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Heat stress effects on the lactation performance, reproduction, and alleviating nutritional strategies in dairy cattle, a review

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Abstract Heat stress response in dairy cattle affects milk production, quality, body temperature, and other parameters. Dairy cows will most likely experience increased heat stress with unabated global warming. Elevated temperatures and humidity reduce feed intake, harm reproductive potential, and reduce milk production. Heat stress is more common in high-yielding cows than in low-yielding ones. In addition to reducing milk production, heat stress can also reduce milk quality. During lactation, internal metabolic heat production can further reduce cattle's substances to high temperatures, resulting in altered milk composition and decreased milk yield. Several studies proposed various nutritional strategies such as dietary fats, dietary fibers, microbial diets, mineral substances, vitamins, metal ion buffers, plant extracts, and other anti-stress additives. This review addresses the challenging study on the effects of heat stress on nutritional and fed intake perturbations, milk and components yield, immune system activation, and reproduction parameters. It proves that specific nutritional strategies effectively mitigate the harmful effects of heat stress in dairy cattle.

Keywords: dairy cows, heat stress, nutritional strategy, performance, reproduction

1. Introduction

Heat stress (HS) significantly reduces animal milk, meat, and reproduction productivity. An internal energy resource shift might explain these adaptive systems (Wanjala et al 2023). The high temperatures may negatively impact dairy and beef cattle regarding milk production, reproduction, welfare, and health. (Noordhuizen and Bonnefoy 2015). Exceptionally high-yielding dairy cattle would be susceptible because their thermo-neutral zone is limited compared to low-yielding cows. Heat stress is a form of hyperthermia (elevated body temperature) in which the body's physiological systems fail to regulate the body temperature within a normal range. Heat stress is the most pervasive adverse environmental influence on animal health performance globally, even though numerous environmental elements can affect an animal's immune system and production(Dahl et al 2020). Due to lower milk production, poor reproductive function, and increased culling caused by heat stress, the dairy sector in the United States loses $900 million annually(Kasimanickam and Kasimanickam 2021). Global warming has recently accelerated, wreaking havoc on agricultural industries, including livestock (Joo et al 2021). Heat stress, which adversely affects productivity, health, reproduction, and general well-being in dairy cows, continues to be one of the most important factors restricting milk output (Tao et al 2020). While the most well-known impacts of heat stress on dairy cattle are related to production responses, early research demonstrated that high temperatures significantly affect calves' physiological responses from conception to lactation(Dahl et al 2020). Recent studies show that heat stress diminishes DMI and milk yield compared to moderate-temperature conditions (Bernabucci et al 2014; Joo et al 2021). A negative genetic link between temperature-humidity index (THI) and productive and reproductive qualities was also discovered (Bernabucci et al 2014). Dairy cows exposed to humidity and temperature issues in controlled-climate chambers demonstrated typical heat stress responses to extreme short-term heat (Garner et al 2017). Heat stress harms animal health, production, and breeding performance (Bernabucci et al 2014; Dahl et al 2020). This study's goal is to review the negative impacts of heat stress on dairy cows, including how it affects milk production efficiency and mitigation tactics.

2. Effects of heat stress on the performance of dairy cows

2.1. Feed intake perturbation and nutrient digestibility

The lower intake of warm-exposed animals explains how heat stress affects production and reproduction in biological environments (Conte et al 2018). Milk yield and heat stress are inversely related (Becker et al 2020). Meeting a high-producing cow's requirements is difficult due to appetite loss caused by stressful heat conditions (Becker et al 2020; Bernabucci et al 2014). Heat stress may cause lactating cows to enter a negative energy balance(Becker et al 2020) and may reduce energy availability from reduced feed intake and increased maintenance expenses (Becker et al 2020).

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2.2. Rumen fermentation

Heat stress influences rumen fermentative processes with effects on the physiology and production of dairy cows (Wang et al 2022). Ruminal pH and acetate concentration in cows exposed to HS dropped, while ruminal lactate concentration rose (Kim et al 2022). Heat stress mainly affects performance through reduced feed intake associated with reduced rumination, resulting in the decreased production of the natural buffer, saliva. Heat-stressed cows have an increased abundance of lactate-producing bacteria, such as Streptococcus and unclassified Enterobacteriaceae, and soluble carbohydrate utilizers, such as Ruminobacter, Treponema, and unclassified Bacteroidaceae (Kim et al 2022). Due to their strong heat resistance, fibrobacteres, cellulolytic bacteria, multiply during HS. Under HS circumstances, the acetate-producing bacteria Actinobacteria and Acetobacter shrank (Kim et al 2022). Heat stress alters the rumen fermentation of dairy cows, affecting the rumen papillae's metabolism and, thus, the epithelial barrier function (Guo et al 2022). Zhao et al (2019) reported that heat stress resulted in the reduction of pH and acetate levels in the rumen; however, heat stress resulted in an increase in lactate levels in the rumen. No significant differences in propionate and butyrate levels were observed between the heat-stressed and control groups.

2.3. Milk and components yield

Heat stress is one of the most severe issues affecting cattle production potential. High core-body temperature changes reduce milk production, protein percentages, fat, solids, and lactose content. A 0.2 kg decrease in milk output per unit increased beyond 72 in THI(Pragna et al 2017). High-yielding cows are more vulnerable to thermal stress than low-yielding cows because the feed conversion ratio and milk production raise the thermos-neutral zone to lower temperatures(Pragna et al 2017). Heating stress can also influence milk composition and yield high-yielded races (Das et al 2016).

3. Effect of heat stress on metabolism and immune system activation

Animals exposed to high ambient temperatures have physiological changes such as increased blood flow to the periphery to dissipate heat and decreased blood flow, nutrition, and oxygen supply to splanchnic tissues (Cantet et al 2021). The creation of new diseases is typically tied to climate change and the survival of microbes or their vectors. These illnesses may aggravate heat-induced immune suppression, which is mediated through the hypothalamic-pituitary-adrenal (HPA) and sympathetic-adrenal-medullary (SAM) axes (Bagath et al 2019).

3.1. Endocrine system

Heat stress has been reported to induce increased blood cortisol concentrations, which have been shown to inhibit the production of cytokines such as interleukin-4 (IL-4), IL-5, IL-6, IL-12, interferon γ (IFNγ), and tumor necrosis factor-α (TNF- α)(Bagath et al 2019). In dry cows, heat stress reduces immunoglobulin responses to ovalbumin vaccination, but this effect fades with cooling after parturition(Dahl et al 2020). On the other hand, when dry, cows are subjected to heat stress carryover effects on the innate arm of the immune system in early lactation(Dahl et al 2020). Oxidative stress, rumen translocation, and the production of pro-inflammatory mediators are all caused by metabolic changes and gastrointestinal dysfunction, and they all work together to trigger a systemic inflammatory response (Cantet et al 2021). Furthermore, heat stress reduces the natural barriers of an animal to bacteria and potentially increases the level of endotoxin, which may have other undesirable effects on vaccines containing whole cells of target bacteria (Meng et al 2013). Heat stress alters the neuroendocrine profile by stimulating the Sympathetic-Adrenal Medullary (SAM) and Hypothalamic-Pituitary-Adrenal (HPA) axes. In heat-stressed animals, the HPA axis is activated to release cortisol, which results in lipolysis and proteolysis for energy production. More adrenaline is released when the body is under heat stress raising the heart rate and blood pressure to help the body deal with the circumstance (Pradhan and Bengal 2022). Glucocorticoids act on CNS and thereby inhibit TSH secretion, and plasma T3 & T4 levels decreased to reduce metabolic rate and body heat generation. These hormonal changes in the body are required for a 'fight-or-flight' response. Heat shock proteins (HSPs) such as Hsp70 and Hsp90 play a predominant role as a biomarker of heat stress. Phytochemicals like curcumin, lycopene, and antioxidants like Vitamin C are used to treat a heat-stressed victim (Pradhan and Bengal 2022). Glucocorticoids released during heat stress activate latent viruses, via i) directly acting on the viral genome, and ii) decreasing the immunological memory responses(Meng et al 2013). Chronic heat stress negatively impacts the immune system in mice and increases their susceptibility to infections by increasing the number of CD4+, CD25+, Foxp3+, IL-1,0, and TGF-β which is associated with a suppression of the adaptive immune response(Meng et al 2013).

3.2. Oxidant and Antioxidant index

Chen et al (2022) reported that all serum oxidative trends varied across the early lactation period; however, the serum biochemical parameters in the primiparous cows were higher than those of the multiparous cows in the same month.

Due to high ambient temperatures with high relative humidity, dairy cows respond by the change in physical, biochemical, and biological pathways to neutralize heat stress resulting in decreased production performance and poorer immunity resulting in an increased incidence of intra-mammary infections (IMI) and higher somatic cell count (SCC)(Rakib et al 2020). In vitro studies on bovine polymorphonuclear cells (PMN) suggested that heat stress reduces the phagocytosis capacity and oxidative burst of PMN and alters the expression of apoptotic genes harming the immune system, which may explain the increased susceptibility to IMI(Rakib et al 2020). Li et al (2017) reported that heat stress significantly decreases malondialdehyde levels, and displayed a significant increase in levels of cortisol, interleukin (IL)-10, IL-1b, and tumor necrosis factor-α. They also reported that opposite changes in serum endotoxin and immunoglobulin G levels were observed with the increasing THI, and the HS notably decreased the triiodothyronine level, although the thyroxine level was reduced (Li et al 2021).

4. Effect of heat stress on reproduction

Heat stress during the summer disturbs reproductive processes in farm animals as it affects the physiology of the reproductive tract by several means, like hormonal imbalance, decreased oocyte and semen quality, and decreased embryo development and survival.

Heat causes decreased secretion of the luteinizing hormone and oestradiol, which causes reduced length, and intensity of estrus expression, increased incidence of anoestrus, and silent heat in farm animals (Singh et al 2021). Oocytes exposed to thermal stress lose their competence for fertilization and development into the blastocyst stage, which results in decreased fertility because of the production of quality oocytes and quality oocytes and embryos. Low progesterone secretion also inhibits the embryo's growth by limiting endometrial function. Heat stress also increases endometrial prostaglandin F2α release, which threatens the maintenance of pregnancy (Singh et al 2021).

4.1. Effects on the spermatogenesis and follicular development

Heat stress reduces oocyte competence, thereby causing lower fertility in animals. Few studies have examined the impact of chronic and acute heat stresses on ovarian function and heat shock protein (HSP) gene expression during ovarian injury. Chronic and acute heat exposures produce significant morphological damage in animals (Bei et al 2020). During heat stress, cows are less likely to show signs of estrus or heat related to decreased blood hormones. Estrus events are shortened and not as intense as during the winter months. Heat stress shortens and intensifies estrus in dairy cows, increases anestrus and silent ovulation, and decreases the number of mounts in hot weather compared to cold weather(Takahashi 2012). Heat stress can impair the activity of tissues and organs in dairy cows and impede the synthesis of some proteins and hormones, leading to low fertility by interfering with the synthesis of proteins and hormones associated with reproductive organs (Liu et al 2019). During the first follicular wave, the number of large strands (diameter 10 mm) was significantly higher in the cooled group, resulting in 53% more large follicles in the heat-stressed group.

Furthermore, the number of small and medium follicles was higher in the cooled group than in the heat-stressed group during the second follicular wave. However, the dominating ovarian follicles in the heat-stressed group were smaller or the same size as those in the thermoneutral group during the second follicular wave. To maintain a temperature lower than the core body temperature needed for proper spermatogenesis, the testis is hung in a scrotum outside the body in males (Takahashi 2012). In bulls, the bovine testicular temperature must not exceed 33–34.5°C for normal spermatogenesis(Takahashi 2012; Thundathil et al 2012). Hyperthermia has a detrimental effect on testicular functions, such as inhibiting spermatogenesis in cows. An increase in testicular temperature because of elevated ambient temperature or scrotal insulation impairs spermatogenesis and reduces semen quality and sperm production(Thundathil et al 2012). The sperm cells most sensitive to heat are pachytene spermatocytes, spermatids, and epididymal sperm(Thundathil et al 2012). Elevated testicular/epididymal temperature (because of scrotal insulation) has harmful effects on sperm morphology, motility, the viability of sperm fertilizing capacity, and the developmental competence of resulting embryos(Thundathil et al 2012).

4.2. Effects on heat behavior and insemination

Heat stress causes decreased estrus expression, decreased fertilization rate, and increased embryonic mortality in cattle. Heat stress during the breeding season has been linked to reduced conception in dairy cows. Furthermore, adverse effects of heat stress have been observed from 42 days before to 40 days after breeding(Kasimanickam and Kasimanickam 2021). These authors reported that control (CON) cows produced more gestation day 7 (GD-7) transferrable embryos following superovulation compared with HS cows (84.8 vs. 53.1%; $P < 0.001$). They also reported that the weight (31.4 ± 4.3 vs. 42.4 ± 6.2 mg) of GD-16 conceptus was greater for CON compared with HS cows ($P < 0.05$). Control cows produced more filamentous conceptus (25 mm) than HS cows (71 vs. 45%; $P < 0.05$) (Kasimanickam and Kasimanickam 2021). When comparing CON cows to HS cows, progesterone (2.09-fold) was greater, cortisol (1.86-fold), prolactin (1.60-fold), substance-P (1.55-fold), isoprostane-8 (1.34-fold), and prostaglandin F metabolites (1.97-fold) were reduced ($P < 0.05$). The GD-16 conceptus length was adversely correlated with substance-P, isoprost8, progesterone, and the THI ($P < 0.05$) (Kasimanickam and Kasimanickam 2021).

4.3. Effect on pregnancy rate

The pregnancy rate is the percentage of non-pregnant cows that become pregnant during 21 days. Each 21-day rate is preferred over the service period as an indicator of reproductive success because the pregnancy rate is clearly specified and readily available (Dash et al 2016). Heat stress causes changes that make detecting estrus more complex, resulting in fewer successful artificial inseminations and fewer pregnancies. Heat stress-induced increases in core body temperature (CBT) in dairy cows can negatively affect performance. An increase in rectal temperature of 1.8 °F (1

°C) occurring 12 h post-insemination decreased pregnancy rates by 16% (Allen et al 2013). Another study reported an increase in uterine temperature of 0.9 °F (0.5 °C) on the day of or the day after insemination decreased conception rates by 13% and 7%, respectively (Allen et al 2013). Embryos are sensitive to the harmful impacts on d1 following artificial insemination but develop substantial resistance to d3 (Allen et al 2013).

4.4. Effects on the embryo development

Thermal stress also affects embryonic effectiveness in dairy animals. HS causes embryonic death by interfering with protein synthesis and oxidative cell damage, reducing interferon-tau production for signaling pregnancy recognition and increasing the expression of stress-related genes involved with apoptosis (Dash et al 2016). Endometrial function and embryo development are hampered by low progesterone secretion. Lactating cows were exposed to HS on the first day after estrus, which reduced the proportion of embryos that developed to the blastocyst stage on the eighth day after estrus (Dash et al. 2016). Heat stress slows the growth of embryos and increases early embryonic loss (Kasimanickam and Kasimanickam 2021). Although it impacts the embryo during the pre-attachment stage, it has less impact as it grows(Kasimanickam and Kasimanickam 2021). Heat stress's detrimental effects on embryonic survival lessen as pregnancy continues(Kasimanickam and Kasimanickam 2021). Heat stress hampered embryo viability and development on Day 8 when super-ovulated cows were exposed to heat stress on Day 1 but not on Days 3, 5, or 7(Kasimanickam and Kasimanickam 2021). After the first few days of pregnancy, the harmful effects of heat stress reduce embryonic mortality due to the improved resistance of embryos to the cellular disruption brought on by the elevated temperature (Kasimanickam and Kasimanickam 2021).

5. Nutritional approaches to reducing the effects of heat stress on dairy cows

The main goal of nutritional management during heat stress is to maintain a healthy rumen function while providing an optimal nutrient supply to limit negative energy balance. This goal relies mainly on providing highly digestible feed and a balanced ratio while maintaining a safe forage-to-concentrate ratio. Researchers tested various components to alleviate heat stress in milk cows on DMI, milk output and composition, rectal and cutaneous temperature, respiration, and cardiac velocity (Table 1). Several feed additives, including live yeast cultures, buffers, fat-soluble vitamins (such as A, D, and E), niacin, and selenium, can be taken into account for their capacity to enhance rumen function and immunological response as well as to optimize energy utilization and feed conversion efficiency. Several researchers found that heat tolerance was reduced by supplementing dairy cows' diets with dietary fatty products (Table 1). Yan et al (2016) studied a dietary fat component (net energy for lactation of 6.95 MJ/kg) and found that it decreases feed intake by -3.32% and yield by +4.53%, milk fat by +23.3%; reduces the temperature by -0.95% at 14:00h, respiration rate by -7.30% at 14:00h and increase FCM and milk energy.

Other research looked into the effectiveness of dietary fiber in reducing the harmful effects of thermal stress in cows and studied the impact of using a 16.5% corn silage component replaced with soy hull. It increased milk yield by +6.06% and milk fat by 6.50%. It grew in vitro organic matter (OM) and neutral detergent fiber (NDF) digestibility, feed intake per meal and meal duration, 4% FCM, and economically corrected milk yield. Other researchers reported that using 12% shredded beet pulp instead of corn silage with a THI that exceeded 68 for 19h/day, exceeded 70 for 16h/day, or exceeded 72 for 13h/day improved an increase by +6.23% milk yield by +8.62% milk protein(Naderi et al 2016). They discovered its improved milk lactose content, neutral detergent insoluble crude protein, rumen pH, ammonia nitrogen concentration, and milk urea concentration. The adverse effects of heat stress on dairy cows have been suggested to be reduced by dietary microbial additions. Results from tests using live yeast live bacterial inoculants, and yeast culture varied (Table1). Yeast culture (240g/d) was also tested by Zhu et al (2016) in an average of 68 to 86 of HTI and reported that it improved an increase by +3.3% of milk yield and decreased rectal temperature by -0.77% at 14;30h. The study also increased net energy balance efficiency and reduced milk urea nitrogen concentration. A recent study (Salvati et al 2015) using live yeast (10g/d of live yeast ($25x10^{10}$CFU live cells and $5x10^{10}$cfu dead cells)) in an average of 71.8 of THI (60.5 to 85.1) showed an increase by +5.12% of milk yield and a decreasing of respiration rate by -14.3%. The authors also reported a rise in ECM, 4% FCM, and milk lactose secretion. Using inoculants ($4x10^9$ CFU of a combination of Lactobacillus and Propionibacterium) in temperatures between 33°C and 35.1°C showed an increase of +7.57% in milk yield, +6.90% in milk protein.

Choi et al (2021) reported that the use of RPT supplementation with 30 g RPT resulted in significant increases in the DMI and milk yield compared to the control group, showing a quadratic effect ($P < 0.05$); the lactose concentration was higher in the 30 g RPT group and 60 g RPT groups ($P < 0.05$). In addition, they reported that concentrations of 3.5% FCM, ECM, milk protein, milk fat, β-casein, monounsaturated, and polyunsaturated fatty acids were significantly higher in the 30 g RPT group with the 60 g group ($P < 0.05$). They also reported non-significant differences in the factors listed above between the 30 g RPT and control or 15 g RPT groups (Choi et al 2021). Dietary treatment did not affect DMI. Saturated fatty acid supplementation increased ($P < 0.05$) milk yield and solids-corrected milk (SCM). Milk fat yield and the percentage were increased by feeding SFA ($P < 0.05$). Ma et al 2021 reported that the use of NCG treatment significantly increased milk yield and reduced MUN ($P < 0.05$). Milk protein from dairy cows fed the low NCG diet increased by 7.36% compared to the control. Meanwhile, compared to the control, low, medium, and high NCG doses reduced MUN by 17.73%, 13.46%, and 16.31%, respectively. They also found no significant differences between NCG-treated and control groups in DMI, milk fat, somatic cell count (SCC), or lactose percentage. NCG increased quadratically milk yield (P = 0.04), milk protein (*P* = 0.01), and MUN (*P* = 0.09). The milk yield results indicated that NCG at a dosage of 20 g/day per cow was optimal; additionally, NCG did not affect apparent nutrient digestibility (*P* > 0.05) (Ma et al 2019). Dietary chromium (6 mg/d/head) increased feed intake by +10.5 % and milk yield by +11.9 % in THI ranging from 90 to 99. The study also found an increase in the percentage of pregnant females during the first 28 days of breeding and decreased body weight loss. The efficacy of vitamins in alleviating the harmful effects of heat stress was tested and found to have a variety of effects, including an increase in immune function and reproductive performance, a decrease in rectal temperature by -0.44, and a decrease in vaginal temperature (Zimbelman et al 2013) a decreasing of core body temperature and vaginal temperature and an increasing of water intake (Rungruang et al 2014). Diverse outcomes were obtained from tests on the effectiveness of metal ion buffers in reducing the harmful effects of heat stress in dairy cows. It has been investigated whether some plant extracts can lessen the detrimental effects of heat stress on dairy cows. The usage of *Radix bupleurum* extract has a beneficial impact on feed intake (+9.09%), milk yield (+8.23%), milk protein (+8.99%), milk fat (+10.8%), rectal temperature (-0.51%), and respiration rate (-8.12%) (Pan et al 2014). A recent study (Shan et al 2018) tested a Chinese herbal medicine mixture comprised of eighteen herbs (50/100g/day) and showed a positive added-value by increasing by +3.68/1.84% of milk yield in day14 of the experiment, +10.7/13.2% of milk yield d in day28 and 11.3/14.6% of milk yield in day42. On the other hand, it increased milk protein by +2.60/4.91% on day14, milk protein, and milk fat by +4.96/6.71%, and +16.2/20.3%, respectively, on day28; +4.65/7.27% and 19.0/17.6% respectively on day42. The authors also reported increased leucocyte and lymphocyte counts in peripheral blood, immune function, and decreased apoptosis rate of the lymphocytes, serum Bax level, IL 1, Bax, and Bak mRNA expression (Shan et al 2018). Testing additional anti-stress additives on the market revealed promising results for reducing the adverse effects of heat stress in dairy cows. Some of them contain monensin, which is dry matter γ-Aminobutyric acid (Cheng et al 2014), immunomodulatory in lactation (Leiva et al 2017; Hall et al 2018), immunomodulation during the dry period (Fabris et al 2017; Skibiel et al 2017), and rumen-protected capsule consisting of minerals and vitamins (Khorsandi et al 2016).

Table1 Nutritional strategies for the alleviation of the detrimental effects of heat stress in dairy cow.

Treatment and dose	Animal information	THI	DMI	MY	3.5%FCM	ECM	MP	MF	HR	ST	RT	RR	Reference
SCFP (dose g/head) ^{1}= 0g ^{2}=19g	144±5 DIM, 2.3±0.1 parity, n=20	64.8; 7days	^{1}=15.7 ^{2}=16.4	32.9 32.0			3.12 3.11	3.80 3.96	87 85	33.8 33.9	39.7 39.9	87 91	Al-Qaisi et al (2020)
RPT (dose g/head) ^{1}=0g, ^{2}=15g, ^{3}=30g, ^{4}=60g/head	74.3±7.1DIM, n=16, Milk yield=33.55±3.74 kg	Average 80 to 89; 24 days	^{1} 19.49 ^{2} 20.28 ^{3} 22.35 ^{4} 19.50	32.52 32.90 35.53 29.76	32.52 33.39 35.15 28.55	37.13 38.93 40.22 32.74	0.98 1.00 1.04 0.89 (kg/d)	1.53 1.63 1.65 1.29 (kg/d)	95 93 97 91	35.79 36.26 36.04 36.01	38.61 38.83 38.78 38.43		Choi et al (2021)
SFA (dose, %) ^{1}=0, ^{2}=1.5, ^{3}=3	184±17 DIM, n=48, Milk yield=30.8±3.3kg, 2.2±1.5 parity	Average 77.4 to 89.6; 10 weeks	^{1} 20.2 ^{2} 20.1 ^{3} 20.2	26.4 28.6 28.6			3.37 3.67 3.81 (%)	3.3 2.09 3.06 (%)			39.08 38.94 39.08	62.27 64.35 64.70	Wang et al (2010)
NCG (dose g/head) ^{1}=0,^{2}=15 ^{3}=20, ^{4}=25	154±13.6 DIM, n=48	Average 72 to 87.7; 60 days	^{1} 22.7 ^{2} 23.4 ^{3} 23.2 ^{4} 22.7	29.9 31.3 31.5 31.2			3.27 3.49 3.36 3.35 (%)	3.69 3.73 3.70 3.69 (%)					Ma et al (2021)

RPT: rumen-protected tryptophan, THI: temperature-humidity index (THI, duration of exposure), DMI: dry matter intake (kg/d), ECM: energy-corrected milk, FCM: fat-corrected milk, SFA: saturated fatty acid, NCG: N-carbamylglutamate, SCFP: *Saccharomyces cerevisiae* fermented product, HR: heart rate (beats/min), RR: respiratory rate (breaths/min), RT: rectal temperature (°C), ST: skin temperature (°C), MP: milk protein, MF: milk fat, MY: milk yield (kg/day)

6. Final considerations

Heat stress is the primary factor reducing milk production in dairy cows, resulting in significant economic losses for livestock farmers worldwide. A heat-stressed lactating cow undergoes several post-absorption metabolic changes, reducing feed intake and the overall energy balance. Few studies have confirmed the negative effect of heat stress on dairy cow performance and demonstrate that the negative impact of THI lasts longer than the commonly reported 2 to 4 days. Heat stress causes physiological dysfunction in dairy cows, including decreased milk yield, fertility, feed intake, lying time, ease of movement, rectal and cutaneous temperature, and respiration rate. Heat stress has also been linked to lower milk protein, fat, FCM, and ECM levels, and lower milk quality. High-producing dairy cows appear more susceptible to heat stress than low-producing dairy cows. On the other hand, several studies proposed nutritional strategies for mitigating the effects of heat stress on dairy cows, with positive outcomes in milk yield and quality and dairy cow welfare. Among the dietary systems tested to alleviate the adverse effects of heat stress in dairy cows are dietary fat, dietary fiber, microbial additives, minerals, vitamins, metal ion buffer, plant extracts, and other anti-stress additives. However, more research is required to identify all heat stress effects and strategies for maintaining dairy cow performance and health.

Ethical considerations

Not applicable.

Conflict of Interest

The authors declare that they have no competing interests.

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