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Review Article

Exploration of the Relationships between Production Performance and Heat Stress Response by Ruminant Animals due to Feed Additives

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Abstract

Heat stress poses a significant challenge to ruminant livestock production because it affects feed intake, milk yield, reproductive performance, and overall health. This review explores the relationship between production performance and heat stress response in ruminants using feed additives. Heat stress leads to physiological and behavioral changes that compromise productivity. To mitigate these effects, the study reported that various feed additives are currently being employed as feed additives. These additives are beneficial because they enhance feed efficiency, antioxidant capacity, gut health, and nutrient absorption, thereby improving the animals' resilience to heat stress. Despite these advancements, the effectiveness of feed additives can vary depending on specific conditions and the needs of the animals. This study concluded that it is important to continue research that could optimize feed additive use and develop sustainable strategies to counteract the negative effect of heat stress in ruminant animals. This is because relying on such scientific evidence, livestock production performance ensures animal welfare and profitability can be enhanced in the face of climate change. This strategic use of feed additives offers a potentially viable solution to increase the sustainability and resilience of ruminant production systems, promoting a balance between productivity and environmental stewardship.

Keywords: Animal welfare; Feed additives; Feed intake; Heat stress; Production performance; Ruminants

Introduction

Heat stress is a significant challenge in livestock production, particularly for ruminant animals such as cattle, sheep, and goats (Sejian *et al*. 2018). This stress can lead to reduced feed intake, decreased milk production, compromised reproductive performance and increased disease susceptibility (Sikiru *et al*. 2023). One approach to mitigate the effects of heat stress is using feed additives because these additives can enhance the animals' ability to cope with high temperatures, thereby improving their overall production performance (Abdel-Moneim *et al*. 2021). Heat stress occurs when an animal's heat load exceeds its capacity to dissipate heat, and this condition could become exacerbated in ruminants due to their higher metabolic heat production during digestion and common signs of these compromise heat stress in ruminants are increased respiration rate, elevated body temperature, reduced feed intake, and changes in behavior such as seeking shade or water as mentioned in Fig. 1 (Kishore *et al.* 2016)

This can negatively impact on production performance associated with heat-stressed ruminants often reduce their feed intake to minimize metabolic heat production. This reduction negatively impacts nutrient intake and digestion efficiency; in dairy cattle, heat stress can significantly decline milk yield and quality. The energy that would have typically been used for milk production is usually redirected to maintain homeostasis. For beef cattle and other meat-

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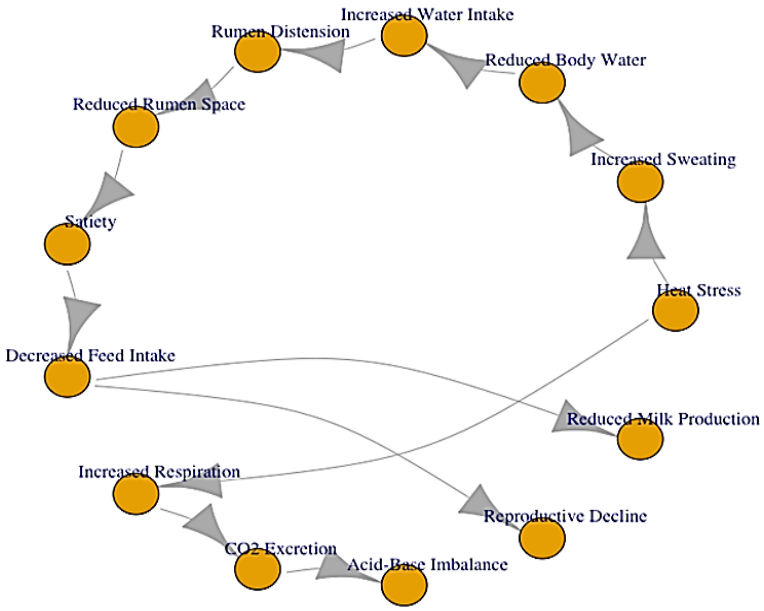

Fig. 1: Results of heat stress in dairy cows (Atrian and Shahryar 2012)

producing ruminants, heat stress (Fig. 1) can slow growth rates and impair reproductive performance, leading to economic losses (Yadav *et al.* 2016).

Meanwhile, feed additives are substances added to animal feed to improve its nutritional value, enhance growth, or mitigate stress effects. Several feed additives have been studied for their potential benefits in the context of heat stress. Supplementing ruminant diets with electrolytes can help maintain fluid balance and reduce the severity of dehydration during heat stress (Yue *et al.* 2023). Additives such as Vitamin E, selenium and beta-carotene can enhance the antioxidant capacity of ruminants, protecting cells from heat-induced oxidative damage. Yeast and probiotics can improve gut health and nutrient absorption, potentially offsetting some of the negative impacts of reduced feed intake during heat stress. Some plant-based additives, such as herbal extracts and essential oils, have been shown to have cooling effects or reduce ruminants' metabolic heat production (Avendaño-Reyes *et al.* 2010).

Therefore, it is pertinent to understand the relationships between feed additives and production performance in association with the effectiveness of feed additives in mitigating heat stress for enhanced production performance, which depends on several factors. This is because different additives work through various mechanisms, and their effectiveness can vary based on the specific needs and conditions of the ruminants. This enables the correct dosage and method of administering feed additives, which are crucial for achieving the desired effects without causing adverse reactions. Hence, conducting comparative studies to understand the effectiveness of various feed additives under different environmental conditions and in different ruminant species is a necessity. In addition, understanding of the long-term effects of using feed additives as supplements for promoting animal health and production performance will provide more comprehensive insights. An evaluation of the cost-effectiveness of using feed additives as a heat stress mitigation strategy in livestock production will be necessary to promote their practical applications in livestock production (Yue *et al.* 2023).

The aforementioned are critical because of their relationship with animals' welfare because within a given farm setting, whether the welfare of the animals will be affected due to changes in duration, frequency and severity of heat stress is questionable (Herbut *et al.* 2021). Unfortunately, it is believed that the current situation on the effect of heat stress reactions on the care of the animals is associated with cost loss of revenue due to excessive heat, especially for dairy cows, which are more prone to stress, as reported by Bernabucci *et al.* (2014). Heat stress may make the body temperature, health, and some productivity components of dairy cows respond negatively not only separately but also may do so simultaneously. An example of these is the rise in rectal temperature as well as respiratory rate, the decrease in feed intake, the drop in milk yield, the decline in milk quality and the weakening of the reproductive function (Effect of heat stress mitigations on physiological, behavioural and hormonal responses of Buffalo calves (Chikkagoudara *et al.* 2022).

Unfortunately, ruminant productiveness performance studies have revealed that heat stress is one of the issues experienced by the agricultural community, limiting production output (Henry *et al.* 2018). Due to the insufficiency of the animals' systems to regulate their body

temperature, they experience heat stress, comprising all classes of ruminant animals, including dairy, beef, sheep and goats. Ruminants live in more difficult physiological conditions during the hot summers as they present lower feed intake, not-so-good utilisation of feed, inhibition in milk yield, and even lower reproductive success. This undesirable effect not only harms farmers' profit in livestock but also creates concerns over the welfare of animals and sustainable farming practices (Renaudeau *et al*. 2012).

Through the research of scientists specialized in animal nutrition gave way to animal breeding and the farmers production performance increase and furthermore, to the impact reduction of heat stress. Utilization of additives embedded in feed for the improvement of heat tolerance of ruminants and maximizing nutrient utilization under heat stress is a strategy. The notable novelty is the blending of a broad array of substances, such as plant extracts, probiotics, prebiotics, antioxidants, and enzymes that work differently and have their own advantages for the health and growth of ruminants (Sejian *et al*. 2015).

Heat stress is a challenge for ruminants that reduces their feed intake, and the biological reason why we utilize feed additives to ease this stressed-out status of animals is that these additives modulate physiological responses, enhance immunological function, promote nutrient absorption, and promote overall metabolic resilience. Thus, ruminants' diets are highly fortified to help the farm animals cope against heat stress and continue producing, making their farmers prosper even amid climatic problems (Renaudeau *et al*. 2012).

The rising global temperatures, primarily caused by human activities such as burning fossil fuels and deforestation, have led to more frequent and intense heat waves. This phenomenon, known as climate change, has far-reaching consequences, significantly impacting animal agriculture. Livestock, particularly ruminants, are highly susceptible to heat stress, which can negatively affect their productivity, health and welfare (McGrath *et al*. 2018). This offers an opportunity for the researchers to evaluate the effect of various feed additives on improving the performance traits of temperate animals under inevitable heat stress. In addition, balanced diet development and improved feeding practices are being implemented to take synergistically different sides of ruminants' health and production on one hand and the environmental issues on another (McGrath *et al.* 2018). In conclusion, the way of taking advantage of scientific evidence as the basis to implement strategies for feed additives is found to be a viable alternative to increase the sustainability and resilience of the ruminant production systems in the light of climate change (Kapila *et al.* 2016).

Modus Operandi of Data Acquisition

Search strategy and article selection

A systematic literature search was conducted using electronic databases, including PubMed, Google Scholar, and Science Direct. The following keywords were used individually and in combination to identify relevant articles: "heat stress," "feed additives," "ruminants," "production performance," "antioxidants," "probiotics," "enzymes" and "nutrient utilization." The search was limited to articles published in English and peer-reviewed journals.

Inclusion and exclusion criteria

Studies were included if they met the following criteria, Investigated the effects of feed additives on heat stress mitigation in ruminants. Production performance parameters (*e.g*., milk yield, feed intake and growth rate) were included as outcome measures and a controlled experimental design was employed with a control group and treatment group(s), provided sufficient data for qualitative analysis. Studies were excluded if they met the following criteria: they focused solely on the effects of heat stress without evaluating feed additives. Involved ruminant species not typically used in livestock production. Lacked a control group or did not provide quantifiable data.

Data extraction and analysis

Relevant data were extracted from the selected articles, including the type of feed additive, dosage, duration of supplementation, ruminant species, production performance parameters and key findings. The extracted data were synthesized and analyzed to provide a comprehensive overview of the relationship between feed additives, heat stress response, and production performance in ruminants.

Heat stress and ruminants

For ruminant animals, such as cattle, sheep, and goats, heat stress is a serious problem, especially in areas with hot, muggy weather. Because it cannot effectively regulate body temperature in extreme heat, ruminants are at the same time more stressed by the hot weather (Das *et al*. 2016). So, to keep the temperature down and to regulate body heat, ruminants tend to undergo physiological and metabolic variations when the temperature-humidity index (THI) is above the normal thermo-neutral zone (Salah *et al*. 2014), a details regarding the heat stress and THI are mentioned in Table 2. These reactions vary by species, including panting, gasping, sweating, minimizing food consumption, changing hormone levels in the organism and adjusting blood flow. However, prolonged exposure to hot temperatures creates some very serious health and productivity issues for ruminants. In this case, there are negative effects in the form of milk production, gestation rate, immune system function and disease incidence (Das *et al*. 2016).

As a result of these, improving water and shade access, installing ventilation in the housing facilities, changing the meal feeding by reducing heat production

during the digested process, and using additional cooling techniques such as fans or misting sprinklers have been reported as effective techniques for lowering heat stress in ruminant (Renaudeau *et al*. 2012; Schauberger *et al*. 2020). Long-term methods that have succeeded in nullifying heat stress on ruminant productivity also emphasize breeding programs designed for magnifying thermotolerance genes and selecting heat-tolerant types. This is because as the heat stress effect on livestock well-being and health is harmful, producers must also develop forethought management techniques and use breeding with suitable animals. The goal is to ensure they can operate economically and ecologically well in the face of the climate change (Nienaber and Hahn 2007).

Currently, improvements in nutritional, managerial, and genetic techniques are being used to lessen the negative effects of heat stress on dairy cows. It has long been believed that dietary approaches should be utilized in conjunction with cooling solutions (fans, ventilation and spray and shades) when it comes to dairy cows under heat stress (Sejian *et al*. 2015). This review aims to evaluate the effectiveness of several dietary alterations (nutritional strategies) that have been successfully applied in recent years to dairy cows under heat stress. By considering a broad range of these dietary approaches, we hope to find hints or viewpoints that will allow the selection of the best approach for certain dairy farms to enhance cow production and health during heat stress.

Methods to Reduce Heat Stress on Animals

Management techniques

Dairy cattle's surroundings can be effectively modified with the help of fans, shade, mist, and fan systems, and night grazing to avoid heat stress in hot climates. Various approaches can be used depending on the climate (Salah *et al*. 2014). Every technique requires us to lower the cows' body temperature till it eventually drops. We divide the various climates into four categories *i.e*., extremely humid, mildly humid, low humid and very dry to aid in comprehension.

Two principles underpin any environment's physical alteration: safeguarding the cows from elements that exacerbate heat stress and promoting the animal's ability to expel heat through evaporation. Using a cooling system is a very good way to lessen the effects of heat stress on cows. Every cooling system's main goal is to lower the barn's air temperature so that the cow's body temperature stays as close to normal as feasible (Jordan 2003). Cattle cannot sweat out their body warmth in extremely humid regions. The climate's humidity prevents cows from sweating; therefore, we have to find alternative ways to cool the animals without relying on their sweating systems. In extremely humid climates, cows need to moisten their skin with huge drops of water to stay cool. Forced ventilation is necessary in hot, humid subtropical climates because evaporative cooling is insufficient in these conditions (Fournel *et al*. 2017).

Ventilation is an excellent practice for cows kept in free stalls. Heater air moves around and is expelled from the house thanks to ventilation. In addition to the fog method, ventilation will significantly drop house temperature and improve cow welfare (Godyn *et al*. 2018). Sprinklers cannot produce an efficient cooling system without fans or fans without sprinklers. Sprinklers can be put in at several barn locations or on the roof.

In humid environments, spray and fan systems can be used to reduce the effects of heat stress. Using fans or allowing natural air flow will also speed up evaporation. In many nations, fans are the most widely utilized kind of cooling equipment. As long as the air temperature is lower than the skin temperature of the cow, fans can boost air movement, which in turn increases the rate at which heat is lost from the cow's body surface. Evaporative cooling is achieved in climates with low relative humidity by the use of tiny spray or fog systems. These systems cool the air surrounding the dairy cows (Lina *et al*. 2017).

Dairy cows may sweat in extremely dry areas, which release most of the body's heat. Consequently, using shades is a good idea in arid conditions. The simplest way to shield animals from direct sunlight during the summer day is to provide them with simple shade. Shades lessened the harmful effects of sun radiation (Collier *et al*. 2006). There should be adequate shade for cows kept in pasture or on a dry lot. The amount of radiant heat load that calves experience will decrease by shade; this is especially true for cattle with black hides (Anderson *et al*. 2013).

Although natural shading, such as trees, is useful, most shades are made of heat-conductive metals, which can be stressful, especially if the surface of the shade is dark. This is a result of dark materials' ability to absorb light. Dark metals are particularly problematic in this context because they first absorb sunlight before spreading to the surface of dairy cows (Berman 2005). If cows are kept in open enclosures, natural wind may cause an increase in body heat loss; however, the air temperature must be lower than the body temperature. The cow's skin will absorb heat from the surrounding air if the ambient temperature exceeds the skins. Dairy cattle might experience heat stress from moving air when the outside temperature rises above 39°C (Herbut *et al*. 2018). Another important managing factor in heat stress is the transport time of cows. One effective recommendation is that transport be done early in the day in the summer or every hot climate.

Research indicates that effective heat stress management techniques in dairy cattle significantly improve animal performance, particularly in terms of milk production, feed intake, and physiological responses such as hormonal regulation and blood parameters. Implementing cooling systems, including fans, sprinklers and misting systems, leads to increased milk yield in dairy cows. Studies

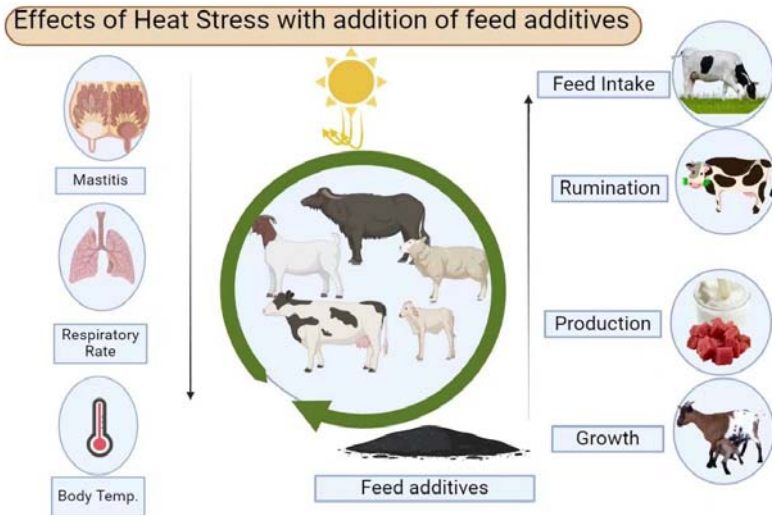

Fig. 2: Effects of heat stress with feed additives

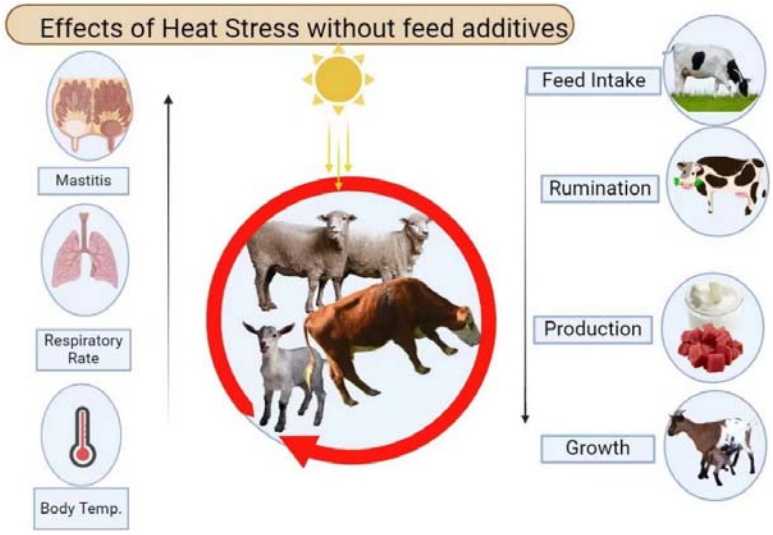

Fig. 3: Effects of heat stress without feed additives

show that when cows are housed in properly ventilated environments with cooling systems, their milk yield can increase by up to 10-15% compared to those under unmanaged heat stress conditions. In extremely humid climates, forced ventilation and skin wetting with large water droplets have been found to maintain normal body temperatures, reducing the risk of heat-related declines in milk production and overall welfare (Muhammad *et al.* 2023).

Feed intake is another key indicator affected by effective management. Heat stress typically reduces feed intake in cows, negatively impacting their energy balance and milk production. However, cooling systems and the provision of shade help maintain normal feeding behaviour, with studies indicating that cows managed under optimal conditions show a 5-7% improvement in feed intake during the summer months. This improvement leads to better nutrient absorption and energy availability, directly correlating with increased milk yield and overall body condition. Additionally, proper management improves hormonal balance, with cows experiencing less cortisol and adrenaline spikes, reducing stress and improving reproductive efficiency (Kang *et al.* 2023).

Blood parameters and hormone levels are also positively impacted by improved management techniques. Cows that are cooled and provided with shade exhibit lower levels of heat stress markers, such as reduced blood cortisol and lower rectal temperatures. These cows also maintain more stable levels of thyroid and growth hormones, which are critical for metabolism and milk production. Moreover, cows in managed environments show improved immune function, as indicated by stable white blood cell counts, and

reduced oxidative stress, which enhances overall health and productivity (Shah *et al.* 2020).

Nighttime or late evening grazing

Since heat stress is typically felt in the presence of sunlight, evening or night-time grazing during the summer is an efficient way to lessen the effects of sunlight. After around 3 p.m. both the air temperature and the amount of sun radiation start to decrease. In most places, the sun sets fairly low after 6 p.m. thus cows are not stressed after that time. Cows should always have access to enough shade and clean water when they can't be let out to pasture in the evening or at night (Andersson 2009).

Research supports the use of night-time or late-evening grazing as an effective management strategy to reduce heat stress in dairy cattle, particularly in hot climates. Solar radiation strongly influences heat stress, which peaks during the day, making grazing during the cooler hours of the evening or night beneficial for animal welfare and performance. Cows allowed to graze during the evening or night have a significantly lower rectal temperature and respiratory rate than those grazing during the day. By shifting grazing times to cooler periods, cows experience less thermal discomfort, leading to improved feed intake and better nutrient utilization, which positively impacts milk production (Atkins *et al.* 2020).

Cows grazing at night had higher feed intake and exhibited improved metabolic efficiency. This shift in grazing behaviour aligns with cooler temperatures, allowing cows to maintain a stable internal temperature, which supports lactation and metabolic processes. Moreover, blood cortisol levels, a stress marker, are generally lower in cows that graze during the cooler parts of the day, leading to a more favourable hormonal profile for milk production and reproduction. This strategy not only enhances animal welfare but also optimizes productivity in regions where daytime heat can compromise performance (Lardy *et al.* 2024).

Late evening grazing was associated with increased rumination activity and improved digestion due to the more comfortable temperatures. In regions with hot summers, adopting night-time or late-evening grazing can reduce the negative impact of heat stress on feed conversion, milk composition, and fertility rates. Implementing this strategy, alongside providing shade and access to water during the day, can ensure dairy cows maintain higher production levels while mitigating the harmful effects of heat stress (Bargo *et al.* 2002).

Postponing the afternoon milking

When big dairy farms are located in hot regions or throughout the summer, the majority of the lactation cows wait a long time to be milked, which causes them to suffer from heat stress. The fact that these cows aren't milking causes them to emit a lot of heat, which is uncomfortable for them. Delaying afternoon milking for one to two hours is a useful strategy for preventing heat stress (Spiers *et al*. 2018).

Access to water during times of heat stress is essential and a widely used strategy to reduce heat stress in all climates without relying on humidity levels. Water needs for lactating cattle are higher than those of dry cows. Every dairy cow requires 4-5 kg of water for every kg of milk that is produced in normal circumstances (Perano *et al*. 2015). As a result, high-producing dairy cows require more water than low-producing dairy cows, and they will also be more vulnerable to the negative effects of heat stress.

According to Kadzere *et al*. (2002), it is determined that when dairy cows experience heat stress, their water requirements rise by 1.2 to 2.0 times. Water temperature is crucial; dairy cattle require higher or moderate water temperatures to help them expel heat from their bodies. It is better to swim in cool waters to avoid heat stress. Potable, uncontaminated and pure water is ideal. When cows are exiting the milking parlour, having access to clean, cold water helps them drink more water when they're feeling hot. When cows are exiting the milking centre, a 2.5 m water trough is sufficient for milking parlours with 25 stalls or fewer per side (Sindhöj and Rodhe 2013).

Animal heat stress management uses various techniques to reduce exposure to high temperatures and heat load. Among the management strategies are (Renaudeau *et al*. 2012; Sejian *et al*., 2015; Henry *et al*. 2018):

- Ensuring animals have access to places with shade, like trees or shelters, so they can escape the harsh sun is known as providing adequate shade.
- Enhancing Ventilation: To improve air circulation and lessen heat build-up, housing facilities can install fans, misters, or ventilation systems.
- Appropriate Housing Design: Creating animal housing buildings with elements like open sides, elevated roofs, and reflective roofing materials that promote natural ventilation and temperature control.
- Water Provision: Make sure that there is always access to cool, pure water to help with evaporative cooling, avoid dehydration, and maintain body temperature.
- Time management: To reduce animal heat stress, schedule tasks like feeding, handling, and transportation for later in the day.
- Preventing Overcrowding: Lowering stocking density to improve airflow and heat dissipation while preventing overcrowding.

Nutritional Techniques

One of the most significant variables influencing heat stress is nutrition as mentioned in Fig. 2, different feed additives in diet reduced the heat stress in different animals. However, without feed additives in diet the animals are suffering heat stress as mentioned in Fig. 3. Modifications to feeding

schedules and ration formulation can lessen the detrimental effects of heat stress on dairy cows. Ratio adjustments should be made gradually and before the arrival of hot weather. The amount of dry matter that cows consume decreases due to heat stress, and they need more energy and protein in hot conditions (Ominski *et al*. 2002). Consequently, to keep dairy cows functioning properly in a hot climate, feeds must be increased in calories and bypass protein. In order to make up for the decline of DMI in a hot climate, we must first raise it. Next, we must adopt high-energy diets by utilizing fat or readily available grains.

One unique quality of fat is that it has far smaller heat increments than other natural meals. It is possible to reduce the detrimental effects of heat stress on dairy cows' energy intake by using fatty feeds or calcium salts of fatty acids to improve the energy supply for the animals during the summer (Terada 1996). These diets cause cows to pant, have a lower body temperature (BT) and produce more milk. One good bypass protein source is fish meal, which is found in many protein supplements. This protein supplement reduces body heat generation for cows kept in hot climates (Terada 1996).

Cows' appetites become low during hot weather and periods of heat stress; any treatment that increases an animal's appetite can assist in reducing the harmful effects of heat stress. Animal appetites are stimulated when extra feeds or supplements, like molasses or citrus pulp, are used. Molasses is an excellent choice in hot and dry climates because cows' perspiration excretes large amounts of bodily electrolytes, including potassium. Since molasses is a rich source of potassium, using it in place of excreted potassium can eliminate acid-base imbalance.

Increasing the frequency of feedings is one more dietary strategy to reduce heat stress. Feeding herds three times a day is a standard practice in most dairy herds worldwide. However, if we raised the number of feedings from three to four times a day, the body produced less heat, and this less heat product of the body led to a reduction in heat stress. Attention is another essential component that increases the body's heat production (Ominski *et al*. 2002).

The amount of low-quality fiber in the diet is one of the main variables influencing the incidence of heat stress. High hay content in the diet causes more heat to build up and ultimately worsens the consequences of heat stress. Reduced Hays levels are a crucial preventive strategy since it reduce heat increment and discomfort. Using high-quality forages is another suggestion to lower the heat generated during feed digestion and assimilation. Using fibrinolytic enzymes can improve the digestibility of fodder fiber if there is an insufficient supply of high-quality forages (Atrian and Shahryar 2012).

Animal heat stress can be significantly reduced by nutritional techniques that maximize nutrient intake and promote physiological adaptability. Among the dietary strategies are (Mader *et al*. 2002; West 2003; Rhoads *et al*. 2013):

- Balanced Rations: Creating diets that are both nutritionally enough for animals and minimise the amount of heat produced during digestion.
- Electrolyte Supplementation: To replenish electrolytes lost *via* perspiration and preserve electrolyte balance, add electrolyte supplements to drinking water or feed.
- Superior fodder: Providing superior fodder that has a sufficient amount of fibre to maintain rumen function and inhibit the generation of metabolic heat.
- Energy Density Adjustment: Modifying diets to meet energy needs while lowering metabolic heat output by adding readily digestible fats or carbohydrates.
- Antioxidant Supplementation: Adding antioxidants to diets, like vitamin E or selenium, can lessen oxidative stress and lessen the harm that heat stress causes to cells.
- Water additions: To improve water intake and help thermoregulation, add water-soluble additions to drinking water, such as vitamin C or organic acids (Table 1).

Use of different feed additives in diet of ruminants on production performance

Dairy cows: Heat stress is one of the many stressors that dairy cows are particularly vulnerable to, and it can harm their overall health, milk supply, and productivity. Dairy cows commonly sustain similar enhanced feed additives to take care of the issues of production performance, which may hamper their productive performance. Among the instances are (Kadzere *et al*. 2002; Das *et al*. 2016):

- Rumen Modifiers: By facilitating nutrient uptake, enhancing rumen fermentation, and contributing to digestive well-being for dairy cows, the use of probiotics, prebiotics, and yeast-based supplements can be promoted for healthier cows.
- Energy Supplements: Dairy producers can increase calorie intake in an energy-dense manner without the increased risk of rumen acidosis by including foods high in fats or oils in their normal diet. This protects cows from milk blockage and sickness.
- Protein Supplements: A high-quality protein is introduced into the diet, which includes soybean meal or bypass protein, this allows the present rate of the protein in milk and reproduction of the bovine dairy cows to be enhanced alongside their overall productivity.
- Mineral and vitamin supplements: In the case of dairy cows, the dietary supplementation to make up for the lack of critically needed vitamins and minerals that are vital in the operation of the immune system, reproductive performance, and milk quality can be used as a strategy.

Beef cattle: Beef cattle farming has also grappled with various issues associated with the animals' performances, nutrient use and heat stress (Madzingira 2018). Beef cattle are fed a variety of feed additives to increase profitability and production efficiency, such as: Beef cattle are fed a variety of feed additives to increase profitability and

Table 1: Use of different feed additives in the diet of different animals to reduce the heat stress

S. No.	Item	Species	Dose	Duration	Findings	Ref.
01	Betaine, Vitamin E and C	Chicken	1200 ppm	42 d	Increase the production performance and reduced the heat stress in chicken	Al-Sultan *et al*. (2019)
02	Betaine	Dairy cow	15 g/day	60 d	Increased the Milk Production, Rumen fermentation, Feed intake, and improved antioxidant profile	Shah *et al*. (2020)
03	Polyherbal vitamin C	Dairy cow	20 g/d	131 d	Improved gestation rate, beneficial health effects, reduced Mastitis problems improved immunity	Martinez *et al*. (2022)
04	Organic acid and pure botanical	Dairy cow	75 mg/kg	14 d	Improved production and Energy correlated Milk and Nitrogen efficiency	Fontoura *et al*. (2022)
05	Immunomodulatory feed ingredient	Beef cattle	56 g/d	106 d	Reduced the heat stress, improved the health status	Colombo *et al*. (2019)
06	Phytogenic feed additive	Heifers	0.25 g/d	7 d	Increased O2 Levels in blood, improved Oxidative stress, immunity,	Wickramasinghe *et al*. (2023)
07	Citrus extract	Dairy cow	4 g/cow/d	28 d	Reduced Heat stress and somatic cell count	Havlin and Robinson (2015)
08	OmniGen-AF®	Dairy cow	50 g/d	84 d	Reduced rectal, body surface temperature, reduced heat stress in grazing cows	Gandra *et al*. (2019)
09	Dihydropyridine	Dairy cows	3 g/day	104 d	Improved feed intake reduced heat stress, improved antioxidant profile, improved microbiota	Yu *et al*. (2010)
10	Probiotic Chinese Herbal compounds	Dairy cows	--	60 d	Improved Production performance, Immunity,	Wang *et al*. (2017)

production efficiency, such as: Growth Promoters: To enhance feed efficiency, raise average daily growth, and have a better carcass quality, cattle feeds are the frequently always add ionophores like monensin or lasalocid to be the growth promoters. Implantation: The specific role of hormones implants in the feeding system is to stimulate growth with a shortened period of fattening and the development of lean muscle, as well as to facilitate the digestive tract and weight gain in cattle. Feed Supplements for Well-Being: Beef animals' feed commonly comprises antibiotics, probiotics, and direct-fed microbes (DFMs) to support gut health, thus reducing disease vulnerability and increasing performance. Antioxidants: The beef cattle diet can be fortified with antioxidants of vitamin E or selenium, which, in turn, will reduce oxidative stress and increase resistance to infection (Tahreem *et al*. 2019).

Despite these advancements in the beef cattle industry, industry operators are still facing some challenges related to environmental sustainability and animal welfare. Solutions to some of these challenges include using feed additives, which could benefit growth and health and can contribute to environmental issues such as nutrient runoff and greenhouse gas emissions. This is why farmers are increasingly adopting precision feeding techniques and exploring alternative feed ingredients to mitigate these impacts. Additionally, a growing focus is on improving animal welfare through better housing conditions, access to clean water and stress reduction practices. These efforts aim to create a more sustainable and ethical beef production system.

Moreover, consumer preferences are shifting towards more natural and organic beef products, prompting the industry to adapt. There is a rising demand for beef free from antibiotics and synthetic growth promoters, which has led to the development of new feed additives and management practices. Research is ongoing to find natural alternatives that can provide similar benefits to conventional additives. As the industry evolves, balancing productivity with sustainability and consumer expectations will be crucial for the future of beef cattle farming.

Sheep and Goat: In most cases, sheep and goats are essential for the livestock industries and approaches to sustaining animal maintenance outcomes are optimal (Peacock and Sherman 2010). Feed additives that are frequently added to sheep and goat diets are as follows: Feed additives that are frequently added to sheep and goat diets are as follows: Control of Parasites: Proof has been found that forages rich in tannins, such as tree leaves and legumes, have the anthelmintic properties what help get rid of gastrointestinal parasites and as a result enhance the productivity of these animals (Nguyen *et al*. 2005). Ruminal Buffers: The food often added by these animals to their diet magnesium oxide or sodium bicarbonate. Moreover, this action works as a pH buffer and reduces the occurrence of acidosis for better utilization of the nutrients. Supplements with protein: By the use of protein concentrates (soybean meal, lucerne, *etc*.) in addition to sheep and goats, rations recover their growth rates, reproductive potential and ability to more efficient milk or wool production (Salem and Smith 2008). Vitamin and Mineral Supplements: Providing sheep and goats with the proper vitamins and minerals, preferably by adding supplements, provokes healthy immune systems, fruitful reproduction, and generally, their wellbeing (Peacock and Sherman 2010).

Connection between ruminant episodes feed additives and fermentation and digestibility of the food

Recognizing how different feed supplements influence the rumen fermentation and digestion processes when feeding on ruminant animals is the basis for improving the total nutrient utilization rate. For illustration, the growth and

Table 2: Heat stress levels in cattle (Source: Das *et al*. 2016)

Temp		% Relative Humidity																		
°F	°C	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
72	22.0	64	65	65	65	66	66	67	67	67	68	68	69	69	69	70	70	70	71	71
73	23.0	65	65	66	66	66	67	67	68	68	68	69	69	70	70	71	71	71	72	72
74	23.5	65	66	66	67	67	67	68	68	69	69	70	70	70	71	71	72	72	73	73
75	24.0	66	66	67	67	68	68	68	69	69	70	70	71	71	72	72	73	73	74	74
76	24.5	66	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75
77	25.0	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76
78	25.5	67	68	68	69	69	70	70	71	71	72	73	73	74	74	75	75	76	76	77
79	26.0	67	68	69	69	70	70	71	71	72	73	73	74	74	75	76	76	77	77	78
80	26.5	68	69	69	70	70	71	72	72	73	73	74	75	75	76	76	77	78	78	79
81	27.0	68	69	70	70	71	72	72	73	73	74	75	75	76	77	77	78	78	79	80
82	28.0	69	69	70	71	71	72	73	73	74	75	75	76	77	77	78	79	79	80	81
83	28.5	69	70	71	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82
84	29.0	70	70	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83
85	29.5	70	71	72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	83
86	30.0	71	71	72	73	74	74	75	76	77	78	78	79	80	81	81	82	83	84	84
87	30.5	71	72	73	73	74	75	76	77	77	78	79	80	81	81	82	83	84	85	85
88	31.0	72	72	73	74	75	76	76	77	78	79	80	81	81	82	83	84	85	86	86
89	31.5	72	73	74	75	75	76	77	78	79	80	80	81	82	83	84	85	86	86	87
90	32.0	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88
91	33.0	73	74	75	76	76	77	78	79	80	81	82	83	84	85	86	86	87	88	89
92	33.5	73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90
93	34.0	74	75	76	77	78	79	80	80	81	82	83	85	85	86	87	88	89	90	91
94	34.5	74	75	76	77	78	79	80	81	82	83	84	86	86	87	88	89	90	91	92
95	35.0	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93
96	35.5	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94
97	36.0	76	77	78	79	80	81	82	83	84	85	86	87	88	89	91	92	93	94	95
98	36.5	76	77	78	80	80	82	83	83	85	86	87	88	89	90	91	92	93	94	95
99	37.0	76	78	79	80	81	82	83	84	85	87	88	89	90	91	92	93	94	95	96
100	38.0	77	78	79	81	82	83	84	85	86	87	88	90	91	92	93	94	95	96	98
101	38.5	77	79	80	81	82	83	84	86	87	88	89	90	92	93	94	95	96	98	99
102	39.0	78	79	80	82	83	84	85	86	87	89	90	91	92	94	95	96	97	98	100
103	39.5	78	79	81	82	83	84	86	87	88	89	91	92	93	94	96	97	98	99	101
104	40.0	79	80	81	83	84	85	86	88	89	90	91	93	94	95	96	98	99	100	101
105	40.5	80	80	82	83	84	86	87	88	89	91	92	93	95	96	97	99	100	10	102
106	41.0	80	81	82	84	85	87	88	89	90	91	93	94	95	97	98	99	101	102	103
107	41.5	80	81	83	84	85	87	88	89	91	92	94	95	96	98	99	100	102	103	104

Stress threshold
Mid-moderate stress
Moderate-severe stress
Severe stress

maintenance of the right amounts of bacteria and yeast in the rumen is caused by probiotics and prebiotics (Owens and Basalan 2016). The probiotics, which are alveolar bacteria, promote a microbial balance and better indigestion health by the additional good microorganism growth that supports rumen fermentation (Welch *et al*. 2022). This food group consists of non-digestible carbohydrates that can function as energy sources for the proliferation and fermentation of beneficial gut microbes. Volatile fatty acids also foster the development of the hindgut wall, which works together with the assistance of prebiotics on nutrient digestibility and absorption by improving the rumen fermentation efficiency (Chen *et al*. 2021).

Complex plant polysaccharides, such as cellulase and amylase, are critical in enzyme provisioning, which further results in competition between sugar and carbohydrate breakdowns. Rumen microorganisms that are bacteria or protozoa may utilize this enzymatic action to ferment fibrous feedstuffs more easily (Calusinska *et al*. 2020). The animal may then have a higher energy-intake, providing them with more energy. Moreover, enzymes do the job perfectly by breaking protein molecules into shorter peptide or amino acid chains, which also improves microbial protein synthesis in the rumen and utilization by ruminants.

By using diets supplemented with microbial agents like yeast and yeast cultures, dairy cows have found much-improved rumen fermentation, which eventually resulted in better digestibility, enhanced feed intake and feed efficiency, and more milk. Yeast culture might be more effective in reducing oxygen pressure in the rumen and escaping its oxidation. Those factors produced by *Saccharomyces cerevisiae*, which are in yeast cultures, are beneficial in a way they help optimal breastfeeding performance (Westendorf and Wohlt 2002).

Another group of feed additives, just like ionophores, performs a function by preventing some bacteria from developing in the rumen. Ionophores like monensin and lasalocid, which interfere with fermentation patterns by specifically targeting certain bacteria, are helpful in these respects because they promote an increase of propionate and reductions of methane (Meiring 2014). In the case of ruminant animals, this shift in the fermentation due to the

ionophores can be seen as a distinctive trait. This can provide more feed efficiency, increased utilization of nutrients, and an increase in the available energy.

Adding magnesium oxide and Sodium bicarbonate as buffers that keep the rumen pH in the optimum range performs an important role in protecting the rumen against acidification. Buffering resists complex acidic fermented formation and also prevents rumen acidosis, a condition manifested by pH decrease that may limit microorganism activities and digestibility for feedstuff concerned by introducing a high acid-buffering system in the process (Elmhadi *et al*. 2007). These agents increase feed efficiency by smarten if the rumen pH is stabilized and creating an appropriate environment for rumen bacteria. This essentially aids in better digestion of fiber and a higher absorption rate of nutrients.

Tying the last one, it is beneficial for antioxidants to be present in rumen microbes' bodies in the form of vitamin E and selenium because it helps them to prevent oxidative damage. One possible harmful side of fermentation is the production of reactive oxygen species (ROS) that are toxic to the cells of microorganisms (Kumar *et al*. 2009). Not unexpectedly, Se promotes milk quality, immune response, and dairy cow health and these three aspects are all due to the role of Se as an antioxidant and metabolism booster in the digestion system; thus, the redox balance in the system is strengthened (Sejian *et al*. 2015). Heating affected dairy cows in interesting ways, as the movement of plasma selenoprotein P was impaired - reducing the ability to carry the majority of selenium. Forceville *et al*. (2022) stated that Se supplementation can elevate plasmatic Se levels and lead to plasma selenoprotein P upsurge. This could be a conservatory mechanism for cows against the harsh heat. Therefore, this stress is alleviated by the addition of antioxidant sources, which further promote the fermentation and health of the rumen. The inclusion of antioxidants in animal diets has been known to increase nutrition in the body and its utilization by acting as a shield for microbial populations, improving both animal health and performance.

Feed additives in the edible microbiota of ruminants

Various feed additives impact the microbial communities in the rumen of various ruminants in different ways, and these impacts are complex. For instance, it has been shown that probiotics and prebiotics can change the composition and activity of the rumen microbiota. Probiotics are live, helpful microorganisms that aid in the growth of good bacteria in the rumen, supporting a healthy microbial balance. Prebiotics are indigestible carbohydrates that support good bacteria's growth and metabolic activity by acting as a substrate. Together, probiotics and prebiotics create a favorable rumen environment that enhances bacterial diversity and functionality.

A crucial process that molds the rumen microbiota is the breakdown of complex plant polysaccharides into simpler sugars and carbohydrates, aided by enzymes. This enzymatic activity increases the amount and diversity of fermentable substrates available to rumen bacteria, influencing microbial populations. Moreover, enzyme supplementation facilitates the breakdown of proteins into peptides and amino acids and provides essential resources for the growth and metabolism of microorganisms. Ionophores are an extra category of feed additives that target certain bacterial populations to selectively affect the rumen microbiome. Ionophores that prevent the growth of gram-positive bacteria that create methane, including lasalocid and monensin, protect other microbial groups. The rumen's fermentation and metabolic processes are altered by microbial makeup variations (Keskin and Durgan 1997).

The rumen's pH is stabilized with buffering agents like sodium bicarbonate and magnesium oxide, indirectly affecting the rumen bacteria. By neutralizing excess acids produced during fermentation, buffering chemicals enhance the environment for rumen bacteria. This promotes the formation of acid-tolerant species and enhances microbial activity. Lastly, antioxidants like vitamin E and selenium contribute to their continued health by protecting rumen populations from oxidative stress. Reactive oxygen species produced during fermentation can have detrimental consequences on the viability and function of microorganisms. Antioxidant supplementation preserves the rumen's microbial diversity and metabolic activity by lowering oxidative damage.

Impact of feed additives on ruminant immune system: Amino acid and fatty acid profile

Understanding how various feed additives affect the immune system and amino acid and fatty acid profiles in different ruminants is crucial to maximizing animal health and performance. Probiotics and prebiotics play a major role in how the immune system functions, promoting a healthy gut microbiota. The gut barrier function also benefits from the use of probiotics and prebiotics (Tsiplakou *et al*. 2018). A positive effect may be observed in the supply of SCFAs (short-chain fatty acids), such as acetate, propionate and butyrate. These immune cells are not only provided with energy but also with tools for controlling inflammatory events. In addition, probiotics and prebiotics could achieve a superior amino acid profile in ruminants by strengthening amino acid absorption rates (Choubey *et al*. 2015). Enzyme supplements should be regularly included in the ruminant dietary menu since they enhance nutrient absorption and digestion, which will help improve the ruminants' amino acid and fatty acid levels. Enzymes expand the abundance of amino acids and fatty acids for absorption into the blood by fitting small sub-units into large and complex proteins. It could be that the activation of the immune system and those that involve proteins and lipids metabolism occurs (Kumar *et al*. 2022).

It is evident that monensin and lasalocid, as ionophores, act as fermentation regulators and can modulate the rumen's microbial population, which is known to affect the immune function of ruminants. These additions seem to stimulate the production of SCFAs and other fermentation products in the intestinal ecosystem, which has immunomodulatory effects. It is also possible that ionophores influencing the fatty acid composition of ruminant's tissues can change the fatty acid profile of meat and dairy goods (Khan *et al*. 2023). So, boosting rumen health and rumen acidosis could lead to magnesium oxide and sodium bicarbonate that improve immune function in herbivores. An important role of buffering parties is contributing towards proper gut milieu maintenance for impeccable immune response and less likely occurrence of digestive diseases as they control the rumen pH level. In addition, by improving the efficiency of nutrient uptake and use, the factors underlying acidification may also indirectly affect the pattern of amino acids and fatty acids occurring in the body. During oxidative stress, quality antioxidant supplements like vitamin E and selenium have crucial roles in improving immunity and protecting ruminants from many health problems (Feizi *et al*. 2024). On the other hand, the antioxidants aid in strengthening a sound immune system and act as the scavengers of free radicals, inhibiting oxidative damage to cells, including tissues, by reducing their effect.

Moreover, the antioxidants most likely cause changes in fatty acids and amino acids metabolic profiles by controlling their synthesis and catabolism. Overall, varied feed additive patterns in ruminant immunity are as complicated and swerving as their effects on the fatty acid and amino acid profiles. Manipulating such substances in ruminant diet and their outlook should be done by knowing how they function in physiological situations (Hassan and Karsli 2022). Through the practice of special selection and optimum use of feed additives, livestock producers may improve the immunological functions, nutritional profiles and general health and performance of their cattle.

Research has consistently demonstrated the potential of feed additives to enhance ruminant production performance. A variety of additives have been studied, including probiotics, enzymes, yeast, and organic acids. Probiotics, consisting of beneficial microorganisms, have shown promise in improving feed efficiency, rumen fermentation, and animal health. Enzymes, such as cellulases and xylanases, can degrade plant cell walls, increasing the digestibility of fibrous feedstuffs (Eigenberg *et al.* 2007). Yeast additives have been found to stimulate rumen microbial activity, leading to improved nutrient utilization and weight gain. Organic acids, such as formic and propionic acid can help maintain rumen pH, reduce pathogen populations and enhance feed intake. While the positive effects of feed additives are well-documented, it is important to note that their efficacy can vary depending on factors such as the specific additive, the type of ruminant, the quality and composition of the diet, and the environmental conditions. Therefore, careful evaluation and optimization of feed additive use are essential to maximize their benefits for ruminant production (Singh and Yadav 2014).

Effect of different feed supplements on antioxidant profile

In animals, oxidative stress is connected to increased levels of free radicals, which can damage cell membranes and DNA. The logistics of antioxidant profile preservation, cellular integrity maintenance, heightened levels of oxidative stress and overall health and general well-being depend on an in-depth understanding of how feed additives affect ruminate animals (Farahat *et al*. 2016). Prescribing supplements with antioxidants like vitamin E and selenium is a good idea because they are revered as agents that can get rid of free radicals and thus avert huge oxidation damage to the tissues and the cells. Antioxidants keep away the reactive oxygen species in cells to prevent lipid peroxidation, thus, they ensure the structural and functional integrity of the cellular membranes and organelles (Jiang *et al*. 2015). The addition of antioxidant supplements, like those that are enriched with, for instance, GPx, CAT CAT, and SOD, enables animals to better shield from anoxic compounds since they cover the necessary antioxidant defense system. These prohibited enzymes, in cooperation, represent a decisive natural safety mechanism for ROS detoxification and prevention of oxidative toxicity, also maintaining cellular homeostasis, which finally leads to the rejection of disease states involving oxidative stress (Zhang *et al*. 2012). Antioxidants can also take ruminants into the narrow type and high-quality product phases from milk and dairy. Antioxidants, in many cases, produce a good shelf-life for the products and consumer acceptance through slowing lipid oxidation and keeping the same freshness and taste of meat, dairy, and other fresh products. Besides, processing and storage stages can be limited in maintaining the nutrients and providing more bioavailability of essential milk nutrients. Meat can increase the nutrient value associated with it (Kishawy *et al*. 2020). The potency of antioxidant supplementations will differ between ruminants due to variables such as diet, ecological conditions, and physiological status. Since oxidants inherent to forage plants are ordinarily taken up by ruminants grazing on the pasture, it may lead to an increase of antioxidants in them. Besides that, farm animals fed a diet of high concentrates may need additional antioxidants to counteract the oxidative stress from increased metabolism and product demand due to metabolic activity (Yengkhom *et al*. 2019).

Conclusion and Recommendations

This paper shows feed additives' significant role in mitigating the adverse effects of heat stress, which remains a critical challenge in livestock production, impacting feed intake, milk production, reproductive performance, and

overall animal health. The strategic use of feed additives, such as growth promoters, antioxidants, probiotics, and plant-based extracts, has demonstrated potential in enhancing ruminants' heat tolerance and production efficiency. Feed additives help maintain fluid balance, reduce dehydration, and enhance ruminants' antioxidant capacity, protecting them from heat-induced oxidative damage. Moreover, they improve gut health and nutrient absorption, offsetting some negative impacts of reduced feed intake during heat stress. However, the effectiveness of these additives can vary based on the specific needs and conditions of the animals, emphasizing the importance of correct dosage and administration. As climate change exacerbates heat stress, feed additives will become increasingly vital. Therefore, continued research and development will be essential to identify the most effective additives and their optimal usage to ensure sustainable, resilient, and profitable ruminant production systems.

Furthermore, addressing the challenge of heat stress is crucial, as extreme temperatures adversely affect meat and milk yield globally. To counter the inhibitory effects of heat stress and enhance ruminant output, a series of nutritional interventions, including the use of probiotics, prebiotics, enzymes, ionophores, buffer agents, and antioxidants, offers an effective alternative. These feed additives aim to optimize rumen fermentation, improve nutrient assimilation, boost immune function and strengthen heat stress resilience. Employing these components, particularly specialized feed tubs, helps maintain rumen health, preserve metabolic balance, and reduce the physiological challenges imposed by elevated temperatures. The astute use of feed additives will improve production efficiency and contribute to environmentally friendly practices, thereby enhancing sustainability. As the climate continues to change, incorporating innovative heat stress prevention techniques and advancing the application of feed additives will allow farmers to maintain profitable and welfare-focused ruminant production systems in a sustainable and green manner.

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Conflict of Interest

All authors declare that there is no conflict of interest exist.

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Data sharing is not applicable to this article as no new data were created or analyzed in this study. Any figures or tables generated for this review are derived from data reported in the cited publications.

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