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HEAT STRESS RESPONSE IN DAIRY CATTLE

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Abstract
Indonesia is a tropical country with high ambient temperatures and humidity. In Indonesia's hot and humid summer, dairy cows cannot dissipate enough body heat to prevent a rise in their body temperature. Increasing air temperature, temperature humidity index, and rectal temperature above a critical threshold are associated with decreased dry matter intake (DMI), milk production, and milk production efficiency. Modifications including shades and cooling fans can help dissipate body heat, lower body temperature, and increase BMI. Genetic selection for heat tolerance is possible, but continued selection for better performance without consideration for heat tolerance will result in greater susceptibility to heat stress. The nutritional requirements of dairy cows change during heat stress, and ration reformulation to account for reduced DMI, the need to increase nutrient density, alter nutrient requirements, avoid excess nutrients and maintain normal rumen function is required. Sustaining cattle performance in hot and humid climate conditions in the future will likely require increased cooling capabilities, continued advances in nutritional formulations, and the need for genetic advances that include selection for heat tolerance or identification of genetic traits that enhance heat tolerance.
Keywords: dairy milk, heat stress, lactation

RESPON CEKAMAN PANAS PADA SAPI PERAH

Abstrak
Indonesia sebagai negara tropis dengan suhu lingkungan yang tinggi dan memiliki kelembaban. Kondisi panas dan lembab umum terjadi di Indonesia. Pada musim panas, sapi perah tidak dapat membuang panas tubuh yang cukup untuk mencegah kenaikan suhu tubuh. Meningkatkan suhu udara, indeks kelembaban suhu dan suhu rektal naik di atas ambang kritis berhubungan dengan penurunan asupan bahan kering (DMI) dan produksi susu serta dapat mengurangi efisiensi produksi susu. Modifikasi termasuk tempat berteduh dan menambah kipas untuk pendinginan dapat menghilangkan panas tubuh, menurunkan suhu tubuh dan meningkatkan DMI. Seleksi genetik untuk toleransi panas dimungkinkan, tetapi seleksi lanjutan untuk kinerja yang lebih baik tanpa adanya pertimbangan untuk toleransi panas akan menghasilkan kerentanan yang lebih besar terhadap cekaman panas. Kebutuhan nutrisi sapi perah berubah selama stres akibat cekaman panas, dan reformulasi ransum untuk memperhitungkan penurunan DMI, kebutuhan untuk meningkatkan kepadatan nutrisi, mengubah kebutuhan nutrisi, menghindari kelebihan nutrisi dan pemeliharaan fungsi rumen normal diperlukan. Mempertahankan kinerja sapi dalam kondisi iklim yang panas dan lembab di masa depan kemungkinan akan membutuhkan peningkatan kemampuan pendinginan, kemajuan lanjutan dalam formulasi nutrisi, dan kebutuhan untuk kemajuan genetik yang mencakup seleksi untuk toleransi panas atau identifikasi sifat genetik yang meningkatkan toleransi panas.
Kata Kunci*: *susu sapi, cekaman panas, laktasi

INTRODUCTION

The Indonesian people are familiar with cow's milk for a long time and also aware of its relatively high nutritional value (Ministry of Trade, 2014). Fresh milk production in Indonesia is only able to meet 22% of the national milk demand. Meanwhile, milk consumption is increasing continuously and there is a national target to self-supply a minimum of 60% Indonesian national production in 2025, therefore establishing the importance of increasing Indonesian dairy cows' productivity (Budiman and Alta, 2022). Milk and dairy products are nutrient-dense foods, providing energy and high-quality protein with a range of essential micronutrients (especially calcium, magnesium, potassium, zinc and phosphorus) in an easily absorbed form (Muehlhoff *et al*, 2013). According to the

Central Statistics Agency (BPS) in 2019, Indonesia's milk consumption was 16.23 liters/capita/year. This amount has increased of 0.20 liters/capita/year from the previous year. It is worth considering that although Indonesia's population reached 270.20 million people, as per the census in September 2020, Indonesian milk production currently reaches 4.3 million tons per year on the supply side. However, the contribution of domestic milk to the national milk demand is relatively low, at approximately 22.7% while the majority of the milk demand is fulfilled through imports (Ditjennak, 2017). As a result, Indonesia dairy industry holds promising prospects for continuous development. Moreover, most of the national milk production is produced by dairy farms, so that it can further increase milk production and increase the population on a dairy farm scale.

Nowadays, dairy farming is mostly located in the highlands such as Pangalengan, Lembang, Baturaden and other areas, while the practice in the lowlands is still rare. Lowland is an area that is characterized with temperature and humidity condition that inhibit dairy farming development. Opportunities to develop dairy farming in the lowlands can only be realized if these factors can be overcome.

Temperature and humidity are one of the most important environmental factors that can affect dairy cattle in adaptation, distribution, and vegetation. Research shows that relatively high temperatures combined with high humidity can have a negative effect on the production and reproduction of dairy cows (Purwanto *et al*., 1993; Atrian and Shahryar, 2012). Dairy cows can produce good productivity when kept in the right environment with the right temperature and comfortable humidity. Conversely, dairy cows will experience stress, decreased productivity (Purwanto *et al*., 1993; Nardone *et al*., 2010) and milk quality (Hill and Wall, 2015) will also decrease when reared outside their comfort zone. Research has shown that heat stress in dairy cows can reduce milk production by up to 0.6-1.4 kg for every 1°C increase in temperature (Atrian and Shahryar, 2012). St-Pierre *et al*. (2003) stated that the US had experienced a loss of around USD 900 million due to decreased milk production caused by heat stress. During hot temperatures, dairy cows adapt by increasing heat loss through skin evaporation and respiration, and this results in decreased feed intake, redistribution of blood, decreased immunity, and changes in endocrine function (Marai et al., 2007). Thyroid and cortisol hormones are also known to play an important role in the adaptation process (Todini *et al*., 2007), especially in metabolic processes. In addition, an increase in body temperature in dairy cows is known to correlate closely with a decrease in thyroid gland activity which causes lower thyroid concentrations and higher cortisol concentrations (Megahed *et al*., 2008; Soltan, 2010). Such conditions cause the concentration of cortisol to be one of the parameters of physiological stress. Changes in animal physiology are the basis of animal thermoregulation to maintain temperature stability and prevent hyperthermia.

MATERIALS AND METHODS

The writing of this paper was carried out by means of library research, which is a collection of literature or research in which the object of research is obtained through a variety of library information (scientific journals, books, and proceedings). Sites that were used to view literature include https://books.google.co.id/, https://scholar.google.com/, https://sciencedirect.com/, https://www.journalofdairyscience.org/, and https://www.researchgate.net/. A literature search was carried out using several keywords such as milk, heat stress, and lactation. The data used in this journal is secondary data, namely data obtained not by direct research but obtained from the results of previous studies.

Conditions of Dairy Cow in The Tropical Environment

Environmental conditions

Climate is a natural phenomenon that is driven by a combination of several elements, namely solar radiation, temperature, humidity, clouds, rain, evaporation, air pressure, and wind. The tropics can be divided into two main climate groups, namely the wet tropics and the tropics. Indonesia is included in the humid tropics which is characterized by relatively high air humidity, generally above 90%, high rainfall, and annual average temperatures above 18°C and usually around 23°C and can reach 38°C in the dry season. More specifically, Indonesia is included in the secondary area of tropical rainforest (humid tropics). The comfortable air temperature for dairy cattle ranges from 15-22°C (Nurdin 2011), therefore, dairy cattle are commonly reared in places with such temperature, for example, Lembang highlands, according to the weather park, has a temperature varying from 14°C to 26°C and rarely below 13°C or above 28°C, are often used as dairy farms area. According to McDowell (1972) cattle kept in areas with comfortable environmental conditions (comfort zone), are areas that are most suitable for the life of these livestock. Dairy cattle raised in tropical climates suffer heat stress more frequently, due to their high productivity, undergoing heat stress-induced physiological and behavioral changes, where high ambient temperature, relative humidity, and solar radiation impede heat dissipation (Silva *et al*. 2002). In dairy cattle, for example, one of the biggest obstacles is associating highly productive genotypes with genotypes adapted to these hot environments, because cows that are better adapted generally have lower levels of food consumption and milk production (Façanha et al., 2008).

Impact of Climate on Changes in Cattle Behavior, Body Temperature, Decreased Dry Matter Intake (DMI) and Milk Yield

The term heat stress is used broadly and more precisely which can refer to the climate, the effects of climate on the cow, or the productive or physiological response by that cow. According to Lee (1965) the definition of stress is used by physiologists, where stress indicates the amount of force outside the body's system that tends to displace the system from its quiescent state or its usual state, or the ground state caused by the impact of stress. Therefore, external environmental factors of the cow may contribute to stress (in this case heat stress) while displacement of the cow from a state of rest, the cow will respond to external stress, or heat strain.

Lower altitude causes an increase in ambient temperature (Hecker and McGarvey 2011; Tanuwiria *et al*. 2011). Previous studies reported that ambient temperature is an important factor influencing feed and drinking water consumption. For example, Hidayat *et al*. (2019) showed a decrease in feed consumption as the temperature of the cage increased. Meanwhile, Loyau *et al*. (2014) and Na *et al*. (2020) show reports with increased consumption of drinking water and ambient temperature. This eating and drinking behavior are closely related to the instinct of dairy cows to maintain body homeostasis by maintaining a balance between environmental heat radiation and metabolic heat. This condition has an impact on reducing the time needed to consume feed and rumination, conversely increasing the proportion of time for drinking activities. This is also supported by other behaviors, such as lying down. Lomb et al. (2018) reported that lying down is an attempt by cattle to evaporate body heat by conduction techniques. Therefore, cows in the lowlands of 350-500 masl spend more time lying down than those in plains > 550 masl. This result was also shown by Hetti *et al.*, (2014), Gray *et al*., (2015) and Gleret *et al*., (2016). However, better adaptation in Pasundan cattle was suggested by Mushawwir *et al.*, (2020). The ambient temperature dramatically affects the physiological condition of livestock. This condition can be exacerbated when there is an interflow of high air humidity and ambient temperature. Therefore, dairy cows must adjust their body temperature to the ambient temperature as homeothermic cattle. The body's regulation of adjusting the physical conditions of the environment to temperature involves all organs (Monteiro *et al.,* 2016; Mushawwir *et al.,* 2018; Na *et al.*, 2020).

The effects of hot and humid conditions are thought to be expressed through the effects of body temperature in cattle. Berman *et al.*, (1985) suggested that the upper limit of environmental temperature at which Holstein cattle might maintain a stable body temperature is 25 to 26°C, and that practices above 25°C should be followed to minimize increases in body temperature. However, one of the main challenges is the combination of the effects of high relative humidity with high ambient temperatures. At 29°C and 40% the relative humidity of the milk of Holstein, Jersey and Brown Swiss cattle was 97%, 93%, and 98% of normal, but when the relative humidity was increased to 90% the results were 69%, 75%, and 83% of normal (Bianca et al., 1965). One must understand the cooling methods used by homeotherms to understand the reasons for the effect of relatively high humidity. The effect of humidity is shown through the effect of increasing body temperature on cow performance. The estimated reduction in milk production was 0.32 kg per unit increase in humidity (Ingraham, 1979), and milk yield and

TDN intake decreased by 1.8 and 1.4 kg for each 0.55°C increase in rectal temperature (Johnson et *al*., 1963). Although some combination of temperature, humidity, and radiant energy impacts heat in cows, with sufficient nightly cooling, cows can tolerate relatively high daytime air temperatures. Igono *et al*., (1992) reported that despite high ambient temperatures during the day a cold period of less than 21°C for 3 to 6 hours minimized the reduction in milk yield.

Heat Production Metabolism

Heat production from metabolic functions accounts for about 31% of the energy intake of a 600 kg cow producing 40 kg of milk with a 4% fat content (Coppock, 1985). Physical activity increases the amount of heat produced by skeletal muscles and body tissues. Heat dissipation by maintenance at 35°C increases by 20% compared to other monetary conditions (NRC, 1981), resulting in an increase in the energy production of the cow which often ignores the yield of milk. Heat production in the body is related to increased milk production as a metabolic process, as well as feed intake with increased digestive needs. Heat load is accumulated by cows that are experiencing heat stress, this is the amount of heat accumulated from the environment and the failure to dissipate heat associated with the metabolic process.

With similar body size and surface area, lactating cows store more heat than nonlactating cows, and will have more difficulty dissipating heat during hot, humid conditions. Non-lactating, or low-milk yield (18.5 kg/d) and high-producing (31.6 kg/d) cows generate 27 to 48% more heat than non-lactating cows despite having a lower body weight (752, 624, and 597 kg for non-lactation) (Purwanto *et al*., 1990). Berman *et al*. (1985) stated that the cow's rectal temperature increased by 0.02°C/kg FCM for cattle production >24 kg/day.

Physiological Effects of Heat Stress

Many physiological changes occur in the digestive tract, acid-base chemistry, and blood hormones during hot weather; lack of nutritional intake as a response from the cow but many changes occur as a result of internal tension. Temperature-sensitive neurons are located throughout the animal's body and transmit information to the hypothalamus, which causes many physiological, anatomical or behavioral changes in an attempt to maintain heat balance (Curtis, 1983). During heat stress, cattle respond by reducing feed intake, decreasing activity, seeking shade and wind, increasing respiratory rate, and increasing peripheral blood flow and sweating. This response has a deleterious effect on the production and physiological status of the cow.

Cows fed ad libitum, whether in a comfortable thermal environment, in a stressful thermal environment, or were fed limited intake in a comfortable thermal environment, had the same milk yield. For restricted diets and with thermally stressed treatments, blood flow tends to be lower compared to cows fed ad libitum in thermal comfort, indicating blood flow is responsive to DMI levels (Lough et al., 1990). For cattle subjected to the same treatment as that of Lough *et al*. (1990), portal plasma flow was reduced by approximately 14%, for cows in thermal comfort with limited intake or in thermal stress when compared to thermal comfort, cows that were fed ad libitum (McGuire et al., 1989). Part of the negative effect of heat stress on milk production can be explained by reduced nutrient intake and decreased absorption of nutrients by cow offal. Blood flow shifted to peripheral tissues for cooling purposes can alter nutrient metabolism and contribute to lower milk production during hot weather.

Increased Physiological Response

An increasing physiological response indicates an animal's ability to maintain its body condition through respiration, heart rate, and body temperature (rectal surface and skin temperature). Ruminants dissipate heat mainly through evaporation by sweating, whereas a small part of evaporation was achieved by breathing. Furthermore, environmental heat radiation triggers hormonal action, especially epinephrine. Several previous studies have shown that lowland cattle have higher daily concentrations of epinephrine than upland cattle. Mushawwir *et al.*, (2021) reported that epinephrine increased gluconeo-mediated vasodilation. The results of other studies show that epinephrine also increases blood flow rate (Ippolito *et al*., 2014; Khan *et al*., 2015; Adriani and Mushawwir 2020). An increase in blood flow rate is necessary to dissipate body heat through the sweat glands and partly through moisture from the respiratory gluconeo. Involvement of organs in achieving body heat homeostasis, organs respond with different degrees of activity. This thermoregulation effort seems to be responded to by the organs more intensively, through increased heart rate and higher frequency of work of the respiratory tract (Wang *et al*., 2007), then manifested by higher body surface temperature and higher rectal temperature (Mushawwir *et al*., 2007; 2010; 2011). Physiological status illustrates that the interaction of organs in regulating heat and maintaining the body is very necessary because it is a complex physiological and biochemical mechanism. As a result, the need for more energy (Tian *et al*., 2015) and nutrients in the basal ratio must be more complex (Grelet *et al*., 2016; Suryaningsih *et al*., 2019; Hidayat *et al.,* 2019). In addition, decreased digestion of crude fiber (Renaudeau *et al*. 2012) and the rate of conversion of gluconeo-noncarbohydrates to pyruvate (gluconeogenesis) have increased (Mushawwir *et al.,* 2010; Pickler *et al.*, 2013; Gray *et al.,* 2015; Mushawwir *et al.*, 2021). There were also changes in the profile of carbohydrate metabolism (Dhanasekaran *et al.,* 2011; Mushawwir *et al.,* 2020) and increased levels of free radicals such as ROS (Burdick *et al.*, 2011; Eyng *et al.,* 2015; Siskos *et al.,* 2017).

Blood Biochemistry

Specific responses regarding cardiac function and metabolic changes were associated with treatment sites at different altitudes. It is known that the -GT enzyme has a high concentration in cardiac tissue cells. As previously explained, lower elevations have higher temperatures. Therefore, homeostatic efforts involving heart work (Seok *et al.*, 2019; Mushawwir *et al.,* 2020) in the context of providing energy (Tanuwiria *et al.*, 2011; Roland *et al.,* 2016) can increase cardiac cell death. (necrosis). Several previous studies have shown that necrosis increases with increasing temperature in cattle pens (Xu *et al.,* 2015; Tian *et al.,* 2016; Lomb *et al.,* 2018). Increased cardiac cell death with increased temperature impacts the migration of the -GT enzyme into the vascular system to increase the levels of this enzyme in the blood plasma. The results of previous studies indicate that cell death (necrosis) causes increased migration of metabolites into the vascular system (Ippolito *et al.,* 2014; Valle *et al.,* 2017; Tanuwiria and Mushawwir 2020). -GT enzyme levels appeared to increase in the dairy group with increasing age of lactation at low altitude rearing locations, namely 49.46 IU/L in the lactation group III. Although this phenomenon does not occur in groups of dairy cattle kept at an altitude of > 700 meters above sea level. Slimens *et al.,* (2016) reported that cell death (necrosis and apoptosis) increased with metabolism and age. Livestock kept in a temperature zone that corresponds to the thermoneutral zone of dairy cows causes no stimulation of the activation of the hormone epinephrine from norepinephrine (Vizzotto *et al.,* 2015; Mushawwir *et al.,* 2018). Instead, these hormones are triggered by neurotransmitters due to stimulation of nerve receptors (Ippolito *et al.,* 2014). Epinephrine is the terminal compound for alpha-epinephrine receptors in the vessel wall (Gehrke *et al.,* 2013; Cai *et al.,* 2014; Mushawwir *et al.,* 2020). As a result, it causes increased vasodilation or dilation (Gray *et al.,* 2015; Siskos *et al.,* 2017) and increases heart rate (Hecker and McGarvey 2011; Mingoti *et al.*, 2016).

The increase in levels of the *Soluble Transferrin Receptor protein and Total Iron Binding Capacity* occurs with increasing height. This increase in levels is due to lower oxygen concentrations at high altitudes, to increase the expression of these two types of proteins and support oxygen distribution throughout tissues. These changes can also be caused by continuous tissue growth to increase the capacity for lipid synthesis (Tian *et al.,* 2015). Moreover, it increases metabolism due to tissue mass (Carrol *et al.,* 2016; Ammer *et al.,* 2018). This increases liver mass and causes gluconeogenesis (Adriani and Mushawwir 2020; Tanuwiria and Mushawwir 2020; Mushawwir *et al.,* 2021). Furthermore, the reproductive potential of lowland dairy cows (300-500 masl) is lower than that of upland dairy cows. This potential is indicated by circulating FSH levels in the blood, and FSH levels in dairy cows for lowlands to highlands are 7.85; 12.73, and 13.69 ng/mL. This increase indicates the growth activity of follicles and egg cells in dairy cows. Several previous studies (Mingoti *et al.,* 2016; Monteiro *et al.,* 2016) have shown a very high correlation between FSH levels and folliculogenesis activity. This potential indicates that high FSH levels support high milk production (Roland *et al.,* 2016; Tian *et al.,* 2016; Siskos *et al.,* 2017; Mushawwir *et* *al.,* 2020). Several studies have shown that the height factor plays an important role in milk synthesis in dairy cows, but it is also largely determined by the feed factor (Fabris *et al.,* 2017; Sisay *et al.,* 2018; Hidayat *et al.,* 2019). However, altitude is very decisive and is closely related to temperature and humidity (Mushawwir *et al.,* 2020). It is also closely related to heat and radiation regulation (Burdick *et al.,* 2011); other research shows that the rate of energy use is only to maintain heat balance inside and outside the body (Ippolito *et al.,* 2014; István *et al.,* 2020). Quality feed contributes to the ability of lowland dairy cows to produce high levels of milk.

Research by Renaudeau *et al.,* (2012) and Seok *et al.,* (2019) stated that the addition of methionine and lysis with glutamic acid can support the production of dairy cows under heat stress. Other measures show that chitosan can be influenced in regulation and avoid tissue damage and support protein synthesis in growth by providing livestock (Mushawwir *et al.,* 2021). Associated with the increase in the biosynthetic capacity of milk by alveolar cells in mammary tissue, of course, is related to the precursors of milk formation (Seok *et al.,* 2019). High precursor requirements can intensify the formation of glucose from various sources, such as protein (Mushawwir *et al.,* 2011; Pickler *et al.,* 2013; Khan *et al.,* 2015). It can also promote an increase in the metabolic rate of the rumen cavity and villi in dairy cows (Tanuwiria *et al.,* 2011; Fabris *et al.,* 2017, Ammer *et al.,* 2018; Hidayat *et al.,* 2019; István *et al.,* 2020; Adriani *et al.,* 2021). Based on the results of the current study, the proportion of time spent by cows in expressing their behaviors is compensation for their physical environmental conditions (temperature and humidity) in each topography. Likewise, in thermoregulation to maintain their normal physiology. Changes in blood metabolism is a metabolic profile that shows the homeostatic conditions that have been achieved.

Improving the Performance of Cattle in Hot and Moist Conditions

Impact of Changing Cattle Environment

Shelter. One of the first steps to be taken to reduce the effects of heat stress is to protect cows from direct and indirect solar radiation. It is estimated that total heat stress can be reduced from 30 to 50% with well-designed shelters (Bond and Kelly, 1955), and *shading* is one of the more easily applied and economical methods of minimizing heat from solar radiation. Cows in shade with no shade had lower rectal temperatures (38.9 and 39.4°C) and reduced respiratory rates (54 and 82 breaths/min), and produced 10% more milk when shaded (Roman-Ponce *et al.,* 1977). Unshaded cows had reduced rumen contractions, higher rectal temperatures and reduced milk production compared to shaded cows (Collier *et al.,* 1981).

Cooling Dairy Cows. Although shade can reduce heat accumulation from solar radiation, it has no effect on air temperature or humidity, so additional cooling is required for lactating dairy cows in hot and humid climates. A number of cooling options are available for lactating dairy cows based on a combination of convection, conduction, radiation, and evaporation principles. Air movement (fans), spraying the cows, evaporation to cool the air, and shading to minimize radiation transfer are used to increase heat dissipation. Any effective cooling system must consider intense solar radiation, high ambient temperatures, and normally high daytime humidity, as well as conditions at night. These vulnerable conditions require a cooling system to be able to maintain the normal body temperature of dairy cows.

Genetic Selection

Dairy cows predicted by genome breeding values to be heat tolerant, have a slight decrease in milk production, and reduced increase in core body temperature, during a simulated heat wave compared to cows predicted to be heat susceptible. Thus, genomic selection for heat tolerance can improve the resilience and welfare of dairy herds worldwide and future dairy farm productivity can anticipate the incidence and duration of heat stress-related events (Garner *et al*., 2016).

Feed Management

Forage. Using higher quality forages can increase the energy content of the feed and reduce the heat of fermentation compared to feeding lower quality forages. Brown stem forages (i.e., corn silage or sorghum forages) may be more useful in heat-stressed dairy cattle feeds to increase fiber digestibility and, therefore, the amount of energy recovered from the feed consumed. (Amaral-Phillips,)

Modifying mineral supplementation. Dairy cows experiencing heat stress will sweat, which contains high amounts of potassium and sodium, increasing their need for these minerals in the ration during summer. To achieve increased concentrations of potassium and sodium and maintain an adequate diel cation-anion difference (DCAD), increased amounts of sodium bicarbonate or potassium carbonate, or both may need to be added to the feed. Additionally, higher amounts of potassium can reduce magnesium absorption, thereby increasing magnesium requirements. Dairy cows that are stressed due to heat must be fed adequate amounts of minerals and vitamins, especially antioxidant nutrients (Amaral-Phillip,)

CONCLUSION

High ambient temperature coupled with relatively high humidity can reduce the ability of lactating dairy cows to dissipate excess body heat. Cows with high body temperatures show a lower DMI response and produce milk at lower efficiency, reducing profitability for dairy farms in hot and humid climates. Despite adequate cooling systems, production efficiency in humid climates is lower than in dry climates and often lacks the ability to maintain normal body temperature. The need for further genetic selection for better DMI and milk yields with less heat-tolerant cows, coupled with the unknown associated with future global warming, suggests that heat stress will be worse for dairies in the future. An improved and more efficient cooling system, especially one that can cool cows at night when the humidity is high, is required to face future challenges. There is some genetic variation in cows with cooling abilities, indicating that there are heat-tolerant cattle to be genetically selected for, and cross-breeding may also offer opportunities. Continued progress in feeding is necessary as livestock are selected to produce more milk, but remain at lower intakes due to environmental pressures. Developing a nutritional strategy that supports yields while also addressing the metabolic and physiological disturbances caused by heat strain, will help dairy cows to maintain a more normal metabolism for increased performance.

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