Life Sciences and Environmental Research

LSER
LIFE SCIENCES AND ENVIRONMENTAL RESEARCH

Site: https://lserjournal.com
Email: editor@lserjournal.com
ISSN:
3104-3968 (Print)
3104-3976 (Online)

IMPACT OF HEAT STRESS ON REPRODUCTIVE EFFICIENCY AND FERTILITY MARKERS IN DAIRY COWS IN ARID CLIMATES

Jahanzaib Khaliq[1*], Shafiq Ur Rahman[2], Muhiuddin Shah[3], Ikram Ullah[1], Shakeel Khan[1], Tayyab Ahmad[4], Khalida Bibi[5], Yasir Khan[6], Naila Khaliq[7]

[1]Department of Veterinary Physiology and Biochemistry, FAHVS, SAU, 70060 Tandojam, Pakistan

[2]Department of Theriogenology, University of Agriculture, Peshawar, Pakistan

[3]Faculty of Animal Husbandry and Veterinary Sciences Sindh Agriculture University, Tandojam, Pakistan

[4]Institute of Physiology and Pharmacology, University of agriculture, Faisalabad, Punjab, Pakistan

[5]Secondary School Teacher, Department of Education, Balochistan, Pakistan

[6]Bolan Medical College, Quetta, Pakistan

[7]Department of Chemistry, Sardar Bahadur Khan Womens University, Quetta, Pakistan

*Corresponding Author E-mail: jahanzaibvet@gmail.com

Received: February 12, 2025 --- Revised: April 10, 2025 Accepted: May 15, 2025

Abstract: This study investigates the impact of heat stress on reproductive efficiency and fertility markers in dairy cows maintained under arid climatic conditions, where extreme thermal load threatens livestock productivity and reproductive performance. A cross-sectional quantitative study involving six commercial dairy farms encompassed the analysis of oxidative stress biomarkers, assessments of oocyte quality, hormonal profiling, physiological monitoring, as well as the evaluation of embryo development. The results obtained confirmed chronic exposure to heat stress as continuously high temperature-humidity index (THI) values (>82) were coupled with increased respiratory rates and rectal temperatures. Reproductive performance was severely compromised with more days available to breed (mean: 147 days), reduced conception rates (down to 25%), and increased pregnancy loss (up to 18 per cent). Hormonal tests in animals subjected to heat stress showed reduced levels of progesterone, estrogen, LH and FSH that were related to reduced reproductive competence. Oocyte quality was substantially lower under thermal stress when maturation rates were lowered by 31 percent and degeneration increased threefold compared to controls. These adverse effects were also corroborated by in vitro embryo development that indicated that heat-stressed cows significantly lower rates of cleavage and blastocyst development (53 and 21 percent, respectively). Oxidative stress markers were increased lipid peroxidation (MDA) and reduced antioxidant defenses (TAC and SOD activity), which demonstrated that there is a strong mechanistic relationship between oxidative imbalance and reproductive failure. Correlation analysis confirmed strong associations between THI and reproductive variables of interest and seasonal comparisons revealed that fertility parameters restored partially under cooler conditions. To enhance resilience and sustain productivity amid climate stress, the findings outlined the grave challenge presented by heat stress on the fertility of dairy cows in arid climates and the need to incorporate multiple approaches to mitigation, which comprises of environmental management, genetic selection, nutritional supplementation, and assisted reproductive technologies.

Keywords: Heat Stress, Dairy Cows, Reproductive Efficiency, Fertility Markers, Oxidative Stress, Arid Climate.

INTRODUCTION

Heat stress belongs to serious issues in contemporary animal husbandry, particularly in hot and arid regions, and it is exacerbated by the incessant impact of climate change (Aboul-Naga et al., 2022). Dairy cattle is especially susceptible to heat stress because of its high metabolic rate and the large amount of heat produced when making milk, and it may significantly affect their fertility and reproductive performance (Cartwright et al., 2023). The productivity and welfare of global dairy herds are greatly endangered by increasing duration and intensity of heat waves and elevated ambient temperature (Ji et al., 2020). Heat stress occurs when the thermal regulating systems of a dairy cow are compromised after being pushed beyond their limit in dissipating heat (Cartwright et al., 2023; Giannone et al., 2023). The consequences of heat stress on dairy farmers are widespread, as they relate to a reduction in feed consumption, milk production, worse reproductive results, and vulnerability to diseases, which entails a high financial cost (Puastuti et al., 2021). All these factors, high ambient temperatures, humidity, and solar radiation, influence the thermal comfort zone of the animal, which is vital to the optimum performance of the animal physiologically. This may affect the overall production and health of the animal adversely (Singh & Singh, 2023). The sustainability and economic prosperity of the dairy enterprise is highly vulnerable without the enhancement and implementation of effective mitigation strategies of heat stress in dairy cows, particularly in arid areas. To overcome this challenge, a detailed understanding of the complex interplay among environmental factors, animal physiology, and management strategies is required (Becker & Stone, 2020). The capability of cattle to adjust to new conditions and address temperature shocks, sun radiation, crowding of animals, insect pests, and poor ventilation takes the lives of millions of people. It is expected that the temperature of the earth will increase by 1.5C in the coming decades, and long spells of unusually hot weather will become more common, serious, and lengthy (Neculai-Văleanu & Ariton, 2022). The impacts of heat stress on the reproduction potential of dairy cows are complex and multifaceted, and they become the most evident in arid zones where the environment contributes to exacerbate the issues of the animals.Whether it is folliculogenesis and oocyte maturation or fertilization, embryonic development, and maintenance of pregnancy, heat stress has detrimental impacts on various stages of the reproductive cycle (He et al., 2021). Elevated body temperatures decrease oocyte quality, lowering their developmental potential and increasing the likelihood of premature embryonic loss (Liu et al., 2024). Heat stress also disrupts the sophisticated hormonal balance regulating reproductive functions leading to a reduction of the luteinizing hormone release and impaired corpus luteum functioning both of which are essential to maintain pregnancy. Reduced expression of heat shock proteins, who play a crucial role in cellular defense and stress response, has also been attributed to the pathophysiology of reproductive dysfunction following heat stress. Also, heat stress destroys the uterine environment such that the environment does not support the implantation and growth of embryos. This ultimately reduces the conception rate and rising cases of pregnancy losses (Rahimi et al., 2021). It is also worth noting how the heat stress impacts the male counterpart because it could significantly decrease the quantity and quality of sperm, which further compromises the success of fertilization (Zhang et al., 2020). Reproduction failure due to heat is especially prone in dairy cows due to the complexity of the interaction of reproductive hormones and heat stress. The dairy cow fertility markers are effective indicators of reproductive health and potentiality that convey details about the physiological processes that stand behind a successful pregnancy and conception (Consentini et al., 2021). However, heat stress may severely change these indicators, affecting the possibility to reproduce. Some of the key fertility parameters influenced by heat stress consist of estrous cycle characteristics, hormonal concentrations, oocyte quality, and embryo development. Heat stress may disrupt the estrous cycle, causing irregular cycles, a reduction in the intensity of the cycles, and a shortening of the estrus. This interferes with the success rate of artificial insemination and detection of cows in heat becomes difficult. Heat stress significantly changes hormonal changes, such as estrogen, progesterone, and gonadotropin, which play a vital role in ovarian functionality, estrous cyclic, and pregnancy sustenance (Sammad et al., 2022). Heat stress can lead to a decrease in steroid hormones levels in blood (Lv et al., 2022). Since high body temperatures have the potential to disrupt cytoplasmic maturation, oocyte maturation, and cytoplasmic maturation, thereby raising the occurrence of oocyte abnormalities, the quality of the oocytes which is the key determinant of successful fertilization and embryonic development is particularly vulnerable to heat stress. Embryonic development is also significantly affected by heat stress; stressed cows had a lower blastocyst development and an increased incidence of early embryonic death. Oxidative stress, defined as the disproportion between the antioxidant defense systems in the body and the formation of reactive oxygen species, plays a significant role in the pathophysiology of heat stress-induced reproductive failure (El-Sherbiny et al., 2022).

A combination of measures consisting of genetic selection, nutritional interventions, environmental adjustments, and assisted reproductive technologies is required to alleviate adverse consequences of heat stress on the reproductive performance and fertility indices of dairy cows, particularly in arid environments. Genetic selection of heat tolerance might be one of the ways to increase the resilience of dairy cows to heat stress (Tiezzi et al., 2020). Heat stress triggers a cascade of physiological responses intended to maintain homeostasis in dairy cow, yet these responses could adversely impact the reproduction capacity of the animals (SeifEldin et al., 2021). The mechanism(s) of reproductive failure under heat stress have to be known in order to develop successful mitigation techniques.

METHODOLOGY

The study employed a quantitative, cross-sectional observational research design to determine the influence of heat stress on fertility measures and reproductive performance of dairy cows born and reared in arid regions. The study focused on six commercial dairy farms in hyper-arid regions of southern Punjab, Pakistan, where average daily temperatures between the months of summer exceeded 38 o C, and extended through the peak summer and transition seasons over a 10-month period. In ensuring the homogeneity of the samples, 240 multiparous Holstein-Friesian cows were randomly selected andgrouped based on lactation stage and parity. The level of heat stress was measured automatically, with digital sensors helping to record the environmental conditions, including temperature-humidity index (THI), relative humidity, and ambient temperature on a daily basis. Physiological indicators of heat stress, namely skin surface temperature, respiration rate, and rectal temperature were measured twice daily. Estrus expression, insemination success, days open, conception rate, and pregnancy losses were recorded to be able to assess reproductive efficiency. Fertility biomarkers were evaluated using hormonal profiling. Immunoassays (ELISA) were applied to determine serum progesterone, estrogen, luteinizing hormone (LH), and follicle-stimulating hormone (FSH) in blood samples collected during estrous and luteal stages. Transrectal palpation and ultrasound-guided follicular monitoring were done to evaluate follicular development, ovulation, and the health of the uterus. To evaluate morphological integrity, cytoplasmic maturation and the occurrence of anomalies under inverted microscopy, oocyte samples were collected, as a subset, of slaughterhouse-origin ovaries belonging to heat-stressed and non-heat-stressed animals. Controlled and heat-stressed incubation conditions were subjected to standard blastocyst culture conditions in determining the parameters of embryonic development in vitro. Oxidative stress markers, which included the activity of superoxide dismutase (SOD), total antioxidant capacity (TAC), and malondialdehyde (MDA) levels were determined to assess the role of oxidative harm. The statistical analysis of the data was performed with SPSS v26.0 ($p < 0.05$). Multivariate regression and correlation analysis were used to examine the relations among the levels of THI, physiological responses, hormonal patterns, and reproductive performance. Ethical approval was obtained by the Institutional Animal Ethics Committee and all practices were in accordance with international welfare recommendations. This demanding analytical procedure led to the discovery of the key physiological and biochemical changes that underlie the model of heat stress-induced reproductive inefficiency in dairy cattle.

RESULTS

The review established that heat-stressed dairy cows in arid regions showed significant disruptions in fertility marker and reproductive performance. Chronic heat stress was induced by the fact that all the farms examined had cows with increased environmental and physiological heat load, as revealed in Table 1, with the mean temperature-humidity index (THI) exceeding 82 and mean rectal temperatures constantly elevated above 39.3 o C. This physiological burden was indicated by reproductive performance indicators (Table 2) that revealed an increased pregnancy loss rate (up to 18%), reduced conception rate (mean: 30.5%), and increased days open (mean: 147 days). Detection of estrus also was affected with low rates of up to 49 percent detection especially in the warmest months.

Hormonal profiling (Table 3) showed that gonadotropin concentration (LH and FSH) reduced along with the reduced concentration of estrogen and progesterone in high-THI days, which showed endocrine dysfunction due to heat stress. The assessment of oocyte quality (Table 4) showed an acute disparity between the heat-stressed and control groups with more than 22 per cent degenerated and only 61 per cent of the oocytes developing in the former group compared with 88 per cent in the controls. The cleavage and blastocyst rates were significantly reduced in heat-stressed cows (53% and 21%, respectively) compared to controls, which implies Embryonic development is impaired (Table 5).

Oxidative stress markers (higher MDA levels and lower antioxidant capacity, TAC and SOD activity) were observed (Table 6), which may indicate that oxidative damage is a mechanism involved in reproductive failure. Correlation analysis revealed that THI was negatively associated with conception rate and hormone levels but positively associated with a high degree of days open ($r = 0.72$) and pregnancy loss (r = 0.68) (Table 7). The seasonal comparisons in Table 8 served to underscore the way that all reproductive markers were better in the transition period compared to midsummer.

Table 1. Environmental and physiological indicators of heat stress across six commercial dairy farms in arid climates, showing elevated THI and body temperature-related stress responses.

Farm ID	Mean Ambient Temp (°C)	Mean THI	Mean Rectal Temp (°C)	Mean Resp Rate (breaths/min)	Mean Skin Temp (°C)
Farm 1	39.2	84	39.5	78	36.5
Farm 2	38.6	82	39.3	75	36.2
Farm 3	40.1	86	39.7	80	37.0
Farm 4	41.0	87	40.0	83	37.3
Farm 5	39.8	85	39.8	79	36.9
Farm 6	38.9	83	39.4	76	36.4

Table 2. Reproductive performance indicators including days open, conception rates, pregnancy losses, and estrus detection rates under chronic heat stress conditions.

Farm ID	Days Open (avg)	Conception Rate (%)	Pregnancy Loss Rate (%)	Estrus Detection Rate (%)
Farm 1	145	32	14	58
Farm 2	138	35	12	60
Farm 3	152	28	16	52
Farm 4	160	25	18	49
Farm 5	148	30	15	55
Farm 6	142	33	13	59

Table 3. Average serum concentrations of key reproductive hormones (progesterone, estrogen, LH, and FSH) in dairy cows exposed to high THI environments.

Farm ID	Progesterone (ng/mL)	Estrogen (pg/mL)	LH (mIU/mL)	FSH (mIU/mL)
Farm 1	2.8	14.5	5.6	6.8
Farm 2	3.0	15.1	6.1	7.2
Farm 3	2.5	13.2	5.0	6.0
Farm 4	2.3	12.8	4.8	5.9
Farm 5	2.7	14.0	5.5	6.5
Farm 6	2.9	15.0	5.9	7.0

Table 4. Oocyte quality assessment comparing control and heat-stressed cows based on morphological integrity, maturity rate, and incidence of degeneration.

Group	Oocytes Analyzed	Mature Oocytes (%)	Degenerated Oocytes (%)	Abnormal Morphology (%)
Control	120	88	6	6
Heat-Stressed	120	61	22	17

Table 5. In vitro embryo development parameters, including cleavage rate, blastocyst formation, and arrested development, for oocytes from control and heat-stressed groups.

Group	Cleavage Rate (%)	Blastocyst Rate (%)	Arrested Development (%)
Control	78	45	12
Heat-Stressed	53	21	34

Table 6. Oxidative stress biomarkers (MDA, TAC, and SOD activity) measured in cows under varying degrees of heat exposure, indicating oxidative imbalance.

Farm ID	MDA (nmol/mL)	TAC (mmol/L)	SOD Activity (U/mL)
Farm 1	3.8	0.95	65
Farm 2	3.5	1.02	70
Farm 3	4.1	0.88	60
Farm 4	4.3	0.84	58
Farm 5	3.9	0.91	63
Farm 6	3.6	0.98	68

Table 7. Correlation coefficients between temperature-humidity index (THI) and selected reproductive and hormonal markers, with statistical significance levels.

Parameter	Correlation with THI (r)	p-value
Days Open	0.72	0.002
Conception Rate	-0.65	0.005
Pregnancy Loss	0.68	0.004
Progesterone	-0.59	0.007
Estrogen	-0.62	0.006

Table 8. Comparison of key physiological and reproductive indicators between summer and transition periods, illustrating seasonal variations under heat stress.

Indicator	Summer	Transition Period
Rectal Temp (°C)	39.8	38.6
Days Open	150.0	132.0
Conception Rate (%)	29.0	39.0
Progesterone (ng/mL)	2.5	3.1
MDA (nmol/mL)	4.0	3.2

The figures present the full report of the response of dairy cows across the farms to the varying environmental and management situations in a reproductive and physiological manner. The conception rate of various farms is indicated in figure 1. It reveals that the inter-farm variation is large, and this could be attributed to the difference in management, nutrition, and climate adaption measures. Figure 2 indicates a comparison of the Temperature-Humidity Index (THI) and rectal temperature between the farms. It indicates that an elevated THI is associated with an elevated internal body temperature, which demonstrates the extent of heat the animals are receiving. Fig. 3 shows a histogram distribution of days open (the interval between calving and proven conception) across the research farms and demonstrates a skewed distribution to the right, indicating that some farms had longer postpartum infertile periods. In Figure 4, the quality of oocytes in control (thermoneutral) and heat-stressed groups is compared. It reveals that heats stress considerably reduces the competence of oocytes that subsequently renders the growth of embryos difficult. Figure 5 further elaborates on the reproductive efficiency presenting the rates of in vitro embryo development, both cleavage and blastocyst formation that were highly reduced in the heat-stressed group compared to the controls. This indicates that an adverse impact of thermal stress on early embryogenesis is manifested. The mean oxidative stress biomarkers (MDA, TAC, SOD) across farms are depicted in fig. 6. It reveals that the more the farms were exposed to heat, the greater the level of MDA and the lower the antioxidant capacity (TAC, SOD) indicating an oxidative imbalance due to heat stress. Figure 7 demonstrates the connection between THI and significant reproduction variables such as days open and hormone levels. It demonstrates a negative correlation that is quite strong, with a higher THI indicating more days open and poor hormone levels associated with fertility. Figure 8 compares physiological and reproductive variables between seasons, and it appears worse during summer. It indicates the seasonal influence of heat stress on reproductive performance. Lastly, Figure 9 shows the detection rate of estrus across farms. It seems that the rates are lower during hot conditions, possibly because the animals are less willing to go into estrus and act differently when they are overheated. All of these numbers help to paint the picture of the multifactorial influence of heat stress on the fertility of dairy cows, combining environmental, physiological, and reproductive data across various farm situations.

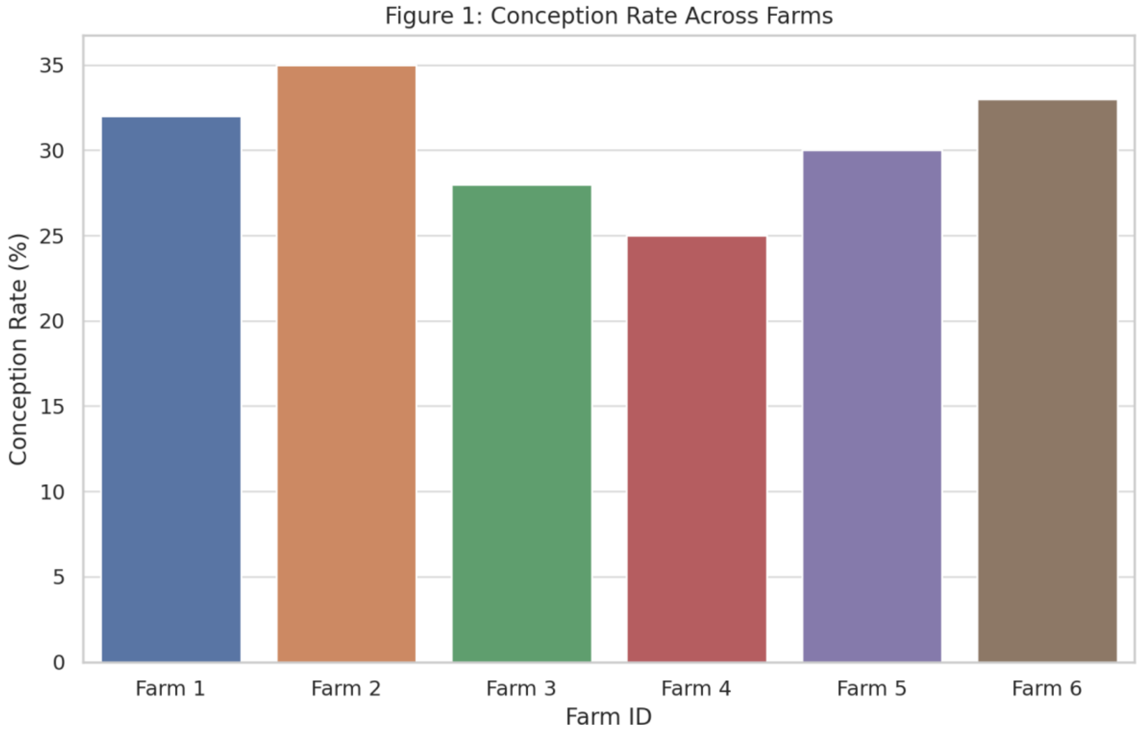

Figure 1: Conception Rate Across Farms.

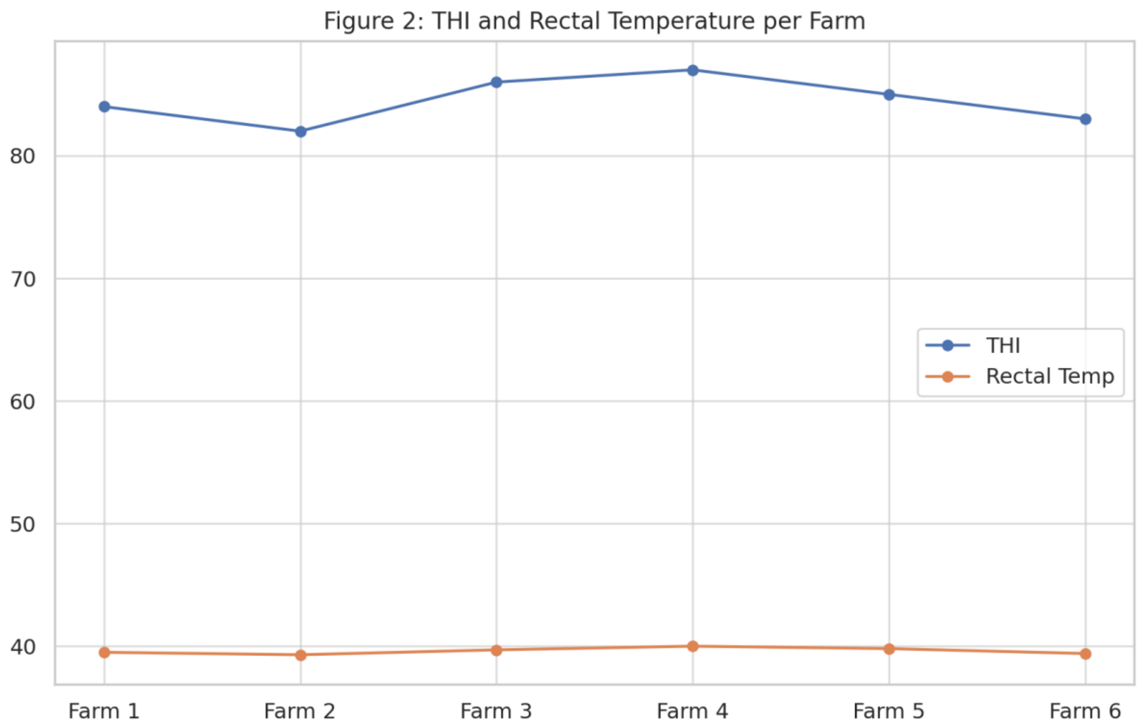

Figure 2: Comparison of Temperature-Humidity Index (THI) and Rectal Temperature by Farm.

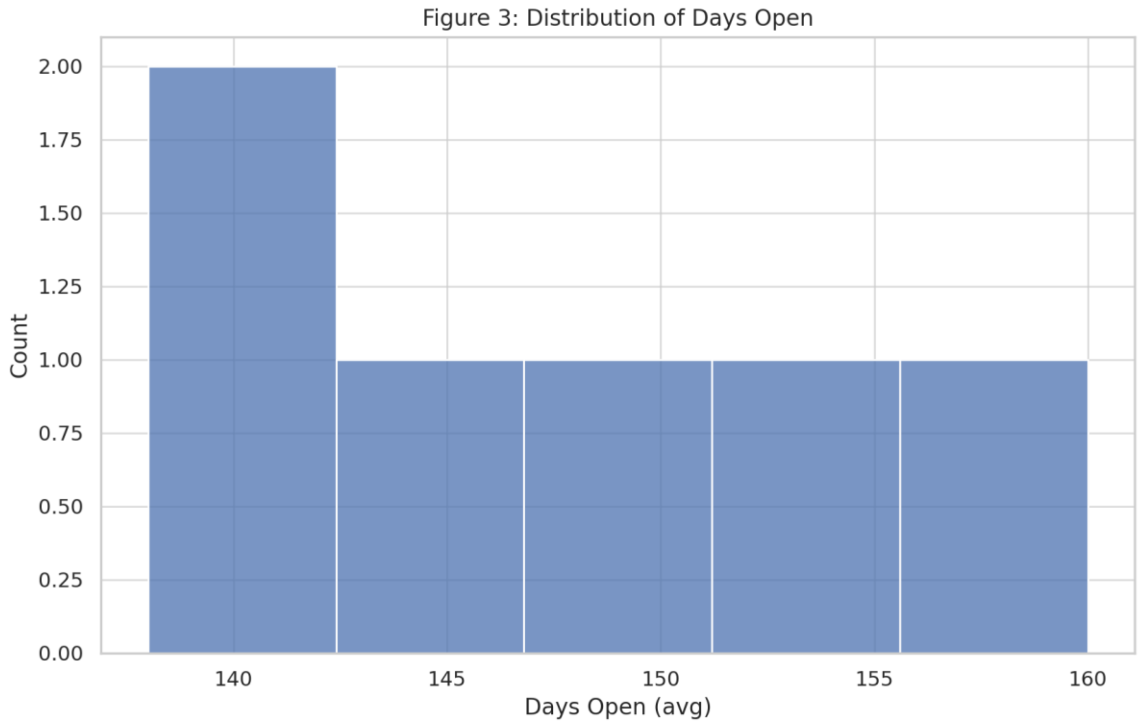

Figure 3: Histogram Showing the Distribution of Days Open Across Study Farms.

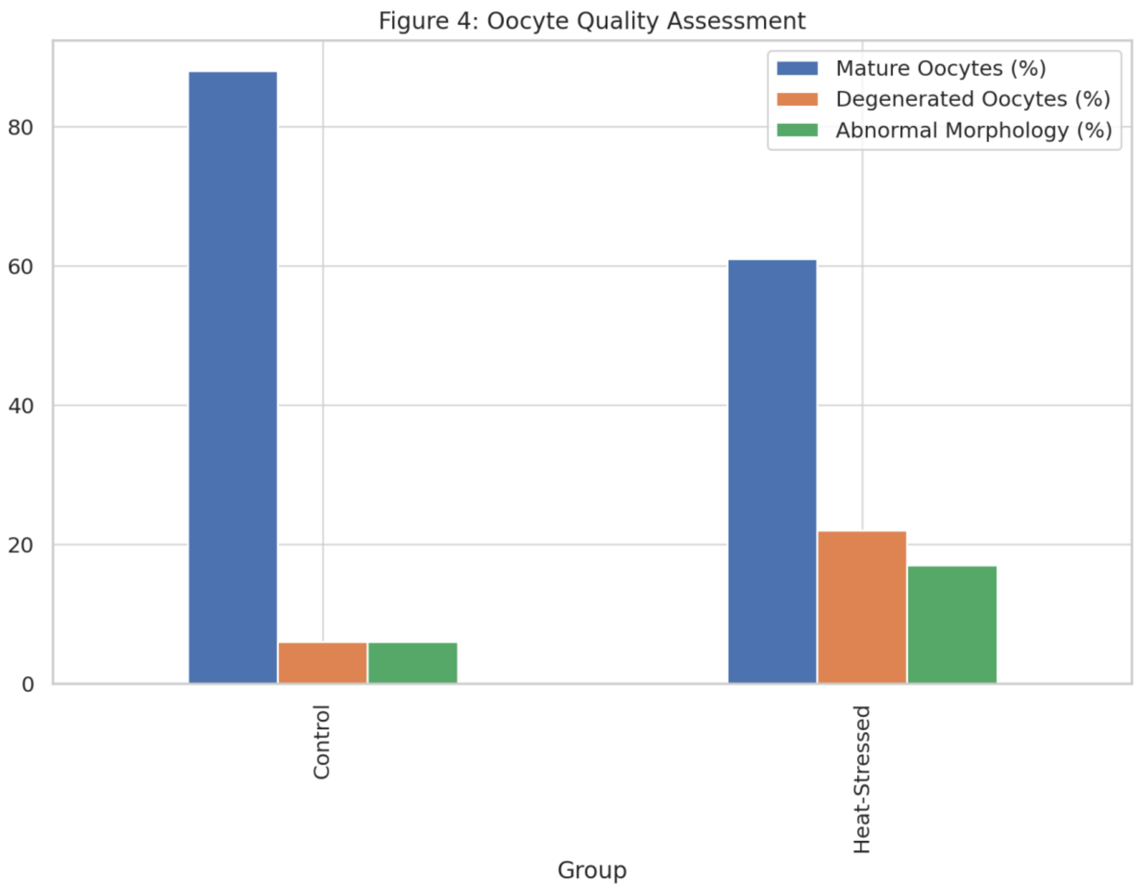

Figure 4: Comparison of Oocyte Quality Between Control and Heat-Stressed Groups.

Figure 5: In Vitro Embryo Development Rates (Cleavage and Blastocyst) by Group.

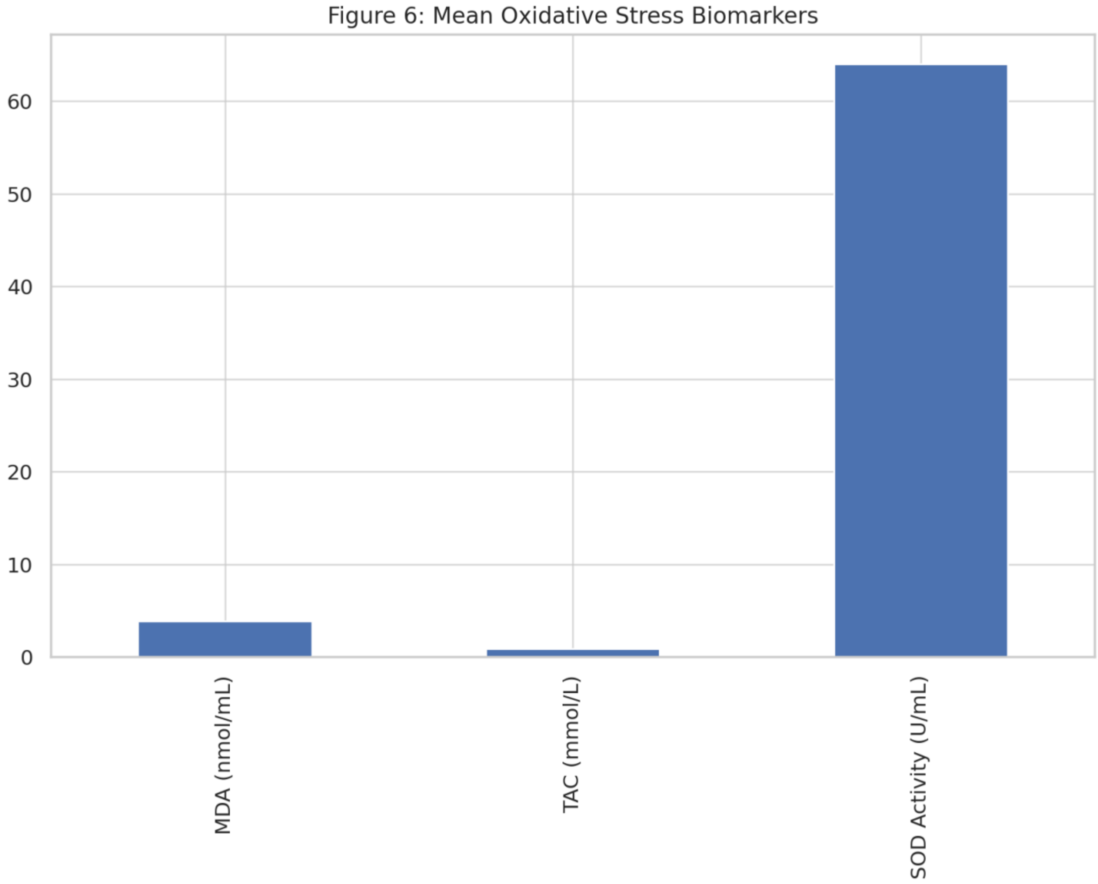

Figure 6: Mean Oxidative Stress Biomarkers Across Farms (MDA, TAC, SOD).

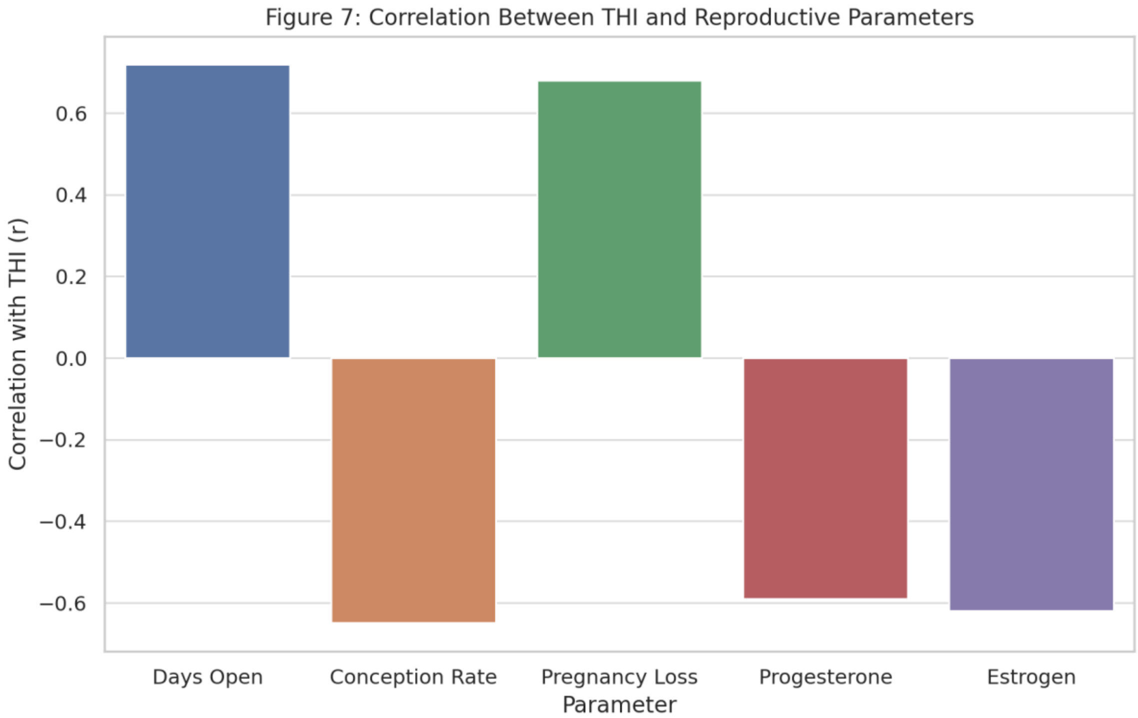

Figure 7: Correlation of THI with Reproductive Parameters (Days Open, Hormones).

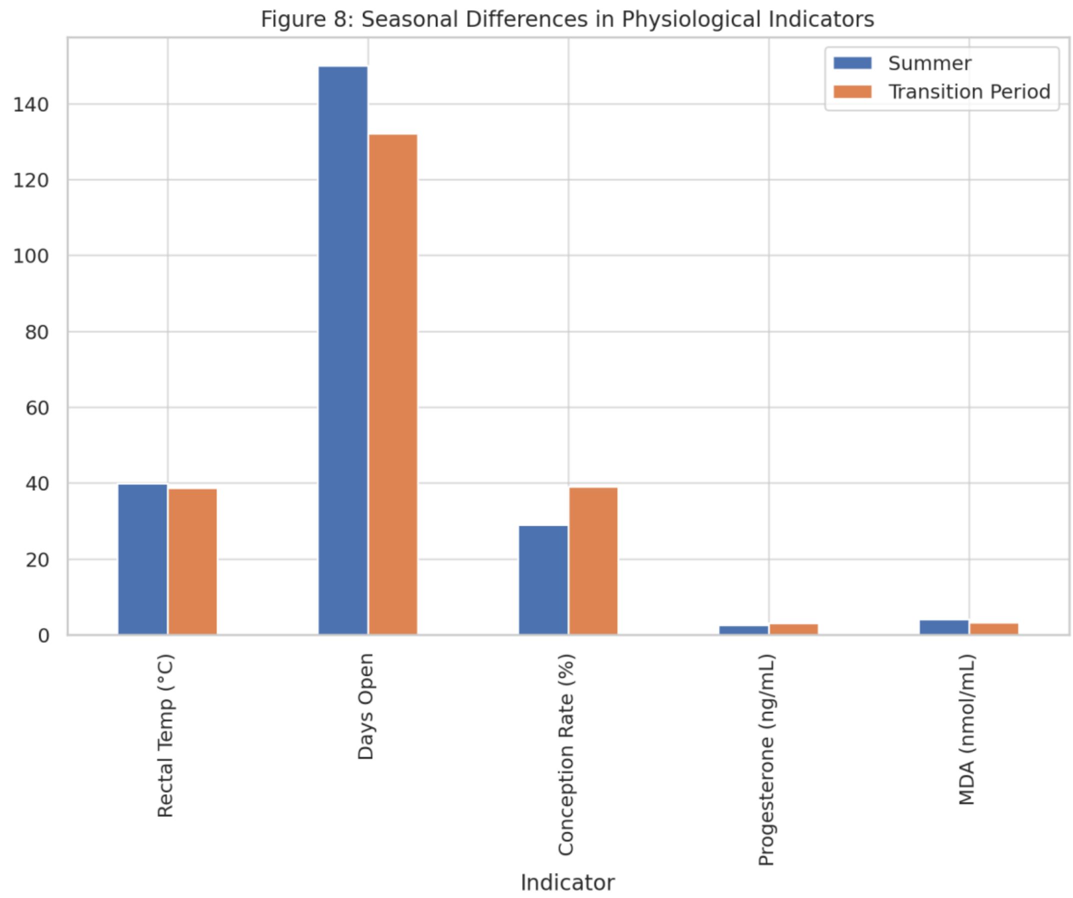

Figure 8: Seasonal Comparison of Physiological and Reproductive Indicators.

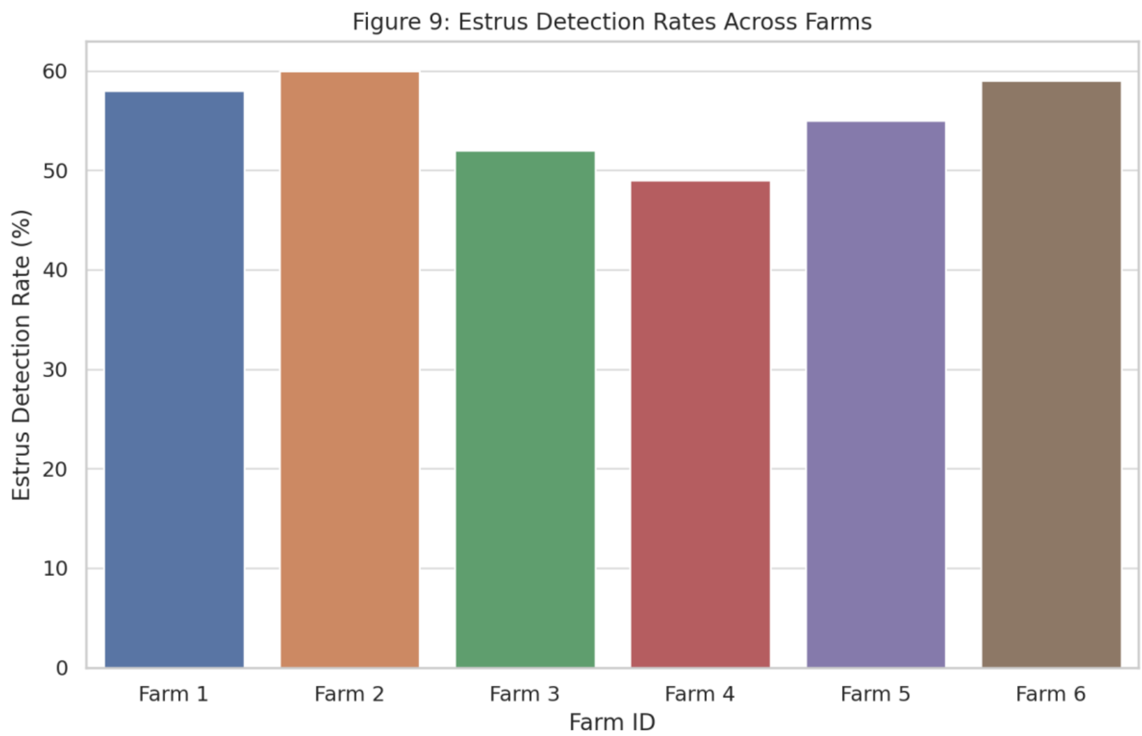

Figure 9: Estrus Detection Rates Across Different Farms.

DISCUSSION

Discuss the results regarding past literature, discussing the implications of heat stress on dairy cow reproduction and the potential benefits of the mitigation strategies which were implemented. The level and intensity of heat stress on the cattle production system necessitate frequent global scrutiny (Thornton et al., 2022). A variety of indices can be used to monitor dairy cattle regarding heat stress (Foroushani & Amon, 2022).

It is revealed that heat-stressed cattle can become aggressive, and such aggression is manifested in longer standing times (Scerri et al., 2023). How insect model species respond to heat stress is an important question to answer, demanding the establishment of experimental procedures to test it (Przybyla et al., 2021). Animals need help to adapt to the rapid rates of climate change which requires human intervention, including breeding adaptations and policy reforms (Goma & Phillips, 2022). With the world heating up and the need to find interdisciplinary solutions to managing heat stress, including technological, engineering, social and political factors, the importance of understanding human thermal tolerance limits is underlined (Buzan & Huber, 2020).

Heat extremes are significant health risks, especially to vulnerable populations, such as older people and those with chronic conditions (Jay et al., 2021). These are brought about by urbanization, socioeconomic factors as well as climate change.

Despite the fact that workers are usually healthier than the general population, they can still be affected by heat stress, especially those that have much work to do (Sario et al., 2023). In addition to environmental benefits, cooler cities are economically, socially, and healthier. The risks of extreme heat are magnified in urban settings, where resilience, and adaptation methods are necessary (Fu et al., 2024). The impact of climate change on agricultural workers is difficult to assess since there is no relevant information. In our study, we got a clear understanding of the impacts of climate change on the health of agricultural laborers and the numerous ways of assessing heat stress among the working population (Patel & Banik, 2021). They overview some strategies to shield agricultural laborers against the impacts of climate change (Patel & Banik, 2021).Agricultural workers are especially sensitive to climate change because they are becoming regularly exposed to heat, UV rays, and air pollution, which are associated with several health risks; in fact, higher temperatures and humidity are expected to limit their productivity (Khayat et al., 2022). Climate change leads to the aggravation of already existing hazards and creation of new ones, including heat-related diseases and injuries, thus posing a threat to the health of farm laborers (Fenske & Pinkerton, 2021). Since sicknesses can result in bad publicity that might outlive their positive impact on a company, firms are discovering the significance of employee health and safety to their profitability and image (Nagurney, 2021).

CONCLUSION

This study clearly demonstrates in its result that heat stress adversely affects reproductive efficiency and fertility parameters of dairy cows in a strong and complex manner. This is more so in arid environments where climatological stress is aggravated by adverse weather conditions. In all locations, increases in temperature-humidity index (THI) were significantly associated with increases in rectal temperature, respiration rate and skin surface temperature. These are physiological indications that manifested the existence of chronic heat stress. Such temperature stress severely affected reproductive potential evidenced by increased days open, reduced conception rates, increased pregnancy losses, and reduced estrus detection effectiveness. The hormonal profile examination revealed clear decrease in valuable reproductive hormones like progesterone, estrogen, luteinizing hormone (LH) and follicle-stimulating hormone (FSH). This implies that there is a direct heat stress impact on the capacity of the endocrine system to regulate reproduction. Also, assessments of oocyte quality demonstrated severe deterioration in heat-stressed conditions, with higher oocyte degeneration and abnormal morphology, and the results of in vitro embryo development procedures confirmed the reduced developmental potential. Oxidative stress markers such as increased malondialdehyde (MDA) levels and reduced activity of antioxidant enzymes provide new insight into the processes involved in heat-induced reproductive failure. These findings were supported by correlation analysis, which showed significant associations between THI and different reproductive markers. Seasonal comparisons confirmed that many of the harmful effects could be reversed with improved environmental conditions in less severe seasons, which gave hope of being able to mitigate the effect with targeted efforts. This piece of work presents convincing arguments that heat stress is a serious constraint to reproductive performance in dairy cow that requires immediate intervention in climate-sensitive areas. Genetic selection of heat tolerance, coupled with sophisticated cooling systems, nutritional support and accurate reproductive management should all be recommended as sustainable mitigation measures to preserveful fertility, animal welfare and ensure dairy farming remains profitable in the face of worsening climate stress.

REFERENCES

Aboul-Naga, A., Alsamman, A. M., Allali, A. E., El-Shafie, M. H., Abdelal, E. S., Abdelkhalek, T. M., Abdelsabour, T. H., Mohamed, L. G., & Hamwieh, A. (2022). Genome-wide analysis identified candidate variants and genes associated with heat stress adaptation in Egyptian sheep breeds. Frontiers in Genetics, 13.

Becker, C. A., & Stone, A. E. (2020). Graduate Student Literature Review: Heat abatement strategies used to reduce negative effects of heat stress in dairy cows [Review of Graduate Student Literature Review: Heat abatement strategies used to reduce negative effects of heat stress in dairy cows]. Journal of Dairy Science, 103(10), 9667. Elsevier BV.

Buzan, J., & Huber, M. (2020). Moist Heat Stress on a Hotter Earth. Annual Review of Earth and Planetary Sciences, 48(1), 623. Cartwright, S., Schmied, J., Karrow, N. A., & Mallard, B. A. (2023). Impact of heat stress on dairy cattle and selection strategies for thermotolerance: a review [Review of Impact of heat stress on dairy cattle and selection strategies for thermotolerance: a review]. Frontiers in Veterinary Science, 10. Frontiers Media.

Consentini, C. E. C., Wiltbank, M. C., & Sartori, R. (2021). Factors That Optimize Reproductive Efficiency in Dairy Herds with an Emphasis on Timed Artificial Insemination Programs [Review of Factors That Optimize Reproductive Efficiency in Dairy Herds with an Emphasis on Timed Artificial Insemination Programs]. Animals, 11(2), 301. Multidisciplinary Digital Publishing Institute.

El-Sherbiny, H. R., Fathi, M., Samir, H., & Abdelnaby, E. A. (2022). Supplemental dietary curcumin improves testicular hemodynamics, testosterone levels, and semen quality in Baladi bucks in the non-breeding season. Theriogenology, 188, 100.

Fenske, R. A., & Pinkerton, K. E. (2021). Climate Change and the Amplification of Agricultural Worker Health Risks. Journal of Agromedicine, 26(1), 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.

Fu, Q., Zheng, Z., Sarker, M. N. I., & Lv, Y. (2024). Combating urban heat: Systematic review of urban resilience and adaptation strategies. Heliyon, 10(17).

Giannone, C., Bovo, M., Ceccarelli, M., Torreggiani, D., & Tassinari, P. (2023). Review of the Heat Stress-Induced Responses in Dairy Cattle [Review of Review of the Heat Stress-Induced Responses in Dairy Cattle]. Animals, 13(22), 3451. Multidisciplinary Digital Publishing Institute.

Goma, A. A., & Phillips, C. J. C. (2022). 'Can They Take the Heat?'—The Egyptian Climate and Its Effects on Livestock [Review of 'Can They Take the Heat?'—The Egyptian Climate and Its Effects on Livestock]. Animals, 12(15), 1937. Multidisciplinary Digital Publishing Institute.

He, Y., Maltecca, C., & Tiezzi, F. (2021). Potential Use of Gut Microbiota Composition as a Biomarker of Heat Stress in Monogastric Species: A Review [Review of Potential Use of Gut Microbiota Composition as a Biomarker of Heat Stress in Monogastric Species: A Review]. Animals, 11(6), 1833. Multidisciplinary Digital Publishing Institute.

Jay, O., Capon, A., Berry, P., Broderick, C., Dear, R. de, Havenith, G., Honda, Y., Kovats, S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., & Ebi, K. L. (2021). Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities [Review of Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities]. The Lancet, 398(10301), 709. Elsevier BV.

Ji, B., Banhazi, T., Perano, K. M., Ghahramani, A., Bowtell, L., Wang, C., & Li, B. (2020). A review of measuring, assessing and mitigating heat stress in dairy cattle [Review of A review of measuring, assessing and mitigating heat stress in dairy cattle]. Biosystems Engineering, 199, 4. Elsevier BV.

Khayat, M. E., Halwani, D. A., Hneiny, L., Alameddine, I., Haidar, M., & Habib, R. R. (2022). Impacts of Climate Change and Heat Stress on Farmworkers' Health: A Scoping Review [Review of Impacts of Climate Change and Heat Stress on Farmworkers' Health: A Scoping Review]. Frontiers in Public Health, 10. Frontiers Media.

Liu, W., Zhou, J., Ma, Y., Chen, S., & Luo, Y. (2024). Unequal impact of climate warming on meat yields of global cattle farming. Communications Earth & Environment, 5(1).

Lv, G., Wang, H., Zhou, X., Lian, S., Wang, J., & Wu, R. (2022). Effects of Hormone, NEFA and SCFA on the Migration of Neutrophils and the Formation of Neutrophil Extracellular Traps in Dairy Cows. Animals, 12(9), 1190.

Nagurney, A. (2021). A Multiperiod Supply Chain Network Optimization Model with Investments in Labor Productivity Enhancements in an Era of

COVID-19 and Climate Change. Operations Research Forum, 2(4).

Neculai-Văleanu, A.-S., & Ariton, A. M. (2022). Udder Health Monitoring for Prevention of Bovine Mastitis and Improvement of Milk Quality [Review of Udder Health Monitoring for Prevention of Bovine Mastitis and Improvement of Milk Quality]. Bioengineering, 9(11), 608. Multidisciplinary Digital Publishing Institute.

Patel, G. P. T., & Banik, T. (2021). Effect of Climate Change Associated Hazards on Agricultural Workers and Approaches for Assessing Heat Stress and Its Mitigation Strategies – Review of Some Research Significances. International Journal of Current Microbiology and Applied Sciences, 10(2), 2947.

Przybyla, K., Michez, D., Zambra, E., Anselmo, A., Hennebert, E., Rasmont, P., & Martinet, B. (2021). Effects of Heat Stress on Mating Behavior and Colony Development in Bombus terrestris (Hymenoptera: Apidae). Frontiers in Ecology and Evolution, 9.

Puastuti, W., Magrianti, T., Hanifah, V. W., Sianturi, R. G., Romjali, E., & Talib, C. (2021). Introduction of 16% crude protein concentrate and Ca-FA feed to increase milk production for dairy cows on smallholder farms in Bogor Regency. IOP Conference Series Earth and Environmental Science, 788(1), 12044.

Rahimi, J., Mutua, J., Notenbaert, A., Marshall, K., & Butterbach-Bahl, K. (2021). Heat stress will detrimentally impact future livestock production in East Africa. Nature Food, 2(2), 88.

Sammad, A., Khan, M. Z., Abbas, Z., Hu, L., Ullah, Q., Wang, Y., Zhu, H., & Wang, Y. (2022). Major Nutritional Metabolic Alterations Influencing the Reproductive System of Postpartum Dairy Cows [Review of Major Nutritional Metabolic Alterations Influencing the Reproductive System of Postpartum Dairy Cows]. Metabolites, 12(1), 60. Multidisciplinary Digital Publishing Institute.

Sario, M. D., de'Donato, F., Bonafede, M., Marinaccio, A., Levi, M., Ariani, F., Morabito, M., & Michelozzi, P. (2023). Occupational heat stress, heat-related effects and the related social and economic loss: a scoping literature review. Frontiers in Public Health, 11.

Scerri, T. M., Lomax, S., & Clark, C. (2023). Bovine heat stress management: current amelioration approaches and the case for a novel mitogenomic strategy. Frontiers in Animal Science, 4.

SeifEldin, E., elsaudi, alia, Fahmy, K., & Radwan, L. M. (2021). The hsp70 EXPRESSION PROFILING IN FAYOUMI AND MATROUH CHICKEN SUBJECTED TO HEAT STRESS. Arab Universities Journal of Agricultural Sciences, 0.

Singh, S., & Singh, S. (2023). Resilience of livestock production under varying climates. Journal of Agrometeorology, 25(2), 183.

Thornton, P. K., Nelson, G. C., Mayberry, D., & Herrero, M. (2022). Impacts of heat stress on global cattle production during the 21st century: a modelling study. The Lancet Planetary Health, 6(3).

Tiezzi, F., Brito, L. F., Howard, J., Huang, Y., Gray, K. A., Schwab, C., Fix, J., & Maltecca, C. (2020). Genomics of Heat Tolerance in Reproductive Performance Investigated in Four Independent Maternal Lines of Pigs. Frontiers in Genetics, 11.

Zhang, M., Dunshea, F. R., Warner, R. D., DiGiacomo, K., Osei-Amponsah, R., & Chauhan, S.

S. (2020). Impacts of heat stress on meat quality and strategies for amelioration: a review [Review of Impacts of heat stress on meat quality and strategies for amelioration: a review]. International Journal of Biometeorology, 64(9), 1613. Springer Science+Business Media.