

Effect of Climatic Stress on Behavior, Milk Production and Milk Composition of Dairy Cattle: A Bird's Eye View

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ABSTRACT

Aim of the Study: The aim of this study was to explore how climatic heat stress during Pakistan's extended summer season affects dairy cattle productivity, physiological responses, behaviour, and milk quality, with particular focus on somatic cell count and thermal stress indicators.

Methodology: This study was based on a critical review of available scientific literature and reported field observations related to heat stress in dairy cattle. Published research concerning temperature–humidity index (THI), animal responses to thermal stress, changes in milk yield and composition, and the use of cooling systems such as fans and sprinklers was examined, with emphasis on conditions comparable to Pakistan's climate.

Findings: The reviewed evidence showed that heat stress negatively influences milk production, feeding behaviour, and metabolic balance in dairy cattle. Elevated environmental temperatures cause a shift in nutrient utilization from production towards maintenance, resulting in reduced fertility and higher disease risk. An increase in somatic cell count was frequently observed, indicating stress on the mammary gland and reduced milk quality. Cooling interventions generally improved animal comfort and reduced stress, although their effectiveness depended on management practices and environmental severity.

Conclusion: Heat stress remains a major limiting factor for dairy productivity under Pakistan's climatic conditions. While body cooling strategies show potential in reducing its adverse effects, locally generated comparative data are still limited. Further field-based studies are needed to develop climate-specific management practices that can sustainably improve dairy cattle performance.

Keywords: Heat stress; THI; Dairy Cow; Cattle; Animal Response.

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1. INTRODUCTION

In rural areas, principally, the worldwide dairy business is vital for preserving economic stability, employment, and food security (Thornton et al., 2009). However, climatic stress a situation made worse by the constant problems of climate change is posing an increasing threat towards wellbeing also productivity of dairy cows (Renaudeau et al., 2012). Dairy animals' thermal equilibrium is impacted by climate stress, particularly heat stress, which can affect in changes to their metabolism, behavior, and physiology (Collier et al., 2006). The health, productivity, and profitability of animals are thus threatened by these disturbances (Collier & Gebremedhin, 2015; Polsky & von Keyserlingk, 2017).

The frequency and ruthlessness of heatwaves, ambient temperatures, and humidity levels have all considerably increased in recent decades. The dairy industry is meaningfully impacted by such circumstances, exclusively in tropical and subtropical areas where temperature extremes are more obvious (Herbut et al., 2018; da Silva et al., 2021). Reduced feed intake, poor reproductive performance, heightened vulnerability to illnesses, and most significantly a drop in milk yield and quality are all direct and indirect effects of climate stress (Li et al., 2016; West, 2019; Grossi et al., 2019).

On the dairy production system, two affects have been noted of climatic modification: Effects on farm animals directly, like productivity loss and another one is health related issues, and effects on feed and fodder crop yield indirectly, like enhanced susceptibility to diseases (Gauly et al., 2013). Dairy cows experience heat stress due to the excess heat generated by warming, which immediately manifests as a reduction in milk output (Das et al., 2016). The animal experiences innate physiological modifications to cool its body and maintain a steady body temperature throughout periods of continuous temperature increases over its thermoneutral zone.

2. BEHAVIORAL CHANGES IN DAIRY CATTLE UNDER CLIMATIC STRESS

In dairy cow, behavioral responses are frequently the first signs of stress (Polsky & von Keyserlingk, 2017). The most frequent behavioral changes that occur when cattle are exposed to heat stress are when their intake of dry matter decreases and their intake of water increases. This means that the dairy animal will start eating less and drinking more. In this way, the animal's energy reserves begin to be used more for body cooling, and when food intake is reduced and energy is used for body cooling, dairy production drastically declines. Heat stress also affects farm animals' development performance, which lowers meat output. On the other hand, heat stress also affects the animals' capacity to milk optimally and consume less feed (West, 2003; Rhoads et al., 2009). Lying time may reduce by over 4 hours per day during hot periods, which compromises rest and rumination (Cook et al., 2007). In an observational study, 28 out of 100 cows exhibited signs of aggression or restlessness under elevated THI conditions (Schütz et al., 2020). Cows seek isolated and shaded areas due to which social interactions also decline, resulting in reduced grooming and feeding synchrony (Polsky & von Keyserlingk, 2017). Around 10–25% feed intake gets dropped, especially during peak heat hours, ultimately leads to a negative energy balance (Rhoads et al., 2009). These behavioural shifts are critical as they serve as early indicators of heat stress and guide timely involvement. Heat stress also affects farm animals' development performance, which lowers meat production because of reduced feed intake (Rowlinson, et al., 2008). It also affects the animals' capacity to milk as best they can. Heat stress has a detrimental effect on the mammary gland's uptake of glucose, blood supply to the mammary glands, and milk release and synthesis (Rhoads et al., 2013).

Animals use these responses as existence methods to diminish the negative impacts of harsh environmental situations. In order to reduce heat load and preserve homeostasis, cows under heat stress exhibit a variety of behavioral changes (Polsky & von Keyserlingk, 2017; Salama et al., 2014). Lower feed intake is one of the most perceptible behavioral changes. In order to reduce the amount of metabolic heat produced during digestion, cows often eat less during the hottest hours of the day. Dairy cattle modify their feeding habits, favoring to graze or feed in cooler times like the early morning or late evening, rendering to studies by West (2019) and Kaur et al. (2021). Cows try to control their body temperature through evaporative cooling, which fallouts in decreased feed intake and increased water

consumption (Belhadj Slimen et al., 2016; Rhoads et al., 2017). In order to reduce endogenous heat generation, cows may also stand for longer periods of time, look for areas that are shaded or have decent ventilation, and become fewer active (Herbut & Angrecka, 2018; Schütz et al., 2020).

Table 1: *Behavioural Changes of Dairy Cows at Different THI Levels*

THI Level	Lying Time (min/day)	Rumination Time (min/day)	Standing Time (min/day)
<68	720	500	180
68-72	650	450	230
73-78	580	400	280

(Lovarelli et al., 2024)

The changes in behavioral patterns are considered as a key handling tactics, but they could also result in ineffectual efficiency if they have been continued over prolonged periods of time. Addingly, as a substitute of resting down, cows show more restlessness and standing duration for extended period of time, which can ultimately enhance their surface area contact for heat dissipation (Allen et al., 2015). Additionally, people often pursue out shady locations and raise their respiratory rates and pant during their exposure to heat stress (Polsky & von Keyserlingk, 2017; Vizzotto et al., 2019). These communicative modifications have a negative impact on the welfare of the animals despite being adaptive in nature and have been associated with less laying times and advanced energy expenditures more often (Kovács et al., 2018).

A compound index that has been used to calculate climatic stress is called, Temperature Humidity Index (THI). To measure the presence and intensity of heat stress in heat-stressed dairy cows, THI is more commonly used and has a strong correlation with biological pointers like body temperature and rate of respiration (Thom, 1959; Yan et al., 2021).

For calculating Temperature Humidity Index (THI), the formula used is,

$$\text{“THI} = 1.8 \times T + 32 - (0.55 - 0.0055 \times RH) \times (1.8 \times T + 32 - 58)\text{”}$$

Where T was the temperature in degrees Celsius, and RH was the relative humidity. A specific range of THI can be tolerated by cows without affecting their output. However, when THI surpasses a certain threshold, heat stress occurs, cows are unable to regulate their thermal balance, and their overall welfare, milk production, and reproductive performance are all negatively impacted (Polsky and von Keyserlingk, 2017; Becker et al., 2020). This can also result in significant financial losses (Gunn et al., 2019). When THI levels rise beyond 80, cows experience increased stress, which causes the release of stress hormones. This lowers feed intake, which in turn affects and significantly lowers milk supply and metabolism (Murphy et al., 2002).

Basically, summer season is subdivided into two seasons, Dry Summer and Wet Summer. In Dry Summer, THI vale remains below 40. On the other hand, In Wet Summer, THI value enhanced to above 70, and it’s more dangerous where livestock production seriously been affected (Marai, et al., 2017).

Table 2: *Heat stress categories according to THI and their effects on dairy cattle productivity*

Heat Stress Level	THI	Effects
Mild	72-78	Mild Heat Stress Reduced Fertility
Moderate	78-82	Reduced Milk Production
Severe	82 or Higher	Significant Milk Production Losses Severe Heat Stress Symptoms

These gears allow for the revealing of refined changes in activity patterns, standing time, and respiration rates permitting farmers to take pro-active measures and enrich welfare and productivity under exciting environmental conditions (Cooke et al., 2020).

In an observational study, 28 out of 100 cows showed signs of aggression or restlessness under prominent THI conditions (Schütz et al., 2020).

Table 3: Behavioural alterations observed in 100 dairy cows during high THI (>82).

Behavior	Number of Cows	Notes
Aggression	28	Head-butting Vocalization
Extend Standing	45	Over 12hrs per day.
Reduced Rumination	60	Less social licking observed

3. IMPACT ON MILK PRODUCTION

When dairy cattle are exposed to heat stress, one of the features that is most straightaway compressed is milk output. Due to Between 5°C and 25°C, the thermoneutral zone of dairy cows clearly falls, away which, the reduction in their milk production started occurring. When temperature enhances above certain range, cows started to express the signs of heat stress. Milk production decreases to around 10% to 25% when cows been suffering from severe heat stress (Collier et al. (2017).

The factors that are involved in reduction of milk yield due to heat stress are reduction in DMI Reduced feed intake, and the energy reserves that have been used for heat mitigation processes from the body instead of generating production of milk (Dikmen & Hansen, 2009; Tian et al., 2015). Because of the higher metabolic requirements of young calves, High-producing cows in their initial lactational stages are predominant at risk. (Sejian et al., 2018).

It can be concluded from the above results that there is a major need of better farm managerial practices, including the use of cooling systems, nutritional needs, and genetic selection is also needed for environment to be thermotolerant (Bouraoui et al., 2019; Tao & Dahl, 2017).

4. EFFECT ON MILK COMPOSITION

The stress generated by extreme climatic environment not only affecting the milk yield like decreases the quantity but also its composition gets severely affected. Like Protein content, fat content, solid not fats and somatic cell count around 10-15% (Dunshan et al., 2019). The number of somatic cells count also increases due to the occurrence of subclinical mastitis.

In addition to this, milk quality could also be further worsened by subclinical mastitis, (Machado et al., 2020; Pasqui et al., 2019). In milk, the presence of stress-related metabolites like cortisol and heat shock proteins could be an additional area of increasing scientific level of interest (Yang et al., 2022; Min et al., 2017). Due to the result of these compositional modifications, the nutritional content of milk may be lessened down and make it less suitable for the making of yogurt and cheese (Gernand et al., 2019). Thus, in order to fulfil the needs of market level as well as regulatory desires during heat stress, it is vibrant to preserve the quality of milk.

Table 4: Milk Compositional Changes at Different THI Levels.

THI Level	Milk Fat (%)	Milk Protein (%)	Milk Yield (kg/day)
<68	3.6	3.2	35
68-72	3.4	3.1	33
73-78	3.2	2.9	30
>78	3.0	2.7	27

(Bouraoui et al., 2002; Gorniak et al., 2014),

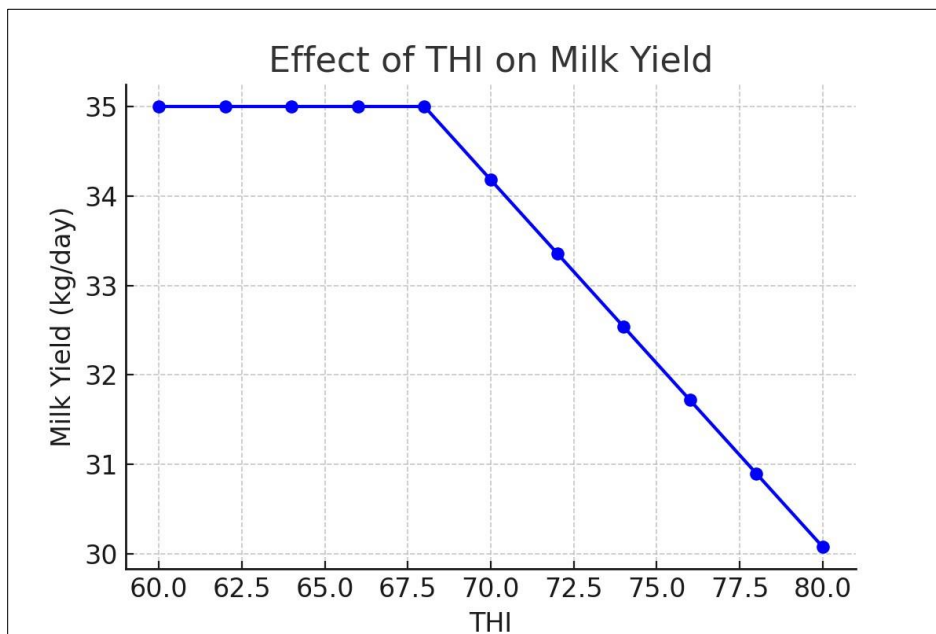
5. STATISTICAL DATA AND CASE STUDIES

One of the research studies conducted by Schütz et al. (2020) quantified that, out of 100 cows, 28 exhibited noticeable aggression or restlessness due to ongoing discomfort from heat stress, ultimately indicating elevated stress levels. An increase of approximately 4 liters per day in milk yield was observed with the use of ceiling fans and sprinklers, under identical feeding conditions, in comparison to the control groups (Tao & Dahl, 2017). Case studies from Israel and Australia have shown that modified feeding practices and strategically installed cooling systems mitigated the impact of THI and enhanced animal welfare scores by up to 25% (Lees et al., 2019; Kendall et al., 2007). This statistical observational study requires high adaptive managerial tactics (Baumgard & Rhoads, 2017).

6. GRAPHICAL ILLUSTRATION

This given figure 1 demonstrates that when the THI enhances, milk yield significantly gets declines, that eventually designates greater amount of heat stress (Zimbelman et al., 2009)

Figure 1: *Effect of THI on Milk Yield*



7. MITIGATION STRATEGIES

To ensure sustainable dairy production under changing climatic scenarios, educated farmers and climate-resilient policies are equally important (Renaudeau et al., 2012). The nutritional solutions concentrate on increasing the energy density of diets in order to make up for decreased feed consumption. Antioxidants, electrolytes, and rumen-protected amino acids are kinds of dietary supplements that can reduce oxidative stress and enhance metabolic processes (Chen et al., 2024; Johnson et al., 2018). According to (Belhadj Slimen et al. (2016), feeding schedules that are shifted to cooler times of the day also promote higher intake of feed and enhanced the overall efficiency of dairy cow.

Genetic selection is also one of the long-term remedies for heat stress. Through breeding programs, resilience can also be increased that include heat-tolerant features, such as slick hair genes or crossbreeding with native breeds (Renaudeau et al., 2012; Dikmen et al., 2018). Using key techniques of genomic selection to find animals with higher heat tolerance while preserving productivity attributes has showed potential (Nguyen et al., 2017; Samarai et al., 2021). In dairy operations, decision making has

been improved thanks to digital technologies and automated sensors that monitor physiological indicators, animal behaviour, and environmental variables in real time (Shu et al., 2021). Collectively these tactics support dairy farming's sustainability in the face of climate change.

8. RESEARCH GAPS AND FUTURE DIRECTIONS

Deprived of considering their collaborating effects with housing, nutrition, and breed, most studies isolated their individual variables like temperature or humidity (Renaudeau et al., 2012).

For instance, the mutual impact of flooring type (e.g., sand vs. concrete) and ventilation on behaviour under stress is underexplored (Herbut et al., 2018).

Similarly, short-term trials have been used by most of the researchers, while long-term longitudinal studies are essential to realize intergenerational effects (Nardone et al., 2010).

A notable void exists in behavioral analytics using AI-driven video surveillance, which can revolutionize early stress detection (Schlageter-Tello et al., 2015).

Moreover, for heat tolerance in dairy breeds, the genetic basis gets remain underutilized; although some QTLs have been identified, selective breeding strategies are not widely executed (Dikmen et al., 2012).

In tropical countries, the adoption of cooling technologies and adaptive practices gets hinder due to the lack of technical knowledge and limited resources (Kadzere et al., 2002).

To estimate the productivity losses at farm, regional, and national levels, it's a need of the time to link the data of climatic stress with economic modelling (St-Pierre et al., 2003). In the upcoming years, research must emphasize the multidisciplinary support, collaboration, integrating climatology, animal science and technology to get suggested sustainable solutions (Polsky & von Keyserlingk, 2017).

9. CONCLUSION

Excessive heat stress prominently compromises the welfare and productivity of dairy cattle (Collier et al., 2006). These effects severely impact physiological stability, behavioral patterns, milk yield, and its composition (Baumgard & Rhoads, 2013). Under excessive heat stress conditions, with the production of milk being dropped to as much as 30% and calving rates reduced to almost around 55%, the economic implications are profound (StPierre et al., 2003). Similarly, increased somatic cell counts indicates shorter shelf life of milk products. (Machado et al., 2020). Behavioral alterations such as reduced lying time, increased aggression, and lower feed intake not only affect welfare but also serve as early indicators of stress (Polsky & von Keyserlingk, 2017). Given the ongoing enhanced pace of climate change, proactive adaptation is no longer optional but become useful or helpful for maintainable dairy farming in the 21st century. (Nardone et al., 2010).

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