advances in Technology

Adv. Technol. **2024**, 3(2), 135-151

Review

Effect of Heat Stress on Cattle: A Review

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Received: 01 August 2023; Revised: 03 October 2023; Accepted: 30 November 2023; Published: 05 April 2024

Abstract
Heat stress in livestock animals is one of the promising topics discussed especially with climate change. Even though it is complicated to accurately measure at which point the cattle may suffer from heat stress due to different external and internal factors, mitigation of heat stress is quite important because a cow can lead to hyperthermia if it couldn't maintain the thermoneutrality of its body. A great number of researches were conducted to find out the factors that lead to heat stress and the effects of heat stress on the production, reproduction, respiratory rates, heart rate, and feeding behaviors of cattle. Mitigation strategies for heat stress were also revealed under different means by mitigating heat exchange pathways which lead to accumulate the heat within the body, and management strategies including nutritional management. The present review was to elaborate on those findings to critically evaluate how dairy cattle are affected by heat stress in the livestock industry and the investigated mitigation strategies of heat stress to regulate the body heat of cattle.

Keywords: cattle, heat stress, livestock, mitigation, production, reproduction

Introduction

A combination of external forces acting on an animal resulting in conditions higher than the temperature range of the Thermoneutral Zone of animals and generating a physiological response is known as heat stress [1-3]. When an animal does not achieve an equilibrium between heat retention and heat dissipation, as a result, heat stress occurs [4]. Temperature within a range of -0.5 to 20.0 °C can be considered as the thermal comfort zone for dairy cattle [5]. The upper critical air temperature is the air temperature which is at which the animal increases the heat production due to its body temperature increment as a result of inadequate evaporative heat loss is reported to range from 25-26 °C for dairy cattle, irrespective of their previous acclimatization and milk production [5-7]. Air temperature, relative humidity, solar radiation, precipitation, and air movement are the major environmental factors affecting the occurrence of heat stress in animals [1], and out of these, the elevated air temperature can be considered as the leading factor responsible for the heat stress in cattle [8]. On the other hand, breed, age, lactation stage, level of milk production, levels of feed and water intake, feed composition, and body condition score are also considered as the other factors of heat stress [5, 7].

Main Factors Responsible for the Occurrence of Heat Stress in Cattle

Air Temperature

Dairy cattle begin to experience heat stress at comparatively lower temperatures than humans. The air temperature and relative humidity in the surroundings have a considerable effect on this operation of releasing excess heat into the atmosphere [9]. As the air temperature increases above the thermal comfort zone, there is a higher possibility for the occurrence of heat stress especially if the relative humidity is also high [10]. Hence, it is essential to release surplus heat into the atmosphere to maintain the body temperature of cattle within the thermal comfort zone [11, 12].

The primary thermoregulatory mechanism of mammals is maintaining a body temperature higher than the ambient temperature to maintain an efficient heat exchange between the body of the animal and the environment. The heat exchange happens mainly via four means; conduction, convection, radiation, and evaporation. Among these four, conduction, convection, and radiation require a temperature gradient for heat exchange, and evaporation requires a vapor pressure gradient. When ambient temperature reaches body temperature heat loss can happen only through evaporation. If the ambient temperature exceeds the body temperature, the direction of the temperature gradient changes, and heat will flow in the opposite direction. Besides, the animal becomes heat-stressed in such conditions, especially when it exceeds the thermal comfort zone [13].

Relative Humidity

Relative humidity gives an idea about the level of saturation of air at a given temperature [14]. The amount of water vapor present in the surrounding air affects the rate of the evacuation of water from the skin and lungs of cattle through evaporation. As the average daily temperature goes beyond the thermal comfort zone of the animal, the level of moisture in the atmosphere becomes a critical factor in regulating the homeostasis of animals. To maintain the regular physiological conditions and behavioral patterns of dairy cows, 60-80% relative humidity is considered as appropriate [5]. Sweat glands are present in cattle and they can successfully remove excess heat from their bodies to the atmosphere quickly by sweating as the evaporative cooling principle when the ambient temperature increases and the temperature gradient decreases between the animal and the air. At lower relative humidity, air is not saturated with water vapor and there is no obstruction for the addition of water vapor into the atmosphere. Hence cattle could withstand even higher temperatures when lower relative humidity prevails because excess heat is removed by sweating.

The normal capacity of cattle to dissipate heat loads by sweating and panting is impaired during hot and humid weather, thus heat stress happens even faster in cattle under these conditions [15]. According to Bianca, (1965), the average apparent milk yields of Holstein, Jersey, and Brown Swiss dairy cattle breeds were 97, 93, and 98%, respectively at a temperature of 29 °C and relative humidity of 40% [16]. While the relative humidity was increased to 90%, the milk yields were reduced to 69, 75, and 83%, respectively. It revealed that there is a drastic reduction in milk yield along with the increase in relative humidity.

Temperature Humidity Index (THI)

THI is a variable that is frequently used as an indicator of heat stress of cattle reared in stalls as well as of cattle reared in pasturelands [17]. It is a value reflecting the cumulative effects of the thermal stress level correlated with air temperature and humidity. This index is generally used as a measure of heat stress and in the evaluation of thermal comfort for dairy cows and other livestock. This index was developed for the evaluation and elimination of heat stress-induced losses as a weather safety index.

The reported threshold values for heat stress among cows and its impact on productivity have altered as different authors have expressed different threshold values for THI, in general from the range varied from 68-74 units whereas several researchers classified THI under different levels of stress on the cattle (Table 1) [18]. The threshold values for THI were assessed by considering the productivity of dairy cows. As a by-product of milk production, dairy cows produce metabolic heat and hence higher yielding animals undergo heat stress at relatively low THIs than lower yielders [7]. A value of 72 and 74 were assigned as the threshold values for the high-yielding and low-yielding cows, respectively. Most of the other authors have indicated 72 as a critical threshold value for THI and values above it may cause a reduction in the productivity of cattle [19-21].

Table 1. Different THI classifications with special reference to the level of stress on the cattle

THI Value	Degree of stress	Reference/s
<71	Comfort zone	[22,23]
72-79	Mild stress	
80-89	Moderate stress	
>90	Severe stress	
<74	Normal	[24]
75-78	Alert	
79-83	Dangerous	
>84	Emergency	

Solar Radiation

One of the predominant environmental factors impacting livestock is solar radiation. Global radiation primarily involves radiation coming directly from the sun as well as diffused radiation and/or reflected by clouds. The effect of radiation can be the key determinant of the conditions in the environment in which the cows are reared, especially in the case of pasturelands. Cattle reared in pasturelands are more exposed to solar radiation. Hence, cattle on pasture are more susceptible to heat stress than cattle reared in sheds [25]. The potential of animals to cope with heat stress caused by solar radiation relies on the physical properties of their skin and coat [26, 27].

The darker surfaces absorb more heat while lighter surfaces absorb less heat [28]. In view of the aforementioned fact, the dark-coated cattle breeds absorb more heat loads from solar radiation than the breeds with light-colored coats [29]. As revealed from previous studies, short-wave radiations are transmitted effectively through the light-colored coat which lacks melanin pigmentation [27, 30, 31]. Long hairs provide a shield against incoming short-wave radiation, but they also maximize heat stress by minimizing heat dissipation to the outside. In a tropical area, a Holstein cow on an open pasture will consume up to 640 Wm^{-2} of radiant energy. Short-wave radiation accounts for 297.9 Wm^{-2} or 46.6 % of the total radiation received by a cow in a tropical area exposed to the sun. Direct solar radiation accounts for around 65 % of this total whereas long-wave radiation (342 Wm^{-2}) makes up 53.4 % of the overall radiation received by the cow [32].

Cattle Breed

In comparison to European (exotic) breeds, indigenous cattle breeds in most developing countries are depicted as the hardiest breeds, as they have more potential to survive and give good yields even under harsh conditions because of their specific physiological and genetic adaptations [33]. Sweating efficiency, poor tissue tolerance, coat texture, and color are all heritable traits for maintaining body temperature, but there is evidence of an improved potential for thermoregulation in *Bos taurus* cattle by nutritional management. Since coat color is linked to the amount of heat consumed by solar radiation, there is also evidence that hair color affects the cow's susceptibility to heat stress. Black steers had a 16% higher internal flow of heat at the skin than brown steers and a 58% higher inward flow than white steers in *Bos indicus* cattle. Dark-coated *Bos taurus* cattle had better heat transfer to the skin, a higher body temperature, and slightly smaller weight gains than white-coated cattle, with the effect amplified by the coat's wooliness [34].

The productivity of cattle correlates with the output of metabolic heat. Thus, when the productivity of cattle increases, the amount of metabolic heat produced also increases. Owing to their increased metabolic rate linked with milk production, high-producing exotic dairy breeds are more vulnerable to the detrimental impacts of heat stress [35]. *Bos indicus* subspecies have a better capacity to control their body temperature because under elevated temperatures in tropical regions, less deleterious effects on cells of zebu than on cells of European breeds. The effect of lower metabolic rates and greater heat loss capability by thermoregulatory processes results in this potential, helping to reduce heat stress. Furthermore, hair coat leads to improved conductive and convective heat loss while reducing the absorption of solar radiation in Zebu cattle. In comparison to hair coats that are dark in color or denser and woolly, sleek, shiny hair coats reflect a higher percentage of incident solar radiation [36]. Even though the Zebu cattle production capacity is lower than that of high-producing exotic and crossbred cattle, their level of production is relatively constant under severe environmental conditions whereas high-producing exotic and crossbred animals fail in this process.

Comparatively, indigenous breeds retain their reproductive capacity during times of intense heat stress, water shortages, and decreased grazing supply due to their small body size whereas the large exotic animals may face reproductive impairments that could be related to their high energy consumption [37].

Cattle breeders have therefore attempted to incorporate the desirable traits of exotic breeds and zebu breeds as an alternative to overcome the heat stress of cattle in tropical regions, by creating crossbred animals such as Girolando which is the offspring of the Holstein (European) and Gir (zebu) crossbreeding [38].

Housing of Cattle

Based on the cattle rearing system (indoor or outdoor), the effect from the above-mentioned environmental determinants of heat stress like air temperature, relative humidity, and solar radiation can vary in proportion. In the case of rearing cattle on pastures, the main risk factor is solar radiation and it can be mitigated by the construction of a stall. Although protection is provided from adverse climatic conditions in indoor cattle rearing systems, restricted efficacy of natural ventilation would be a great problem, and therefore mechanical ventilation is implemented [6]. Cattle reared under shade are less susceptible to heat stress than those reared in pasturelands. The amount of shade provided also affects the risk of exposure to heat stress. However, an intensive housing system with proper ventilation and cooling mechanisms provides a comfortable environment for the animals. Hence, the cattle that are managed under those systems are less susceptible to heat stress. The material of construction also has a considerable influence on heat stress [39].

According to Armstrong, (1994), the location, size, and orientation of the shade are important and the design and the management of shade depend on the climate of the area. Generally, a mature dairy cow requires a shaded area of 3.5 to 4.5 m^2. It is important to construct the shade structure for a height of at least 4.3 m in order to reduce the amount of reflected solar radiation reaching the cows while directing it in an East-West direction in high-temperature areas to avoid falling of direct sunlight and in North-South direction in low-temperature areas.

Effect of Heat Stress on Cattle

Effect of Heat Stress on Reproduction of Cattle

According to many researchers [40-43], the reproductive tract, as well as the reproductive physiology of cattle, are highly sensitive to heat stress. Additionally, heat stress was defined as the environment that acts to drive the body temperature above the set point temperature of a particular mammalian species [3]. He further explained that the reproduction disruption due to heat stress can be identified as two main mechanisms such called homokinetic changes to regulate body temperature and failure of homokinetic systems to regulate reproduction during heat stress. According to Ealy et al, (1995) it was observed that the decreased embryonic development under 41 °C for 3 hours of heat shock under *in vitro* fertilization (IVF) is more similar to the body temperature of a heat-stressed cow [44].

In another study Barati et al, (2008) recorded that a significantly smaller proportion of oocytes (14-29%) reached their meta phase II when they were exposed to 41 °C, compared with the oocytes that were exposed to 38.5 °C [45]. It further explained that the elevated temperature had significant effects on meiotic competence as well as the oocyte quality. The cows under heat stress consisted of a longer period of non-cyclic reproductive phases with short estrus cycles (Table 2).

Table 2. Estrus cycle length of *Bos indicus* cattle under thermoneutral (CG) and heat stressed (HS) conditions

Estrus cycle (days)	CG No./Total (%)	HS No./Total (%)	P values	Reference
21	31/35 (88.6)	15/24 (62.5)	0.0200	[45]
< 21	3/35 (8.6)	9/24 (37.5)	0.0086	
> 21	1/35 (2.9)	0/24 (0.0)	0.2018	

However, the thermotolerant breeds of *Bos indicus* required long-term exposure to elevated temperatures to show destruction in reproduction (Table 3) [46].

Table 3. Mean estrus cycle length, Serum progesterone concentration and Cortisol concentrations of *Bos indicus* cattle under thermoneutral (CG) and heat stressed (HS) conditions during phase 1 (before the micro climate manipulation), Phase 2 (during the micro climate manipulation of HS group; 38 °C and 80% relative humidity (RH) under a cold fluorescent light from 6:00 to 18:00 h, followed by 30 °C and 80% RH from 18:00 to 6:00 h; 28 days), and phase III (after the micro climate manipulation of HS group; 28 -147 days)

Variable	Phase I		Phase II		Phase III		Reference
	CG	HS	CG	HS	CG	HS	
Estrus cycle (days)	-	-	19.8±1.2	21.0±0.0	20.7±0.5*	17.5±0.8*	[45]
P4 (ng/mL)	2.4±0.7	3.1±1.2	1.5±0.3	1.7±0.5	2.3±0.2*	1.7±0.3*	
Cortisol (µg/dL)	2.3±0.5^{a}	3.2±0.8^{a}	2.4±0.2^{a}	2.4±0.2^{a}	1.9±0.2^{b}	1.3±0.1^{b}	

$^{a, b}$*: within a raw consecutive phase with different superscript letters differed (p<0.0001)*
** Treatments (CG and HS) differed at p<0.05*

Most of the reviewers have explained the seasonally elevated temperatures that effect on forming heat stress of cattle [47-49]. Cows which calved in the summer season had a greater number of services per conception and consisted of low conception rates than the other seasons [47]. Compared to *Bos indicus, Bos taurus* (Holstein) had a lower percentage of normal oocytes and the developing oocytes to 8-cell, morula, and blastocyst stages in hot seasons. But there were no significant differences observed in normal oocyst and oocyst development in *Bos indicus* (Brahman) during the different seasons [48]. The lower concentrations of LH were found in heat-stressed cows and it suggested that the heat stress-related decline of LH caused the series of destructions related to the reproduction including the above-mentioned oocyst maturation, ovulation, and formation of functioning corpus luteum [50]. It was reported that the duration of estrus was shortened due to the heat stress, because the estradiol-17 concentration in plasma was decreased during the pro-estrus period up to 2.96±0.25 ng/mL at 32 °C and RH 67.3% in Holstein heifers [51]. Furthermore, the pregnancy rate was detected as 6 % of the imported cows in Sri Lanka which were most of the days exposed to moderate heat stress with THI beyond 78. The body temperature of those used imported animals during that experiment was recorded between 39.4-40.3 °C. The detected pregnancy rate was beyond 20% where the THI was below 78 and also the body temperature was detected as below 39.4 °C [52]. Moreover, it was reported that the seasonal variations affect significantly on ejaculate volume, concentration, total sperm, and initial motility of sperms in bulls, and increase in semen attributes were due to the effect of lower temperature on sensitive stages of spermatogenesis during summer [53]. This also agreed with the findings of [54]. It revealed that the highest mean values of individual motility and sperm concentrations (77.61±0.33 % and 954.4 ± 38.42 million/mL, respectively) were observed during dry summer while the lowest was observed during the autumn. It further explained that the mass activity of sperms was lowest in the humid summer while it was highest during the dry humid and spring seasons. Thus, it was concluded that the better-quality semen was produced by Sahiwal bulls during spring and the dry summer while humid summer and autumn seasons negatively affected the semen quality [54]. However, Bhakat et al., (2014), reported that there was no significant effect of season on ejaculation volume, mass activity, total sperm output, and pH whereas significant effect on sperm concentration, sperm abnormalities, and osmolality in the semen of Karan Fries bulls as crossbred bulls [55]. The sperm viability, membrane integrity and acrosome integrity were significantly decreased during the hot-humid seasons. Seminal plasma enzyme concentrations were significantly higher in hot-humid seasons than in the winter. There was no significant difference in the color of semen, plasma testosterone and prostaglandin concentrations whereas estradiol concentration were significantly altered in Karan Fries crossbred bulls during different seasons (Table 4). Furthermore, it suggested that the adverse effects on bi-physical characteristics of semen of this crossbred during hot humid seasons may be due to rationale beyond the hormone responses [56].

Table 4: Mean plasma testosterone, estradiol, prostaglandin E_2 concentrations (Mean ± SEM) in Karan Fries crossbred bulls during different seasons (n=40)

Hormone	Hot humid	Winter	Reference
Testosterone (ng/mL)	9.50 ± 0.93	9.26 ± 0.99	[56]
Estradiol (pg/mL)	360.40 ± 12.97	318.90 ± 15.19*	
Prostaglandin E_2 (pg/mL)	23.88 ± 0.81	21.11 ± 1.39	

Effect of Heat Stress on the Production of Cattle

Extended periods of high environmental temperature and high humidity caused to destruct the dissipation of body heat of cattle and it leads to reduce the milk yield of lactating cows and the efficiency of milk production [5]. It is considered as the primary factor which caused the reduction of the milk production in dairy cows and ultimately caused severe economic loss among the livestock farmers [57]. Environmental temperature exceeding the higher or lower levels of thermal comfort zones of animals with special reference to cattle caused to alter the yield, the neuro-endocrine mechanism, and environmental physiological functions relevant to the maintenance of lactation [58]. Late gestation heat stress which was 60 days prepartum had significant negative effects on early and mid-lactation milk production and milk fat content of Holstein Friesian. But it wasn't affected the late lactation milk production and milk fat content [59]. It was also reported that the decline of milk production was 0.32 kg per unit increase in the temperature humidity index (THI). It further explained that the shaded cows produced milk that contained more fat percentage than non-shaded cows at THI above 74 [60] . The reduction of the milk yield was linear between the THI values from 60 to 80 which elaborated that the greatest decrement of yield occurred below the threshold THI value 72. The average loss of milk was 2.2 kg per day where the THI values between 65-73. Similarly, 17 hours of exposure to an average THI value of 68 led 2.2 kg decrement of the milk yield per day as well. Furthermore, it explained that a Holstein cow that produces 35 kg of milk per day required additional cooling when the average THI value at 68 for 17 hours to withstand the heat stress [13]. Osei-amponsah et al., (2020) explained that the average daily milk production of Holstein Friesian was significantly dropped when the THI was increased low to high followed by a moderate THI [61].

The rectal temperature of heat-stressed dried Holstein cows was detected as 39.2±0.1 °C during the afternoons under tropical climates of Florida [62]. The elevated rectal temperature of heat-stressed Holsteins in Arizona during July was detected as 0.95 °C increment even though the ambient temperature was dropped down to 29.4 °C during the night for 8 hours. This indicated that the heat gain due to the elevated ambient temperature was maintained in the body for entire 24 hours even though there was a reduction of ambient temperature for considerable hours within that particular day. Although the reduced intake of feeds due to heat stress had a minor effect on the loss of synthesis of milk, it was responsible for 35% of the milk yield lost [63].

The decreased average dry period, body weight, and subsequent calf weight was evident in dry Holsteins either under heat stressed conditions and cooling conditions where the fans and sprinklers were automatically activated when the ambient temperature exceeded 21.1 °C. However, the decrement of those factors was less intense under cooling conditions relative to heat stressed conditions [62]. Moreover, these findings were closely similar to the previous findings (Table 5) [63].

Table 5: Dry period length, rectal temperature, BW, Subsequent calf weight of cows exposed to heat stress and cooling conditions during dry period

Variable	Treatment		SEM	*p* value	Reference
	Heat stress (HS)	Cooling (CL)			
Dry period length (days)	38.93	42.21	1.47	0.13	[62]
Rectal temperature a.m., (°C)	38.81	38.60	0.03	< 0.001	
Rectal temperature p.m., (°C)	39.40	39.04	0.04	< 0.001	
Calf weight (kg)	41.63	46.45	1.33	0.01	
BW change (prepartum)[1] (kg)	−15.3	−1.9	4.60	0.05	
BW change (postpartum)[2] (kg)	−37.7	−53.4	10.2	0.29	
Dry period length (days)	38	45	3	0.12	[63]
Calf weight (kg)	31	44	2	< 0.001	
BW[3] (kg)	633	698*	16	0.01	

[1]*Prepartum accumulative BW change was calculated by deducting data at −32 and −18 d relative to calving and calving by data at dry off*
[2]*Postpartum accumulative BW change was calculated by deducting data at 14, 28, and 42 d relative to calving by data at calving*
[3]*BW was reported at −46, −32, −18, and 0 d relative to expected calving date*
* *P < 0.01*
\+ *HS; n = 15, CL; n = 14*
++ *HS; n = 09, CL; n = 07*

Furthermore, heat stress is not only affected for the reduction of milk production but also for the component of the milk [57]. It was confirmed that the milk protein concentration also decreased during the heat stress [64]. However, Ingraham et al., (1979) found that the milk temperature and fat percentage of milk was increased by 3% and whilst protein percentage was increased by 2% when the THI varied from low to high by representing a positive correlation between THI, milk temperature, fat and milk protein [60].

Effect of Heat Stress on Feeding, Pulse Rate, and Respiratory Rate of Cattle

Research conducted by using nine crossbred steers (1/4 Angus, 1/4 Hereford, 1/4 Pinzgauer, 1/4 RedPoll) by providing three different temperatures including 18.7 ± 7 °C (dry bulb temperature and dew point temperature of 7 °C), 30±7 °C, and 34±7 °C revealed that the highest feed intake was observed at 18.7±7 °C which was considered as the thermoneutral temperature followed by 30±7 °C and 34±7 °C. It further explained that the feed intake was decreased over the first few days under the heat stress conditions then leveled off and remained low throughout the research study. Although there was a metabolic shift observed between the acute and chronic phases of heat stress, a significant impact on respiratory rate wasn't observed [65]. Respiratory rate is one of the best parameters to indicate the heat stress of cattle [66, 67]. Critical values of respiratory rate for 1/2, 3/4 crossbred, and pure-bred Holstein Friesians were 116, 140, and 168 breathes/min, respectively [67]. In addition to that, the respiration rate of crossbred cows (1/4 Angus, 1/4 Hereford, 1/4 Pinzgauer, 1/4 Red Poll) was observed as 86.0±0.39 and 102.3±0.36 breaths/min under shaded and non-shaded conditions, respectively [68]. Respiration rate interval was drastically decreased under heat stress conditions during daytime up to 635.06±49.73 milliseconds. It was 728.28±31.97 milliseconds under the normal conditions during daytime as well [69].

Further studies had been conducted in a chamber by using Ayrshire, Guernsey, Holstein, and Jersey cows revealed that the hot conditions within the chamber caused to produce a rapid overload of the respiratory system followed by extremely high respiratory rates [70]. Atkins et al., (2018) found that the slope of the respiratory rate was increased at around 70 THI [71]. It further explained that the respiratory rate was remained elevated in the evening and night in spite of the decreasing THI [61, 71]. Additionally, Osei-amponsah et al., (2020) reported that the THI was greatly influenced on the respiratory rate of Holstein Friesian cows [61]. They were breathe faster and frequently panted under high THIs (Table 6).

Table 6. Effect of THI on respiratory rate of Holstein Friesian cattle

Parameter	THI			Reference
	≤ 72	73 – 82	≥ 83	
Sample size (n)	518	1175	666	[61]
Respiratory rate (breaths/min)	$66.0^{c} \pm 18.8$	$81.8^{b} \pm 21.4$	$113.1^{a} \pm 31.5$	
Panting score	$1.38^{c} \pm 0.63$	$1.87^{b} \pm 0.61$	$2.42^{a} \pm 0.64$	

^{a,b,c} *Within rows means with different superscripts differ significantly (p ≤ 0.05)*

Moreover, the body temperature increment was greater with the higher THIs that corresponds with the increased respiration rate of *Bos taurus* cattle. In addition, per °C increment of different variables was also found to be as factors of changing the respiratory rate of *Bos taurus* cattle (Table 7).

Table 7. Respiratory rate increment per °C increment of different variables

Parameter	Increment (breaths/min)	Reference
Respiratory rate per °C increment of ambient temperature	2.8-3.3	[66]
Respiratory rate per °C increment of tympanic temperature	47	
Respiratory rate per °C increment of body temperature	19.8	[71]
Respiratory rate per °C increment of rectal temperature	35.7	[72]

According to Bun et al., (2018), power spectral analysis of heart rate variability is a kind of useful tool to evaluate heat tolerance in cows [69]. Heart rate variability (HRV) was described as the parameter that explains the balance between sympathetic and parasympathetic nervous systems [73]. Research conducted by using Cambodian native zebu Holstein-Friesian cross-bred cows elaborated that the heart rate variability was increased up to 95.45±6.80 bpm under the heat-stressed conditions whereas it was 82.79±3.47 bpm under normal conditions during the daytime [69].

Mitigation of Heat Stress

In hot weather, an animal's body heat is dissipated mostly by elevated respiration rate, panting, increased water intake, sweating, and decreased feed intake and milk yield. Increased standing time, seeking for shade, and reduced activity and mobility are some of the behavioral coping mechanisms [74, 75].

Heat is exchanged through the mechanisms of conduction, convection, radiation, evaporation of water and through exhaled air in animals. Heat is dissipated well via evaporation when the temperature gradient is low and the environmental temperature is higher. Under heat stress, cattle remove excess heat from their body through evaporation mainly by the means of sweating and panting. However, the rate of evaporation depends on several factors like the body size of the animal, thickness of the coat, amount of hair present and the number of sweat glands present [76].

Excess body heat must be dissipated to prevent the animal from contracting hyperthermia, which can be lethal. Hence, maintaining the proper temperature for the cows is critical for maintaining their high productivity and overall health. The adaptive mechanisms of the cows become unsuccessful in eliminating the excess heat produced when the upper critical temperature is exceeded [5, 8]. Therefore, the manual actions should be adopted in such situations in order to remove the excess heat load. Previous studies have demonstrated that by introducing suitable solutions, favorable environmental conditions most importantly the proper air temperature and relative humidity range can be provided for livestock [77].

A major step to be taken to minimize heat stress in cattle is to protect them from direct and indirect solar radiation. The most economical and easy method to minimize the effect of solar radiation is providing a shade. The type of material used in constructions also has a varying effect on the reduction of heat loads [38]. Different methods of increasing shade coverage are stated, such as tree covers, roofs, eaves extensions, and the installation of sunlight-reducing mesh, which can create more pleasant microclimates for cows by reducing solar radiation exposure and lowering ambient temperature [74, 78, 79].

To reduce the heat accumulation caused due to increased ambient temperature and relative humidity, excess cooling is required. Using fans, air conditioning, wetting the animals and evaporative cooling are some techniques used to enhance the dissipation of excess heat loads. According to Hahn et al., (1970), a considerable increment of milk yield could be observed in dairy cattle provided with evaporative cooling. Other options include misting and air mixing instruments, as well as water droplets from low-pressure sprinkler systems [80].

There are variety of techniques for reducing air temperatures below the outside average temperature. Mechanical air conditioning or refrigeration is the most common. Although these methods may increase milk production and reproductive ability of cattle, they are too costly to be used [58, 81]. Evaporative cooling is a more cost-effective option. Evaporative cooling works by evaporating water using the heat from the environment. This reduces the air temperature while increasing the relative humidity. In low-humidity zones, evaporative cooling is most efficient [80]. Air circulation is necessary in the management of heat stress. Air can be transferred naturally or artificially. Open-sided construction that takes advantage of air displacement caused by winds provides efficient ventilation of buildings used to shelter dairy cows in sunny, humid climates. Fans provide mechanical ventilation, also known as forced ventilation even though it can be achieved solely by natural means as well [82].

Nutritional management is another aspect that should be considered in mitigation of heat stress. According to literature, there were clear evidences to state that it is essential to modify the feed for cattle during hot seasons [6, 8, 83-85] . The rations should be reformulated to account for the reduced dry matter intake (DMI), increased nutrient requirement, dietary heat increment and by avoiding the provision of excess nutrients as increase metabolic rates may increase the risk of heat stress [5]. Reduced DMI necessitates increased nutrient density, as well as altered mineral and water needs and digestive tract efficiency. Increasing the amount of fat in the diet raises energy density and reduces overall heat increment, lowering the body heat load [86]. According to Milam et al., (1985), water intake of cattle has increase by 1.2 kg per 1 °C increase in ambient temperature. But *ad libitum* water should be provided during hot seasons in order to avoid the occurrence of heat stress [87].

Conclusion

Heat stress is affected in several ways in cattle farming by predominately reducing reproduction and production performances. Decrement in embryo development, reduced the quality of the oocytes, destruction in oocyte maturation were experienced in cows and the sperm viability, membrane integrity and acrosome integrity were significantly decreased while interrupting the spermatogenesis in bulls. Milk production and the composition of milk are also altered due to heat stress. But there are many mitigation techniques available where the evaporative cooling could be suggested as one of the finest cost effective technique that we can implement to reduce the environmental temperature in order to reduce the heat stress of cattle. Moreover, nutritional management also could be considered as one of the aspects for mitigation of heat stress in cattle.

Conflict of Interest

The authors state that there is no conflict of interest. The authors alone are responsible for the content of this review paper.

References

[1] D.E. Buffington, Collazo-Arocho, A., Canton, G.H., Pitt, D., Thatcher, W.W., and Collier, R.J., Black Globe-Humidity Index (BGHI) as Comfort Equation for Dairy Cows. *Transactions of the ASAE*, **1981**. *24(3)*,0711-0714.DOI: 10.13031/2013.34325.

[2] S. Dikmen and Hansen, P.J., Is the temperature-humidity index the best indicator of heat stress in lactating dairy cows in a subtropical environment? *Journal of Dairy Science*, **2009**. *92(1)*,109-116.DOI: 10.3168/jds.2008-1370.

[3] P.J. Hansen, Effects of heat stress on mammalian reproduction. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, **2009**. *364(1534)*,3341-3350.DOI: 10.1098/rstb.2009.0131.

[4] B.E. Leonard, Stress physiology in livestock. Volume 1, Basic Principles. Edited by Mohammed K. Yousef. CRC Press, Florida, 1985. ISBN: 0 8493 5667 9. *Stress Medicine*, **1986**. *2(4)*,357-358.DOI: 10.1002/smi.2460020413.

[5] J.W. West, Effects of Heat-Stress on Production in Dairy Cattle. *Journal of Dairy Science*, **2003**. *86(6)*,2131-2144.DOI: 10.3168/jds.s0022-0302(03)73803-x.

[6] J.W. Fuquay, Heat Stress as it Affects Animal Production. *Journal of Animal Science*, **1981**. *52(1)*,164-174.DOI: 10.2527/jas1981.521164x.

[7] C.T. Kadzere, Murphy, M.R., Silanikove, N., and Maltz, E., Heat stress in lactating dairy cows: a review. *Livestock Production Science*, **2002**. *77(1)*,59-91.DOI: 10.1016/s0301-6226(01)00330-x.

[8] D.K. Beede, Wolfenson, D., Berman, A., Collier, R.J., Amir, S., Schindler, H., Thatcher, W.W., and Wilcox, C.J.(s), Book Hyperthermal and Nutritional Effects on Milk Production, Udder Health and Reproduction of Dairy Cows, United States Department of Agriculture Location, United States Department of Agriculture, **1984**, pp. Page

[9] J.D. Allen, Hall, L.W., Collier, R.J., and Smith, J.F., Effect of core body temperature, time of day, and climate conditions on behavioral patterns of lactating dairy cows experiencing mild to moderate heat stress. *Journal of Dairy Science*, **2015**. *98(1)*,118-127.DOI: 10.3168/jds.2013-7704.

[10] H.H. Kibler and Brody, S., *Influence of temperature, 5" to 95"F, on evaporative cooling from the respiratory and exterior body surfaces in Jersey and Holstein cows*, in *Jersey and Holstein Cows*. 1950.

[11] C. Lambertz, Sanker, C., and Gauly, M., Climatic effects on milk production traits and somatic cell score in lactating Holstein-Friesian cows in different housing systems. *Journal of Dairy Science*, **2014**. *97(1)*,319-329.DOI: 10.3168/jds.2013-7217.

[12] D.L. Hill and Wall, E., Dairy cattle in a temperate climate: the effects of weather on milk yield and composition depend on management. *Animal*, **2015**. *9(1)*,138-149.DOI: 10.1017/s1751731114002456.

[13] R.J. Collier, Zimbelman, R.B., Rhoads, R.P., Rhoads, M.L., and Baumgard, L.H. *A re-evaluation of the impact of temperature humidity index (THI) and black globe humidity index (BGHI) on milk production in high producing dairy cows*. **2005**. pp. 113-125.

[14] M.E. Jensen, R.D. Burman, and R.G. Allen, Evapotranspiration and irrigation water requirements: ASCE—Manuals and Reports on Engineering Practice. No. 70. The Society, New York, NY, **1990**,pp. 332.

[15] M. Yousef, Stress physiology in livestock. Volume I. Basic principles. Ed, Vol.: Boca Raton, Florida, Volume I. Basic principles, CRC Press.

[16] W. Bianca, Section A. Physiology. Cattle in a hot environment. *Journal of Dairy Research*, **1965**. *32(3)*,291-345.DOI: 10.1017/s0022029900018665.

[17] E.C. Thom, The Discomfort Index. *Weatherwise*, **1959**. *12(2)*,57-61.DOI: 10.1080/00431672.1959.9926960.

[18] H. Hammami, Bormann, J., M'hamdi, N., Montaldo, H.H., and Gengler, N., Evaluation of heat stress effects on production traits and somatic cell score of Holsteins in a temperate environment. *Journal of Dairy Science*, **2013**. *96(3)*,1844-1855.DOI: 10.3168/jds.2012-5947.

[19] O. Ravagnolo, and I. Misztal, Genetic component of heat stress in dairy cattle, parameter estimation, *Journal of Dairy Science*. **2000.** *83*,2126– 2130.

[20] J. Bohmanova, I. Misztal, and J.B. Cole, Temperature-humidity indices as indicators of milk production losses due to heat stress, *Journal of Dairy Science.* **2007.** *90*,1947–1956.

[21] J. Brouček, P. Novák, J. Vokřálová, M. Šoch, P. Kišac, and M. Uhrinčat, Effect of high temperature on milk production of cows from freestall housing with natural ventilation, *Slovak Journal of Animal Science*, **2009**. *42(4)*,167– 173.

[22] F. Wiersma, Temperature-humidity index table for dairy producer to estimate heat stress for dairy cows. Department of Agricultural Engineering, University of Arizona, Tucson, **1990**.

[23] D.V. Armstrong, Heat stress interactions with shade and cooling, *Journal of Dairy Science*, **1994.** *77*,2044-2050.

[24] G.L. Hahn, J.B. Gaughan, T.L. Mader, and R.A. Eigenberg, Chapter 5: thermal indices and their applications for livestock environments. In: De Shazer JA (ed) Livestock energetics and thermal environment management. ASABE, St. Joseph, **2009**,113–130.

[25] S. Davis, and T.L. Mader, Adjustments for Wind Speed and Solar Radiation to the Temperature-Humidity Index, *Nebraska Beef Cattle Report*. **2003**,49-51.

[26] P.E. Hillman, Lee, C.N., Carpenter, J.R., Baek, K.S., and Parkhurst, A. *Impact of Hair Color on Thermoregulation of Dairy Cows to Direct Sunlight*. in *2001 Sacramento, CA July 29-August 1,2001*. **2001**. American Society of Agricultural and Biological Engineers.

[27] R.G.d. Silva, N. La Scala, J., and Tonhati, H., Radiative properties of the skin and haircoat of cattle and other animals. *Transactions of the ASAE*, **2003**. *46(3)*.DOI: 10.13031/2013.13567.

[28] Transfer processes in animal coats. I. Radiative transfer. *Proceedings of the Royal Society of London. Series B. Biological Sciences*, **1975**. *188(1093)*,377-393.DOI: 10.1098/rspb.1975.0026.

[29] V.A. Finch, Bennett, I.L., and Holmes, C.R., Coat colour in cattle: effect on thermal balance, behaviour and growth, and relationship with coat type. *The Journal of Agricultural Science*, **1984**. *102(1)*,141-147.DOI: 10.1017/s0021859600041575.

[30] J.C. Hutchinson and Brown, G.D., Penetrance of cattle coats by radiation. *Journal of Applied Physiology*, **1969**. *26(4)*,454-464.DOI: 10.1152/jappl.1969.26.4.454.

[31] K.G. Gebremedhin, Ni, H., and Hillman, P.E. *Temperature profile and heat flux through irradiated fur layer.* in *Proceedings of the 5th Livestock Environment Symposium, St Joseph, MI*. **1997**. pp. 226–233.

[32] R.G. da Silva, Guilhermino, M.M., and de Morais, D.A.E.F., Thermal radiation absorbed by dairy cows in pasture.

International Journal of Biometeorology, **2009**. *54(1)*,5-11.DOI: 10.1007/s00484-009-0244-1.

[33] M.M. Rojas-Downing, Nejadhashemi, A.P., Harrigan, T., and Woznicki, S.A., Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, **2017**. *16*,145-163.DOI: 10.1016/j.crm.2017.02.001.

[34] V.A. Finch, Body Temperature in Beef Cattle: Its Control and Relevance to Production in the Tropics. *Journal of Animal Science*, **1986**. *62(2)*,531-542.DOI: 10.2527/jas1986.622531x.

[35] D. Renaudeau, Collin, A., Yahav, S., de Basilio, V., Gourdine, J.L., and Collier, R.J., Adaptation to hot climate and strategies to alleviate heat stress in livestock production. *Animal*, **2012**. *6(5)*,707-728.DOI: 10.1017/s1751731111002448.

[36] P.J. Hansen, Physiological and cellular adaptations of zebu cattle to thermal stress. *Animal Reproduction Science*, **2004**. *82-83*,349-360.DOI: 10.1016/j.anireprosci.2004.04.011.

[37] P. Pragna, Sejian, V., Soren, N.M., Bagath, M., Krishnan, G., Beena, V., Devi, P.I., and Bhatta, R., Summer season induced rhythmic alterations in metabolic activities to adapt to heat stress in three indigenous (Osmanabadi, Malabari and Salem Black) goat breeds. *Biological Rhythm Research*, **2017**. *49(4)*,551-565.DOI: 10.1080/09291016.2017.1386891.

[38] P.I. Otto, Guimarães, S.E.F., Verardo, L.L., Azevedo, A.L.S., Vandenplas, J., Sevillano, C.A., Marques, D.B.D., Pires, M.d.F.A., de Freitas, C., Verneque, R.S., Martins, M.F., Panetto, J.C.C., Carvalho, W.A., Gobo, D.O.R., da Silva, M.V.G.B., and Machado, M.A., Genome-wide association studies for heat stress response in Bos taurus × Bos indicus crossbred cattle. *Journal of Dairy Science*, **2019**. *102(9)*,8148-8158.DOI: 10.3168/jds.2018-15305.

[39] D.E. Buffington, Collier, R.J., and Canton, G.H., Shade Management Systems to Reduce Heat Stress for Dairy Cows in Hot, Humid Climates. *Transactions of the ASAE*, **1983**. *26(6)*,1798-1802.DOI: 10.13031/2013.33845.

[40] E.R. Jordan, Effects of Heat Stress on Reproduction. *Journal of Dairy Science*, **2003**. *86*,E104-E114.DOI: 10.3168/jds.s0022-0302(03)74043-0.

[41] P.J. Hansen, Reproductive physiology of the heat-stressed dairy cow: implications for fertility and assisted reproduction. *Animal reproduction*, **2019**. *16(3)*,497-507.DOI: 10.21451/1984-3143-AR2019-0053.

[42] P. Devi, Debbarma, S., Kumar, G., and Thakur, P., Effect of heat stress on reproduction in farm animals and its mitigation: A review. *Journal of Entomology and Zoology Studies*, **2019**. *7(2)*,342-345.

[43] D. Wolfenson and Roth, Z., Impact of heat stress on cow reproduction and fertility. *Animal frontiers : the review magazine of animal agriculture*, **2018**. *9(1)*,32-38.DOI: 10.1093/af/vfy027.

[44] A.D. Ealy, Howell, J.L., Monterroso, V.H., Aréchiga, C.F., and Hansen, P.J., Developmental changes in sensitivity of bovine embryos to heat shock and use of antioxidants as thermoprotectants2. *Journal of Animal Science*, **1995**. *73(5)*,1401-1407.DOI: 10.2527/1995.7351401x.

[45] F. Barati, Agung, B., Wongsrikeao, P., Taniguchi, M., Nagai, T., and Otoi, T., Meiotic competence and DNA damage of porcine oocytes exposed to an elevated temperature. *Theriogenology*, **2008**. *69(6)*,767-772.DOI: 10.1016/j.theriogenology.2007.08.038.

[46] J.R.d.S. Torres-Júnior, Pires, M.d.F.A., de Sá, W.F., Ferreira, A.d.M., Viana, J.H.M., Camargo, L.S.A., Ramos, A.A., Folhadella, I.M., Polisseni, J., de Freitas, C., Clemente, C.A.A., de Sá Filho, M.F., Paula-Lopes, F.F., and Baruselli, P.S., Effect of maternal heat-stress on follicular growth and oocyte competence in Bos indicus cattle. *Theriogenology*, **2008**. *69(2)*,155-166.DOI: 10.1016/j.theriogenology.2007.06.023.

[47] N. Ghavi Hossein-Zadeh, Mohit, A., and Azad, N., Effect of temperature-humidity index on productive and reproductive performances of Iranian Holstein cows. *Iranian Journal of Veterinary Research*, **2013**. *14(2)*,106-112.

[48] A. Rocha, Randel, R.D., Broussard, J.R., Lim, J.M., Blair, R.M., Roussel, J.D., Godke, R.A., and Hansel, W., High environmental temperature and humidity decrease oocyte quality in but not in cows. *Theriogenology*, **1998**. *49(3)*,657-665.DOI: 10.1016/s0093-691x(98)00016-8.

[49] S. Dash, Chakravarty, A.K., Singh, A., Upadhyay, A., Singh, M., and Yousuf, S., Effect of heat stress on reproductive performances of dairy cattle and buffaloes: A review. *Veterinary world*, **2016**. *9(3)*,235-244.DOI: 10.14202/vetworld.2016.235-244.

[50] E. Gilad, Meidan, R., Berman, A., Graber, Y., and Wolfenson, D., Effect of heat stress on tonic and GnRH-induced gonadotrophin secretion in relation to concentration of oestradiol in plasma of cyclic cows. *Reproduction*, **1993**. *99(2)*,315-321.DOI: 10.1530/jrf.0.0990315.

[51] F.C. Gwazdauskas, Thatcher, W.W., Kiddy, C.A., Paape, M.J., and Wilcox, C.J., Hormonal patterns during heat stress following PGF2α-tham salt induced luteal regression in heifers. *Theriogenology*, **1981**. *16(3)*,271-285.DOI: 10.1016/0093-691x(81)90012-1.

[52] W.M.N.K. Jayathilake, H.T.S.I. Madushanka, W.M.T.D. Rathnakumara, Y. Prashanth, K. Nizanantha, G.D.R.K. Perera, and P.A.B.D. Alexander, Effect of environmental heat stress on pregnancy rate of imported dairy cattle, In: *Proceedings of 12th international research conference - general sir john Kotelawala Defence University*. **2020**, pp 205.

[53] K.G. Bhave, Jawahar, K.T.P., Kumarasamy, P., Sivakumar, T., Joseph, C., Shirsath, T., Deshmukh, P., and Venkataramanan, R., Genetic and non-genetic factors affecting semen production and quality characteristics of Gir cattle breed under semi-arid climate. *Veterinary world*, **2020**. *13(8)*,1714-1718.DOI: 10.14202/vetworld.2020.1714-1718.

[54] M.F. Bhutta, Tariq, M., Tunio, M.T., Sufyan, A., Abdul Rauf, H., Javed, M., and Imran, S., Season Induced Changes in Seminal Characteristics of Sahiwal Breeding Bulls. *Advances in Animal and Veterinary Sciences*, **2020**. *8(6)*.DOI: 10.17582/journal.aavs/2020/8.6.601.607.

[55] M. Bhakat, Effect of Season on Semen Quality of Crossbred (Karan Fries) Bulls. *Advances in Animal and Veterinary Sciences*, **2014**. *2(11)*,632-637.DOI: 10.14737/journal.aavs/2014/2.11.632.637.

[56] N.S. Jalmeria, Panth, S., Pandita, S., Roy, A.K., Ashutosh, M., Mohanty, T.K., Bhakat, M., Punetha, M., and Gupta, D., Seasonal variations in hormones and enzymes of seminal plasma and its relationship with semen quality in crossbred cattle bulls. *Biological Rhythm Research*, **2018**. *51(4)*,633-643.DOI: 10.1080/09291016.2018.1548873.

[57] P. Pragna, Archana, P.R., Aleena, J., Sejian, V., Krishnan, G., Bagath, M., Manimaran, A., Beena, V., Kurien, E.K., Varma, G., and Bhatta, R., Heat Stress and Dairy Cow: Impact on Both Milk Yield and Composition. *International Journal of Dairy Science*, **2016**. *12(1)*,1-11.DOI: 10.3923/ijds.2017.1.11.

[58] H.D. Johnson, Environmental temperature and lactation (with special reference to cattle). *International Journal of Biometeorology*, **1965**. *9(2)*,103-116.DOI: 10.1007/bf02188466.

[59] R.B. Moore, Fuquay, J.W., and Drapala, W.J., Effects of Late Gestation Heat Stress on Postpartum Milk Production and Reproduction in Dairy Cattle. *Journal of Dairy Science*, **1992**. *75(7)*,1877-1882.DOI: 10.3168/jds.s0022-0302(92)77947-8.

[60] R.H. Ingraham, Stanley, R.W., and Wagner, W.C., Seasonal effects of tropical climate on shaded and nonshaded cows as measured by rectal temperature, adrenal cortex hormones, thyroid hormone, and milk production. *Am J Vet Res*, **1979**. *40(12)*,1792-1797.

[61] R. Osei-Amponsah, Dunshea, F.R., Leury, B.J., Cheng, L., Cullen, B., Joy, A., Abhijith, A., Zhang, M.H., and Chauhan, S.S., Heat Stress Impacts on Lactating Cows Grazing Australian Summer Pastures on an Automatic Robotic Dairy. *Animals : an open access journal from MDPI*, **2020**. *10(5)*,869.DOI: 10.3390/ani10050869.

[62] S. Tao, Bubolz, J.W., do Amaral, B.C., Thompson, I.M., Hayen, M.J., Johnson, S.E., and Dahl, G.E., Effect of heat stress during the dry period on mammary gland development. *Journal of Dairy Science*, **2011**. *94(12)*,5976-5986.DOI: 10.3168/jds.2011-4329.

[63] B.C. do Amaral, Connor, E.E., Tao, S., Hayen, J., Bubolz, J., and Dahl, G.E., Heat-stress abatement during the dry period: Does cooling improve transition into lactation? *Journal of Dairy Science*, **2009**. *92(12)*,5988-5999.DOI: 10.3168/jds.2009-2343.

[64] M.L. Rhoads, Rhoads, R.P., VanBaale, M.J., Collier, R.J., Sanders, S.R., Weber, W.J., Crooker, B.A., and Baumgard, L.H., Effects of heat stress and plane of nutrition on lactating Holstein cows: I. Production, metabolism, and aspects of circulating somatotropin. *Journal of Dairy Science*, **2009**. *92(5)*,1986-1997.DOI: 10.3168/jds.2008-1641.

[65] T.M. Brown-Brandl, Nienaber, J.A., Eigenberg, R.A., Hahn, G.L., and Freetly, H., Thermoregulatory responses of feeder cattle. *Journal of Thermal Biology*, **2003**. *28(2)*,149-157.DOI: 10.1016/s0306-4565(02)00052-9.

[66] J. Gaughan, Holt, S., Hahn, G., Mader, T., and Eigenberg, R., Respiration rate: Is it a good measure of heat stress in cattle? *Asian-Australasian Journal of Animal Sciences*, **2000**. *13(Supplement Vol C)*,329-332.

[67] V.C. Dalcin, Fischer, V., Daltro, D.d.S., Alfonzo, E.P.M., Stumpf, M.T., Kolling, G.J., Silva, M.V.G.B.d., and McManus, C., Physiological parameters for thermal stress in dairy cattle. *Revista Brasileira de Zootecnia*, **2016**. *45(8)*,458-465.DOI: 10.1590/s1806-92902016000800006.

[68] R.A. Eigenberg, Brown-Brandl, T.M., Nienaber, J.A., and Hahn, G.L., Dynamic Response Indicators of Heat Stress in Shaded and Non-shaded Feedlot Cattle, Part 2: Predictive Relationships. *Biosystems Engineering*, **2005**. *91(1)*,111-118.DOI: 10.1016/j.biosystemseng.2005.02.001.

[69] C. Bun, Watanabe, Y., Uenoyama, Y., Inoue, N., Ieda, N., Matsuda, F., Tsukamura, H., Kuwahara, M., Maeda, K.-I., Ohkura, S., and Pheng, V., Evaluation of heat stress response in crossbred dairy cows under tropical climate by analysis of heart rate variability. *The Journal of veterinary medical science*, **2018**. *80(1)*,181-185.DOI: 10.1292/jvms.17-0368.

[70] J.E. Legates, Farthing, B.R., Casady, R.B., and Barrada, M.S., Body Temperature and Respiratory Rate of Lactating Dairy Cattle Under Field and Chamber Conditions. *Journal of Dairy Science*, **1991**. *74(8)*,2491-2500.DOI: 10.3168/jds.s0022-0302(91)78426-9.

[71] I.K. Atkins, Cook, N.B., Mondaca, M.R., and Choi, C.Y., Continuous Respiration Rate Measurement of Heat-Stressed Dairy Cows and Relation to Environment, Body Temperature, and Lying Time. *Transactions of the ASABE*, **2018**. *61(5)*,1475-1485.DOI: 10.13031/trans.12451.

[72] R.J.C.R.B. Zimbelman, Rhoads, R.P., Rhoads, M.L., Duff, G.C. and Baumgard, L.H., *A re-evaluation of the impact of temperature humidity index (THI) and black globe humidity index (BGHI) on milk production in high-producing dairy cows.* in *24th Southwest Nutrition and Management Conference*. **2009**.

[73] G. Baselli, Cerutti, S., Civardi, S., Liberati, D., Lombardi, F., Malliani, A., and Pagani, M., Spectral and cross-spectral analysis of heart rate and arterial blood pressure variability signals. *Computers and Biomedical Research*, **1986**. *19(6)*,520-534.DOI: 10.1016/0010-4809(86)90026-1.

[74] F.D. Rensis and Scaramuzzi, R.J., Heat stress and seasonal effects on reproduction in the dairy cow—a review. *Theriogenology*, **2003**. *60(6)*,1139-1151.DOI: 10.1016/s0093-691x(03)00126-2.

[75] K.E. Schütz, Rogers, A.R., Cox, N.R., and Tucker, C.B., Dairy cows prefer shade that offers greater protection against solar radiation in summer: Shade use, behaviour, and body temperature. *Applied Animal Behaviour Science*, **2009**. *116(1)*,28-34.DOI: https://doi.org/10.1016/j.applanim.2008.07.005.

[76] R.J. Collier and Gebremedhin, K.G., Thermal Biology of Domestic Animals. *Annual Review of Animal Biosciences*,

2015. *3(1)*,513-532.DOI: 10.1146/annurev-animal-022114-110659.

[77] K.A. Janni and Allen, D.M. *Thermal Environmental Conditions in Curtain Sided Naturally Ventilated Dairy Freestall Barns*. in *Livestock Environment VI, Proceedings of the 6th International Symposium 2001*. American Society of Agricultural and Biological Engineers.

[78] S. Angrecka and Herbut, P., Impact of Barn Orientation on Insolation and Temperature of Stalls Surface. *Annals of Animal Science*, **2016**. *16(3)*,887-896.DOI: 10.1515/aoas-2015-0096.

[79] S. Angrecka, Herbut, P., Nawalany, G., and Sokołowski, P., The impact of localization and barn type on insolation of sidewall stalls during summer. *Journal of Ecological Engineering*, **2017**. *18(4)*,60-66.DOI: 10.12911/22998993/74398.

[80] H. LeRoy and Osburn, D.D., Feasibility of Evaporative Cooling for Dairy Cattle Based on Expected Production Losses. *Transactions of the ASAE*, **1970**. *13(3)*,0289-0291.DOI: 10.13031/2013.38588.

[81] G.L. Hahn and Osburn, D.D., Feasibility of Summer Environmental Control for Dairy Cattle Based on Expected Production Losses. *Transactions of the ASAE*, **1969**. *12(4)*,0448-0451.DOI: 10.13031/2013.38862.

[82] J.T. Strickland, Bucklin, R.A., Nordstedt, R.A., Beede, D.K., and Bray, D.R., Sprinkler and Fan Cooling System for Dairy Cows in Hot, Humid Climates. *Applied Engineering in Agriculture*, **1989**. *5(2)*,231-236.DOI: 10.13031/2013.26507.

[83] R.J. Collier, Beede, D.K., Thatcher, W.W., Israel, L.A., and Wilcox, C.J., Influences of Environment and Its Modification on Dairy Animal Health and Production. *Journal of Dairy Science*, **1982**. *65(11)*,2213-2227.DOI: 10.3168/jds.s0022-0302(82)82484-3.

[84] J.W. West, Interactions of Energy and Bovine Somatotropin with Heat Stress. *Journal of Dairy Science*, **1994**. *77(7)*,2091-2102.DOI: 10.3168/jds.s0022-0302(94)77152-6.

[85] J.W. West, Hill, G.M., Fernandez, J.M., Mandebvu, P., and Mullinix, B.G., Effects of Dietary Fiber on Intake, Milk Yield, and Digestion by Lactating Dairy Cows During Cool or Hot, Humid Weather. *Journal of Dairy Science*, **1999**. *82(11)*,2455-2465.DOI: 10.3168/jds.s0022-0302(99)75497-4.

[86] D. Beede and Shearer, J., Nutritional management of dairy cattle during hot weather. **1991**.

[87] K.Z. Milam, Coppock, C.E., West, J.W., Lanham, J.K., Nave, D.H., Labore, J.M., Stermer, R.A., and Brasington, C.F., Effects of Drinking Water Temperature on Production Responses in Lactating Holstein Cows in Summer. *Journal of Dairy Science*, **1986**. *69(4)*,1013-1019.DOI: 10.3168/jds.s0022-0302(86)80496-9.