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Review Article

Effect of heat stress on dairy cow production, reproduction, health, and potential mitigation strategies

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ABSTRACT

Extreme weather events are becoming more common and more severe as a result of climate change, and this has serious implications for the future of livestock, farmer income and livelihoods, and food security worldwide. Dairy cattle have become more heat sensitive due to selective breeding for higher production and increased feedlot operations. The harmful effects of heat stress cause hyperthermia, oxidative stress, and other physiological changes in dairy cows. Environmental heat stress causes a decrease in feed intake, leading to a decrease in milk production in dairy cows. The main method to check for reductions in milk production in dairy cows during the summer is an accurate evaluation of heat stress and effective mitigation strategies. Three primary management strategies have been proposed to reduce heat stress and stabilize dairy cattle performance in increasingly hot and humid climates. Short-term management options include physical alteration of the environment and nutritional management, while long-term management strategy includes discovering heat-tolerant genetic traits and genomic selection for heat tolerance. This review looks at how heat stress has affected the dairy industry's sustainability and elaborates on genomic selection for thermotolerance in dairy cattle as sustainable breeding practices to increase dairy cows' ability to withstand high temperatures.

Key words: Climate change, Dairy cows, Genomic selection, Heat stress, Management strategies

INTRODUCTION

Extreme weather events are becoming more common and more severe as a result of climate change, and this has serious implications for the future of livestock, farmer incomes and livelihoods, and food security worldwide (Lipper *et al.,* 2014). The climate is projected to change rapidly, with global warming expected to increase by 1.5 degrees Celsius by 2040 and the average surface temperature predicted to increase by 1.88 degrees Celsius by 2100 (Jevrejeva *et al.,* 2016; Geiger *et al.,* 2021). Heat stress (HS) caused by climate change is a major factor that affects global livestock production. The strength of HS is governed by several factors that act together, including but not limited to air temperature, humidity, sunshine, and wind velocity (Kadzere *et al.,* 2002; Herbut *et al.,* 2018). When an animal cannot disperse an excess of endogenous heat to maintain homeothermic properly, hyperthermia arises due to an imbalance between metabolic heat generation and body heat degeneracy (Berman, 2011; Bernabucci *et al.,* 2014). These environmental conditions affect animal development, reproduction, and productivity (Osei-Amponsah *et al.,* 2019).

Reduced milk production can be traced to several causes, including increased body temperature that causes a decrease in feed intake, changes in hormone profiles, and modifications in energy metabolism (Baumgard *et al.,* 2007; Collier *et al.,* 2008). HS has been shown to affect milk production in dry cows during successive lactations by altering the mammary gland (Rhoads *et al.,* 2009; Carabaño *et al.,* 2019). Due to decreased feed intake, milk production drops from 25% to 40% in dairy cows with HS (Baumgard *et al.,* 2011). The dairy industry suffers a significant financial burden when milk production decreases by 10 to 35% during the hot summer (St-Pierre *et al.,* 2003). Annual financial losses due to high-stakes syndrome in the dairy sector can be attributed to several factors, the most prominent of which is a decrease in milk production. However, reduced reproductive efficiency increases diseases, and increased mortality plays a role (Vitali *et al.,* 2009). For example, heat stress causes billions of dollars per year in losses in cattle production worldwide (Osei-Amponsah *et al.,* 2019). In the United States, heat stress is responsible for between \$1.69 and \$2.36 billion yearly economic losses to the livestock industry. The dairy industry accounts for \$897 to \$1500 million of these losses. The pork industry generates between \$299 and \$316 million, while the poultry sector generates between \$128 and \$165 million (St-Pierre *et al.,* 2003). Milk production decreases, reproduction slows, metabolic problems increase, and immune systems weaken due to high blood pressure, all contributing to economic losses in the dairy sector (Sordillo, 2016; Zigo *et al.,* 2021).

More studies are needed on how to adapt to climate change, particularly in developing countries (Escarcha *et al.,* 2018). As the world population increases, it will become more necessary to expand livestock production to meet food demand (FAO, 2018; Henry *et al.,* 2018). The incidence, duration, and severity of HS in dairy cattle will increase as global warming continues (Min *et al.,* 2007; Theusme *et al.,* 2022). Therefore, it has become a problem for the global dairy sector to reduce the impact of HS on dairy herd production (Bouraoui *et al.,* 2002). This review looks at how heat stress has affected the dairy industry's sustainability and elaborates on genomic selection for thermotolerance in dairy cattle as sustainable breeding practices to increase dairy cows' ability to withstand high temperatures.

THERMONEUTRAL ZONE

Cattle can keep their core body temperature stable within relatively tight parameters. The thermoregulation systems in these animals are activated when exposed to temperatures that cause pain, cold, or heat (Lezama-García *et al.,* 2002). The goal of these processes is to maintain an internal temperature that is within the physiologically tolerable range. Body heat production equals body heat dissipation in the thermoneutral zone (TNZ). The animals are in the thermal comfort range when confined within the thermoneutral zone. As a result, the body's metabolism drops to its minimum level (Lezama-Garca *et al.,* 2002). This disorder prevents the animal from using its normal physiological processes to lose heat to its surroundings or produce its own internal thermal energy. As a result, it can maintain equilibrium in body temperature with its surrounding environment and direct all of its available energy toward achieving optimal performance levels. In this circumstance, the sensory processes of heat exchange are sufficient to keep the temperature at thermal equilibrium (Mota-Rojas *et al.,* 2021).

Minimal physiological expenses and maximum productivity are typically achieved within the TNZ. The TNZ range of an animal depends on several factors, including its age, breed, species, kind of feed consumed, diet composed of, the initial state of temperature acclimatization, production method, special housing and pens, tissue insulation, external insulation, and behavior (Mota-Rojas *et al.,* 2021). The best thermal neutral zone is an ambient temperature below 21 °C throughout the day (Kolbe *et al.,* 2022). Dairy cows can only perform at their highest levels of efficiency if they maintain a constant core body temperature in the TNZ. TNZ ranges from 1.7 °C to 21 °C for lactating dairy cattle and depends on the breed, degree of acclimatization, milk production, and dry matter intake (Kolbe *et al.,* 2022). When an organism's temperature deviates too far from its optimal level, it hinders its ability to carry out production operations (Heal & Park, 2016). Even slight increases in core temperature significantly affect tissue and endocrine function, affecting fertility, growth, breastfeeding, and working ability (Angilletta, 2009; Heal & Park, 2016).

When AT increases and exceeds the UCT limit in the homeotherm zone; as a result, animals have difficulty activating evaporative thermolysis systems (Kamal *et al.,* 2016; Sejian *et al.,* 2018). Animals rely on water evaporation to rid their bodies of the excess heat that their metabolisms produce (Smith *et al.,* 2015). Cattle begin to change their behavior as the variation in environmental temperature reaches the limit of the UCT. Performance deteriorates when body temperature rises above the UCT, causing a decrease in milk production and a change in milk composition when the cow experiences heat stress. They respond to a rise in temperature by increasing their need for shade, drinking and feeding less, and decreasing their activity near cooler surfaces (Ratnakaran *et al.,* 2017; Madhusoodan *et al.,* 2019). When an animal's body temperature increases above its ability to cool itself by evaporation, a condition known as hyperthermia sets in and ultimately causes death (Figure 1).

The LCT is the temperature below which an increase in its heat production rate is required to keep the internal temperature constant (Figure 1). When the ambient temperature drops below the LCT, the animal's thermoregulation system swings into action to maintain body heat or generate more heat inside the animal. This is accomplished by consuming more food, which generates metabolic heat by breaking down nutrients in the digestive system (Hankenson *et al.,* 2018). To retain heat, animals form groups, avoid lying on frigid surfaces, and expose themselves directly to solar radiation if they have access to these resources (Nardone *et al.,* 2006). Animals can die if the circumstances of their environment do not change to make them more thermally comfortable (Nardone *et al.,* 2006; Collier & Gebremedhin, 2015).

HEAT STRESS IN DAIRY COWS

The term "stress" refers to the intensity of external pressures destabilizing an organism's internal systems from their neutral or ground position (Kadzere *et al.,* 2002). Heat stress, in the context of a dairy cow, can be thought of as the sum of all pressures that cause the cow to make modifications on scales from molecular to ecological to prevent physiological malfunction and better suit its environment (Kadzere *et al.,* 2002; Gagge & Gonzalez, 2010). Homeotherms exert considerable effort to maintain proper biochemical reactions and physiological processes linked to metabolism to maintain their core body temperature within relatively restricted limits. An animal must maintain homeothermy by being in thermal equilibrium

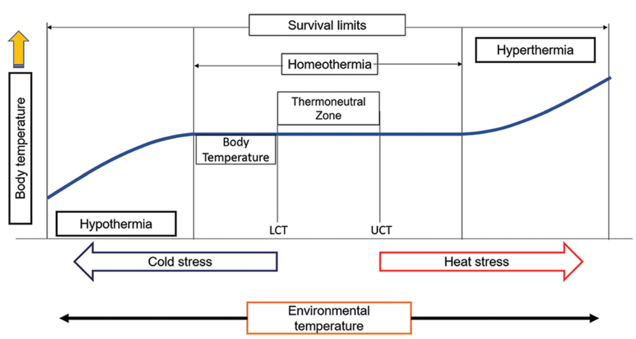

Figure 1: Variation in body temperature with increased or decreased environmental temperature. LCT is the lower critical temperature, and UCT is the upper critical temperature (Ehrlemark & Sallvik, 1996)

with its surroundings, including radiation, air temperature, movement, and humidity (Aggarwal & Upadhyay, 2013). There is a comfort zone for lactating dairy cows where the temperature remains between 5 ^{O}C and 25 ^{O}C, known as the thermoneutral zone (TNZ) (Golher *et al.,* 2021). The cow is under heat stress when outside temperatures exceed 26 °C and cannot cool off properly. In the absence of extreme heat stress, the thermoregulatory systems of the body typically keep temperatures within 1 ^{O}C of normal (Rejeb *et al.,* 2016).

Temperature readings have been used to evaluate the effects of thermal stress and relief (Berman, 2005). The body temperature of dairy cattle is a sensitive measure of thermal stress due to the high sensitivity of animals to heat (Gebremedhin *et al.,* 2016; Shu *et al.,* 2021). The temperature-humidity index (THI) was proposed as an indication of thermal climatic conditions by McDowell *et al.* (1976). The air temperatures of the wet and dry bulb for a given day are used to obtain the THI in the following manner.

$$THI = 0.72(W + D) + 40.6 \quad (2.1)$$

where W is the temperature of the wet bulb, and D is the dry bulb in ^{O}C.

Comfortable temperatures have a THI of 70 or less, stressful temperatures of 75-78, and extremely uncomfortable temperatures of 78 or more, rendering thermoregulation mechanisms ineffective and rendering lactating cows incapable of maintaining appropriate body temperatures. Milk synthesis is traditionally believed to decrease when THI reaches 72 (Herbut & Angrecka, 2012; Bernabucci *et al.,* 2014). The threshold for heat stress was estimated to be a THI value of 72 for production and around 68 for reproduction. Increased respiration rates and rectal temperatures are hallmarks of heat stress, linked to reduced metabolism and poor reproductive performance in dairy calves. Therefore, herd management choices are influenced by estimated THI based on ambient temperature (AT) and relative humidity (RH) for dairy cattle during the warm season (Kadzere *et al.,* 2002; Bohmanova *et al.,* 2007).

RESPONSE TO HEAT STRESS

Homeotherms like dairy cows have evolved to thrive in essentially temperature-neutral habitats. Natural metabolic balance is disrupted by HS, which often results in a positive feedback loop after temperatures rise above the UCT (Kadzere *et al.,* 2002; Polsky & von Keyserlingk, 2017). The metabolism of significant nutrients in dairy cattle increases metabolic heat production, making the high-producing cow susceptible to high ambient temperatures and humidity (Sammad *et al.,* 2020a). Assuming that the methods for dissipating heat are the same since TNZ shifts downward as milk output, feed intake, and heat generation increase, high-producing cows are much more affected than low-producing cows (Sammad *et al.,* 2020b). The dairy cows' physical, metabolic, and physiological processes are activated to mitigate the effects of heat stress and keep the body at a constant temperature (Polsky & von Keyserlingk, 2017; Michael *et al.,* 2022). Most of the changes involve lowering its metabolic rate and increasing the rate at which heat is lost to the environment. Increased respiration rates, rectal temperature, heart rate, panting, drooling, intense sweating, decreased feed intake, and reduced milk production are the reaction of dairy cows to temperatures in TNZ (Roth, 2008; Hempel *et al.,* 2019). Depending on the breed, dairy cows may physically respond differently to heat stress. Compared to Bos taurus cattle, Bos indicus and other tropical breeds are less susceptible to temperature stress (Kadzere *et al.,* 2002; Bilby, 2011). Different breeds of cattle react differently to heat stress because their genes have evolved to cope with different temperatures (El-Tarabany & El-Tarabany, 2015).

The animal cools in several ways, including convection, radiation, evaporation of water, and exhaled air (Dahl, 2020; Brito *et al.,* 2021). At higher temperatures, vaporization replaces radiation and convection as the environment's primary means of heat dissipation. When environmental temperatures rise, a cow's primary evaporative cooling method is thermal sweating. The latent heat of vaporization is the energy needed to turn it into a gas. As external temperatures increase and the temperature variance between the cow and the air decreases, a larger fraction of the cow's metabolic heat is lost by evaporation (Silanikove, 2000; Atrian & Shahryar, 2012).

EFFECT OF HEAT STRESS ON THE NUTRITION AND METABOLISM OF DAIRY COWS

Reduced metabolism in cattle under heat stress was related to decreased thyroid hormone secretion and motility, leading to increased intestinal fullness (Kadzere *et al.,* 2002; Patra & Kar, 2021). High temperatures of 35 °C reduce the plasma concentration of growth hormone and the rate at which it is secreted (Collier *et al.,* 2008; Roushdy *et al.,* 2018). When THI increases to more than 70, growth hormone levels in milk from cows with low, medium, and high production decreases, indicating that growth hormone production was repressed to reduce metabolic heat output (Roushdy *et al.,* 2018). Heat-stressed cows had lower plasma growth hormone levels even when fed the same amount as when not under heat stress (Farooq *et al.,* 2010). During heat stress, the thyroid hormones triiodothyronine (T3) and thyroxine (T4) decrease, which they attributed to efforts to reduce their metabolic heat output (Kadzere *et al.,* 2002; Settivari *et al.,* 2007). Higher levels of adrenaline and norepinephrine in the blood plasma of dairy cows were related to heat stress (Rhoads *et al.,* 1986).

Lactating dairy cows have a total body water content between 75% and 81% of their body weight (Kadzere *et al.,* 2002). The environment, temperature, humidity, dry matter intake (DMI), feed composition, and milk production significantly regulate milk consumption in lactating dairy cows (Gorniak *et al.,* 2014). High-yielding cows have a higher

DMI than low-yielding cows and a positive correlation between DMI and water intake (Huhtanen *et al.,* 2007). HS increases the plasma and extracellular fluid volume to help the stressed cow maintain a stable body temperature (Bernabucci *et al.,* 2010). Cows experiencing HS have a higher rumen water content than usual because their water turnover rate is elevated (Conte *et al.,* 2018). HS reduces blood flow to the epithelium surrounding the rumen and reduces reticular motility and rumination in farm animals (Conte *et al.,* 2018; Meneses *et al.,* 2021). HS increases digesta volume and water content in the rumen, making it more able to act as a pool of water to mitigate the impact of HS on rumen motility (Meneses *et al.,* 2021). Heat-stressed cattle had lower ruminal pH and higher concentrations of lactic acid, which could reduce rumen motility (Yadav *et al.,* 2013). Up to 25% of the body weight of ruminants comes from digesta fill, most of which is produced in the rumen, where the dry matter to water ratio is roughly 1:20 (Van Soest, 2018; Cagle *et al.,* 2019). Increased intestinal fullness can contribute to heat discomfort in high-yielding cattle (Aggarwal & Upadhyay, 2013). HS would limit motility due to its decreased concentrations of VFA in cattle rumens (Conte *et al.,* 2018).

Milk production decreases due to HS because the rostral cooling region of the hypothalamus stimulates the medial center of satiety, which impedes the lateral appetite center (Jose *et al.,* 2020). The decrease in feed intake was the main reason for the observed decrease in milk production. The diet of ruminants can be affected by hormones that regulate their gastrointestinal motility (Aggarwal & Upadhyay, 2013). HS causes a decrease in appetite, which can be associated with fullness in the stomach (Yadav *et al.,* 2013). Lactating cows' feed intake decreases at an AT of 26°C (Kadzere *et al.,* 2002), and this decrease can reach 40% at an AT of 40 °C (Tao & Dahl, 2013). Heat stress reduces roughage intake and rumination in high-yield lactating dairy cows (Han *et al.,* 2019). In addition to consuming less feed, heat-stressed cows alter their feeding regimens to lower their endogenous heat output during the warmest hours. Depending on the degree of dietary fiber, ruminal fermentation contributes between 3 and 8% of the total endogenous heat produced by bovines (Min *et al.,* 2019).

HEAT STRESS EFFECT ON MILK PRODUCTION

Animal performance is frequently inhibited by climatic parameters such as AT, sunlight, RH, airflow, and the relationships between these variables (Habeeb *et al.,* 2018). Dairy cattle have been found to react differently physiologically and productively depending on the type and duration of heat stress they experience. Several studies have found a decrease in milk and fat production as a direct effect of high AT (Binsiya *et al.,* 2017; Habeeb *et al.,* 2018). HS accounted for 3 to 10% of the variation in lactation milk production (Aggarwal & Upadhyay, 2013). The ideal temperature range for lactating cows is 5 to 25 °C, where milk production is at its highest (Kadzere *et al.,* 2002). There may be a 10%-40% drop in milk production if cows are exposed to AT above the maximum limit of their comfort zone (Michael *et al.,* 2022). However, the effect of HS on milk production varies according to the cow's genetic potential to produce milk, the stage of lactation, and the degree of heat. This means that high-producing dairy cows lose more milk than medium- or low-producing cows when HS is present (Bernabucci *et al.,* 2010; Min *et al.,* 2019). When dairy cows are exposed to HS, milk production decreases by 35% in medium-lactation cows but only by 14% in early lactation cows (Bernabucci *et al.,* 2010). HS increases oxidative stress, which changes mammary secretory tissue cell metabolic and molecular activity, decreasing cellular efficiency for synthesizing milk components (Gao *et al.,* 2019).

EFFECT OF HEAT STRESS ON THE REPRODUCTION OF DAIRY COWS

Seasonal high environmental temperatures were associated with the poor reproductive success of dairy cows for many different reasons (De Rensis *et al.,* 2015; Woodroffe *et al.,* 2017). The high AT well above the TNZ of cattle dramatically decreased the conception rate, likely leading to increased embryonic loss (De Rensis & Scaramuzzi, 2003). Selection for milk production led to deficits in thermoregulatory abilities under heat stress. This accentuates the seasonal decline in fertility caused by HS (Wathes *et al.,* 2007). Holstein cows that are estrous in the summer have 4.5 mounts per estrus, while those that are estrus in the winter have 8.6 mounts per estrus (Sammad *et al.,* 2020a). Heat stress decreased peripheral estradiol-17b concentrations in the estrus (Ghosh *et al.,* 2017). When animals were exposed to HS between days 3 and 5 of the estrous cycle, the dominant follicular fluid contained much more androstenedione and significantly less estradiol-17b (Orief *et al.,* 2014). Another reason for the decrease in fertility during summer in hot places was the decline in bull fertility caused by heat stress (Hansen, 2007).

Heat stress also negatively affects early embryonic development and the ovum and sperm in the reproductive canal (Hansen, 2007). Furthermore, heat stress may have altered the hormonal balance of the dam (Ayo *et al.,* 2011). In culture, heat shock from mature bovine oocytes can lead to lower protein synthesis, fertilization rate, and subsequent developmental competence (Nabenishi *et al.,* 2012). The number of cells in bovine embryos flushed from super-ovulated heifers on days 6 or 7 of pregnancy was reduced when they were subjected to heat shock in culture (Nabenishi *et al.,* 2012).

EFFECT OF HEAT STRESS ON THE HEALTH OF THE DAIRY COW

During the warmer months of the year, the prevalence of animal diseases in dairy cows is known to increase for several reasons (De Rensis & Scaramuzzi, 2003; Nardone *et al.,* 2010). Conditions in an environment that range from warm to hot and humid are optimal for the growth of vectors and other disease-causing agents (Kadzere *et al.,* 2002). Warmer summer months in tropical regions see an increase in ticks and other internal parasites, compelling farmers to drench and dip their animals more often than in the cooler winter months (Silanikove, 2000). Heat stress can directly and negatively affect the health of dairy cows and parasite problems that can arise during the warmer months (Silanikove, 2000; Das *et al.,* 2016).

Clinical or subclinical health problems are caused by the impact of HS on the physiological processes of the high-producing cow. 24% of cows who gave birth in the summer retained the placenta and developed postpartum metritis, while this occurred in just 8% of cows during the cooler months of the year (Adnane *et al.,* 2017; Temesgen *et al.,* 2022). The effects of heat stress on dairy cows during the summer were shown to be solely responsible for this difference, which had a significant level. Additionally, cows with retained placenta and postpartum metritis were shown to have longer gestation periods than those without these symptoms (Dubuc *et al.,* 2011). Early pregnancy is linked to the retained placenta and postpartum metritis, which have serious financial implications for dairy producers (Dubuc *et al.,* 2011; Mordak & Stewart, 2015). In certain cases, numerous neuroendocrine changes caused by heat stress can shorten the gestational period (De Rensi & Scaramuzzi, 2003; Khodaei-Motlagh *et al.,* 2011). Compared to the colder months, scorching summer caused 11% greater ketosis in dairy cows (Biswal *et al.,* 2016; Wu, 2020).

POTENTIAL MITIGATION STRATEGIES FOR HEAT STRESS IN DAIRY COWS

Environment management

Environmental management is required in most regions of the world to improve cow welfare and reduce loss of production under harsh temperature conditions throughout the summer (Nienaber & Hahn, 2007). Shade, appropriate air exchange, excellent air movement, drinking water, and evaporative cooling are currently accessible methods to reduce the heat stress of dairy cows (Nienaber & Hahn, 2007; Henry *et al.,* 2018). The installation of fans has been shown to decrease environmental temperatures, alleviate HS, and improve respiratory and rectal temperatures and metabolic rates (Castro-Montoya & Corea, 2021). During the warmer months, air exchanges are required every minute or less to remove moisture, gases, heat, and other contaminants from the animal area. Turbulent airflow around cows increases convective heat transmission, improves evaporation, and eliminates hot patches (Kuczynski *et al.,* 2011). In resting, feeding, and holding facilities, air speeds of 3.5 to 5 miles per hour (mph) are desirable. Water is used in evaporative cooling to promote heat transmission from cows. Because evaporative cooling systems include the introduction of water into the air of the animal area, ventilation systems with adequate air exchange are required to remove moisture-laden air and circulate fans to accelerate evaporation (Adin *et al.,* 2009).

Providing cows with self-controlled showers offers cooling on an individual animal basis while reducing group water use (Polsky *et al.,* 2017). Physical constructions that provide shade, such as trees, roofs, or fabrics, can provide more favorable microclimates for cows due to the decrease in exposure to solar radiation and AT. Cow body temperature and respiration rate are reduced when protected from direct sun exposure (Polsky *et al.,* 2017; Heras-Molina *et al.,* 2020). However, depending on the climatic conditions, dairy cows have various preferences for a shade structure, which should be addressed when developing farm heat abatement options (Tucker & Schütz, 2009). Although cattle prefer natural shade, livestock shading can be achieved using trees, buildings, or mobile constructions. By decreasing insolation and surface temperature and improving heat conduction from the cow's body to the environment, barn orientation may also help alleviate HS (Angrecka & Herbut, 2016).

Feeding management

Heat stress affects several systems in cows, including feeding and digesting, milk production, and reproduction (Atrian & Shahryar, 2012). Fortunately, there are a variety of strategies to help cows cope with heat stress, including nutrition assistance. The reduction in feed intake caused by heat stress can be mitigated partly by boosting the metabolizable energy (ME) ratio and the density of nutrients (Atrian & Shahryar, 2012). The maintenance needs for ME increases by 10-15% at 85-105°F compared to 65-70°F because heat dissipation requires more energy (Early, 1998). Feeding protein-deficient diets increase the heat burden on cows due to increased heat output from tissue protein metabolization (Forbes, 2007). Supplemental protein can help reduce heat stress and improve dry matter intake (DMI) under heat stress. Because bypass fats do not affect rumen fermentation, they are an excellent alternative to increasing total fat in feed during hot weather (Shwartz *et al.,* 2009).

In hot weather, increasing the frequency of feeding has been shown to minimize heat production and equalize nutrient absorption by spreading the total increase in heat caused by feeding and digesting over a longer period. It may also help to maintain constant rumen fermentation by helping the digestion of greater concentrates without lowering the pH of the rumen or the acetate-propionate ratio (Kaufman, 2016). The peak generation of heat from digestive activities occurs around three hours after consumption by cows. Feeding cows earlier in the morning and later in the evening than usual could help them reach these peaks during the colder periods of the day (Mader *et al*., 2010). Cool, clean, easily available, free choice water is critical for helping cows cope with heat stress (Aublet *et al.,* 2009; Mader *et al*., 2010). To increase fiber intake and maintain optimal rumen activity, provide high-quality feed to your highest-yielding cows under the greatest stress. Reduce the amount of starch in food and increase the fat content to maintain energy to reduce the heating impact of fermentation on the rumen. To best meet farm objectives, choose the most suitable form of fat supplement according to the fatty acid composition of the supplement (Moran, 2005; Knapp *et al.,* 2014). Increasing the pH of rumen, yeast, and rumen buffers can help reduce the danger of acidosis (Humer *et al.,* 2018).

Supplementation of vitamins, minerals, and electrolytes in diets

When cows are stressed by heat, their potassium loss increases five times due to perspiration (Kadzere *et al.,* 2002). Concentrates are often potassium-deficient; therefore, potassium supplementation is required in the diet of dairy cows when concentrate feeding is increased (Soetan *et al.,* 2010; Wilhelm-Olany, 2019). Sodium supplementation is recommended, as heat-stressed cows excrete more sodium through their urine. Due to their buffering capabilities, dietary bicarbonates (HCO3) can also be beneficial (Mader *et al.,* 2010; Kundu *et al.,* 2013). Adding buffers to ration concentrates provides rumen-calming support, with a recommended dose of approximately a third-pound buffer to 45 pounds DMI. Trace minerals such as Mn, Zn, Mo, P, and Se have improved metabolic state and general health (Bicalho *et al.,* 2014). B-complex vitamins, ascorbic acid, vitamin E (tocopherol), rumen-protected niacin, and nicotinic acid are all useful (Taniguchi *et al.,* 2006). Thiazolidinediones (TZD) can increase glucose use and energy breakdown and maybe a beneficial therapy during HS (Taniguchi *et al.,* 2006; Schoenberg & Overton, 2011). Dietary betaine, such as TZD, can be a preferable alternative in heat-stressed nursing cows (Wang *et al.,* 2019). Chromium supplementation has also increased energy metabolism and output in heat-challenged nursing cows (Knapp *et al.,* 2014; Bin-Jumah *et al.,* 2020). In animals, niacin (vitamin B3) has been shown to increase vasodilation and lipid metabolism. Niacin reduces the effects of HS and increases metabolism in nursing dairy cows (Panda *et al.,* 2017). Niacin at 6g/cow/day is recommended to lower skin temperature and increase milk production. Heat stress depletes vitamin C levels in plasma and tissue; therefore, supplementation may be necessary (Dos Santos *et al.,* 2019; Bin-Jumah *et al.,* 2020).

Selection for heat tolerance

Cattle suffering from heat stress can be helped with shade structures, fans, and sprinklers (Moran, 2005). However, this might not be a viable option in the prevalent pastoral systems in many nations. Furthermore, the modification of its environment and its management as a mitigation strategy for heat stress in dairy cows is temporary. Dairy cows produce less milk when temperature and humidity exceed a specific threshold, and genetics correlate with the degree to which milk production drops. Different authors have shown that the degree to which milk production decreases in response to increased HS differs between animals and is only a weak to moderately heritable trait (Ravagnolo *et al.,* 2000; Bernabucci *et al.,* 2014). Rectal temperature and the rate at which milk production drops in hot weather are two measures of heat tolerance in dairy cattle that can be influenced by selective breeding due to their low (0.1) to moderate (0.3) heredity (Ravagnolo *et al.,* 2000; Dikmen *et al.,* 2012; Nguyen *et al.,* 2016). Given the size of the estimated heritability, genetic selection for resistance to HS may be feasible. Increasing the temperature tolerance would be an additional tactic with long-lasting results. To breed dairy cows that are more heat tolerant and have a smaller decrease in milk production during heat stress conditions, breeding values for heat tolerance in dairy cattle must be determined (Dikmen *et al.,* 2012; Nguyen *et al.,* 2016).

Genes involved in heat tolerance

The degree to which dairy cattle handle high temperatures depends on genetics and physiology. According to genomic research, certain areas of the genome appear to be significant in controlling body temperature in dairy cattle, suggesting that heat tolerance is a quantitative trait impacted by multiple regions of the genome (Nguyen *et al.,* 2016). The slick hair gene in cattle is one of the most significant thermotolerant genes discovered to date. A dominant gene called the slick hair gene produces animals with extremely short and smooth hair (Huson *et al.,* 2014). There was a significant difference between respiratory rate, sweat rate, vaginal temperature, and rectum temperature of slick and normal-haired Holstein cattle (Dikmen *et al.,* 2014). One reason why slick-haired animals can better regulate body temperature is an increased sweating rate (Dikmen *et al.,* 2008). Holsteins with slick hair have a greater thermoregulatory capacity than animals with non-slick hair, and their milk production decreases less dramatically over the summer. During heat stress, smooth-haired Holstein cows can control their body temperature more successfully than wild-type cows (Dikmen *et al.,* 2008; Dikmen *et al.,* 2014).

The Slick gene has been identified as a significant candidate gene that affects hair length and controls heat tolerance in Bos taurus cattle (Olson *et al.,* 2003). Huson *et al.* (2014) identified a consensus area for the SLICK locus on *BTA20*, including *SKP2* and *SPEF2* as probable candidate genes. Dikmen *et al.* (2013) reported that *BTA24* is the main genomic region associated with rectal temperature. Other SNPs associated with RT were located in *BTA16, BTA5*, *BTA4*, and *BTA26*. Macciotta *et al.* (2017) also detected *BTA26* as a genomic region associated with milk production under HS conditions. Luo *et al.* (2021) identify *FAM107B* and *PHRF1* as the main candidate genes that influence the response of dairy cattle to heat stress. Among the 200 differentially expressed genes found by Liu *et al.* (2020), several were associated with heat tolerance and can be used for the Marker Assisted Selection Program to improve heat tolerance and minimize loss of production in dairy cows. These genes include *IGFB2*, *OAS2*, *MX2*, *IFIT5*, *FGF2*, *ALAS2*, *AOX1*, *SCT*, *TGFB2*, *BPI*, *GPX2*, *EGF*, and *IFIT2*. Cheruiyot *et al.* (2021) identified specific potential variations and genes associated with the nervous system (*ITPR1*, *ITPR2,* and

GRIA4) and neuroactive ligand-receptor interaction activities for heat tolerance (*NPFFR2*, *CALCR*, and *GHR*). Grisart *et al.* (2004) identified the substitution of non-conservative lysine into alanine (*K232A*) in the *DGAT1* gene, which was projected to be the nucleotide of causative quantitative traits underlying a quantitative trait locus) that affects milk fat composition. Littlejohn *et al.* (2016) discovered that the percentage of milk fat and other traits related to milk compositions are strongly influenced by a group of 17 non-coding variations throughout *MGST1*. Carvalheiro *et al.* (2019) found evidence linking *REG3A* and *REG3G* to the sensitivity of beef cattle to adverse conditions. Zeng *et al.* (2018) suggested that the two mutations of the *PRLH* and *SOD1* genes in Chinese cattle were associated with heat tolerance.

Deng *et al.* (2010) postulate that *EIG121* is connected to endosome-lysosome compartments and may play a crucial role in autophagy. *EIG121* may protect cells against cell death under adverse circumstances, such as starvation and exposure to cytotoxic chemicals, by upregulating the autophagy pathway. Sigdel *et al.* (2019) reported that at least three distinct genomic regions in *BTA5*, *BTA14*, and *BTA15* were shown to be highly correlated with milk production in the face of heat stress. Such areas contain potential genes, including (*HSF1*, *MAPK8IP1*, and *CDKN1B*), that are directly involved in the cellular response to heat stress. Zamorano-Algandar *et al.* (2021) reported that three SNPs in *AVPR1A*, *PRLR,* and *SSTR2* were related to the opening day, while five SNPs in *IGFBP2*, *IGFBP5*, *PRLR*, *PIAS1*, and *SSTR2* were shown to be related to the pregnancy rate in Holstein cattle. Hernandez-Cordero *et al.* (2017) identified seven SNPs within seven genes (*AVPR1A*, *Furin*, *IGFBP5*, *IGFBP6*, *PMCH*, *PRLR,* and *STAT5B*) that were found to be related to milk yield in heat-stressed Holstein cows.

Genomic selection

Genomic selection is an attractive option because it enables the selection of young bulls (and heifers) based on heat tolerance to GEBV and other traits (Figure 2). A heat tolerance selection program should aim to breed more resilient dairy cattle (Nguyen *et al.,* 2016). Milk production and conception rates naturally drop in summer, but this decline can be mitigated by selective breeding to tolerance to heat (Sammad *et al.,* 2020a). For dairy bulls, commonly chosen for breeding based on GEBV rather than progeny testing, heat tolerance is necessary if such a trait should be considered. Since most young dairy bulls have already been genotyped, the comparative cost of extra GEBV is relatively cheap, making adding a GEBV for heat tolerance even more advantageous. Subsequently, the frequency of occurrence is expected to increase, and it will be crucial to accelerate the heat tolerance breeding process in specific dairy regions to adapt to future climates (Chang-Fung-Martel *et al.,* 2017). To determine estimated genomic breeding values (GEBV) for heat tolerance, Nguyen *et al.* (2016) used only genotyped sires in the reference set and only first-parity data to achieve precision for heat tolerance with changes in milk, fat, and protein yields of 0.48, 0.50, and 0.49 in Holstein validation sires and 0.44, 0.61, and 0.53 in Jersey validation sires. Gene expression breeding values (GEBV) for heat tolerance were positively correlated with fertility (0.29-0.39 in Holstein and 0.15-0.27 in Jerseys) but negatively correlated with several productivity traits. On the other hand, selection might result in cows with less resistance to cold. Therefore, before introducing heat tolerance into dairy cattle selection criteria, it is necessary to examine the negative correlations between heat tolerance and other economically important traits (Osei-Amponsah *et al.,* 2019).

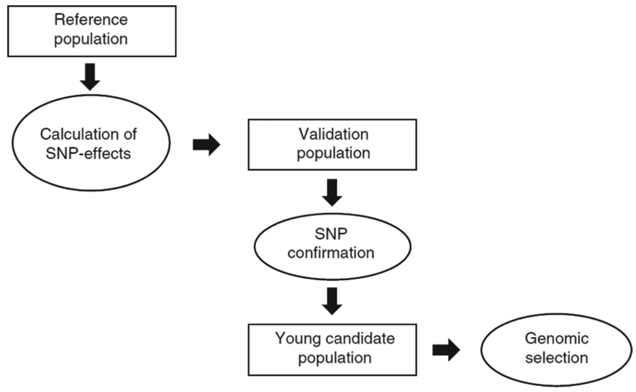

Figure 2: Schematic illustration of population and genomic selection (Calus *et al.,* 2013)

Creating a reference population of genotyped animals exhibiting heat tolerance phenotypes, the choice of the phenotypic itself, and the model used to incorporate genomic information pose the most hurdles in building a GEBV for heat tolerance (Osei-Amponsah *et al.,* 2019). When considering the phenotype to select, some studies have combined test day records for milk yield traits with THI as a measure of heat load to assess heritable components of heat tolerance (Bernabucci *et al.,* 2014; Nguyen *et al.,* 2016). Animal thermal adaptations and performance can be evaluated using several methods, including monitoring changes in internal body temperature and THI. The drop rate in milk production related to variability in response to HS was first measured using daily milk yield and temperature-humidity data (Ravagnolo *et al.,* 2000). Due to the availability of large datasets from regular recordings on dairy farms, this approach has been widely used (Nguyen *et al.,* 2016). Since heat stress is already a part of dairy cattle breeding programs in several regions of the world, much work has been put into finding breeding solutions. As THI increased above a thermoneutral threshold, Ravagnolo *et al.* (2000) found that heat tolerance exhibited an increase in additive genetic variation. Another theory suggests that the variation in heat tolerance increases with each consecutive lactation (Aguilar *et al.,* 2009; Bernabucci *et al.,* 2014). Protein production in Australian dairy cattle decreased to a THI of 60. Reduced milk production can be used as heat tolerance since it is easily collected on a massive scale by integrating data from weather stations and herd recording systems. For practically all genotyped sires, this allows us to calculate the daughter trait deviations (DTD) for the trait in question, paving the way for building a large reference population to calculate GEBV (Nguyen *et al.,* 2016).

CONCLUSIONS

The negative consequences cause hyperthermia, oxidative stress, and other physiological changes in dairy cows. These cause a decrease in feed intake, leading to a decrease in milk production in dairy cows. The main method to check for reductions in milk production in dairy cows during the summer is an accurate assessment of HS and effective mitigation strategies. Three primary management strategies have been proposed to reduce HS and stabilize the performance of dairy cattle in increasingly hot and humid climates. Short-term management options include physical alteration of the environment and nutritional management, while long-term management strategy includes a genomic selection for heat tolerance.

Therefore, it may be possible to prevent substantial economic losses caused by heat stress by identifying certain genes or gene markers associated with heat tolerance and the genomic selection of animals with such genes. Ultimately, examining the negative correlations between heat tolerance and other economically important traits is necessary before introducing heat tolerance into dairy cattle selection criteria.

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