Review on performance responses of dairy cattle against thermal stress

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Abstract

This manuscript is aimed at reviewing the performance responses of dairy cattle against thermal stress resulting from climate change. Climate change is the major factor that largely affects the dairy industry. Thermal stress (TS) is the perceived discomfort and physiological strains associated with exposure to excessive ambient temperature. Temperature and Humidity Index (THI) have been adopted to describe thermal conditions that drive thermal stress in dairy cattle. The effects of TS are devastating in the dairy industry if not managed well. The thermo-neutral zone for dairy cattle and calves in the tropics is THI <72. Milk yield reductions of up to 50% have been reported for Holstein cows due to thermal stress under summer climate conditions. Moreover, thermal stress is associated with alterations in milk composition. TS reduces the length and intensity of estrus manifestation. Moreover, 80% of estrus may be unnoticeable during the summer season in temperate regions, which further reduces fertility. Conception rates of dairy cows may drop up to 20–27% in the summer season. Climate-induced thermal stress resulted in a decrease of 3.5 kg and 25 kg in the birth weight and weaning weight of Fogera calves, respectively. Dry matter feed intake was reduced by 9.6%. Commonly used thermal stress reduction strategies included modification of the physical environment, breeding for heat-tolerant dairy cattle, and nutritional management. The productive and reproductive traits are susceptible to the negative impacts of thermal stress with an increase in THI above 68.0 for Holstein Frisian cattle and their crosses and 72 for tropical cattle under an open shed system. Mitigations of thermal stress by breeding heat-tolerant animals, using a loose house system, and season-based feeding should be considered an integral component of the dairy cattle management system.

Keywords: Thermal Stress; Climate Variable; Performance Response; Mitigation Measures; Dairy Cattle.

Introduction

Climate change is a major concern/issue that largely affects the dairy industry. By the year 2100, the mean global temperature may be 1.1-6.4 °C warmer than in 2010 (Sheikh *et al.*, 2017). The impact of climate change can be direct or indirect. Livestock, depending on the species and level of productivity, have an optimal environmental zone and they must be maintained within this zone for optimal growth, lactation, and reproductive functions (Armstrong, 1994). Thermal stress is the perceived discomfort and physiological strains associated with exposure to an extremely hot or cold environment. Thermal stress includes both thermal stress during the extreme summer season as well as cold stress during the extreme winter season. The surplus of produced heat needs to be emitted into the surrounding air. However, this is difficult when the air temperature is already high and relative air humidity is elevated. As a result, the body temperature of animals increases. To prevent overheating, cows consume less feed, which leads to lower milk production. Moreover, thermal stress is most often conditioned by air temperature (Temp), relative air humidity (RH), solar radiation, and air movement velocity (West, 2003; West *et al.*, 2003). The temperature and Humidity Index (THI) was first introduced by Thom (1959) to describe the effect of ambient temperature on humans but has been adapted to describe thermal conditions that drive thermal stress in dairy cattle (De Rensis *et al.*, 2015). It is divided into categories that potentially indicate the level of thermal stress. Armstrong (1994) used THI <72 [Temp=23.9 °C and RH=65% or Temp=32.2 °C and RH=0%] as a thermal comfort zone, 72 to 78 as mild TS, 79-88 as moderate TS, 89-98 as severe TS and >98 as danger TS. Nevertheless, THI <68 [Temp=22.2 °C and RH=45% or Temp=26.7 °C and RH = 0%] was defined to be outside the thermal danger zone for cows. Mild signs of TS are observed at THI of 68 to 74, and a THI ≥75 will cause drastic decreases in production performance (Collier *et al.*, 2009; De Rensis *et al.*, 2015). Various authors (Mader *et al.,* 2006; Bohmanova *et al.*, 2007) have described the thermo-neutral zone for various mammals, as indicated earlier. Habeeb *et al.* (2018) better described the thermo-neutral zone of cattle in tropical countries like Ethiopia and Egypt. According to his report, cattle were in comfort zone if (THI < 68), mild discomfort zone if (68 < THI < 72), discomfort if (72 < THI < THI < 79), danger (79 < THI < 84), and emergency (THI > 84).

The effects of TS are devastating in the dairy industry unless managed well. Milk yield reductions of up to 50% have been reported for Holstein cows due to thermal stress during the summer climate condition in the open shed cattle management as compared to the winter (Baumgard and Rhoads, 2013). Moreover, thermal stress is associated with alterations in milk composition, somatic cell counts, and mastitis incidences (Pragna *et al*., 2017). High-yielding breeds are more susceptible than low-yielding breeds (Sunil *et al*., 2011; Pragna *et al*., 2017). The feed nutritional requirements of the high-yield dairy animals are high as they utilize the feeds for maintenance and production. When the external temperature goes beyond its thermal neutral zone, the animal experience thermal stress. As a result, the animal decreases their feed intake dramatically to reduce the internal heat production as a cooling mechanism of their body, and thereby their milk production goes do as compared to the low-yielding dairy animals. TS reduces the length and intensity of estrus besides increasing the incidence of anestrous and silent heat in farm animals (Kadokawa *et al*., 2012; Singh *et al*., 2013). Moreover, 80% of estrus may be unnoticeable during summer, which further reduces fertility (Rutledge, 2001; Singh *et al*., 2013). Conception rates of dairy cows may drop up to 20–27% in summer (Shiekh *et al*., 2017). It also affected testicular volume, hormonal profiles, sexual behavior, and semen quality, which affect the reproductive performance of males (Abera *et al*., 2020). Besides, thermal stress has been also associated with the deterioration of embryo development and increased embryo loss in cattle (Hansen, 2007). Thermal stress also causes severe economic loss in approximately 45%-60% of dairy farms around the world (Bernabucci *et al.,* 2010; Pragna, *et al*., 2017). Commonly used TS reduction strategies included modification of the physical environment, breeding for heat-tolerant dairy cattle, and nutrition management (Armstrong 1994; Silanikove, 2000). Despite various studies conducted at different research centers and universities to examine the impact of thermal stress on cattle performance, there has been insufficient review and publication of these findings. Therefore, the objective is to review the performance responses of dairy cattle against thermal stress.

Thermal stress in Cattle

Responses of Cattle to Thermal Stress

The efficiency of conversion of food energy for maintenance and production while maintaining a reasonable thermal balance of the animals in its environment is seldom achieved in tropical climates for the most highly productive stocks. As animal agriculturalists strive for an increased rate of growth, lactation, and fertility by improved feeding, especially in the more stressful humid tropics they are immediately confronted with the problems of dissipation of the increased metabolic heat. The genetic blending of heat in addition to nutritional adaptability and disease resistance with productivity is essential for animal production in climate zones where portions of the day, seasons, or year exceed the thermo-neutral zone for production. Stress may be climatic, nutritional, or internal, pathogens or toxins (Stott, 1981). The thermo-neutral zone (TNZ) of dairy animals ranges from 5 °C to 25 °C [THI<68/72], within which they maintained a physiological body temperature of 38.4-39.1°C (Yousef, 1985) (Figure 1). However, air temperatures above 20-25°C in a temperate climate and 25-37°C in a tropical climate, enhance heat gain beyond that lost from the body and induces thermal stress (Vale, 2007; Sunil *et al*., 2011) (Figure 2). As a result, Body Surface Temperature (BST), Respiration Rate (RR), Heart Rate (HR), and Rectal Temperature (RT) increase which in turn affects feed intake (FI), production, and reproductive efficiency of the animals (Figure 3). RT greater than 39.0°C and RR greater than 60/min indicated that cows were undergoing thermal stress sufficient to affect milk yield and fertility (Kadokawa *et al*, 2012). Respiration rates are the recommended measure of heat stress because there is little to no lag time compared to body temperatures and milk production. Normal respiratory rates for adult dairy cattle range from 40 to 60 breaths per minute (bpm). If more than 10% of cows have a respiratory rate exceeding 100 bpm, the situation is considered an emergency, and immediate action should be taken (https://extension.umn.edu/dairy-milking-cows/heat-stress-dairy-cattle).

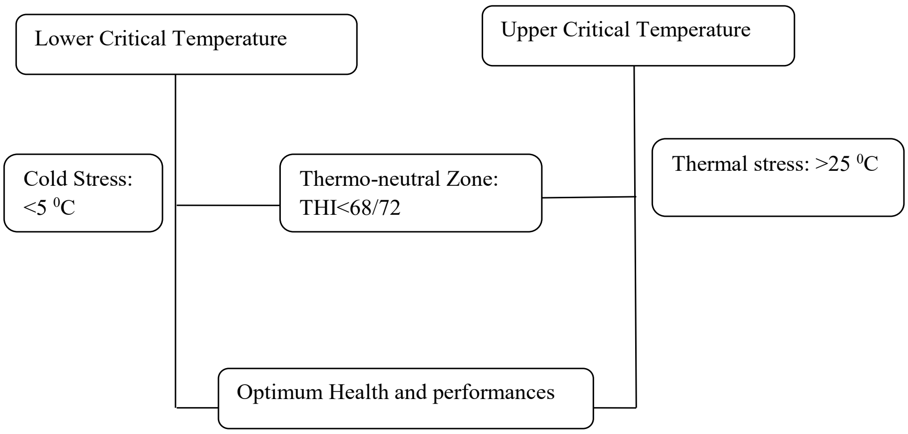

Figure 1. Thermo-neutral zone of dairy cattle. Source: Adopted and modify from Yousef (1985)

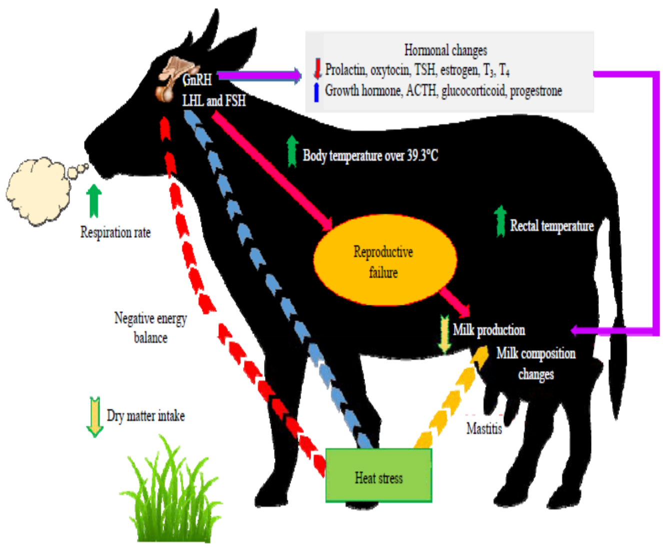

Figure 2. How dairy cattle do experience thermal stress, Source: Atrian and Shahryar (2012)

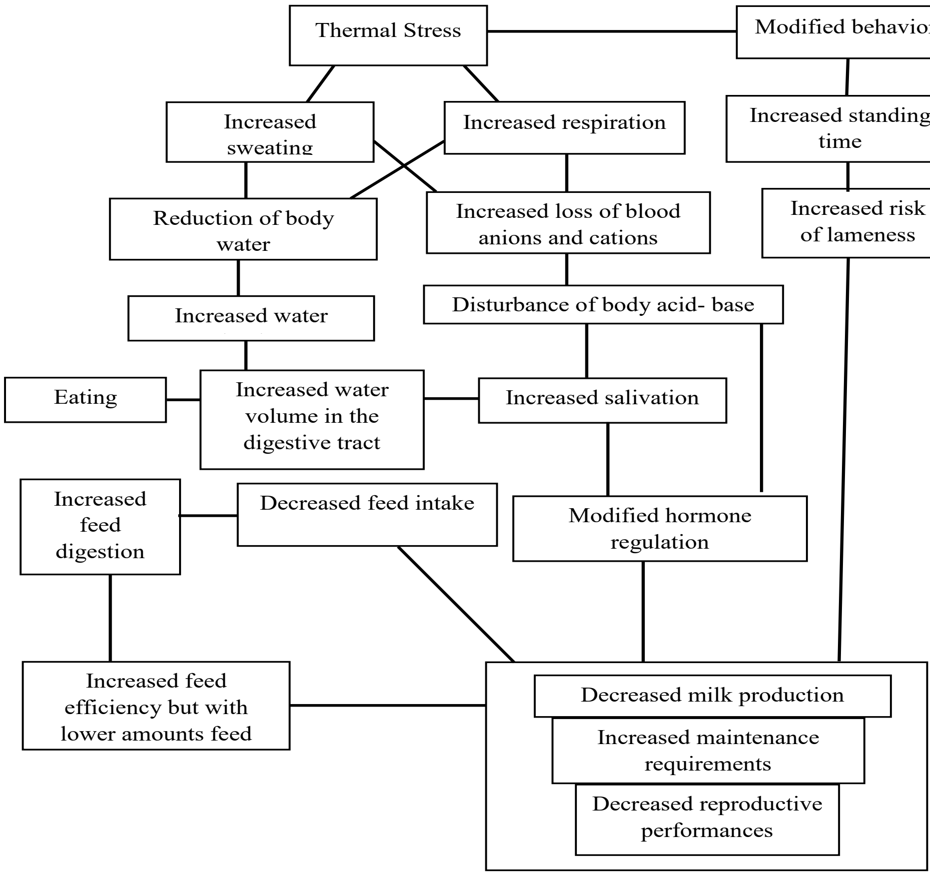

Figure 3. The Responses of dairy cattle to Thermal Stress. Source: Atrian and Shahryar (2012)

THI as a Predictor for Thermal Stress

THI is a single value depicting the integrated effects of air temperature and humidity associated with the level of Thermal stress. It is a useful and easy way to assess the risk of Thermal stress and was first introduced to describe the effect of ambient temperature on humans but later it has been adapted to describe thermal conditions that drive Thermal stress in dairy cattle (De Rensis *et al.*, 2015). This index has been developed as a weather safety index to control and decrease Thermal stress-related losses (Bohmanova *et al.*, 2007).

THI is widely used in hot areas all over the world and is commonly used as a practical indicator for the degree of stress on dairy cattle caused by weather conditions (Hahn and Mader, 1997). However, some studies show that THI values only serve as a rough measure of the HS effect on production (Polsky *et al.*, 2017). THI does not account for the effects of wind speed and solar radiation. However, Mader *et al.* (2006) extended the THI to include wind speed and solar radiation, to improve its effectiveness. Solar radiation can greatly influence heat load while changes in wind speed result in altered convective cooling. Different temperature and humidity Index equations (Table 1) have been previously developed by various workers to describe the severity of Thermal Mader *et al.*, 2006; Bohmanova *et al.*, 2007).

Table 1. THI estimation equations for different classes of dairy cattle

No	THI Equations	Classes of dairy animals	References
1	THI8 = (0.8 × Tdb) + [(RH/100) × (Tdb − 14.4)] + 46.4	For lactating dairy cattle	Mader *et al.*, 2006
2	THI = Temperature – (0.55 – (0.55x (RH/100) x (Temperature – 58)	For Pregnant dairy cattle	Amundson *et al.*, 2015
3	THI = (0.8 × Tmax) + (% average RH/100) × (Tmax – 14.4) + 46.4	For growing calves	Nienaber *et al.*, 1999

NB: Those equations which place more weight on the humidity work better in humid climates, whereas in drier climates, those which place more weight on the temperature work best (Bohmanova *et al.*, 2007).

THI classification and levels of Thermal stress

McDowell *et al.* (1976) developed THI and identified three different classes of THI as: comfortable (<70), stressful (71-78), and extreme distress (>78). Moran (2005) described five categories of THI as: no stress (THI<72), severe stress (78-89), very severe stress (89-98), and dead cows (>98). The LWSI described the TS zone into 4 categories with different ranges of THI under each category like normal (≤74), alert (75-78), danger stress (79-83), and emergency stress (THI≥84) in livestock (Hahn *et al.*, 2000; Nienaber *et al.*, 2003). Bohmanova *et al.* (2007) indicated a THI of >65 as an upper-critical THI for lactating cows associated with decreasing milk and protein yields whereas Brugemann *et al.* (2012) indicated a THI of 60 as upper critical THI for lactating HF cows associated with decreasing milk and protein yields. Garcia-Ispierto *et al.* (2006) developed five THI classes as:<70, 71-75, 76-80, 81-85, and >85, and reported that a conception rate declined from 30.6% to 23% when THI>85 for 1-3 days before insemination. The negative effects of thermal heat stress on growth traits were observed when THI >67-72 (Abera *et al.*, 2021). The symptoms of when animals are exposed to different levels of thermal stress are presented in Table 2 and Figure 4.

Table 2. Influences of TS on performances of cattle at different THI levels.

THI	TS level	Symptoms	References
>72	Mild	Cows likely begin experiencing TS and their calf rates affected	(Bohmanova *et al.*, 2007; Verkerk, 2009; Nidumolu *et al.*, 2010).
>78	Moderate	Cows' milk production is seriously affected	(Bohmanova *et al.* 2007; Verkerk, 2009; Nidumolu *et al.*, 2010).
>82	Severe	Very significant losses in milk production are likely, cows show signs of severe stress and may ultimately die	(Bohmanova *et al.*, 2007; Verkerk, 2009; Nidumolu *et al.*, 2010).

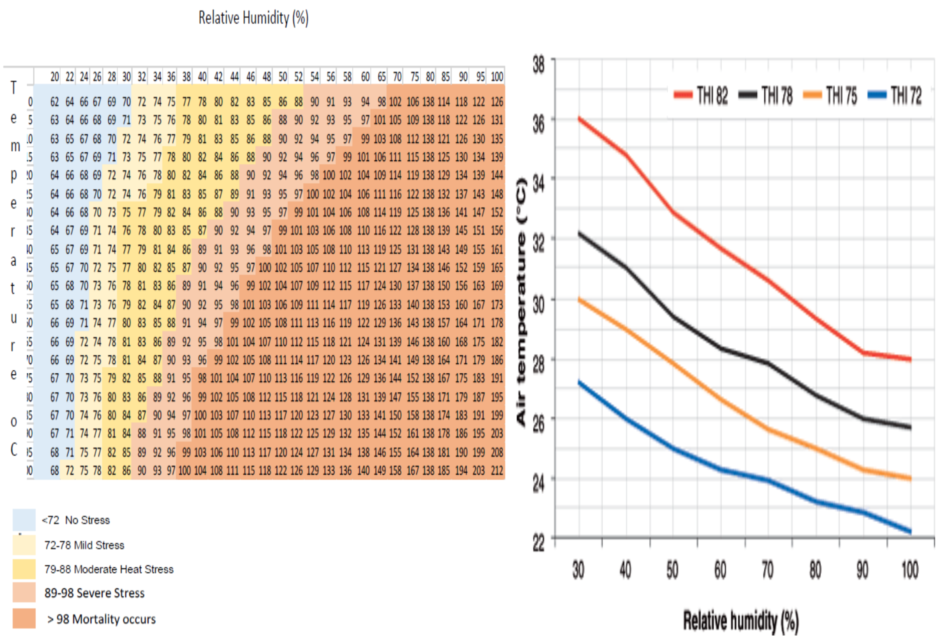

Figure 4: Bovine Temperature-Humidity Index Charts (Armstrong, 1994) (left) and (Nidumolu *et al.*, 2010) (right)

Thermal stress tolerance variations in cattle

The differences among different livestock for heat tolerance can provide the breeders opportunities to plan and perform breeding for heat resistance. Based on Thermal stress tolerance capability differences among different livestock (cattle), the following generalizations were drawn and summarized. Compared to beef cattle, dairy cattle are more vulnerable to thermal stress. Additionally, high-yielding cattle producing over 10 liters of milk per day are less tolerant of heat than low-yielding cattle producing less than 10 liters per day. *Bos taurus* cattle are more affected by thermal stress than *Bos indicus*, but Jersey cattle have a better ability to withstand thermal stress and adverse climatic conditions than other exotic dairy breeds. As a result, they are the preferred breed for tropical and subtropical environments because they sweat and drink more in hot weather (Sharma *et al.,* 1983; Bajagai, 2011). Lactating cows were also less resistant to thermal stress than dry-off cows. The impact of thermal stress on cows varied based on their lactation stage, with mid-lactation cows being more affected than early and late-lactating cows. Multiparous cows were also found to be more susceptible to thermal stress. However, small and young animals were less affected than large and old animals, likely because they are better able to dissipate heat and experience thermal stress less rapidly (Espinoza *et al*., 2009; Verkerk, 2009; Sunil *et al.,* 2011; Pragna *et al*., 2017).

Effects of thermal stress on performance traits

Effects on growth traits

Broucek *et al*. (2008) did a study on the effects of high temperature on the growth, feed intake, and health condition of calves kept in individual hutches in southern Slovakia for 92 days and reported those sixty-six days with a THI value above 72.0 and twenty-six with values higher than 78.0 were found. The calves born during the high-temperature period had the lowest body weight from the first week to the weaning than those born in the low-temperature period. These calves drank water up to the weaning and had the least intake of the starter mixture ($p<0.05$). Lacetera *et al.* (1994) did a study on the effects of temperature on calves and reported that exposure to a hot environment may negatively affect the growth of young calves. He also found lower wither height, oblique trunk length, hip width (−35%, −26%, −29% respectively), and body condition score (0.0 *vs* +0.4 points) in six 5-month-old female Holstein Friesian calves exposed to hot conditions as compared with a control group (the corresponding six sisters of six pairs of twins), kept under thermo-neutrality conditions. Temperatures between 15-29 ◦C do not seem to exert any influence on growth performance. In temperatures above 30 ◦C, adverse effects were recorded in daily weight gain. Under high ambient air temperature and solar radiation, steers reduce daily dry matter intake, hence average daily gain and carcass weight fall, and fat thickness drop (Mitlohner *et al.*, 2002). The birth weight and weaning weight of Fogera calves managed under Metekel cattle breeding and multiplication ranch, were decreased by 3.5 and 25 kg, respectively when THI increases from 67 to 72 (Abera *et al.*, 2021). Abera *et al.* (2021) also reported that at higher environmental THI, the average daily gain and final body weight of the calves were significantly affected in the same breed at Metekel Ranch. However, THI had negative and insignificant influences on different growth traits of Holstein Frisian crosses, maintained under the loose sheds and proper feeding and watering management (Tassew, 2021, unpublished).

Effects on reproduction traits

Thermal stress has adverse effects on the reproduction of dairy cattle (Kadzere *et al.*, 2002; West, 2003; Verwoerd *et al.*, 2006; Hansen, 2007) and conception and mortality rates (Hahn, 1999; Dikmen and Hansen, 2008). Thermal stress does not prevent the occurrence of normal estrus cycles. It does, however, amplify the problem of heat detection by reducing the length of the estrus period, from 18 hours down to about 10 hours, and lowering the intensity of estrus behavior (Shearer, 1990). Thermal stress compromises oocyte growth in cows by altering progesterone, luteinizing hormone, and follicle-stimulating hormone secretions during the estrus cycle (Ronchi *et al.*, 2001), as well as impairing embryo development and increasing embryo mortality (Wolfenson *et al.*, 2000). Moreover, TS may reduce the fertility of dairy cows in summer by poor expression of estrus due to a reduced estradiol secretion from a dominant follicle developed in a low luteinizing hormone environment (De Rensis and Scaramuzzi, 2003). About a 20-27% drop in conception rates (Lucy, 2002) or a decrease in the 90-day non-return rate to the first service in lactating dairy cows (Al-Katanani *et al.*, 1999) can occur in summer. In these situations, the calving interval is longer, the birth rate is lower and farm milk yield per year can be reduced.

Thermal stress during pregnancy slows down the growth of the fetus, although active mechanisms attenuate excursions in fetal body temperatures when mothers are thermally stressed. There are several changes in reproductive performance (decreased fetal growth and calf size, increased risk of early embryonic death, and increased number of AI per conception) have been reported (Upadhyay *et al*., 2009b). Besides, TS has been also associated with deterioration of embryo development and increased embryo loss in cattle (Hansen, 2007). It also affected testicular volume, hormonal profiles, sexual behavior, and semen quality, which affect the reproductive performance of males (Abera *et al*., 2020). In an unpublished study conducted by Tassew (2021), it was observed that under loose sheds with proper feeding and watering management, the impact of THI on age at first service, age at first calving, and weight at first calving was not significant ($p>0.05$). However, the study revealed a negative and significant effect ($p<0.05$) of THI on the number of services per conception and pregnancy period.

Effects on milk production traits

Thermal stress has adverse effects on milk production and reproduction of dairy cattle (Kazdere *et al*., 2002; West, 2003; Verwoerd *et al*., 2006; Hansen, 2007) (Table 3). Reduced performances under heat and cold stress are due to associated effects on thermal regulation, energy balance, water balance, and endocrine changes among other factors. Reduced milk yield under Thermal stress is caused by associated effects on thermal regulation, energy balance, and endocrine changes (Yousef, 1985; Ominski *et al.,* 2002) and reported a decrease of 4.8 % in milk production when cows were exposed to TS compared to their milk production in the thermal neutral zone. Bouraoui *et al.* (2002) reported that for every degree above the temperature humidity index of 69 in dairy cattle a 0.4 kg decrease in milk production. Berman (2005) estimated that effective environmental heat loads above 35°C activated the stress response system in lactating dairy cows. Milk yield reductions of 10 to 40% have been reported for Holstein cows during summer as compared to winter (Broucek, 2009). Brügemann *et al.* (2012) indicated a milk yield decline between 0.08 and 0.26 kg for every increase in THI units in Germany. When the THI value increased from 68 to 78, milk production was reduced by 21%, and dry matter intake was reduced by 9.6% (Bouraoui *et al*., 2002). The reduction in feed intake could be due to the adaptive mechanism of animals to produce less body heat (Veerasamy *et al*., 2015). In 2017, Tibor Könyves and colleagues conducted a study to investigate the correlation between temperature and humidity index and milk production and feed intake of Holstein-Friesian cows across different seasons. The study revealed that thermal stress had a negative impact on daily milk yield, with reductions of 1.32 kg (9.46%), 0.92 kg (9.62%), and 1.27

kg (9.48%) observed as THI values increased from 64 in spring, 66 in autumn, and 42.34 in winter to 79 in summer.

A study by Robert *et al.* (2014) on analysis of Thermal stress in UK dairy cattle and its impact on milk yields indicated that the number of days where the THI exceeds this threshold (>70) could increase to over 20 days yr−1 in southern parts of England by the end of the century. Forough *et al.* (2017) did a study on the Effect of the temperature and humidity index and lactation stage on milk production traits and somatic cell score of dairy cows in Iran and found that the greatest milk yields were recorded in THI≤60 ($p<0.05$). The highest decrease in milk yield in connection with THI values was recorded in the early lactation (0 to 100 DIM). SCS was positively associated with the THI and increased more in an early period of lactation.

In 2016, Kaiser Parveen conducted a study on the impact of thermal stress on Sahiwal cattle performance in Haryana. The study findings showed that the THI values ranged from 57.13 in January to 81.84 in July. Additionally, the study determined that an increase in THI value above 68 resulted in a sudden decrease in the wet average/daily milk yield of Sahiwal cows within the herd. Furthermore, the study developed a prediction equation for Sahiwal's wet average using the THI value, which was represented as Y = 18.28-0.175Xi. THI significantly affected the daily milk yield (DMY) and peak daily milk yield (PDMY) of Holstein Frisian crosses, maintained in the loose housing system with feeding and watering management (Tassew, 2021, unpublished). According to the same author, DMY and PDMY declined by 0.054 kg and 0.10 kg, respectively for a unit increase in THI from the threshold (68 units).

Table 3. The size of milk production reduction with the unit rise in THI

Breeds	THI Variation	MY Reduction	References
HF cows	Unit rise >66	0.23 Kg/D/C	Santana *et al.* (2016)
HF cows	Unit rise of THI	0.14 - 0.2Kg/D/C	Lombertz *et al.* (2014) Ravagnalo *et al.* (2000)
Dairy cows	Unit rise >69	0.41 Kg/D/C	Spiers *et al.* (2004)
Dairy cows	Unit rise of THI>65	0.23-0.59 Kg/D/C	Bohmanova *et al.* (2007)
HF crossbreds	Unit rise of THI	0.43 - 0.886 Kg/D/C	Das (2009) Upadhyay *et al.* (2009)
Sahiwal cows	Unit rise of THI	0.16 Kg/D/C	Upadhyay *et al.* (2009)
Sahiwal cows	Unit rise>62	0.175 Kg/D/C	Kaiser Parveen (2016)
German Cows	Unit rise of THI>60	0.08-0.26 Kg/D/C	Brugemann *et al.* (2012)

Effects on milk composition

In another study, decreased milk protein, lactose, and fat values were recorded during the summer (Gaafar *et al*., 2011). Elevated temperature and humidity can reduce the ability of cattle to dissipate excess heat, which can ultimately lead to TS and associated physiological changes such as reduced milk fat and protein (Chebel *et al*., 2004; Novak, *et al*., 2007; Hossein-Zadeh *et al*., 2013). TS significantly reduced contents from 3.79% milk solids, 3.20% fat, 4.78% protein, 8.69% lactose, 12.48% SNF, and 0.71% ash during the winter season to 3.49%, 3.07%, 4.59%, 8.34%, 11.83%, and 0.67% during the summer season, respectively (Gaafar *et al*., 2011). In addition, milk solid, fat, and protein concentrations in Holstein-Friesian (HF), New Zealand Jersey (NZJ), and HF×NZJ cows tend to decline for THI values of 60, 64.3, 66.7, and 73.3, respectively (Bryant *et al*., 2007). Zedeh *et al.* (2013) reported that Iranian Holstein cows that calved in montTS in THI1 (30-40), and THI2 (41-50) group had a greater amount of milk and milk fats ($p<0.05$) than the cows that calved in months belonging to a month in THI group 4 (81-90).

Economic losses from thermal stress

Thermal stress causes severe economic loss in approximately 45%-60% of dairy farms' incomes around the world (Bernabucci *et al.,* 2010; Pragna, *et al*., 2017). Researchers (St-Pierre *et al.,* 2003; Bernabucci *et al.,* 2010) have documented the adverse impact of warm environments on cattle's productive performance, which can have devastating economic consequences for the global dairy industry. They have estimated a total economic loss incurred by the US livestock sector due to Thermal stress at between 1.69 and 2.36 billion US$. About 45%-60% of this loss was observed in the dairy industry [$897 million] (Bernabucci *et al.,* 2010; Pragna, *et al*., 2017). Upadhyay *et al*. (2009) reported that the annual total milk loss due to thermal stress at the all-India level was 1.8 million tons or approximately 2% of the total milk production of the country amounting to a whopping 2661.62 rupees per year. The negative impact of global warming on total milk production in India is also estimated to be about 3.2 million tons by 2020 and more than 15 million tons by 2050. The study showed that without heat abatement (minimum intensity), total losses across animal classes averaged $2.4 billion annually. However, by 2050, an estimated nine billion people will live on the planet and to feed the planet, we will need to increase food production dramatically.

Thermal stress reduction measures

Researchers (Armstrong, 1994; Silanikove, 2000; Chandra *et al.,* 2015; Amaral-Phillips, 2016) have identified and documented measures for mitigating thermal stress in animals. Commonly used Thermal stress reduction strategies included modification of the physical environment, breeding for heat-tolerant dairy cattle, nutrition management, and timed artificial insemination (TAI) protocol (Armstrong, 1994; Silanikove, 2000). Herd's physical environment management (introduction of shaded areas under which cows can graze via the retention of trees in paddocks and the planting of shelter belts and housing in pens in which they are exposed to evaporative cooling and spray and/or fan cooling (Ghosh *et al*., 2017*)*. Breeding heat-tolerant animals, such as indigenous (Sahiwal), Senepol, and Carona, is a long-term strategy aimed at developing heat-resistant breeds for breeding purposes. Nutrition management is supplying high-energy feeds along with bypass protein and ration with >18% protein, low fiber, vitamins C, E, and A, and minerals such as zinc (Amaral-Phillips, 2016). Scientific literature provides several clear examples where the availability of shade for cattle can significantly reduce their heat load largely by reducing the solar radiation they receive (Armstrong, 1994; Kendall *et al*., 2006; Fisher *et al*., 2008). The scientific literature that monitors animal behavior also reports that cows with access to shade begin to preferentially use it when air temperatures rise above 25°C or when THI is above 73 and that uptake increases exponentially as air temperature increases (Kendall *et al*., 2006). Ghosh *et al*. (2017) did a study on the efficacy of shading and spraying to alleviate Thermal stress and found that the shade of the structure proved to be more successful at reducing moderate and severe Thermal stress occurrence than spray treatment. There were 53% fewer moderate and 86% fewer severe Thermal stress events with the shade treatment. The spray treatment proved effective at reducing only the number of severe Thermal stress events. During the 182 days, 46% fewer severe Thermal stress events were measured for the spray treatment. For low-susceptibility herds, simulated milk loss was 67% lower for the shade treatment and only 20% lower for the spray treatment.

Thermoregulation by the animal itself

In 2009, Verkek identified several processes utilized by dairy cattle to regulate their body temperature. These included seeking areas of pasture with the greatest air movement, standing to increase the body's surface area exposed to air and/or changing orientation concerning the sun, increasing respiratory rate, panting and/or sweating to transfer heat away, reducing or stopping feed intake to minimize heat-generating metabolic processes, searching for water and shade, and seeking minimal shade from the herd itself if no other source of shade is available.

Conclusions

Thermal stress resulted in a decrease in reproductive efficiency, growth, milk production, and composition. The THI is the most commonly used index to measure the level of thermal stress in dairy cattle. The productive and reproductive traits of cattle are susceptible to the negative impacts of Thermal stress with an increase in THI above 68. The effects of thermal stress were higher in the summer seasons from April to September where the average THI level was above 75 than spring and winter seasons. The high-producing dairy cows seem to be more affected by thermal stress than the low-producing ones. The shade structure proved to be successful at ameliorating calculated milk production loss across herds with different susceptibilities to Thermal stress**.** Mitigation of stress due to meteorological factors should be considered an integral component of the cattle management system. Consideration of heat tolerance potential along with performance traits during selection can help to mitigate the impact of Thermal stress. In general, integrated heat mitigation measures need to be adopted to reduce thermal stress to maintain the welfare of animals and prevent economic losses.

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