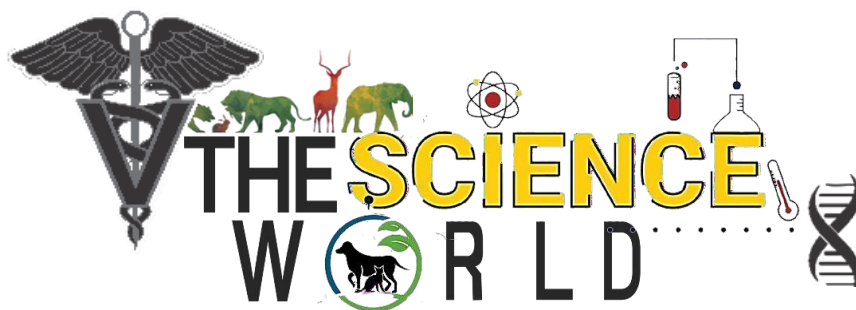




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Heat Stress Management in Dairy Animals for Sustainable Production

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Abstract

India, being a tropical country, experiences high ambient temperatures for a major part of the year, making heat stress one of the most significant environmental challenges facing its dairy sector. Heat stress occurs when animals are exposed to temperatures and humidity beyond their thermoneutral zone, impairing their ability to dissipate excess body heat. The annual milk loss attributable to thermal stress in India has been estimated at about 2 million tonnes, worth nearly Rs. 2,661.62 crores, with global warming projected to further depress national milk production in the coming decades (National Dairy Development Board [NDDB], 2019; Upadhyay et al., 2021). Heat stress disrupts thermoregulation, reduces feed intake and milk yield, alters milk composition, and impairs both male and female reproductive performance. Mitigation strategies such as shade provision, improved ventilation, adequate drinking water, evaporative cooling, close monitoring of the Temperature Humidity Index (THI), and adjustments to feeding routine and ration formulation can substantially reduce the impact of heat stress and support sustainable dairy production. This article reviews the physiological basis of heat stress in dairy animals, its effects on production and reproduction, and the key management strategies available for its mitigation.

Keywords: Heat stress, Dairy animals, Temperature humidity index, Thermoregulation, Mitigation strategies

Introduction

India, being a tropical country, experiences high ambient temperatures for a major part of the year, and these extreme climatic conditions pose significant challenges to dairy production in terms of animal health, productivity and welfare. One of the major environmental challenges faced by the dairy sector is heat stress, which occurs when animals are exposed to temperature and humidity levels beyond their thermoneutral zone. The annual total milk loss due to thermal stress



in India has been estimated at 2 million tonnes, or about 2 percent of the country's total milk production, amounting to nearly Rs. 2,661.62 crores per year (NDDB, 2019). The negative impact of global warming on total milk production in India is further projected at about 1.5 million tonnes by 2020 and more than 15 million tonnes by 2050 (Upadhyay et al., 2021).

Climate change has emerged as one of the principal threats to the livestock sector, with the Intergovernmental Panel on Climate Change estimating that the earth's average temperature may rise by 1.4°C to 5.8°C by the end of this century (IPCC, 2014). Among all climatic variables, environmental temperature appears to play the most critical role in negatively influencing livestock production, making a clear understanding of heat stress physiology and its management essential for sustaining dairy productivity under a changing climate.

Thermoregulation In Dairy Animals

Heat stress in dairy animals is a condition that occurs when the animal's body is unable to effectively dissipate excess heat, leading to a rise in body temperature beyond the normal physiological range; the foremost response of animals under such thermal load is a change in physiological parameters such as heart rate and respiration rate. Thermoregulation refers to the physiological and behavioural processes by which dairy animals maintain their optimal body temperature.

Animal Species	Normal Body Temperature (°F)
Cow (Bos indicus / Bos taurus)	101 – 102.5
Buffalo	99.5 – 102.2
Goat	101.3 – 103.5
Sheep	101.3 – 103.8

Table 1. Normal body temperature in dairy animals

Dairy animals exchange heat with their environment through four principal mechanisms: convection, in which air or fluid movement carries heat away from the body, as when air blows over the animal's skin; radiation, the transfer of infrared heat without direct contact, such as absorbing solar heat during the day and radiating body heat at night; conduction, involving direct contact with surfaces, as when an animal lies on a cool or warm floor; and evaporation, in which sweating and panting convert body moisture into vapour to dissipate heat (Collier et al., 2019).

Temperature Humidity Index And Thermoneutral Zone

The Temperature Humidity Index (THI) reflects the combined effects of environmental temperature and relative humidity on an animal, and is widely used to classify the severity of heat



stress as mild (THI 72 to 79), moderate (THI 80 to 89) or severe (THI 90 or greater) (Collier et al., 2019). THI is calculated as: $THI = 0.80(T) + RH(T - 14.4) + 46.4$, where T is the dry bulb temperature in °C and RH is the relative humidity expressed as a decimal, for example 70 percent as 0.70 (Kibler, 2021).

An animal's thermoneutral zone (TNZ) is the ambient temperature range within which it does not need to expend additional energy to maintain its normal body temperature; for dairy cattle, this zone generally lies between 16°C and 25°C. Once ambient conditions exceed the upper limit of the thermoneutral zone, animals must activate additional physiological mechanisms to dissipate heat, setting the stage for the production and reproductive effects discussed below.

Signs Of Heat Stress

Dairy animals under heat stress display a characteristic set of behavioural and physiological signs, including increased respiration rate and open-mouth panting, excessive salivation and drooling, reduced rumination, seeking of shade or cooler areas, crowding around water troughs, decreased feed intake, and a general reduction in activity and lying time as the animal attempts to minimize additional heat production (Girma & Gebremariam, 2019).

Effects Of Heat Stress On Milk Production And Composition

Heat stress adversely affects both the quantity and quality of milk produced, particularly in high-yielding dairy animals. Effective environmental heat loads above 26°C activate stress-response systems in lactating cows, and maintenance energy requirements can increase by as much as 30 percent under heat stress, so that normal energy intake becomes insufficient to support daily milk production.

THI Threshold	Reported Impact on Milk Yield	Source
>72	10–25% reduction in milk yield under severe heat stress	Renaudeau et al. (2012)
>70	About 10–15% reduction in milk yield during summer	Bernabucci et al. (2022)
>72	Reduction of about 1.8 L/day during high heat stress	Gaughan et al. (2018)

Table 2. Reported effects of heat stress (THI thresholds) on milk yield



Rising environmental temperature also has a direct negative effect on the hypothalamic appetite centre, reducing feed intake. Dry matter intake in lactating cows typically begins to decline at air temperatures of 25–26°C, falls more rapidly above 30°C, and may drop by as much as 40 percent at 40°C, with dry matter intake reduced by about 0.85 kg for every 1°C rise in air temperature (West, 2020). Reducing feed intake is itself a strategy by which animals lower their heat production, since the heat increment of feeding is a major source of internal heat in ruminants; the resulting negative energy balance causes body weight and body condition score to decline.

In terms of composition, heat stress reduces milk fat and protein percentages considerably more than lactose content, since lactose synthesis depends on relatively stable glucose metabolism. Milk fat content can fall through reduced acetate production associated with altered rumen fermentation, while milk protein content declines due to decreased amino acid absorption and hormonal imbalance (Bouraoui et al., 2012). Overall milk fat and protein contents have been reported to drop by roughly 7–10 percent and 5–8 percent, respectively, during periods of high THI, along with reductions in solids-not-fat and an increase in somatic cell count reflecting immune suppression and greater mastitis risk (Upadhyay et al., 2021).

Effects of Heat Stress On Reproductive Performance

Male Reproductive Performance

Heat stress markedly impairs semen quality and male fertility. Younger bulls tend to be more sensitive, showing reduced sperm motility, viability and concentration (Balic et al., 2023), while testicular temperatures above about 35°C compromise sperm membrane integrity (Mishra et al., 2021). Fertilization rates have been reported to fall to around 53.7 percent under heat stress compared with 70.2 percent in unstressed conditions (Rahman et al., 2019). A rise in scrotal temperature of 2–4°C reduces sperm count and increases the proportion of morphologically abnormal sperm (Kastelic et al., 2018), while testicular heat stress disrupts Sertoli cell function and can cause a long-term decline in sperm output (Setchell, 2021) and increased sperm abnormalities with reduced progressive motility (Wolfenson et al., 2023), alongside reduced libido and poorer semen quality generally under thermal stress (Beede & Collier, 2015).

Female Reproductive Performance

In female dairy animals, heat stress suppresses the pre-ovulatory LH surge and lowers circulating estrogen, resulting in weaker or less visible estrus behaviour and making detection of estrus more difficult. Conception rates can fall substantially during hot seasons because of impaired oocyte quality and an altered uterine environment (Hansen, 2019). Progesterone concentration during the luteal phase also declines under heat stress, reflecting impaired corpus luteum function (Wolfenson et al., 2023), and the cumulative effect of these disruptions is lower



pregnancy rates, higher rates of embryonic loss and repeat breeding, and reduced overall reproductive efficiency during the hot season (Upadhyay et al., 2021).

Strategies For Mitigating Heat Stress

Shade and Housing

Shade reduces heat stress by decreasing animals' exposure to direct solar radiation; roofs should preferably be white or light-coloured to maximize reflection of solar heat, and a well-designed shade structure can reduce total heat load by 30 to 50 percent. Roofing materials such as thatch, GI sheet, asbestos sheet or polythene sheet each offer different degrees of insulation and cost, while additional measures such as tree plantation around sheds and providing wallowing facilities for buffaloes further help animals cope with heat.

Ventilation

Proper ventilation is critical for maximizing convective heat loss from cows; air speed within the shed should be maintained between 1.5 and 2.5 m/s during periods of heat stress so that animals can lose heat through evaporation and convection (Smith & Collier, 2019). Ventilation may be achieved naturally, through ridge or side-wall openings, or mechanically, through cross-ventilation or tunnel-ventilation systems, depending on shed design and climatic conditions.

Drinking Water

Ensuring adequate access to clean drinking water is one of the simplest yet most effective ways to reduce heat stress; an increase in air temperature from about 30°C to 35°C can raise water intake in dairy cows by as much as 50 percent. Fresh water should be provided in the exit area of the milking parlour, since cows drink more than half their daily water intake after milking, and troughs should offer 5–7 cm of space per cow, a water depth of at least 7–8 cm, and a flow rate of 10–20 L/min to refill quickly (NRC, 2019).

Animal	Normal Requirement	Requirement Under Heat Stress
Lactating cow	60–120 L/day	100–150 L/day
Dry cow	30–50 L/day	40–80 L/day
Lactating buffalo	70–130 L/day	110–160 L/day

Table 3. Water requirement of dairy animals under normal and heat-stress conditions

Evaporative Cooling

Supplemental cooling using sprinklers or soakers is a particularly effective strategy for high-producing cows. Sprinklers can lower air temperature directly through misting and fogging,



or create an “artificial sweat” effect by soaking the cow's skin so that evaporation draws heat away from the body; misting and fogging systems, delivered through high-pressure pumps and fine mist nozzles, also raise relative humidity and therefore work best in drier climatic conditions.

Monitoring, Feeding Routine and Ration Formulation

Regular monitoring using THI as a management tool, along with periodic recording of body temperature and respiration rate, allows early detection of heat stress and timely intervention. Feeding should be shifted to the cooler parts of the day, such as early morning and late evening, and spoiled feed should be removed promptly to encourage higher dry matter intake. Ration formulation can also be adjusted to increase energy density without raising the heat increment of fermentation, potassium levels should be raised to compensate for losses through increased sweating, and dietary buffers such as sodium bicarbonate should be provided, since heat-stressed cows ruminate less and drool more.

Conclusion

Heat stress is a major constraint to sustainable dairy production in tropical and subtropical regions such as India, adversely affecting thermoregulation, feed intake, milk yield and composition, and both male and female reproductive performance. A sound understanding of the Temperature Humidity Index and the thermoneutral zone, combined with early recognition of behavioural and physiological signs of heat stress, allows timely implementation of mitigation measures. Practical strategies such as adequate shade, effective ventilation, sufficient clean drinking water, evaporative cooling, close monitoring, and appropriate adjustments to feeding routine and ration formulation can substantially reduce the economic and welfare impact of heat stress. As climate change continues to intensify thermal challenges, the adoption of such integrated heat stress management practices will be essential for safeguarding the productivity, reproductive efficiency and welfare of dairy animals.

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