immunoprophylaxis on reproduction function of highly productive cows. In IOP

Conference Series: Earth and Environmental Science (Vol. 935, No. 1, p. 012037). IOP Publishing. Doi:10.1088/1755-1315/935/1/012037

[11] Lukuyu, M. N., Gibson, J. P., Savage, D. B., Rao, E. J. O., Ndiwa, N., & Duncan, A. J. (2019). Farmers' perceptions of dairy cattle breeds, breeding and feeding strategies: a case of smallholder dairy farmers in Western Kenya. East African Agricultural and Forestry Journal, 83(4), 351-367.Doi:10.1080/00128325.2019.1659215

[12] Amamou, H., Beckers, Y., Mahouachi, M., &Hammami, H. (2019). Thermotolerance indicators related to production and physiological responses to heat stress of Holstein cows. Journal of thermal biology, 82, 90-98. Doi: 10.1016/j.jtherbio.2019.03.016

[13] Fabris, T. F., Laporta, J., Skibiel, A. L., Corra, F. N., Senn, B. D., Wohlgemuth, S. E., & Dahl, G. E. (2019). Effect of heat stress during early, late, and entire dry periods on dairy cattle. Journal of Dairy Science, 102(6), 5647-5656. Doi:10.3168/jds.2018-15721

[14] Becker, C. A., Aghalari, A., Marufuzzaman, M., & Stone, A. E. (2021). Predicting dairy cattle heat stress using machine learning techniques. Journal of Dairy Science, 104(1), 501-524. Doi:10.3168/jds.2020-18653

[15] Foroushani, S., & Amon, T. (2022). Thermodynamic assessment of heat stress in dairy cattle: lessons from human biometeorology. International Journal of Biometeorology, 66(9), 1811-1827. Doi:10.1007/s00484-022-02321-2

[16] Corazzin, M., Saccà, E., Lippe, G., Romanzin, A., Foletto, V., Da Borso, F., &Piasentier, E. (2020). Effect of heat stress on dairy cow performance and on the expression of protein metabolism genes in mammary cells. Animals, 10(11), 2124.Doi: 10.3390/ani10112124

[17] Zeng, J., Cai, J., Wang, D., Liu, H., Sun, H., & Liu, J. (2023). Heat stress affects dairy cow health status through blood oxygen availability. Journal of Animal Science and Biotechnology, 14(1), 112. Doi: 10.1186/s40104-023-00915-3

[18] Gernand, E., König, S., &Kipp, C. (2019). Influence of on-farm measurements for heat stress indicators on dairy cow productivity, female fertility, and health. Journal of Dairy Science, 102(7), 6660-6671. Doi:10.3168/jds.2018-16011

[19] 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 System Dynamics, 10(4), 859-884. Doi:10.5194/esd-10-859-2019

[20] Tsai, Y. C., Hsu, J. T., Ding, S. T., Rustia, D. J. A., & Lin, T. T. (2020). Assessment of dairy cow heat stress by monitoring drinking behavior using an embedded imaging system. biosystems engineering, 199, 97-108. Doi:10.1016/j.biosystemseng.2020.03.013