Heat Stress Mitigation in Dairy Cattle: Strategies for Enhancing Productivity and Animal Welfare

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Abstract

Heat stress is one of the most significant environmental challenges affecting dairy cattle worldwide. Elevated ambient temperatures combined with high humidity reduce feed intake, milk production, reproductive efficiency, and immune competence while increasing susceptibility to diseases. Climate change has intensified the frequency and severity of heat stress events, making mitigation strategies increasingly important for sustainable dairy farming. This article reviews the physiological effects of heat stress, methods for identifying heat-stressed animals, and practical mitigation approaches including housing modifications, nutritional management, cooling systems, genetic selection, and precision livestock technologies. Effective implementation of these strategies can improve animal welfare, productivity, and farm profitability.

Keywords: Dairy cattle, Heat stress, Thermal comfort, Milk production, Climate change, Animal welfare

1. Introduction

Dairy cattle are highly susceptible to heat stress due to the substantial metabolic heat generated during milk synthesis. When environmental heat load exceeds the animal's capacity to dissipate body heat, physiological and behavioural adaptations occur that often compromise health, welfare, and productivity.

Heat stress is commonly assessed using the Temperature–Humidity Index (THI), with mild stress typically occurring at THI values above 68–72, although susceptibility varies with breed, milk yield, and management practices (West, 2003; Polsky & von Keyserlingk, 2017).

The increasing frequency and intensity of heat waves associated with climate change have made heat stress mitigation a critical component of sustainable dairy production. Effective strategies—including provision of shade, improved ventilation, evaporative cooling systems, adequate water supply, nutritional interventions, and genetic selection for heat tolerance—can alleviate thermal stress, enhance animal welfare, and sustain milk production under hot environmental conditions (Collier *et al.,* 2019; Bernabucci *et al.,* 2014).

2. Physiological Effects of Heat Stress

Heat stress occurs when environmental heat load exceeds the animal's ability to dissipate body heat, resulting in disruption of homeostasis and activation of numerous physiological defense mechanisms (West, 2003). Dairy cattle maintain a normal core body temperature between 38.0 and 39.3°C, but prolonged exposure to elevated ambient temperatures and humidity impairs thermoregulation and results in hyperthermia

(Bernabucci *et al.*, 2014).

The hypothalamus regulates body temperature by coordinating physiological responses that enhance heat dissipation and reduce metabolic heat production during heat stress (Collier *et al.*, 2019).

Heat-stressed dairy cattle exhibit several physiological adaptations, including increased respiration rate, elevated body temperature, peripheral vasodilation, increased sweating, reduced feed intake and rumination, increased water consumption, endocrine alterations, oxidative stress, immune suppression, and impaired reproductive function. Although these responses help maintain thermal homeostasis, prolonged exposure adversely affects animal health, welfare, and productivity (Bernabucci *et al.*, 2014; Collier *et al.*, 2019).

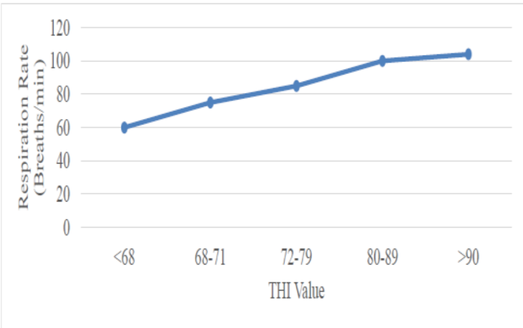

Fig 1: Schematic figure of animal comfort, homeothermic, and survival zones (Oliveira *et al.*, 2025)

2.1 Increased Respiration Rate

Respiration rate is an early indicator of heat stress, increasing from 26–50 breaths/min under thermoneutral conditions to 120–150 breaths/min during severe heat stress. Panting enhances evaporative heat loss but may increase energy expenditure and predispose cattle to respiratory alkalosis due to excessive carbon dioxide loss (Polsky & von Keyserlingk, 2017; West, 2003).

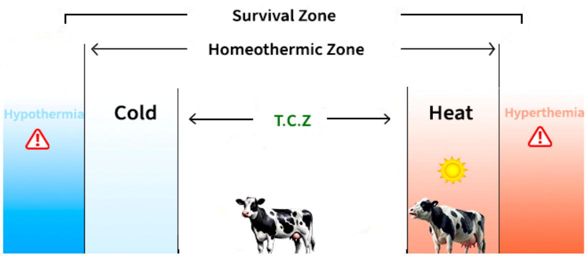

Fig 2: Mean value of Respiration rate within THI range (The University of Minnesota, 2020)

2.2 Elevated Body Temperature

Rectal temperature is considered one of the most reliable indicators of thermal stress. A rectal temperature exceeding 39.2–39.5°C generally indicates significant heat stress, while temperatures above 40°C may severely compromise physiological functions. Persistent hyperthermia adversely affects enzyme activity, cellular metabolism, hormonal regulation, mammary gland function, and embryonic development, ultimately reducing milk synthesis and impairing reproductive performance in dairy cattle (Bernabucci *et al.*, 2014).

2.3 Reduced Feed Intake

One of the most economically significant consequences of heat stress is decreased dry matter intake (DMI). Feed intake may decline by 10–35% depending on environmental severity (NRC, 2001).

Reduced DMI represents a physiological adaptation aimed at minimizing metabolic heat production generated during digestion and ruminal fermentation. However, lower nutrient intake decreases the availability of energy, protein, and minerals required for maintenance and milk synthesis. The reduction in dry matter intake during heat stress induces a negative energy balance, compelling dairy cows to mobilize body fat reserves to meet their maintenance and lactational energy requirements. This metabolic adaptation results in a decline in body condition score and limits the availability of nutrients for milk synthesis, ultimately leading to reduced milk yield and impaired productive performance (West, 2003; Bernabucci *et al.*, 2014).

2.4 Increased Water Consumption

Water is the primary nutrient involved in thermoregulation. Heat-stressed dairy cows often double their daily water intake, consuming 100–180 liters/day, depending on milk yield and environmental conditions (NRC, 2001).

Water plays a pivotal role in thermoregulation by facilitating evaporative cooling through sweating and increased respiratory evaporation, maintaining blood circulation, and supporting normal rumen function. Therefore, unrestricted access to clean, cool drinking water is one of the most effective and economical strategies for alleviating heat stress, preserving hydration, and sustaining physiological and productive performance in dairy cattle (NRC, 2001; Polsky & von Keyserlingk, 2017).

2.5 Decreased Rumination Activity

Rumination decreases significantly during periods of heat stress. Reduced chewing activity lowers saliva production, decreasing ruminal buffering capacity and predisposing animals to subacute ruminal acidosis (SARA).

Reduced rumination during heat stress adversely affects fiber digestion, nutrient utilization, ruminal microbial protein synthesis, and milk fat percentage, thereby compromising digestive efficiency and overall productivity. In modern dairy farming, wearable rumination sensors have emerged as valuable precision livestock technologies for the early detection and continuous monitoring of heat stress, enabling timely management interventions to minimize production losses (Polsky & von Keyserlingk, 2017; Bewley, 2010).

2.6 Endocrine Changes

Heat stress disrupts endocrine function by increasing cortisol and prolactin levels while reducing thyroid hormones (T3 and T4), growth hormone, and insulin-like growth factor-1 (IGF-1). These hormonal changes impair metabolism, reproduction, and milk production by redirecting nutrients toward maintenance and thermoregulation (Collier *et al.*, 2019).

2.7 Oxidative Stress

Heat stress enhances the generation of reactive oxygen species (ROS), leading to oxidative stress and subsequent cellular damage (Bernabucci *et al.*, 2010). Excessive ROS induce lipid peroxidation, protein oxidation, DNA damage, mitochondrial dysfunction, and reduced cellular viability. Concurrently, endogenous antioxidant defense systems, including glutathione peroxidase, superoxide dismutase, catalase, and antioxidant vitamins such as vitamins E and C, become depleted, thereby exacerbating oxidative damage and impairing the physiological resilience, health, and productivity of dairy cattle (Bernabucci *et al.*, 2010).

2.8 Immune Suppression

Heat stress suppresses both innate and adaptive immune responses by impairing neutrophil function, lymphocyte proliferation, antibody production, and cytokine regulation while promoting inflammatory mediators. These immunological alterations increase the susceptibility of dairy cattle to infectious and metabolic disorders, including mastitis, metritis, pneumonia, retained placenta, and lameness, thereby compromising animal health, welfare, and productivity (Lacetera *et al.*, 2005; Bernabucci *et al.*, 2014).

3. Effects of Heat Stress on Milk Production

Heat stress significantly reduces milk yield by altering nutrient partitioning, endocrine function, and mammary gland activity. Milk production may decline by 10–40%, particularly in high-producing Holstein cows, due to reduced feed intake, negative energy balance, impaired rumen function, and altered mammary blood flow (West, 2003). Heat stress also deteriorates milk quality by reducing milk fat, protein, lactose, and casein synthesis while increasing somatic cell count. Additionally, impaired mammary epithelial cell function delays recovery of milk production even after environmental temperatures return to normal (Wheelock *et al.*, 2010; Bernabucci *et al.*, 2014).

4. Effect of Heat Stress on Reproductive Performance

Heat stress is one of the major environmental factors adversely affecting reproductive performance in dairy cattle. Elevated temperatures impair ovarian follicular development, oocyte maturation, fertilization, embryonic survival, and placental growth, leading to reduced fertility. Consequently, conception rates often decline from 40–60% during cooler seasons to below 20% in summer (Hansen, 2009). Heat-stressed cows commonly exhibit silent estrus, shortened estrus duration, delayed ovulation, increased embryonic loss, prolonged days open, and a higher number of services per conception. Similarly, heat stress compromises bull fertility by reducing semen quality, sperm motility, and overall reproductive efficiency (Hansen, 2009; Collier *et al.*, 2019).

5. Impact of Heat Stress on Animal Welfare

Heat stress is a significant animal welfare concern that adversely affects the physical health, behavior, and overall well-being of dairy cattle. Heat-stressed animals commonly exhibit increased standing time, shade-seeking behavior, panting, open-mouth breathing, excessive salivation, reduced feed intake, and increased water consumption as adaptive responses to elevated environmental temperatures. Prolonged exposure leads to chronic discomfort, dehydration, fatigue, and greater susceptibility to diseases. According to the Five Domains Model of Animal Welfare, maintaining thermal comfort is fundamental to ensuring positive welfare outcomes; therefore, effective heat stress mitigation not only improves productivity but also supports ethical and sustainable dairy farming practices (Polsky & von Keyserlingk, 2017).

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