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Effect of heat stress on productive and reproductive performance of dairy cattle: A review

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Abstract
Ever increasing human population is exerting tremendous pressure on natural resources including livestock. Changing global environmental conditions are posing a major threat to the viability and sustainability of livestock production systems in many parts of the World.When climate change occurs, temperatures increase dramatically which impairs the production and reproduction performance, metabolic health status and immune response of different livestock species. Current climate models indicate an increase in temperature by 0.2 °C per decade and predict that the increase in global average surface temperature would be between 1.8 °C to 4.0 °C by 2100. The escalating temperatures have resulted in heat stress becoming an important challenge facing the global dairy industry today. Growing demand for improving milk production and rising temperatures due to global warming has increased the thermal load on dairy animals leading to heat stress. When the heat load of an animal is greater than its capacity to lose heat, a part of the metabolizable energy that is used for production must be diverted to maintain thermal balance. Global warming impairs production and reproduction performance, metabolic health and immune competence of livestock and thus causes decreased milk production and reduced reproductive performance in dairy animal.. In the present review, an attempt has been made to review the impact of heat stress on production and reproduction performance in cattle under the following subheadings.

Keywords: dairy cows, heat stress, production, reproduction performance

1. Introduction
Stress is an unfavorable condition, defined as an external event or condition that stresses a biological system (Collier *et al*., 2017) [10]. It is a reflex reaction, revealed by the animal's inability to cope with its environment, which leads to many adverse consequences, ranging from discomfort to death (Manuja *et al*., 2012) [30]. Stress can be climatic, such as heat or cold, nutritional, such as lack of water or food, pathological, psychological, or managemental in nature. Livestock is subjected to various forms of stress, including physical, chemical, nutritional, psychological, and thermal. Among all, heat stress is the most detrimental, affecting livestock production (Rivington *et al*., 2009, Roth, 2020) [41, 44]. Heat stress is any combination of environmental factors such as air temperature, relative humidity, air movement, and solar radiation that causes the effective temperature of the environment to be higher than the thermoneutral zone of the animal (Herbut *et al*., 2018) [21]. It is the sum of external forces acting on an animal that causes a rise in body temperature and evokes a physiological response (Dikmen and Hansen, 2009) [12].
Livestock maintains their body temperature within a relatively narrow range and both physiological and behavioral responses help in thermoregulation. In order to maintain homeothermy, an animal must be in their thermo neutral equilibrium with its environment. Under thermo neutral environmental conditions most of the domestic animals are able to maintain equilibrium between the heat production and heat loss. Cold and heat stress can result in an inability to maintain this constant body temperature causing animal health, productivity and efficiency to suffer as a result. The thermoneutral zone of dairy animals is between 15 and 25 °C, where they maintain a physiological body temperature of 38.4 - 39.1 °C. Temperatures exceeding 20-25 °C in temperate climates and 25-37 °C in tropical climates like India, increase heat gain beyond that dissipated from the body and thus induces heat stress.
In the dairy sector, heat stress is a huge economic issue. Through physiological and behavioural changes, it has an impact on reproduction, health, and welfare, in addition to milk production. Heat stress negatively influences production and reproduction in dairy cattle (West, 2003; Upadhyay *et al*., 2008; Hyder *et al*., 2017; Polsky and Keyserlingk, 2017; Becker

et al., 2020; Li, 2021) [56, 53, 23, 38, 4]. Though dairy cattle have several adaptive mechanisms to cope with heat stress, these mechanisms only help the animals survive the stress by compromising their production and reproduction performance. Heat stress in cattle reduces feed intake, growth, milk production and reproductive potential; increases susceptibility to diseases and in extreme cases causes death resulting in substantial revenue loss to farmers (Brown-brandl *et al*, 2005; Sejian *et al*., 2012; Noordhuizen and Bonnefoy, 2015) [46, 35]. A clear understanding of the effect of heat stress on dairy animals is required to develop strategies to mitigate the adverse effects. Environmental modifications, genetic improvement, reproductive measures, and dietary management need to be taken into consideration for assisting the dairy animals in responding to the heat stress challenge.

2. Temperature-Humidity Index (THI)

The Temperature-humidity index (THI) is a single measure depicting the combined effects of air temperature and relative humidity (Du Preez, 2000) [14]. This index was developed as a weather safety index to control and decrease the heat stress-related losses in livestock (Habeeb *et al*., 2018) [19]. The environmental temperature alone does not provide complete information on the level of heat stress on animals and thus, temperature combined with relative humidity accurately measures the heat stress intensity.

THI was initially developed by Thom (1959) [52] and later adapted by Kibler (1964) [26] for dairy cows and is commonly used to evaluate the effect of heat stress on the livestock worldwide (Aharoni *et al*., 2002). THI measures the combined effects of ambient temperature and relative humidity (RH) to ascertain heat load intensity and can be used as an indicator of thermal climatic conditions. THI is calculated from dry and wet bulb air temperatures for a particular day according to the formula given by National Research Council (NRC), 1971.

$$THI = 0.72 (Wb + Db) + 40.6$$

Where Wb is wet-bulb and Db is dry-bulb temperatures in °C
THI values were categorized into mild, moderate, and severe stress levels for cattle by the Livestock Conservation Institute (Armstrong, 1994). The upper limit of THI at which cattle maintain stable body temperature was between 72 and 76 (Ravagnolo and Misztal, 2000) [40]. Livestock is comfortable at THI from 65-72, under mild stress from 72-78, and severe stress above 80. High thermal stress (THI>78) requires greater efforts to dissipate heat (Upadhyay *et al*., 2008) [53]. Lactating dairy cows experienced heat stress when THI rises above 72, with severe heat stress occurring when THI exceeds 88 (Thatcher *et al*., 2010) [51]. The relationship between the temperature-humidity index and heat stress levels in dairy cattle is shown in Table 1. The THI up to 72 had no adverse effect, while the severe effects were found on milk production and reproduction for the THI ranging from 90 to 98 and result in death beyond this level (Habeeb *et al*., 2018) [19]. High producing livestock need to be cooled artificially by sprinklers particularly in hot dry conditions or if both high temperature and humidity prevail, increased air movement is required to sustain milk production (Upadhyay *et al*., 2008) [53].

Table 1: Temperature-humidity index (THI) and its relationship with heat stress effects in dairy cattle

THI	Stress level	Effects
<72	None	No adverse effect produced in dairy cows
72 to 79	Mild	Dairy cows adjust by seeking shade, increasing respiration, and dilation of blood vessels. There is minimum effect on milk production
80 to 89	Moderate	The respiration rate and body temperature increase. Feed intake decreases, water consumption increases. Milk production starts to decline. Reproductive performance is also decreased.
90 to 98	Severe	Cows become very uncomfortable. There is rapid respiration (panting) and excessive saliva production. Milk production and reproduction decrease markedly
>98	Danger	Potential cow death occurs

3. Thermo neutral Zone (TNZ)

The Thermo neutral zone (TNZ) is defined as the range of ambient temperature within which thermoregulation is achieved only by control of sensitive heat loss, without regulatory changes in metabolic heat production or evaporative heat loss (IUPS Thermal Commission, 2001) [24].
An animal is assumed to be in its Thermo neutral Zone (TNZ) when it is within a temperature range that needs the least thermoregulatory effort, and temperature regulation is achieved by non-evaporative physical processes alone (Hillman, 2009) [22]. The TNZ is a narrow temperature range when the animal does not have to expend energy to maintain normal body temperature (Becker *et al*., 2020) [4]

The basal rate of heat production within the TNZ is in equilibrium with the rate of heat loss to the external environment. Below the TNZ is the zone of LCT (Lower Critical Temperature) and above is the zone of UCT (Upper Critical Temperature). The TNZ for livestock ranges from 5 to 25°C (West, 2003) [56].

When the ambient temperature decreases, the animal reaches the LCT, and the rate of metabolic heat production of the resting animal is increased by shivering and/or non-shivering thermogenesis to maintain thermal equilibrium. When the ambient temperature increases, the animal reaches the UCT, and the rate of evaporative heat loss of the resting animal is increased (tachypnea or sweating) to maintain thermal balance. (IUPS Thermal Commission, 2001) [24]. Thermo neutral zone of animals depends on the age, breed, feed intake, diet composition, the previous state of temperature acclimatization, production, and the behavior of the animal (Aggarwal and Upadhyay, 2013) [1].

4. Effect of Heat Stress on Milk Production

The significant impact of heat stress is on milk production due to reduced appetite and decreased feed intake. By decreasing feed intake, the cows reduce metabolic heat production to cope with increased ambient temperature. Decreased milk yield under heat stress is caused by associated effects on thermal regulation, energy balance, and endocrine changes (Ominski *et al*., 2002; Usman *et al*., 2013; Min *et al*., 2017; Liu *et al*., 2019) [36, 55, 31].

Ravagnolo and Misztal (2000) [40] reported a decrease in milk yield by 0.2 kg per unit increase in Thermo Humidity Index (THI) when THI exceeded 72 in Holstein Friesian cows. The

HF cows were very susceptible to high ambient temperatures due to their weak thermotolerance (Ouellet *et al*., 2019) [37] as a result of which their milk production declined resulting in substantial economic loss in summer (St-Pieree *et al*., 2003) [49].

Bouraoui *et al*. (2002) [7] reported that reduced feed intake accounts for about 35% of the heat stress-induced decrease in milk synthesis in HF cows. The feed intake dropped within 1 day after the initiation of heat stress, while milk yield decreased after 2 days of heat stress in HF cows (Spiers *et al*., 2004) [48]. Berman (2005) [6] reported that effective environmental heat loads above 35°C activate the stress response systems in lactating HF dairy cows.

Upadhyay *et al*. (2008) [53] observed that a temperature rise of 1.0 or 1.2°C with a minor change in precipitation from March to August in India would affect milk production in cattle and buffaloes. The estimated annual loss due to heat stress at the all-India level is 1.8 million tonnes of milk (Rs 2661.62 crore per year), which is 2% of the country's total milk production. The decrease in milk production will be higher in crossbreds (0.63%) followed by buffalo (0.5%) and indigenous cattle (0.4%). Both increase in T max (>4°C above normal) during summer and decline in T min (<3°C than normal) during winter negatively impact milk production of crossbred cattle and buffaloes.

Heat stress not only affects the quantity but also the quality of milk by altering its various components such as fat %, Solid non-fat (SNF), protein, casein, and lactose content. (Joksimovic-Todorovic *et al*, 2011; Gorniak *et al*, 2014; Garcia *et al*, 2015; Summer *et al*., 2019) [25, 18, 17]. Other milk quality parameters like Somatic cell count (SCC) and bacterial counts are also increased during periods of hot humid weather and it is the higher producing animals that have the highest feed intake which are typically the most severely affected (Nardone *et al*., 2010; Gantner *et al*., 2017) [33, 16]. Heat stress also compromises the immune system in animals making them susceptible to various disease conditions like Mastitis.

Molee *et al*. (2011) [32] found that Holstein crossed with local breeds in the tropics and subtropics perform better than the purebred Holstein and were also resistant to heat stress. Gaafar *et al*. (2011) [15] reported that with an increase in THI from 59.82 in the winter to 78.53 in summer, the total, 305 days and daily milk yield reduced by 39.00%, 31.40%, and 29.84%, respectively in HF cows. Total average milk production/cow was significantly (p<0.05) higher in spring (42.74±4.98 L) compared to summer (39.60±5.091 L). The reduction in milk production was attributed to changes in metabolism, physiology, and feed intake.

Dikmen *et al*. (2014) [13] observed that cows in hot humid climatic regimes show decreased milk yield and feed intake because of their continuous exposure to high humidity and high air temperature. Cowley *et al*. (2015) [11] reported that HF cows subjected to heat stress reduced their ingestion and produced less milk when compared with cows raised in normal climate conditions. Apart from decreased feed intake there is decreased nutrient absorption, alteration in rumen function, and hormonal imbalance which contributes to reduced milk production during heat stress. (Pragna *et al*., 2017) [39]

5. Effect of Heat Stress on Reproduction

Heat stress has a significant adverse impact on the reproductive performance of cattle in both sexes. In females, heat stress hampers the growth of oocytes by altering the secretion of progesterone, luteinizing hormone, and follicle-stimulating hormones during the estrous cycle (Ronchi *et al*., 2001; Shehab-El-Deen *et al*., 2010; Liu *et al*., 2019) [42, 47, 27]. It compromises the maturation and developmental capacity of the ovulating oocyte (Roth, 2017) [43]. Heat stress was responsible for the impaired ovarian function and increased embryonic mortality; delayed fetal growth and increased fetal loss (Wolfenson and Roth, 2000; Benyei *et al*., 2001; Hansen, 2007, Polsky and von Keyserlingk, 2017) [44, 5, 20, 38] and poor estrus expression and endometrial responses (Wolfenson and Roth, 2019) [57] in dairy cows. The conception rate of lactating cows during summer declined by 20 to 27% (Lucy, 2002 and Chebel *et al*., 2004, Schuller *et al*., 2014) [29, 9, 45] and there was a considerable increase in non-return rate to the first service in HF breed of cattle of United States (Al-Katanani *et al*., 1999; Ravagnolo and Misztal, 2002) [3].

Upadhyay *et al*. (2009) [54] reported decreased intensity and length of the oestrus period, decreased growth, size, and development of ovarian follicles, decreased conception rate, decreased fetal growth and calf size, increased embryonic deaths, increased number of AI per conception and increased incidence of silent heat. In bulls, semen concentration, number of sperms, and motile spermatozoa per ejaculation were lower in summer than in winter and spring (Nichi *et al*., 2006) [34].

6. Conclusion

Heat stress is a major challenge faced by the dairy farmers worldwide. There is a need to understand the physiological mechanisms underlying the effects of heat stress on the performance of dairy cattle and also the molecular mechanisms involved which contribute to the thermo tolerance in few breeds of cattle. Adopting suitable managemental, nutritional strategies and genetic manipulations for selecting heat tolerant breeds of cattle can go a long way to mitigate the effects of heat stress in dairy cattle.

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