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Heat stress physiology in dairy cattle under climate change scenarios

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Abstract

Rising global temperatures and frequent heat waves are changing the way dairy cattle function and perform. Cows are particularly vulnerable to heat stress because of their high metabolic demands for milk production and their limited ability to dissipate heat. When animals are exposed to high temperature and humidity, their body systems are forced to work harder to maintain balance, resulting in reduced feed intake, altered hormonal profiles, poor fertility and lower milk yield. These effects are becoming more frequent and severe with climate change. This review discusses the physiology of heat stress in dairy cattle, the ways in which it alters production and reproduction and the possible strategies that farmers and scientists are adopting to reduce its impact. By looking at both the challenges and the opportunities, we can better understand how to sustain dairy farming in a warmer future.

Key words: Dairy cattle, Heat stress, Climate, Physiology, Thermoregulation, Production

Introduction

Milk and dairy products are central to the diet of millions of people across the world. They provide energy, protein, calcium and other essential nutrients that are difficult to replace. Dairy farming also supports the livelihoods of rural families, making it a key part of global food systems (FAO, 2020). But dairy cattle are sensitive creatures when it comes to their environment. They thrive within a narrow comfort zone and are particularly uncomfortable when the weather is hot and humid. Unlike some other livestock species, cows are not very efficient at cooling themselves. Their thick bodies generate large amounts of metabolic heat, especially when they are producing milk.

In recent decades, climate change has brought more days of extreme heat, higher average temperatures and changes in rainfall patterns (IPCC, 2021). These conditions make it harder for cattle to stay cool. Farmers and scientists now use the temperature humidity index (THI) to estimate how hot and humid conditions feel for cows. A THI above 72 usually signals discomfort for dairy cattle (Armstrong, 1994). Unfortunately, this threshold is being crossed more often in many dairy regions, leading to reduced milk yields, fertility problems and health concerns.

How dairy cattle respond to heat

Keeping body temperature in balance: Cows normally maintain a body temperature of around 38.5 degrees Celsius. When the weather is hot, they must get rid of excess heat. They do this through four main routes: conduction, convection, radiation and evaporation. On a dry and breezy day, heat can leave the body fairly easily. But in humid weather, these mechanisms do not work as well, leaving evaporation from panting and sweating as the main ways to cool down (West, 2003). The problem is that cattle do not sweat very efficiently compared to humans or horses. This means they rely heavily on rapid breathing to cool themselves, which comes at a cost.

Physiological responses: When cows are heat stressed, several measurable changes can be seen (**Table 1**).

- Breathing speeds up. Normal respiration is 20 to 30 breaths per minute, but during hot weather it may exceed 80 breaths per minute.
- Rectal temperature rises above 39.5 degrees Celsius. Even small increases can affect enzyme activity and metabolism.

- Hormones shift. The thyroid gland reduces its output to lower metabolic heat production. Stress hormones such as cortisol increase, affecting energy balance and immunity (Bernabucci *et al.*, 2010).
- Blood chemistry changes. Sweating and panting alter electrolytes, leading to dehydration and sometimes to an imbalance in acid–base status.

Table 1. Typical physiological changes in dairy cattle under heat stress

Parameter	Normal condition	Heat stress condition
Rectal temperature	38.5 °C	>39.5 °C
Breathing rate	20–30 breaths per minute	>80 breaths per minute
Feed intake	100 percent	Reduced by 10–30 percent
Milk yield	100 percent	Reduced by 10–30 percent
Estrus expression	Clear	Weak or absent

Behavioural responses: Cows do not just change internally; their behaviour is also affected. They drink more water, spend less time eating, stand rather than lie down and seek shade whenever possible. Reduced feed intake is particularly damaging because it lowers energy supply for milk production (Rhoads *et al.,* 2009).

Impacts of heat stress under climate change

Milk production losses: Milk yield is one of the first casualties of heat stress. High yielding cows are especially vulnerable because they generate more metabolic heat. During hot spells, cows often eat less and the nutrients they consume are diverted to body maintenance instead of milk synthesis. As a result, milk yield can drop by 10 to 30 percent depending on the severity of the heat (St-Pierre *et al*., 2003). Milk composition also changes, with lower fat and protein levels and sometimes higher somatic cell counts, which reflect poorer udder health (Wheelock *et al.*, 2010).

Reproductive challenges: Heat stress also disturbs fertility. Cows may not show clear signs of estrus, making heat detection difficult. Elevated body temperature can damage egg quality, reduce conception rates and increase the risk of early embryo loss (Wolfenson *et al.*, 2000). These effects translate into longer calving intervals and fewer calves over the cow's lifetime, which reduces the overall efficiency of dairy farming.

Health and immunity: A heat stressed cow is also an immunocompromised cow. Research has shown that immune cells do not function as effectively when animals are overheated. Cows become more prone to diseases such as mastitis, metritis and respiratory infections (Collier *et al.*, 2017). Oxidative stress adds to the problem by damaging cells and making cows more susceptible to metabolic disorders.

Economic consequences: The economic cost of heat stress is staggering. In the United States alone, losses are estimated at over 900 million USD every year (St-Pierre *et al*., 2003). For smallholder farmers in tropical countries, the impacts are even more severe, since they often lack the resources to invest in cooling systems. With climate change intensifying, these losses are only expected to grow.

Strategies to cope with heat stress

Breeding and genetics: One of the most sustainable solutions is to develop cows that can withstand higher temperatures. Crossbreeding Holstein cows with more heat tolerant breeds such as those of Bos indicus origin has been successful in many tropical countries. On the scientific front, genes related to heat tolerance such as heat shock proteins are being studied for selective breeding (Lacetera, 2019).

Feeding and nutrition: Smart feeding strategies can also help. Farmers can offer more nutrient dense feeds so cows get more energy from smaller meals. Feeding during the cooler parts of the day encourages intake. Antioxidant supplements such as vitamin E and selenium may reduce oxidative stress (Rhoads *et al.*, 2009).

Housing and environment: Simple changes in housing can make a big difference. Shade, good ventilation and water availability are essential. In more intensive systems, fans, sprinklers and misters can keep cows cool. Some farms even use tunnel ventilation or cooling pads (Collier *et al.*, 2012).

Precision livestock technologies: New technologies are emerging to help monitor heat stress in real time. Sensors that track body temperature, breathing rate and activity can alert farmers before cows reach dangerous levels of stress. This allows targeted cooling and better management.

Conclusion

Climate change is reshaping the way dairy cattle experience their environment. Rising heat and humidity are pushing cows beyond their natural comfort zones, leading to reduced production, poor fertility and increased disease risks. Farmers already see these effects during hot summers and future projections suggest the challenge will intensify.

Understanding the physiology of heat stress helps us design better adaptation strategies. From breeding more resilient animals to improving housing and nutrition, there are multiple ways to support dairy cattle in a warming world. Combining these approaches with modern technologies will be key to safeguarding milk production and animal welfare in the decades ahead.

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