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Review
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PHYSIOLOGICAL AND PHYSICAL RESPONSES OF DAIRY CATTLE TO HEAT STRESS

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Abstract: Herd management and nutrition strategies against increasing negative effects of global warming on farm animals have been the subject of significant debates in recent years. The fact that the changes in the environmental conditions are directly related to the habitats of the animals and the conditions inside the barn can affect the farm animals negatively. Although effects of heat stress differ according to species, especially high-yielding dairy cattle exposed to heat stress, respond with various interactive mechanism such as physiological, biochemical, immunological, anatomical and behavioral. Therefore, with the selection practices that have been going on for many years to improve the yield characteristics of the animals significantly increased. In this respect, the increased heat load in the body of dairy cattle due to the high productivity decreases their tolerance to environmental conditions. This situation adversely affects the productivity of cows with high breeding value. Yield losses, varying according to some factors about heat stress, can be partially explained by decreasing feed intake as a result of a series of hormonal responses affecting appetite center. However, the physiological requirements of cattle must be defined in order to develop appropriate strategies to reduce or eliminate the negative effects of heat stress. In this review, the variations in physiological, biochemical and behavioral mechanisms originating from heat stress in dairy cattle and the care, nutrition and herd management strategies that can be applied to eliminate or reduce the negative effects were discussed.

Keywords: Dairy cattle, Care, Heat stress, Herd management, Nutrition

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1. Introduction

The world is experiencing changes that will affect both local and global agriculture due to global warming in this century (Nardone et al., 2010). Climate change, which is a result of global warming, generally increases the temperatures and the severity of drought throughout the world (Berman, 2019; Cheng et al., 2022). Therefore, the effects of heat stress on animals have been more controversial than cold stress (Cheng et al., 2022).

The variations in environmental conditions, which are directly related to the habitats of animals and conditions in the barn, may adversely affect the economic viability and sustainability of animal production systems (Sejian et al., 2018; Collier et al., 2019). In addition, the yield traits of farm animals have significantly increased with the selection practices. This improvement in the productivity of the animals created a large internal heat strain and increased their sensitivity to high temperatures (Van laer et al., 2014; Sammad et al., 2020). In particular, the high-yielding cows such as Holstein, have a significant metabolic rate and cannot maintain thermal balance in hot conditions (Veissier et al., 2018; Collier et al., 2019). This situation adversely affects the growth, reproductive performance, milk yield and quality, immunity, metabolic and health conditions of cattle (Figure 1). Since it is a very difficult and long process to improve the genetic structure of farm animals in order to reduce this sensitivity to high temperatures, there has been a trend towards improving environmental conditions and feeding management (Collier et al., 2019). For this reason, every detail maintains its importance in understanding the negative effects of heat stress on animals and determining the steps to be taken to improve these conditions. This review has been prepared in order to find out the mechanisms of cattle against heat stress, to facilitate the improvement of environmental conditions and nutritional management.

2. Seasonal Factors and Stress

The effects of environmental conditions (care, nutrition and seasonal factors) on farm animals are numerous and the effect of these conditions has a complex structure (Öten et al., 2004; Alkoyak and Çetin, 2016). Season is an important environmental factor influencing welfare and performance in dairy cattle (Alkoyak and Çetin, 2016; Koç and Uğurlu, 2019; Pinto et al., 2019). In particular, temperature and humidity are the most important factors determining the heat exchange between the body and the environment of animals, and microclimate factors such as air movement and solar radiation are also important climatic stress factors (Herbut et al., 2019). Therefore, among the climatic environmental factors, especially temperature, humidity and wind speed should be at optimum level (temperature 13-18 °C, humidity 60-70%, wind speed 5-8 km/h and moderate solar radiation) (Işık et al., 2016). The dairy cows are more productive among various temperatures, which are considered the 'thermal neutral zone' (TNZ) (Herbut et al., 2019; Collier et al., 2019). When animals are exposed to conditions out of the TNZ, they are able to maintain normal body temperatures against changing temperature within certain limits. However, if ambient temperature moves to more extreme limits, it creates a significant stress factor on the animals (Alkoyak and Çetin, 2016; Işık et al., 2016).

The critical temperatures affecting dairy cows vary according to the age and physiological state of the animals. It has been reported that lower and upper limits of these values are 13 – 26 ˚C, -5 – 26 ˚C, -14 – 25 ˚C and -25 – 25 ˚C for calves drinking milk, growing calves between 50 and 200 kg, dry pregnant cows and the cows in the peak period of lactation, respectively (Collier et al., 2019). As the temperature moves from denoted values to more extreme limits, the metabolism of the animal tries to adapt the changing climate conditions through different adaptive mechanism such as genetic adaptation, physiological adaptation and acclimation to the environment (Ratnakaran et al., 2017). While ruminants can maintain physical balance by increasing feed intake when exposed to cold stress, they cannot maintain this balance at high temperatures this is why the effects of heat stress are mostly emphasized (Durmuş and Koluman, 2019). Cattle adapt to the environment or climate for approximately 2 to 7 weeks when exposed to heat stress (Kamal et al., 2018). However, cattle have difficulties for removing the excess heat accumulation at prolonged high temperatures. This situation creates an important stress factor on animals and affects whole metabolism. The level of arousal in the metabolism of the animals varies according to the duration and intensity of the stress source, as well as the physiological state of the animal and its experience against stress (Ratnakaran et al., 2017; Sejian et al., 2018; Herbut et al., 2019).

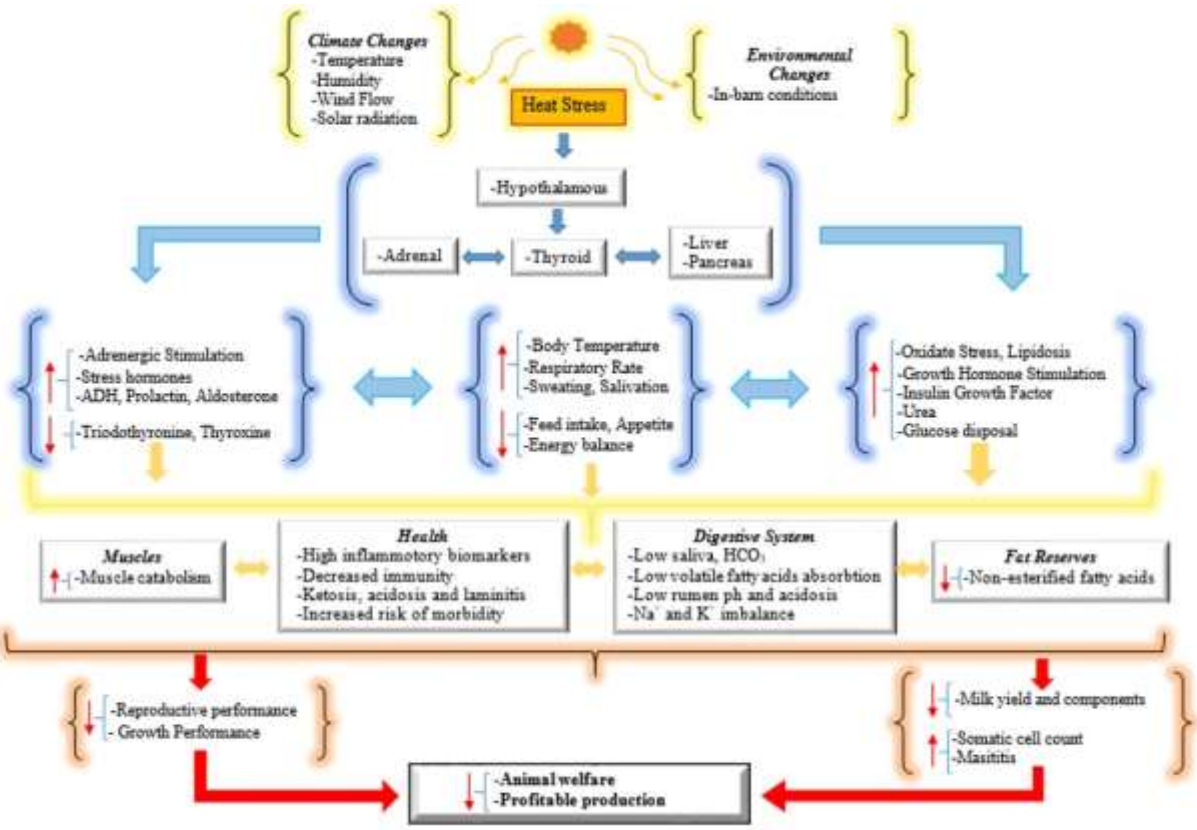

Figure 1. Summary of physiological and biochemical changes due to heat stress in the body of dairy cows. Adapted from Sammad et al. (2020).

3. Physiological Thermal Regulation

The neural process connecting the information from the internal and external thermal environment of the animal until an appropriate response is given that allows the formation of a stable internal environment according to the changing external environment is defined as 'Thermal Regulation' (Collier et al., 2019). In this process, cellular metabolism and endocrine system activity are directly regulated and the connection between the external environment and cellular metabolism is provided. In cattle exposed to environmental stress, peripheral circulation controlled by the hypothalamus aids in heat dissipation from the skin surface through vasodilation (widening of the vessels, reducing blood flow velocity and lowering blood pressure) and perspiration (Idris et al., 2021). These physiological responses are replied by the central nervous system, peripheral nervous system and endocrine components (Charmandari et al., 2005; Niyas et al., 2015; Collier et al., 2019).

The dairy cows respond to stress in two stages (acute and chronic). Acute and chronic stress are controlled by the 'Sympathetic-Adrenal-Medullary (SAM)' and 'Hypothalamus-Pituitary-Adrenal (HPA) axis', respectively (Pehlivan and Dellal, 2014; Bagath et al., 2019). The acute stress responses are short-term (from a few minutes to a few days), and cattle can adapt with short-term physiological adaptation events such as drinking more water, increasing respiration and sweating to reduce the heat load on the body (Idris et al., 2021). The response to these stressors begins via thermal receptors in the skin and hypothalamus that respond to environmental changes. The collected stimuli for perception of stimulants are transmitted to the thalamus, hypothalamus and central nervous system. These centers then respond in various ways to generate a response to the environment. The acute response to environmental stress is mediated by the autonomic nervous system, which increases the release of catecholamine and glucocorticoids, altering metabolism (Collier et al., 2019).

The release of adrenaline or noradrenaline hormones secreted from the adrenal medulla is stimulated during acute stress. This process activates or initiates a series of physiological response in order to create the necessary reaction against stress by using the reserves of body and to provide physical balance (Altınçekiç and Koyuncu, 2012). This set of physiological responses results in elevation of the pulse, blood pressure, respiratory rate, and blood sugar, as well as suppression of certain anabolic events (digestion, reproduction, growth and immune system) (Farooq et al., 2010; Pehlivan and Dellal, 2014; Niyas et al., 2015).

When short-term adaptation pathways fail as a result of prolonged environmental stress, body temperature significantly increases. Against such stressors, animals often show signs such as increasing pulse and sweating rate and standing. Therefore, feed intake is reduced, resulting in yield losses (Idris et al., 2021). In this case, the restoration of homeostatic and physical balance achieved through HPA. The HPA, having more general effect on the animals, appears more slowly than SAM response. Stress perceived by the central nervous system initiates this sequence of responses with the secretion of corticotropin-releasing hormone (CRH) by the hypothalamus. The CRH stimulates the releasing of adrenocorticotropic hormone (ACTH) from the anterior pituitary lobe, and the release of glucocorticoids increases with stimulation of the adrenal cortex (Altınçekiç and Koyuncu, 2012; Pehlivan and Dellal, 2014). Increasing glucocorticoids as a result of the interactions of these hormones play an important role in initiating physiological responses to balance the effect of heat stress. In particular, the heat has a significant effect on carbohydrate, lipid, mineral and protein metabolism to increase blood glucose levels during stress. This interaction is in the direction of providing the energy needed by the body cells and tissues by obtaining glucose from carbohydrates and non-carbohydrate sources (Durmuş and Koluman, 2019).

The cortisol production during acute stress plays an effective role in stimulating the immune system, while cortisol secretion in chronic stress suppresses the immune system (Bagath et al., 2019). The long duration of heat stress and the continuous release of glucocorticoids secreted from the adrenal cortex of the adrenal glands may result in the emergence of many problems such as metabolic disorders, digestive system diseases, slowing of the immune system, suppression of reproduction and growth (Altınçekiç and Koyuncu, 2012; Durmuş and Koluman, 2019). Activities at the cellular level in response to the acute stress stage include homeostatic endocrine, physiological and metabolic responses, while in the chronic stage it includes reprogramming of metabolism by gene expression (Collier et al., 2019).

4. Heat Stress and Behavior

The first response of cattle to environmental changes in their habitat is behaviorally. When cattle are exposed to high temperatures, they show numerous behavioral responses to reduce the heat load. In response to environmental variations, cattle change their behavior to cope with the current situation. Therefore, behaviors provide an idea about the reaction of the animals to the environment (Tölü and Savaş, 2006; Schütz et al., 2010).

In addition to the ambient temperature, solar radiation, airflow and relative humidity in the unshaded areas of the barn affect the formation of heat stress. In particular, solar radiation contributes directly or indirectly to heat load on cattle (Kamal et al., 2018), prompting cattle to seek shade or other cooling structure (Allen et al., 2013; Herbut and Angrecka, 2018).

Seeking for shade or cooling structures is the fastest behavior in cattle, and they try to improve the negative effects of heat load by using shaded areas they can reach (Sejian et al., 2018). Therefore, the most important way to reduce the effects of heat stress is to be protected from solar radiation with well-designed shades (West, 2003). However, in environments where there is no shade or shelters, cattle can respond to heat stress by spending more time around the drinkers (Schütz et al., 2010). In addition, Schütz et al., (2010) reported that cattle with access to more shade also had less physiological (lower respiratory rate) and behavioral responses (spending less time around drinkers) to heat. Although shade is known to be beneficial for dairy cows Correa-Calderon et al., (2004) stated that fan and sprinkler (sprinkler system) are more effective than shade in reducing heat load. It was determined by Correa-Calderon et al., (2004) that body temperature and respiratory rate of Holstein and Brown Swiss cows, meeting the need of cooling only with shaded areas in summer, are higher than those that are cooled with a sprinkler or fan. However, in the study conducted by Schütz et al., (2011) emphasized that the fountain is more effective in reducing heat load, but the animals prefer to use shade in summer. For this reason, when planning shelters, it is thought that creating sufficient shaded areas for animals and designing suitable cooling systems will provide advantages in terms of production as well as reducing heat stress.

The dairy cows rest or lie down for approximately 8 to 16 hours a day (Tucker et al., 2003; Endres and Barberg, 2007; Herbut and Angrecka, 2018). Sufficient rest of dairy cows provides many benefits such as increased blood flow, rumination and milk yield and reduced fatigue stress (Uzal, 2008). However, the sleeping time of animals may decrease due to various stress factors (Uzal, 2008, Ratnakaran et al., 2017). In particular, high temperature increases the standing time of cows (Sejian et al., 2018). This behavior is aimed at maximizing evaporative heat loss from the body surface by standing longer to reduce conductive and radiant heat from the hot surface (Ratnakaran et al., 2017).

The water is the essential nutrient that helps transferring heat from the body to the environment during heat stress (Pereyra et al., 2010; Ratnakaran et al., 2017). The water consumption has a high correlation with milk yield and dry matter consumption (0.94 and 0.96, respectively) (Dado and Allen, 1994). Although there are some equations for calculating, water requirements of ruminants are expressed as 3-4 times the amount of dry matter consumed (Schlink et al., 2010). The increase in breathing and sweating activities of cows faster than normal under heat stress conditions causes an increase in water loss and water consumption (Yavuz and Biricik, 2009). The inability of ruminants to consume as much water as they need has an effect on the decrease in dry matter consumption, which is attributed to heat stress and explained as a result of some hormonal responses. The high temperatures affect the water consumption behavior of dairy cows (Pereyra et al., 2010) and increase water intake (Veissier et al., 2018). In a study by Laínez, and Hsia, (2004), it was determined that the water drinking habits of dairy cows vary according to the season and environmental temperature.

In the study, it was stated that cows drink water during the hottest times of the day in winter while they drink water during the coolest times in summer. In addition, significant increases were observed in the water drinking behavior of the cows after milking and feeding times (Laínez and Hsia, 2004). Similarly, Ratnakaran et al., (2017) emphasized that cows consume about 30-50% of their daily water intake within one hour after milking. In this context, it is important to provide fresh water sources that can be easily accessed by all the cows in the barn and that can meet the water requirements of the animals continuously, in terms of reducing the effects of heat stress.

Advances in technology have allowed image analysis systems, electronic animal recognition systems, pedometers, position sensors and other technologies to be combined with herd management systems (Uzmay et al., 2010; Helwatkar, et al., 2014). These developments have made it possible to determine the activities or behaviors of dairy cattle in the barn, to evaluate the nutrition, welfare and comfort status, to determine the sources of environmental stress and to take preventive health measures (Mattachini et al., 2013; Ratnakaran et al., 2017; Knight, 2020). In particular, the effective use of activity meters (feeding, lying, standing, drinking water, number of daily steps and other behaviors) in controlling the stress factors caused by environmental factors in farms with large herds will be beneficial in terms of profitability.

5. Heat Tolerance and Genes

In studies conducted with dairy cows, it was reported that (Dikmen et al., 2012; Howard et al., 2014) many regions on the genome associated with regulation of body temperature (thermotolerance) were detected. The same researchers emphasized that many genes play an active role in body weight and feed intake, apoptosis events, protein events (HSPH1, TRAP1), calcium ion and protein binding, and the initiation of physiological and metabolic events such as insulin stimulation against the temperature stress of animals. Depending on the amount of heat stress, the increase in the expression of heat shock proteins (HSP) has an effective role in protecting the animal against hyperthermia and circulatory shock (Rout et al., 2018). In this context, HSPs are expressed as highly conserved stress proteins playing an important role in environmental stress tolerance and adaptation in response to stress (Kumar et al., 2015). The HPSs, which are found in all large cells and essential for cellular viability, have molecular sizes between 10-150 kDa. The HSP70 protein, an important member of HSP family, is used as a significant indicator and molecular marker of adaptation to harsh environmental stress, since it is the most excitable protein against environmental stress among all HSPs. This protein has a variety of functions, such as resistance to stress and disease, protecting living cells and ensuring their survival (Patir and Upadhyay, 2010; Habib, 2020). In addition, the HSP70 protein is used as a selection parameter in developing of heat stress resistant breeds in cattle. Therefore, this review focused on the 'HSP70' protein. Such markers play an important role in evaluating the stress adaptation mechanism of farm animals. In addition, the constant change of the climatic environment is a major concern, and the identification and use of genotypes resistant to heat stress reveals the impact on livestock productivity (Archana et al., 2017).

6. Stress and Nutrition

As it is known, heat stress negatively affects the basic physiological mechanism in the rumen of cattle and increases the risk of health problems (Nardone et al., 2010; Yue, et al., 2020). In normal conditions, the frequency of the cows going to the manger varies between 12 and 15 times a day, but in the presence of heat stress, the frequency of going to the manger decreases rapidly (3-5 times a day) (Sammad et al., 2020). Feed intake in ruminant animals starts to decrease when the temperature rises above 25-26 °C, and when it rises above 30 °C, it is much sharper (Cheng et al., 2022) and decreases rapidly and the total decrease in feed intake at 40 °C can reach to 40 % (NRC, 1989). Depending on the severity of the negative energy balance, which is the result of this situation, decreases are observed in body weight and body condition score (Yue et al., 2020). Therefore, heat stress causes a series of hormonal responses affecting the appetite region, thus reducing feed consumption and performance (Albright and Alliston, 1972).

Decreases in production and reproductive performance caused by heat stress can be partially explained by decreased feed consumption, but hormonal imbalance, decrease in rumination and nutrient absorption and increased survival rate and nutrient requirement should also be considered (Collier et al., 2005; Baumgard and Rhoads, 2009). Heat stress, which occurs as a result of body temperature leaving the comfort zone, can also occur as a result of being exposed to high temperatures as well as excessive movement. It is thought that a better understanding of this mechanism may support the development of nutrition strategies to eliminate the negative effects of heat stress on ruminant animals (Min et al., 2017). The physiological sequence of events caused by heat stress on ruminant animals is summarized in Figure 2.

The previous studies report that rumination decreases under dehydration and heat stress conditions (Aganga et al., 1990; Soriani et al., 2013). It is also known that the blood flow in the rumen epithelium is reduced. Numerous studies have shown that heat stress suppresses volatile fatty acid production in the rumen (Tajima et al., 2007; Nonaka et al., 2008). While some studies state that the decrease in feed consumption due to heat stress increases nutrient digestibility (Christopherson, 1985; Nonaka et al., 2008) there are many studies stating contradictory results. It is thought to be due to the fact that less digestive content passing through the digestive tract may have an effect on nutrient digestibility.

When ruminant animals are exposed to heat stress, negative energy balance is usually inevitable (Kaufman et al., 2017), the energy taken with feed consumption cannot meet the energy requirement, the low level of insulin in the bloodstream triggers the breakdown of fats, enabling the fatty acids stored in the adipose tissue to be used for energy purposes (Bell, 1995). Afterwards, as a response to adaptation to low feed intake caused by heat stress, blood insulin level rises again with some changes in carbohydrate, fat and protein metabolism (Rhoads et al., 2009). Although the reasons for the increase in the insulin level are not fully known, it is known that the increased insulin level prevents the conversion of muscle and adipose tissue glucose into the blood, which will be used to convert into efficiency under heat stress conditions (Wheelock et al., 2010; Kaufman et al., 2017).

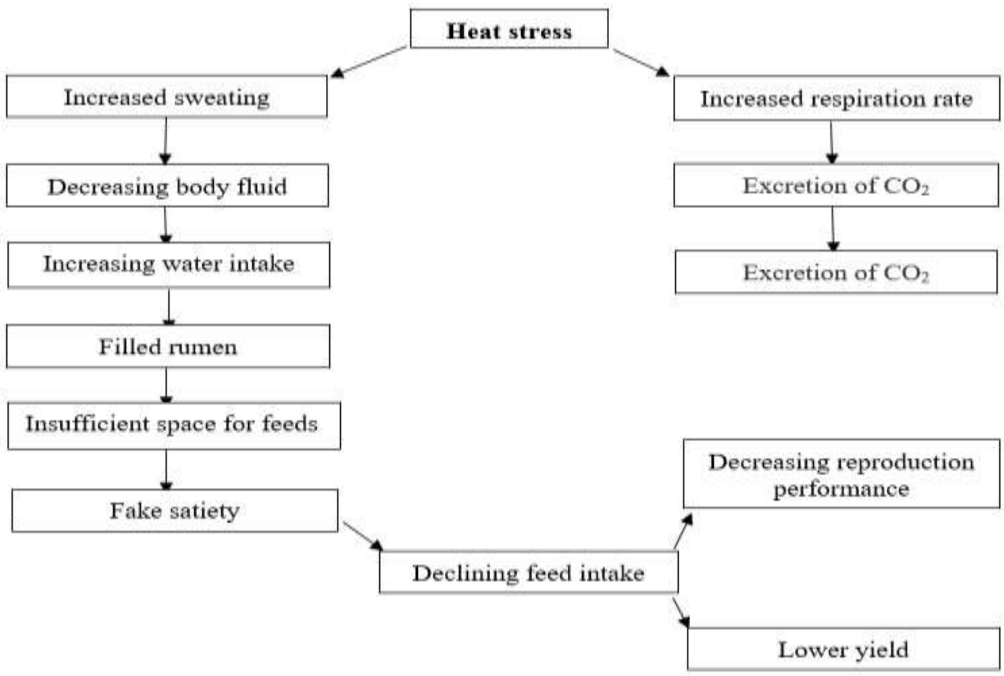

Figure 2. Physiology of ruminants under heat stress conditions (Atrian and Shahryar, 2012).

7. Reproduction

In dairy cows, it is possible to produce milk at an optimum level and to ensure sustainable production conditions by produce one calf per year. In this context, timely and accurate detection of estrus signs of cows is essential for creating profitable breeding (Arı, 2015). When dairy cows are exposed to heat stress, low fertility can be observed because the synthesis of proteins and hormones associated with reproductive organs is suppressed, as well as affecting tissue and organ functions (Liu et al., 2019; Durmuş and Koluman, 2019). The dry matter intake in cows under heat stress decreases rapidly, leading to a negative energy balance. This situation prolongs the negative energy balance period with birth, and therefore insulin, glucose and IGF-I levels in the blood decrease. The decrease in insulin, glucose and IGF-I levels, which are necessary for folliculogenesis, results in disruptions in follicular development, poor oestrus detection and formation of low quality oocytes (De Rensis and Scaramuzzi, 2003).

During acute stress in cows, a decrease is observed in the level of Gonadotropin Releasing Hormone (Gn-RH) secreted from the hypothalamus. The suppression of the synthesis of the Gn-RH hormone indirectly affects the release of Luteinizing Hormone (LH) negatively. This sequence of hormonal interactions can result in delayed release of maturing follicles or absence of ovulation. However, in the case of chronic stress, due to the decrease in the level of estradiol secreted from the follicle, since the ovaries of the animal are directly affected (Sammad et al., 2020), estrus behaviors may be vague or not observed (Arı, 2015). In addition, the physiological events affecting the ability of animal to maintain thermal balance against the heat stress may cause hormonal disruptions and embryonic deaths in the uterine (Cheng et al., 2022). Therefore, service period, calving interval, insemination number per pregnancy, pregnancy rate and reproductive efficiency, which are accepted as important indicators of herd management are also negatively affected (Durmuş and Koluman, 2019). However, Cheng et al., (2022) emphasized that male animals may also experience significant reductions in semen quality and sperm count.

8. Milk Yield Traits

The most important known adverse effect of temperature and humidity on lactating cows is the decrease in milk yield. An index called Temperature-Humidity Index (THI) is used in order to reveal the effects of heat stress in dairy cattle and to control these stress sources in the environment where the animals live. It is considered by many researchers (Yue et al., 2020; Tao et al., 2020) to be an important indicator used to evaluate heat stress in dairy cows. The significant losses in milk yield can be observed when the THI exceeds 68 (Tao et al., 2020). Bouraoui et al., (2002) reported that the milk yield (18.73±0.18 kg) in the spring (mean THI=68) of Holstein cows was higher than the milk yield (14.75±0.18 kg) in the summer (mean THI=78). The same researchers stated that as the THI value increases, the milk protein values decrease and the somatic cell count increases. In addition, Gaafar et al., (2011) determined that heat stress significantly reduces the fat, protein, lactose, dry matter and ash content in milk. In a similar study, Ominski, et al., (2002) reported that the daily dry matter intake of cows exposed to heat decreased by 1.4±0.13 kg, milk yield decreased by 1.7±0.32 kg and non-fat dry matter level decreased by 0.07 ± 0.023 %. However, researchers reported that short-term, moderate heat stress in spring and summer adversely affects the performance of lactating cows. In another study Smith et al., (2013) determined the milk yield in cows exposed to heat stress and not, 34.2 and 35.6 kg, 26.6 and 25.9 kg for Holstein and Jersey, respectively. Moreover, milk fat of both Holstein and Jersey was adversely affected by heat stress. Somatic cell score, which is an important indicator of udder health, was found to be higher in Holstein and Jersey cows exposed to heat stress. In addition, Smith et al., (2013) grouped heat stress as mild, moderate or severe according to THI values and while milk yield of Holstein cows decreased during moderate and severe heat stress, milk yield of Jersey cows was affected during severe stress conditions. Researchers have reported that Jersey cows are more heat tolerant than Holstein cows. On the other hand, Tao and Dahl, (2013) have reported that heat stress negatively affects the regeneration level of mammary cells in cows in the dry period.

9. Conclusion

The heat stress loads significant pressure on protein metabolisms as well as carbohydrate and lipid metabolisms of dairy cows. As a result, it is inevitable that this situation will negatively affect the productivity of cows with high breeding value and result in economic losses. In this respect, the steps to be taken to reduce the effects of heat stress can be defined in two stages. Since strategies for improving environmental conditions will result in a shorter time, the focus should be on improving environmental conditions and feeding management. Therefore, it is important to design and plan the ventilation and cooling systems in the shelters in accordance with the climatic conditions of the region. In addition to ventilation and cooling systems, sufficient areas should be created where cows can reach clean water continuously. In this context, appropriate diet manipulations should be prepared to reduce the stress level in hot and humid seasons. Moreover, digital animal identification systems, pedometers, position sensors and other technologies allowing the determination of the activities or behavior of dairy cattle in the barn should be combined with herd management systems to evaluate of nutrition, welfare and comfort status, as well as the detection of environmental stressors. Improving the genotypic structure of animals, which is the second step to reduce effects of heat stress, is a long-running process.

By determining the regions on the genome related to the regulation of body temperature (thermotolerance), marker-assisted selection practices should be intensified on animals that are resistant to temperature and humidity. Finally, appropriate controlled crossbreeding treatments should be expanded to establish genotypes resistant to heat stress.

Author Contributions

The percentage of the author(s) contributions is present below. The authors reviewed and approved final version of the manuscript.

	I.C.O.	A.A.	H.E.	N.O.
C			50	50
D	50	50		
S			50	50
L	50	50		
W	50	50		
CR	50	50		
SR	50	50		

C=Concept, D= design, S= supervision, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declare that there is no conflict of interest.

References

Aganga AH, Umna NN, Oyendipe EO, Okoh PN, Aduku AO. 1990. Response to water deprivation by Yankasa ewes under different physiological states. Small Rumin Res, 3: 109–115.

Albright JL, Alliston CW. 1972. Effects of varying the environment upon performance of dairy cattle. J Anim Sci 32: 566–577.

Alkoyak K, Çetin O. 2016. Heat stress and prevention ways in dairy cattle. J Bahri Dagdas Anim Res, 5(1): 40-55.

Allen JD, Anderson SD, Collier, RJ, Smith JF. 2013. Managing heat stress and its impact on cow behavior. In Proceeding of Western Dairy Management Conference, March 6-8, Nevada, USA, pp. 150-162.

Altınçekiç ŞÖ, Koyuncu M. 2012. Çiftlik hayvanları ve stres. Hayvansal Üret, 53(1), 27-37.

Archana PR, Aleena J, Pragna P, Vidya MK, Niyas APA, Bagath M, Krishnan G, Manimaran A, Beena V, Kurien EK, Sejian V, Bhatta R. 2017. Role of heat shock proteins in livestock adaptation to heat stress. J Dairy Vet Anim Res, 5(1): 00127.

Arı UÇ. 2015. Physiologic and hormonal effects of heat stress on reproduction in cattle. Türkiye Klinikleri J Reprod Artif Insemin-Special Topics, 1(1): 1-10.

Atrian P, Shahryar HA. 2012. Heat stress in dairy cows. Res Zool, 2(4): 31-37.

Bagath M, Krishnan G, Devaraj C, Rashamol VP, Pragna P, Lees AM, Sejian V. 2019. The impact of heat stress on the immune system in dairy cattle: A review. Res Vet Sci, 126: 94-102.

Baumgard LM, Rhoads RP, 2009. The effects of heat stress on nutritional and management decisions. In Proceeding of Western Dairy Management Conference, March 11-13, Nevada, USA, pp. 191-202.

Bell AW. 1995. Regulation of organic nutrient metabolism during transition from late pregnancy to early lactation. J Anim Sci, 73: 2804-2819.

Berman A. 2019. An overview of heat stress relief with global warming in perspective. Inter J Biometeorol, 63(4): 493-498.

Bouraoui R, Lahmar M, Majdoub A, Djemali M, Belyea R. 2002. The relationship of temperature-humidity index with milk production of dairy cows in a Mediterranean climate. Anim Res, 51: 479-491

Charmandari E, Tsigos C, Chrousos, G. 2005. Endocrinology of the stress response. Annu Rev Physiol, 67: 259-284.

Cheng M, McCarl B, Fei C. 2022. Climate change and livestock production: a literature review. Atmosphere, 13(1): 140.

Christopherson RJ. 1985. The thermal environment and the ruminant digestive system. In: Yousef MK editor. Stress Physiology in Livestock. CRC Press, Boca Raton, 1st ed., Florida, USA, pp. 163-180.

Collier RJ, Baumgard LH, Lock AL, Bauman. DE. 2005. Physiological Limitations: nutrient partitioning. In: Wiseman J, Bradley R editors. Yields of farmed Species: constraints and opportunities in the 21st Century. Nottingham University Press, Nottingham, England, 1st ed., pp. 351-377.

Collier RJ, Baumgard LH, Zimbelman RB, Xiao Y. 2019. Heat stress: physiology of acclimation and adaptation. Anim Front, 9(1): 12-19.

Correa-Calderon A, Armstrong D, Ray D, DeNise S, Enns M, Howison C. 2004. Thermoregulatory responses of Holstein and Brown Swiss heat-stressed dairy cows to two different cooling systems. Inter J Biometeorol, 48(3): 142-148.

Dado RG, Allen MS. 1994. Variation in and relationships among feeding, chewing and drinking variables for lactating dairy cows. J Dairy Sci, 77: 132.

De Rensis F, Scaramuzzi RJ, 2003. Heat stress and seasonal effects on reproduction in the dairy cow—a review. Theriogenology 60: 1139–1151.

Dikmen S, Cole JB, Null DJ, Hansen PJ. 2012. Heritability of rectal temperature and genetic correlations with production and reproduction traits in dairy cattle. J Dairy Sci, 95: 3401-3405.

Durmuş M, Koluman N. 2019. Hormonal Changes caused on ruminant animals exposed to high environment temperature. J Anim Prod, 60 (2): 159-169.

Endres MI, Barberg AE. 2007. Behavior of dairy cows in an alternative bedded-pack housing system. J Dairy Sci, 90(9): 4192-4200.

Ergene O. 2009. Chromosomal, hormonal, nutrition problems and heat stress related early embryonic mortality in cows. J Dicle Univ Fac Vet Med, (2): 36-41.

Farooq U, Samad HA, Shehzad F, Qayyum A. 2010. Physiological responses of cattle to heat stress. World Appl Sci J, 8: 38-43.

Gaafar HMA, El Gendy ME, Bassiouni MI, Shamiah SM, Halawa AA, Abu El Hamd MA. 2011. Effect of heat stress on performance of dairy Friesian cow's milk production and composition. Res, 3: 85-93.

Habib HN. 2020. Molecular characterization of heat shock protein 70 gene in Iraqi buffalo. Iraqi J Vet Sci, 34(1): 139-143.

Helwatkar A, Riordan D, Walsh J. 2014. Sensor technology for animal health monitoring. In Proceeding of 8th International Conference on Sensing Technology, Liverpool, UK, September 2-4, pp. 2-4: 266-271.

Herbut P, Angrecka S, Godyń D, Hoffmann G. 2019. The physiological and productivity effects of heat stress in cattle–a review. Annals Anim Sci, 19(3): 579-593.

Herbut P, Angrecka S. 2018. Relationship between THI level and dairy cows' behaviour during summer period. Italian J Anim Sci, 17(1): 226–233.

Howard JT, Kachman SD, Snelling WM, Pollak EJ, Ciobanu DC, Kuehn LA, Spangler ML. 2014. Beef cattle body temperature during climatic stress: a genome-wide association study. Inter J Biometeorol, 58(7): 1665-1672.

Idris M, Uddin J, Sullivan M, McNeill DM, Phillips CJ. 2021. Non-invasive physiological indicators of heat stress in cattle. Animals, 11(1): 71.

Işık M, Aydinşakir K, Dinç N, Büyüktaş K, Tezcan A. 2016. Antalya koşullarında sıcaklık-nem indeks değerlerinin süt sığırcılığı açısından değerlendirilmesi. Mediterranean Agri Sci, 29(1): 27-31. [In Turkish]

Kamal R, Dutt T, Patel M, Dey A, Bharti PK, Chandran PC. 2018. Heat stress and effect of shade materials on hormonal and behavior response of dairy cattle: a review. Trop Anim Health Prod, 50: 701–706.

Kaufman JD, Pohler KG, Mulliniks JT, Ríus AG. 2017. Lowering rumen-degradable and rumen-undegradable protein improved amino acid metabolism and energy utilization in lactating dairy cows exposed to heat stress. J Dairy Sci, 101: 386–395.

Knight CH. 2020. Review: Sensor techniques in ruminants: more than fitness trackers. Animal, 14(1): 187-195.

Koç HU, Uğurlu M. 2019. Süt sığırlarında ısı stresinin verim özellikleri üzerine etkisi. Lalahan Hay Araşt Enst Derg, 59 (1): 30-35.

Kumar A, Ashraf S, Goud TS, Grewal A, Singh SV, Yadav BR, Upadhyay RC. 2015. Expression profiling of major heat shock protein genes during different seasons in cattle (Bos indicus) and buffalo (Bubalus bubalis) under tropical climatic condition. J Thermal Biol, 51: 55-64.

Laínez MM, Hsia LC. 2004. Effects of Season, Housing and Physiological Stage on Drinking and Other Related Behavior of Dairy Cows (Bos taurus). Asian-Aust J Anim Sci, 17(10): 1417-1429.

Liu J, Li L, Chen X., Lu Y, Wang D. 2019. Effects of heat stress on body temperature, milk production, and reproduction in dairy cows: a novel idea for monitoring and evaluation of heat stress-A review. Asian-Australasian J Anim Sci, 32(9): 1332.

Mattachini G, Antler A, Riva E, Arbel A, Provolo G. 2013. Automated measurement of lying behavior for monitoring the comfort and welfare of lactating dairy cows. Livestock Sci, 158(1-3): 145-150.

Min L, Zhao S, Tian H, Zhou X, Zhang Y, Li S, Yang H, Zheng N, Wang J, 2017. Metabolic responses and Bomics technologies for elucidating the effects of heat stress in dairy cows. Int J Biometeorol 61(6): 1149–1158.

Nardone A, Ronchi B, Lacetera N, Ranieri MS, Bernabucci U. 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livestock Sci, 130(1-3): 57-69.

Niyas PAA, Chaidanya K, Shaji S, Sejian V, Bhatta R, Bagath M, Rao GSLHVP, Kurien EK, Girish V. 2015. Adaptation of livestock to environmental challenges. J Vet Sci Med Diagn, 4 (3): 1-7.

Nonaka I, Takusari N, Tajima K, Suzuki Higuchi T, Kurihara KM. 2008. Effects of high environmental temperatures on physiological and nutritional status of prepubertal Holstein heifers. Livest Sci, 113: 14–23.

Ominski KH, Kennedy AD, Wittenberg KM, Nia SM. 2002. Physiological and production responses to feeding schedule in lactating dairy cows exposed to short-term, moderate heat stress. J Dairy Sci, 85(4): 730-737.

Öten M, Işık M, Çetinkaya M. 2004. Yüksek Sıcaklıklarda Süt Sığırlarının Beslenmesi. Atatürk Üniv Ziraat Fak Derg, 35(3-4): 229-234.

Patir H, Upadhyay RC. 2010. Purification, characterization and expression kinetics of heat shock protein 70 from Bubalus bubalis. Res Vet Sci, 88: 258-262.

Pehlivan E, Dellal G. 2014. Memeli çiftlik hayvanlarında stres, fizyoloji ve üretim ilişkileri. Hayvansal Üretim, 55(1): 25-34. [In Turkish]

Pereyra AVG, May VM, Catracchia CG, Herrero MA, Flores MC, Mazzini M. 2010. Influence of water temperature and heat stress on drinking water intake in dairy cows. Chilean J Agri Res, 70(2): 328-336.

Pinto S, Hoffmann G, Ammon C, Amon B, Heuwieser W, Halachmi I, Banhazi T, Amon T. 2019. Influence of barn climate, body postures and milk yield on the respiration rate of dairy cows. Ann Anim Sci, 19(2): 469–481.

Ratnakaran AP, Sejian V, Jose VS, Vaswani S, Bagath M, Krishnan G, Beena V, Indira Devi P, Varma G, Bhatta R. 2017. Behavioral responses to livestock adaptation to heat stress challenges. Asian J Anim Sci, 11(1): 1-13.

Rhoads ML, Rhoads RP, VanBaale MJ, Collier RJ, Sanders SR, Weber WJ, Crooker BA, Baumgard LH. 2009. Effects of heat stress and plane of nutrition on lactating Holstein cows: I. Production, metabolism, and aspects of circulating somatotropin. J Dairy Sci, 92(5): 1986-1997.

Rout M, Panigrahi S, Pradhan S, Swain K. 2018. Genetic basis of heat tolarance in cattle. Pharma Innovat J, 7(5): 183-185.

Sammad A, Wang YJ, Umer S, Lirong H, Khan I, Khan A, Ahmad B, Wang, Y. 2020. Nutritional physiology and biochemistry of dairy cattle under the influence of heat stress: Consequences and opportunities. Animals, 10(5): 793.

Schlink AC, Nguyen ML, Viljoen GJ. 2010. Water requirements for livestock production: a global perspective. Rev Sci Tech, 29(3): 603-619.

Schütz KE, Rogers A.R, Poulouin YA, Cox NR, Tucker CB. 2010. The amount of shade influences the behavior and physiology of dairy cattle. J Dairy Sci, 93(1): 125-133.

Schütz KE, Rogers AR, Cox NR, Webster JR, Tucker CB. 2011. Dairy cattle prefer shade over sprinklers: Effects on behavior and physiology. J Dairy Sci, 94(1): 273-283.

Sejian V, Bhatta R, Gaughan JB, Dunshea FR, Lacetera N. 2018. Adaptation of animals to heat stress. Animal, 12(2): 431-444.

Smith DL, Smith T, Rude BJ, Ward SH. 2013. Comparison of the effects of heat stress on milk and component yields and somatic cell score in Holstein and Jersey cows. J Dairy Sci, 96(5): 3028-3033.

Soriani N, Panella G. Calamari L. 2013. Rumination time during the summer season and its relationships with metabolic conditions and milk production. J Dairy Sci, 96(8): 5082-5094.

Tajima K, Nonaka I, Higuchi K, Takusari N, Kurihara M, Takenaka A. Aminov RI. 2007. Influence of high temperature and humidity on rumen bacterial diversity in Holstein heifers. Anaerobe, 13(2): 57-64.

Tao S, Rivas RMO, Marins TN, Chen YC, Gao, Bernard JK. 2020. Impact of heat stress on lactational performance of dairy cows. Theriogenology, 150: 437-444.

Tao S, Dahl GE. 2013. Invited review: heat stress effects during late gestation on dry cows and their calves. J Dairy Sci, 96: 4079-4093.

Tölü C, Savaş T. 2006. Çiftlik hayvanlarında sosyal sıra ve agonistik davranışlar. Hayvansal Üret, 47(2): 26-31.

Tucker CB, Weary DM, Fraser D. 2003. Effects of three types of free-stall surfaces on preferences and stall usage by dairy cows. J Dairy Sci, 86(2): 521-529.

Uzal S. 2008. Serbest ve serbest duraklı süt sığırı barınaklarında hayvanların alan kullanımı ve zaman bütçesine mevsimlerin etkisi. Doktora Tezi, Selçuk Üniversitesi, Fen Bilimleri Enstitüsü, Tarımsal Yapılar ve Sulama Anabilim Dalı, Konya,Türkiye, ss. 196.

Uzmay C, Kaya İ, Tömek B. 2010. Süt sığırcılığında hassas sürü yönetim uygulamaları. Hayvansal Üret, 51(2): 50-58.

Van laer E, Moons CPH, Sonck B, Tuyttens FAM. 2014. Importance of outdoor shelter for cattle in temperate climates. Livestock Sci, 159: 87-101.

Veissier I, Van laer E, Palme R, Moons CPH, Ampe B, Sonck B, Andanson S, Tuyttens FAM. 2018. Heat stress in cows at pasture and benefit of shade in a temperate climate region. Inter J Biometeorol, 62(4): 585-595.

West JW. 2003. Effects of heat-stress on production in dairy cattle. J Dairy Sci, 86: 2131–2144.

Wheelock JB, Rhoads RP, VanBaale MJ, Sanders SR, Baumgard LH. 2010. Effects of heat stress on energetic metabolism in lactating Holstein cows. J Dairy Sci, 93: 644–655.

Yavuz HM, Biricik H. 2009. Feeding for dairy cattle during heat stress conditions. Uludag Univ J Fac Vet Med, 28(1): 1-7.

Yue S, Yang C, Zhou J, Wang Z, Wang L, Peng Q, Xue B. 2020. Effect of heat stress on intake, rumen physiology, milk production and composition and supplementation of dietary fiber and dietary fats to alleviate heat stress: a review. Pakistan J Agri Sci, 57(5): 1421-1427.