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Nutritional strategies for amelioration of heat stress in dairy cows: A Review

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Abstract
The livestock sector provides a consistent income to the farmer and acts as a backbone of the national economy along with agriculture and in the near future, this sector will become the major source to provide nutritional security (meat and milk) for the growing population. But the changing climate scenario and global warming are increasing the effect of Heat stress (HS) on animals and it becomes a severe threat to sustainable livestock production. HS compromises the growth, production, and reproduction efficiency of dairy cattle and will cause severe economic losses to the dairy farmer. The adverse effects of HS can be minimized by three types of interventions including genetic manipulation, nutritional interventions, and management practices that help the dairy cow to sustain production and reproduction in hot weather. Among these, nutritional strategies are simple and cost-effective in preventing the adverse effects of HS. This article will discuss various nutritional strategies such as the provision of *ad libitum* cold water, quality protein, fat, minerals, vitamins, and other feed additives necessary for dairy cows to cope with HS and sustain productivity in dairy cows.

Keywords: Climate change, dairy cattle, heat stress, management, nutrition

Introduction

In developing countries like India, livestock plays an important role in the agriculture sector in terms of providing nutritional security to the growing population, contributing to the national economy through the exports of livestock products such as milk and meat, and also providing employment and livelihood to the small and marginal farmers. As the global and Indian population is increasing and is expected to reach 9.7 billion and 1.7 billion respectively, by the year 2050 [1], at the same time the demand for animal-based products will also increase in order to feed the growing population. In this context, sustainable livestock production is very much important. But the changing climate scenario is a serious threat to the livestock production system, the production performance of livestock is declining drastically in tropical countries which is of major concern [2].

As a result of climate change, summer temperatures are increasing every year, which is an alarming threat to the survival of humans and livestock. In the near future, this rise in temperature continues and may become a severe problem for sustainable livestock production. By 2100, the global average surface temperature might increase by 1.8 to 4 °C [3]. In recent years, India also witnessed some hottest summers due to tremendous changes in environmental variables such as increased ambient temperature, relative humidity, solar radiation, and wind speed. As a result of this, the livestock was under moderate to severe HS, especially during hot summer days. Dairy cow health and biological performance are significantly impacted by HS, which lowers milk production and reproductive efficiency [4]. *Bos indicus* cattle have higher sweating capacities and lower metabolic rates than *Bos Taurus* cattle due to genetic differences in heat tolerance.

Heat Stress (HS) in dairy cows

Heat stress or thermal stress, which is defined as the sum of external forces acting on an animal to create an increase in body temperature and cause a physiological reaction, is one of the most important environmental variables affecting livestock production performance. Thermo Neutral Zone (TNZ) is the range of environmental temperature within which the animals use no additional energy to maintain their body temperature. Usually, the animal will dissipate the body heat and maintains the body temperature at a constant level when it is in a thermoneutral zone (TNZ). The normal TNZ temperature for dairy cows lies between 12 and 25 °C [5]. Above the TNZ, animals have to spend energy to lose the excess heat through the skin surface and respiratory tract. Many environmental factors such as solar radiation, ambient temperature, relative humidity, and wind velocity will influence the TNZ and will affect the heat gain and loss from the animal's body [6]. When the temperature exceeds the TNZ, then the thermoregulation becomes difficult, and subsequently animal fails to dissipate the body heat as a result, heat load will be developed and it will head to HS and further, it will compromise the production and reproduction efficiency of the dairy animals [7].

The Temperature-Humidity Index (THI) is used to assess the animal's response to HS. THI is calculated by combining both environmental temperature and relative humidity. There are several equations that are available to calculate the THI, with the help of dry bulb temperature and relative humidity (RH %). When the relative humidity is high in the environment it will depress the evaporative cooling efficiency of the animals, as a result, there will disturbance in heat dissipation and causes heat load in the animal. As a result of the extreme heat load and elevated core body temperature in HS circumstances, the animal is compelled to drastically alter its physiological and behavioural responses, such as increased respiration rate (RR), pulse rate (PR), rectal temperature (RT), and decreasing feed intake [6]. When the THI reaches above the threshold level (> 72) it will lead to hyperthermia-associated discomfort, changes in normal physiological responses, reduced feed intake, and a decline in milk yield [8]. The diet and THI will have an effect on the water intake and DMI in heat-stressed animals [9]. So, the careful measurement of THI along with the physiological parameters like RR, PR, and RT will help in assessing the effect of HS on dairy cows.

$$THI = (1.8 \times T + 32) - (0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)$$ [10, 11]

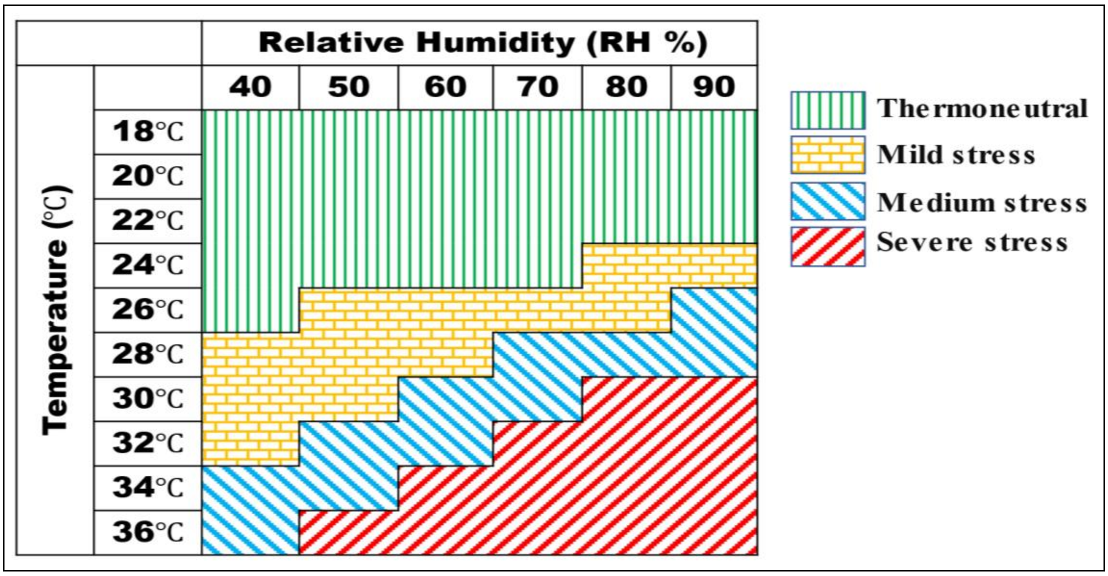

Fig 1: Temperature-Humidity Index

Effect of HS on dairy cows

HS will affect growth, reproduction, and milk production in dairy animals. HS or thermal stress results in a decline in milk production, due to the diversion of energy resources from production to the adaptation pathway, which results in severe economic loss to the dairy industry. When dairy cattle are exposed to HS, initially they will show signs of increased water intake, panting, sweating, respiration rate, and reduced feed intake. But when the exposure to heat load is increased, animals will try to adapt to the conditions by acclamatory homeostasis. However, if the HS is prolonged, the animal will try to dissipate the body heat through the homeostatic mechanisms [12]. In HS cows, increased heat dissipation (via evaporative cooling), increased water intake, reduced feed intake, and reduced milk yield are the typical homeostatic mechanisms. When the temperature is above the TNZ, the hypothalamus will send the signal to activate the heat loss mechanisms such as vasodilation (increased blood flow to the periphery) and sweating [12]. At the same time, heat-stressed cows consume less feed to prevent further metabolic heat load, as a result, they will ruminate less and it results in the entry of fewer buffering agents into the rumen, as the rumination is the key stimulation for saliva production. As a result of hemodynamic redistribution, there will be less blood flow to the gastrointestinal tract, which will negatively affect the digestive process. The decreased feed intake and altered rumen health and digestive processes further affect the quantity and quality of the milk. Heat-stressed cows will show certain behavioural and physiological changes including modified feeding and drinking behaviour, as a result, animals will prefer to consume feed during cooler hours and drink water at frequent intervals.

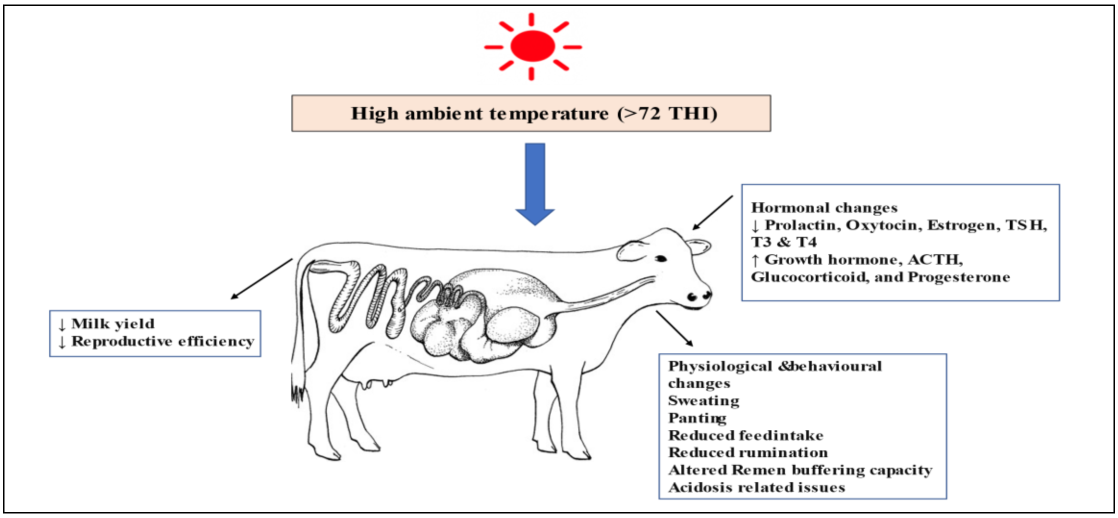

Fig 2: Physiological, behavioural, and hormonal changes of HS in dairy cow

HS is expected to result in an increase in maintenance costs of up to 25% to 30% in lactating dairy cows [9]. In addition to the behavioural and physiological changes, thermal stress also causes hormonal changes through the hypothalamus-pituitary-adrenal axis, by releasing glucocorticoids and aldosterone. The hormonal changes that occur in heat-stressed animals play a role in the decline in milk production. In HS animals, the cortisol level tends to increase and causes the energy diversion from production to a coping mechanism [13]. The circulatory level of epinephrine and norepinephrine will also be higher in hot weather. These endocrinal alterations lower the triiodothyronine (T_3) and thyroxine (T_4) levels in the plasma, leading to a lower metabolic rate and thus decreased heat production [14]. This reduced metabolic rate compromises the production capacity of the animal. In hot summers, a 10 to 35% reduction in milk yield is noticed as a consequence of HS in dairy cattle [15]. Reduced blood flow to the mammary gland and decreased DMI in hot weather were reasons for decreased milk yield in heat-stressed animals. Especially the high producing animals were affected mostly than the low producers.

Strategies to ameliorate HS

There are different ways to minimize the adverse effects of HS on dairy cows or dairy production systems. The approaches are mainly classified into three main categories *viz*. genetic manipulation, manage mental practices, and nutritional intervention. These approaches may help to reduce or ameliorate the impact of HS on dairy cows and help in sustainable production, especially during hot summers in tropical countries. Genetic strategies include the identification of heat-stress genes and the development of heat-tolerant breeds. Whereas the manage mental practices will focus on the physical modification of the environment by providing shade to animals via good shelter design, installing cooling devices, and providing fans, coolers, and sprinklers.

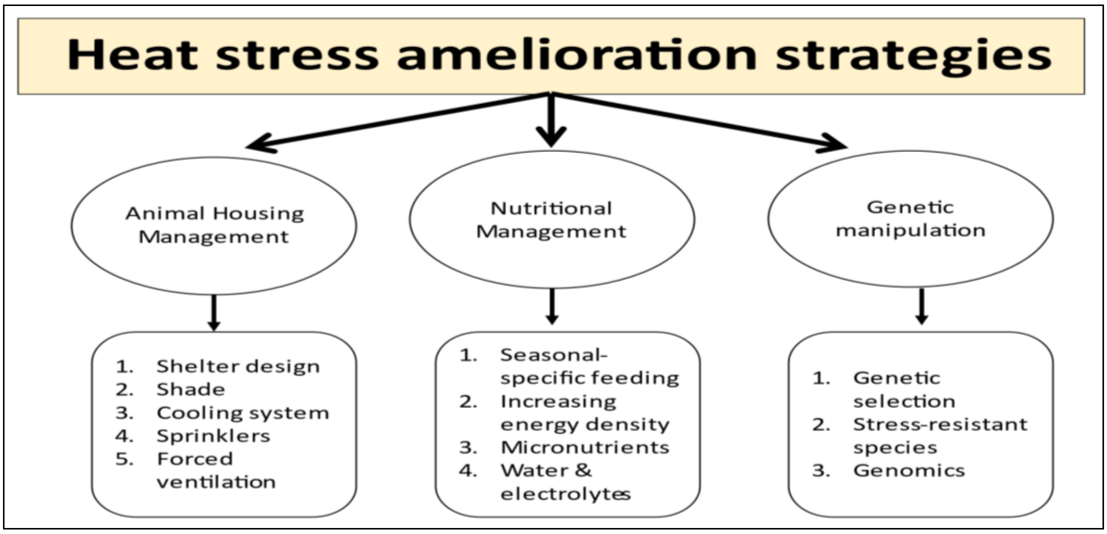

Fig 3: Amelioration strategies of heat stress in dairy cows

Nutritional strategies

The dietary supplementation of various essential nutrients is a simple and cost-effective strategy for HS amelioration in dairy cows. The strategies include i) management of feed & fodder and feed additives ii) increase in feeding frequency iii) change in feeding time (cooler part of the day) iv) providing cool water and optimum ventilation to affected animals with an objective to improve the production efficiency by optimizing the nutrient intake. Dietary manipulation is required in dairy animals that are suffering from HS to maintain adequate nutrient intake and to maintain homeostasis [16].

Fibre

In HS cows, the energy utilization efficiency will be poor due to high maintenance requirements to cope with the internal heat load. So, the approach should be on the increased energy density of the HS cows. Fibre is one of the important nutrients whose levels have to be considered while formulating ration for heat-stressed dairy cows as it influences metabolic heat production, and also maintains normal rumen conditions. But feeding a high-fibre diet to HS cows causes high metabolic heat production and decreased DMI and milk yield. The basic reason behind this is acetate metabolism is associated with more metabolic heat production than propionate. In many studies, increasing the concentrate feed at the expense of fibrous feed was found to reduce the metabolic heat load and improved the energy density of the diet [16]. The increased fibre content in hot weather conditions was associated with increased cortisol levels in dairy cows. Feeding of the low crude fibre (18 to 12% on a dry matter basis) containing ration to lactating cows resulted in a significant decrease in RT, PR, and RR, increased DMI, and milk production in dairy cows [17]. At the same time, the diet should contain adequate fibre to promote chewing and rumination to maintain normal rumen conditions. The level of ADF in the diet of HS cows should not be more than 18-19%, especially during the peak summer.

Protein

Heat-stressed dairy animals experience negative energy balance (NEBAL) which is also synchronized with decreased DMI. Therefore, such dairy cows should be supplemented with increased crude protein levels in the ration to compensate for the decreased DMI. The composition of the dietary protein has to be formulated in such a way that it should have a higher concentration of the rumen undegradable protein (RUDP). RUDP can escape the degradation in the rumen from microbes and so much of that supplied will be available to heat-stressed dairy animals [17]. There are conflicting reports for the inclusion of RUDP in the diet of heat-stressed dairy cows because of decreased DMI, the rate of passage of feed through the rumen slows down so the dietary protein supplemented gets acted upon by ruminal microbes. But as there is decreased DMI, the level of crude protein supplemented should be increased either as RUDP or enhanced protein quality by increasing the number of key amino acids [2]. It is not desirable to feed heat-stressed cows with an excess amount of the rumen-degradable protein as it requires more energy to metabolize and excrete the excess nitrogen as urea [16].

Fat supplementation

In the objective of ameliorating HS exposed by the animal, furthermore, energy supplementation has to be in consideration for diet formulation. Oke, *et al.* [18] reviewed that dietary fibre levels are to be decreased with a simultaneous increase of dietary fat supplementation to help animals combat thermal stress. As increased dietary fat inclusion reported to be providing energy intake and minimizing the HS effect on the animal by decreasing the amount of heat increment across various species were found. The Earlier scientific studies have considered supplementation of dietary fat as one of the alternative measures in providing increased energy supplementation to improve animal performance but supplementation of the dietary unprotected fat in ruminants will be suppressing the rumen motility since the rumen activity is adversely affected by the HS. Hence, the increased supplementation of dietary fat can be considered in the livestock species with decreased crude fibre and protein under HS, but, ruminant species have to be provided with dietary rumen-protected fat.

Vitamin supplementation

Heat-stressed cows tend to consume less feed, and there is always a chance of getting micronutrients such as vitamin and mineral deficiency. Under normal conditions, animals are able to synthesize vitamin C to meet their needs. However, there is a depletion of plasma vitamin C during thermal stress due to reduced synthesis and depletion in body stores [19]. Beneficial effects of supplemental ascorbic acid and vitamin E have been reported under hyperthermia [20]. Vitamin C, E, and methionine have been effective in mitigating the effect of thermal stress on animals in the tropics [21]. Studies reported that the supplementation of niacin (12g/d) to the cows in summer months improved the milk yield [22]. It was also proved that niacin can prevent ketosis and plays a role in lipid metabolism.

Mineral supplementation

Minerals are essential micronutrients in the diet of livestock as they play an important role in many metabolic processes, reproduction, and health. The only source of essential minerals for animals is the diet that they consume. Although, a normal diet may not provide all the essential minerals and additional supplementation of deficient minerals is needed. HS condition in livestock affects the ability to maintain mineral balance [23]. The macronutrient composition in the diets of animals should be taken care of to meet their needs during exposure to harsh environmental conditions. Also, mineral supplements can be useful in correcting the changes in the status of electrolytes, as their mobilization increases during HS.

Sodium (Na^+) and Potassium (K^+) are major electrolyte minerals and are necessary to maintain the water balance and acid-base status of heat-stressed animals in hot climates. The requirement of K^+ increases significantly in HS animals as the K^+ is a main osmotic regulator of water secretion from sweat glands in dairy animals. So, the dietary supplementation of K^+ should be made in HS animals [2]. In support of this, the findings of Sanchez *et al*. [24] showed an improved feed intake and locational performance in HS cows on supplementation of K_2CO_3 and $KHCO_3$ in the diet. Further, Na^+ and Mg^{+2} are the major minerals that compete with K^+ for their intestinal absorption, their concentration also should be increased in the diet of HS animals. In a hot environment, animals will sweat more to maintain their body temperature by evaporative cooling, which results in the loss of more Na^+. In such cases, HS animals require more Na^+ to replace the losses that occurred by the increased sweating. Coppock *et al.* [25] reviewed that supplementation of Na^+, $K^{+,}$ and Cl^- in HS dairy cows improved milk yield, and acid-base balance and lowered the rectal temperature.

Zinc (Zn) is an essential trace element in the diet of livestock which performs numerous biological processes including cellular growth, and immunological, and antioxidant functions. The addition of Zn can improve the antioxidant status of the animal which can help in the amelioration of heat-induced oxidative stress [26]. Zinc has been used as a mineral supplement in the diet of heat-stressed dairy cows to ameliorate the adverse effects of HS.

Selenium (Se) reduces the adverse effects of heat stress on redox balance and metabolism, resulting in improved immune function, milk quality, and dairy cow health [27]. In heat-stressed dairy cows, there was a significant decrease in plasma selenoprotein P, which contains most of the Se [28]. The addition of Se to the diet of dairy cows can significantly raise plasma selenoprotein P and Se concentrations, which might be a potential mechanism to protect them against heat stress [29].

Chromium (Cr) is supplemented in the category of a micro-mineral, having a wide range of physiological roles in a number of oxidation states. Al-Saiady *et al.* [30] supplemented Holstein dairy cows prone to HS with chromium yeast (4 g/day) and observed increased feed intake and milk yield.

Antioxidant supplementation

Antioxidants are compounds which involve in handling the excess concentration and production of free radicals in the system by scavenging those [31]. There are enzymatic antioxidants (superoxide dismutase, glutathione peroxidase, catalase, and thioredoxin reductase) and non-enzymatic antioxidants (Vitamins C, E, beta-carotene, glutathione, Se, etc.). The deleterious effects of HS extend to affect the oxidative status of the animal by inducing oxidative stress in the animal by disturbing the balance between the antioxidant system and free radicals/reactive oxygen species (ROS) [7, 32]. Within the normal physiological range, free radicals and ROS are important in playing various functions in the body mainly involved in reproduction [33].

Supplementing antioxidants to HS and oxidative stress-prone animals helps in combating the negative effects and recouping the health and productivity of the livestock [34]. In normal physiological processes, vitamin E and selenium function to minimize cellular damage from oxidative stress. When these combinations of antioxidants were supplemented in the animals, a synergistic effect was observed in the amelioration of stress than individual supplementation [35].

Feed additives

Betaine

Betaine is a glycine derivative and its supplementation can help in protecting the cells from oxidative and thermal stress. Usually, it is used as a feed additive in dairy cows, which acts as an osmolyte and methyl donor. It can also lower maintenance requirements and metabolic heat production. Daily supplementation of betaine at the rate of 15g/d in concentrate mixture to the grazing dairy cows in hot summer, was reported to improve milk production [36]. Supplementation of betaine (2 g/day) in the diet improved DMI and growth rate in sheep [37]. In most of the studies, betaine supplementation is proven to be beneficial in terms of enhanced production, rumen health, and antioxidant status in heat-stressed animals.

Astaxanthin

It is a xanthophyll carotenoid that possesses anti-inflammatory, antioxidant, and photo protective properties. Supplementation of astaxanthin as a feed additive helped heat-stressed animals to cope with the negative effects of climate change and stress, as well as to boost their productivity under stressful conditions [2]. The supplementation of astaxanthin to the Karan Fries heifers improved the body weight gain and average daily gain with the increased feed intake and minimized the negative effects of thermal stress [38].

Dietary microbial additives

Dietary microbial additives, such as yeast and bacteria have been widely used in dairy cows to increase feed intake and feed efficiency, improve rumen fermentation and digestibility, and ultimately increase milk production. The supplementation of *Saccharomyces cerevisiae* fermentation products @ 120 or 240 g/day lowered the rectal temperature, increased the milk yield and net energy balance, and decreased milk urea nitrogen in Holstein dairy cows compared to control animals [39].

GABA (Gamma-aminobutyric acid)

Gamma-aminobutyric acid (GABA) is an inhibitory neurotransmitter that regulates body temperature and inhibits heat production [40]. GABA directly inhibits cold-sensitive neurons and central or systemic administration of GABA and its agonists results in hypothermia. Cheng *et al.* [41] reported that γ-aminobutyric acid supplementation @ 40 mg/kg, dramatically lowered the rectal temperature, increased the feed intake and milk production, and also improved the milk composition in heat-stressed Holstein dairy cows.

Melatonin

Feed additives such as melatonin, *Chlorophytum borivilianum* (CB) also known as Safed Musli, and others also proved to be helping the heat-stressed animal in improving DMI and productivity [2].

Conclusion

Heat stress adversely affects the productive and reproductive performance of dairy cattle in tropical countries during summer months, resulting in severe economic losses to dairy farmers. In order to maintain sustainable livestock production, the adverse effects of the HS must be minimized by using effective strategies. The combination of manage mental and nutritional strategies can give better results for sustainable livestock production under the changing climate scenario.

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