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Impact of Thermal Heat Stress on Productive and Reproductive Performance of Dairy Animals in respect of Climate Changes-A review

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ABSTRACT

Environmental stress significantly impacts the productive and reproductive performance of dairy animals, which affecting the overall herd profitability and their sustainability. This study reveals that the effects of various environmental stressors such as heat, humidity and dietary factors on milk production, fertility and animal health in both species. High ambient temperature and humidity compromise the thermoregulation mechanisms in animals, thereby reducing in feed intake, altering the metabolism and reducing the milk yield. In addition, heat stress negatively impacts on reproductive processes, leading to irregular estrus cycles, reduced conception rates and increased embryonic mortality. Nutritional stress exacerbates these effects, with imbalances in diet composition compromising metabolic health and productivity. Strategies those mitigate environmental stress include nutritional management, shade provision and improved ventilation systems, aimed at enhancing animal comfort and performance. Understanding the interactions between environmental stressors and physiological responses is important for developing sustainable management practices that optimize dairy production and reproductive outcomes in challenging climates. Reduced fertility in dairy animals causes huge economic losses worldwide. Nutritional and management like cooling systems and ventilation strategies are used to reduce the negative impact of environmental stress on dairy animals. This study attempts to bring outcomes the effects of heat stress and discuss their impact on dairy cows and buffaloes.

HIGHLIGHTS

- Thermal stress is a major environmental challenge affecting the productivity, fertility and health of dairy animals.
- Increasing heat waves due to climate change disrupt metabolism, hormonal balance and behavior, reducing milk yield and reproductive efficiency.

Keywords: Climate change, Dairy animals, Environmental stress, Fertility, Heat stress, Milk production, Nutritional stress, Reproductive performance and Thermoregulation

Dairy sector farming plays a vital role in global agriculture, providing essential nutrients through milk and dairy products. However, the productivity and fertility of animals are significantly affected by various environmental factors, with thermal stress being one of the most important. Stress is a biological response that an animal feels to uncomforted situation ("stress") that is a threat to its homeostasis**.** "An animal's well-being or quality of life is an individual's internal somatic and mental state that is affected by what it knows or perceives; its feelings and motivational state; the responses to internal or external stimuli or environments; interacting variables; and phylogeny and ontogeny". Stress responses include endocrine, paracrine and neurological responses; these stress responses negatively affect the productive and reproductive potential of dairy cattle and buffaloes. Stressors can be of many types, such as climatic, physical, noise, transportation and food deprivation or restriction. Stressors can also be psychological, such as separation from a calf after weaning, social isolation or

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mixing with unfamiliar animals, restraint and handling. Stressors can also be classified as endogenous based on genetic and physiological origins and/or exogenous, if they originate from the social and physical environment. These stresses are responsible for behavioral, metabolic and physiological changes in animals, many stresses directly affect the physiology of dairy animals, mainly heat and cold or climate stress can prove to be detrimental to animal health. Thermal stress occurs when animals are exposed to temperatures outside their thermo-neutral zone, leading to physiological and behavioral adaptations aimed at maintaining body temperature within acceptable limits. For dairy animals, such stress not only affects their welfare but also poses major economic challenges to farmers in the dairy industry at large scale.

Stress is one of the environmental factors that affects and reduces the production and reproduction of livestock, it is considered as the main factor that must be controlled in animal production units, as it is closely related to pathogens and infectious agents and affects the health of animals. Stress is directly responsible for the declining economy of the farm by reducing productive and reproductive performance.

In recent years, climate change has led to an increase in the frequency and intensity of heat waves and extreme temperatures, increasing the challenges faced by dairy farmers worldwide."Atmospheric warming due to global climate change resulting thermal stress is one of the greatest climatic challenges faced by dairy cattle. Loss in production reduced reproductive performance of the animals and increased incidence of diseases and mortality are the major issues of economic importance to dairy farmers in areas of the world where ambient temperature often exceeds upper critical temperature". It is important to understand the complex relationship between thermal stress and dairy animal performance to develop effective management strategies to mitigate its adverse effects. This review explores the effects of thermal stress on the productive and reproductive performance of dairy animals. Bernabucci *et al.* (2014) examines the physiological responses triggered by heat stress, such as changes in metabolism, hormonal balance, and nutrient utilization. In addition, it highlights the implications for milk production, reproductive cycles, fertility rates, and overall herd management practices. By synthesizing current research findings and practical insights, this paper aims to provide a comprehensive overview of how thermal stress affects dairy animals and suggests evidence-based strategies to enhance their resilience and performance under challenging environmental conditions.

Neuroendocrinology impacts on stress

Neuroendocrinological stress in animal is the complex interaction between the nervous and endocrine systems that regulates physiological responses to environmental and management stressors. Stress perception initiates a cascade of neuroendocrine events, primarily mediated through the hypothalamic–pituitary–adrenal (HPA) axis, which plays a central role in maintaining homeostasis under challenging conditions (Moberg and Mench, 2000). In dairy cattle, exposure to stressors such as heat, handling, transportation, and nutritional imbalance activates the hypothalamus to secrete corticotropin-releasing hormone (CRH), which stimulates the pituitary gland to release adrenocorticotropic hormone (ACTH), ultimately inducing cortisol secretion from the adrenal cortex (Das *et al.,* 2016, Dobson *et al.,* 2007).

Cortisol is a primary stress hormone responsible for mobilizing energy reserves; however, chronic elevation of cortisol suppresses non-essential physiological functions such as growth, immune competence, and reproduction. Prolonged stress exposure has been associated with reduced feed intake, altered metabolic efficiency, and impaired milk production, largely due to endocrine-mediated changes in nutrient partitioning (Baumgard and Rhoads, 2013).

Behavioral alterations during stress, including reduced feeding activity, restlessness, and decreased milk yield, are regulated through neurohormonal pathways involving cortisol and catecholamines. Furthermore, elevated stress hormone concentrations negatively influence reproductive efficiency by suppressing the secretion of gonadotropin-releasing hormone (GnRH), luteinizing hormone (LH), and follicle-stimulating hormone (FSH), thereby impairing follicular development, ovulation, and conception rates (Roth, 2017).

Stress also alters nutrient metabolism and digestive efficiency, reducing nutrient absorption and availability for production and reproduction (Kadzere *et al.,* 2002; Van Saun, 2009). Therefore, effective stress management strategies—including proper housing, nutrition, environmental enrichment, and gentle handling—are essential to maintain animal welfare, productivity, and reproductive efficiency (Phillips, 2010; FAO, 2011).

Neuroendocrinology of stress in dairy cattle represented the relationship between the nervous system and the endocrine system, specifically studying how these systems respond to stressors, and how they regulate the animal's physiological processes. Here are some key takeaways from the facts:

1. Stress Response Mechanism

Dairy cattle, like other mammals, respond to stress through activation of the hypothalamic-pituitary-adrenal (HPA) axis. This involves the hypothalamus secreting corticotropin-releasing hormone (CRH), which stimulates the pituitary gland to release adrenocorticotropic hormone (ACTH). ACTH then stimulates the adrenal glands to produce cortisol, a primary stress hormone.

2. Effect of cortisol hormone

Cortisol mobilizes energy reserves in the body, and in the short term inhibits non-essential functions such as physical growth, reproduction and immune response. Elevated cortisol levels due to chronic stress in animals can have a negative impact on the health, productivity and welfare of dairy animals.

3. Behavioral responses during stress

Stress also affects the behavior of dairy animals. They exhibit changes such as reduced food intake, solipsism and reduced milk production. These behavioral changes are often established through neurotransmitters and hormones that affect their mood and motivation.

4. Effects of stress on reproduction

High levels of stress hormones in dairy cattle can reduce their reproductive potential, significantly reducing their fertility and reproductive success. It is especially important in dairy farming that a skilled breeder is required to maintain the productivity of the animal herd.

5. Nutritional Considerations

Stress in dairy cattle can affect their metabolism and absorption of nutrients, adversely affecting their overall health and milk production. Stress alters digestive processes and the ability to utilize nutrients, adversely affecting their physiological biophysical processes, leading to potential economic losses for farmers.

6. Management strategies to eliminate stress

Effective stress management strategies in animal husbandry should reduce their stress as much as possible, such as providing proper housing management and nutrition for them and adopting protocols that promote animal welfare. Techniques such as environmental enrichment and proper management during milking can help reduce stress levels in dairy animals.

To optimize animal welfare, health and productivity in modern agricultural practices, it is important to understand the neuroendocrinological process of stress in animals, in order to gain new insights into stress responses and potential interventions to reduce its negative effects on dairy animals.

Environmental heat

Environmental heat stress occurs when dairy animals are unable to adequately dissipate body heat, resulting in disruptions of thermoregulatory mechanisms such as sweating, respiration, and blood circulation (Collier *et al.,* 2006). High ambient temperature, elevated humidity, solar radiation, and inadequate air movement are major contributors to heat stress, particularly in tropical and subtropical regions (Mader *et al.*, 2006; Gaughan *et al.,* 2008).

Humidity plays a critical role by reducing evaporative cooling efficiency, while excessive solar radiation and low wind speed further exacerbate heat load in dairy cattle (Zimbelman *et al.,* 2009). Clinical symptoms of heat stress include excessive panting, increased heart rate, weakness, restlessness, reduced feed intake, and, in severe cases, heat exhaustion or heat stroke (Silanikove, 2000; West, 2003).

Preventive strategies for environmental heat stress emphasize continuous access to clean drinking water, provision of shade, adequate ventilation, use of fans and sprinklers, and scheduling management practices during cooler hours of the day. Gradual acclimatization and continuous monitoring of environmental conditions using indices such as the temperature–humidity index (THI) are also essential for minimizing heat stress risks (Du Preez, 2000).

Environmental heat stress in animals occurs when they are unable to cool themselves adequately, when the factors that regulate the animal's internal body temperature, such as sweating and circulation, are disturbed by high temperatures and humidity. This can lead to a variety of heat-related illnesses, including heat exhaustion and heat stroke, which are serious and potentially life-threatening. The following are the major factors responsible for environmental heat stress in animals:

Cause of Environmental Heat Stress

1. **Temperature:** Excessive heat increases the risk of stress in animals, especially when the weather has high humidity.
2. **Humidity:** When the body's sweat cannot evaporate easily in saturated air. High humidity reduces the volatility of sweat, which leads to increased heat stress in animals.
3. **Extreme heat:** Direct sunlight or intense heat can make animals feel hotter.
4. **Wind speed:** Wind acclimatizes body temperature by increasing sweat evaporation, but very strong winds can interfere with the volatility of sweat.
5. **Symptoms of heat stress:** It includes excessive sweating, weakness, dizziness, headache, and increased heart rate. Over stress can also cause trouble, restlessness and seizures in animals, creating a medical emergency etc.

Prevention of Environmental Heat Stress

1. **Hydration:** Provide the fresh water to animals for maintain the fluid balance in the body.
2. **Rest and shade:** Tether your animals in a shady or cool place often during the summer season.
3. **Limit outdoor activity:** Schedule strenuous activities like grazing, during the cooler times of the day such as morning or evening.
4. **Acclimatization:** Gradually build up your animals' tolerance to heat by keeping them in warm conditions for longer periods of time.
5. **Monitoring:** Keep an eye on weather forecasts and heat advisories to plan activities accordingly.

For workplaces and outdoor activities, employers and organizers should have protocols to monitor workers and participants for signs of heat stress, provide adequate breaks, and ensure access to shaded areas and hydration stations.

Thermo-neutral Zone and Heat Stress Zone

The thermo-neutral zone (TNZ) represents the range of ambient temperatures within which dairy animals maintain normal body temperature without additional metabolic energy expenditure for thermoregulation. For dairy cattle, the TNZ typically ranges from 5°C to 25°C, during which feed intake, metabolic efficiency, and milk production remain optimal (NRC, 2001).

When ambient temperatures exceed the upper critical temperature of the TNZ, animals enter the heat stress zone, characterized by increased respiration rate, reduced feed intake, and compromised physiological functions (Berman, 2005; Bohmanova *et al.,* 2007). Due to limited heat dissipation mechanisms, high-producing dairy cows are particularly vulnerable to heat stress, necessitating management interventions such as cooling systems and housing modifications (Dahl *et al.,* 2016).

In animal husbandry, an environmental temperature tolerance for all dairy animals is known as the "thermo-neutral zone" and "heat stress zone" concepts. It is the temperature at which animals can maintain normal physiological functions of the body.

Thermo-neutral Zone

The thermo-neutral zone refers to the range of temperatures within which dairy cattle can maintain normal body temperature without expending extra energy to cool or warm up.For dairy cows, the normal thermo-neutral zone is between 5°C to 25°C (41°F to 77°F). Within this range, cows and buffaloes feel comfortable and can consume feed efficiently and maintain milk production. In this zone, the metabolic rate of cows remains stable, and they do not need to use extra energy for temperature regulation.

Heat stress zone

The heat stress zone occurs when temperatures rise above the upper limit of the animals' thermo-neutral zone, which is about 25°C (77°F) for dairy cows and buffaloes. Dairy cows are particularly vulnerable to heat stress because they have limited mechanisms to dissipate heat. Heat stress can lead to reduced feed intake, reduced milk production and health problems such as dehydration and heat stroke. In hot climates or during periods of hot weather, dairy farmers need to take measures to reduce heat stress. This may include providing shade, ensuring adequate ventilation and providing access to cool water.

Thermal stressors effect on production performance

Thermal stress, particularly heat stress, has a pronounced negative impact on the productive performance of dairy animals. Reduced feed intake under heat stress conditions is a primary factor contributing to decreased milk yield, as animals attempt to minimize metabolic heat production (Hansen *et al.,* 2006; West, 2003). Additionally, heat stress alters nutrient partitioning and metabolic efficiency, further reducing milk synthesis (Rhoads *et al.,* 2009; Wheelock *et al.,* 2010).

Milk composition is also affected, with documented reductions in milk fat and protein content, compromising milk quality and economic returns (Shwartz *et al.,* 2009; Bernabucci *et al.*, 2010). Heat stress increases susceptibility to metabolic disorders such as ketosis and rumen acidosis and weakens immune function, leading to higher disease incidence and veterinary costs (Sordillo and Aitken, 2009).

Thermal stress in animals, particularly heat stress, has a negative impact on the productive performance of dairy animals, such as reduced milk production. Heat stress often results in a decrease in milk yield. Reduced feed intake, partly due to physiological metabolic changes aimed at reducing heat production. During heat stress dairy animals reduce feed intake, which directly impacts their milk production (Hansen *et al.*, 2006). Heat stressed cows may also have changes in the milk composition. For example, there may be a decrease in the fat and protein content of milk, which affects the overall quality of milk produced. Heat stress has a negative impact on the reproductive performance of dairy animals. It can lead to imbalances or a decrease in the estrus cycle and a lower conception rate. This results in reduced fertility and longer calving intervals. Heat stress can also predispose animals to metabolic diseases such as ketosis and rumen acidosis. All of these disorders reduce feed intake, and can affect overall health and productivity. During heat stress,dairy cattle divert physical energy from milk production to cooling mechanisms (such as panting and increased respiration); this shift in physiological energy allocation also reduces feed efficiency, meaning more feed needs to be fed per unit of milk produced. Heat stress also affects the immune system of dairy cows, making them more susceptible to diseases and infections. This increases veterinary costs and management challenges on the farm.

Thermal stressors effect on reproductive performance

Heat stress severely impairs reproductive performance in dairy cattle by reducing estrus expression, disrupting hormonal balance, and lowering conception rates (Thatcher *et al.,* 2010). Elevated body temperature negatively affects follicular development, oocyte quality, ovulation, and early embryonic survival, resulting in increased embryonic mortality and extended calving intervals (Hansen *et al.,* 2001). Heat stress also deteriorates semen quality in breeding bulls, reducing sperm motility and viability, thereby compounding fertility challenges in artificial insemination programs (Wolfenson and Roth, 2019; Roth *et al.,* 2000). Management strategies such as estrus synchronization, timed AI, genetic selection for heat tolerance, and improved nutritional support are critical for mitigating reproductive losses.

Heat stress in animals adversely affects the reproductive performance of dairy animals including dairy cattle. Some of the major effects are suggested below. Heat stress decreases the frequency and intensity of estrus (heat) cycles in dairy cattle. This decrease in the expression of estrus makes it challenging for farmers to detect when they are in heat, which can lead to delayed breeding and conception. Heat stress disrupts the normal hormonal balance in dairy cattle, causing irregular estrus cycles. Dairy cattle may experience longer or shorter estrus cycles, which complicates the timing of insemination and reduces fertility rates. Reduced conception rates: Heat-stressed dairy cattle have lower conception rates than dairy cattle under thermo-neutral conditions. This is primarily due to decreased oocyte quality and reduced embryo survival. Heat stress negatively impacts follicular development, ovulation, and early embryonic development. Heat stress during the early stages of pregnancy increases the chances of embryonic death. High temperatures can affect embryo implantation and survival, leading to higher rates of early pregnancy loss. Dairy animals experiencing heat stress often have increased calving intervals due to higher rates of late conception or pregnancy loss. This results in fewer calvings per year, impacting overall herd productivity. Heat stress also affects semen quality in bulls used for artificial insemination. High temperatures can reduce sperm motility, viability, and fertility, further complicating breeding efforts.

Heat stress disrupts the secretion of reproductive hormones such as GnRH, LH and FSH, which are important for follicular development, ovulation and pregnancy establishment. High temperatures can impair the quality of oocytes (eggs) and embryos, causing them to fail to develop normally after fertilization. Heat stress disrupts the metabolic balance in animals, causing metabolic energy to be diverted from reproductive processes to cooling mechanisms and bodily maintenance functions. To reduce the negative effects of thermal stress on reproductive performance, dairy farmers can implement several management strategies such as Provide shade, fans, sprinklers or misters to cool dairy cattle during hot weather, especially in areas where cows rest or congregate Use synchronization programs to control estrus cycles and improve the timing of conception. Consider timed AI (artificial insemination) protocols to maximize breeding success. Breed for heat tolerance traits when selecting replacement heifers or semen for artificial insemination. Ensure dairy cattle receive balanced nutrition to support reproductive health and maintain body condition during periods of heat stress. Closely monitor heat stress indicators and reproductive performance. Keep detailed records of estrus detection, reproductive results, and calving intervals to identify trends and make informed management decisions. By implementing these strategies, dairy farmers can help minimize the adverse effects of thermal stress on reproductive performance, ultimately improving herd fertility and productivity.

Thermal stressors effect on Stress and Fertility

Thermal stress activates the HPA axis, resulting in sustained elevation of cortisol and catecholamines, which suppress reproductive hormone secretion and impair ovarian function (Dobson *et al.,* 2007). Chronic stress disrupts follicular growth, ovulation, fertilization, and embryo development, leading to reduced conception rates and increased pregnancy loss (Roth, 2017). Stress-induced alterations in energy metabolism divert nutrients away from reproductive processes toward survival mechanisms, further compromising fertility (Baumgard and Rhoads, 2013). Additionally, immune suppression associated with chronic stress increases susceptibility to reproductive infections, exacerbating fertility decline (Sordillo and Aitken, 2009). Comprehensive stress-reduction strategies—including environmental modification, nutritional optimization, reproductive monitoring, and welfare-oriented management—are therefore essential to sustain fertility, productivity, and economic viability of dairy farming systems under changing climatic conditions (FAO, 2016; IPCC, 2021).

The effects of environmental temperature on animal health can have profound effects on their estrus cycle and fertility. Their stress cycle involves complex physiological and hormonal responses that directly affect reproductive processes. Activation of the hypothalamic-pituitary-adrenal (HPA) axis Stressors trigger the release of stress hormones such as cortisol from the adrenal glands. This activation begins in the hypothalamus in response to perceived threats or challenges. Elevated cortisol levels during chronic stress disrupt normal physiological functions, including the production of reproductive hormones. Activation of the stress response in animals such as sudden changes in routine, transportation, triggers the release of stress hormones such as cortisol and adrenaline. This activation initiates the stress response cascade, which involves the hypothalamus, pituitary gland, and adrenal glands (HPA axis). Chronic stress can lead to chronically elevated cortisol levels. Elevated cortisol levels from chronic stress suppress the secretion of reproductive hormones such as GnRH (gonadotropin-releasing hormone), LH (luteinizing hormone) and FSH (follicle-stimulating hormone). Disruption of these hormones can lead to irregular estrus cycles, reduced frequency and intensity of estrus and impaired follicular development. Chronic stress can affect ovarian function by altering the growth and maturation of ovarian follicles. This can result in reduced ovulation rates and poor quality of oocytes (eggs). Dairy cows under stress may show reduced behavioral signs of estrus (heat). Dairy cows under stress may show reduced behavioral signs of estrus (heat).

This makes it challenging for animal science scholars to detect to delayed conception and reduced fertility. Stress disrupts the delicate balance of reproductive hormones, affecting the timing and quality of ovulation, fertilization, and embryo development. Stress can alter energy metabolism, diverting resources away from reproductive processes toward survival mechanisms. This can affect overall reproductive performance. Stress-induced disruptions in reproductive hormone balance and ovarian function in dairy cattle decrease the likelihood of successful fertilization. This results in decreased conception rates in stressed cows. This stresses damage pregnancy during the early stages of gestation and may lead to early fetal death or hormonal complications of pregnancy. Animals experiencing chronic stress may have significantly longer calving intervals, leading to delayed conception or increased pregnancy failure, affecting the overall fertility and productivity of the herd. Chronic stress of animals weakens their immune system, making them more susceptible to reproductive infections or diseases that further impair fertility. To prevent stress in dairy animals and reduce the negative effects of stress on their estrus cycle and fertility, farmers can adopt various management strategies, which may improve reproductive success and overall herd productivity.

CONCLUSION

Effective management strategies are important to reduce the negative effects of thermal heat stress. It has been concluded that dairy farmers should adopt environmental management to maintain adequate shade, ventilation and cooling systems to reduce the heat load on cows, as well as proper feed management to provide a balanced diet to meet the nutrient requirements of the animals. Regular assessment of the health and behavior of cows should be done to detect early signs of heat stress and reproductive problems for better health of animals, especially during hot weather. A comfortable environment should be provided to the dairy animals. By adopting all these strategies, dairy farmers will be able to reduce the harmful effects of stress and they can help to optimize both the productive and reproductive performance of animals and ensure the welfare and profitability of their herd.

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