IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)
e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 15, Issue 11 Ser. II (November 2022), PP 01-08
www.iosrjournals.org

A review of the effects of heat stress on physiology, growth, milk and reproduction in ewes

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Abstract:
MENA and Mediterranean climate renders heat stress as one of the most important environmental stressors that adversely impacts livestock and at times even threatens the survival of the animals. Ambient temperature, which is the most significant variable, is one of the climatic factors that can exert stress on a variety of characteristics in sheep, along with humidity, air movement, photoperiod, solar radiation, and wind speed, respectively. For small ruminants, performance and productivity are impacted by heat stress throughout the production phases. However, the impact of these stresses on productivity differs between production systems and agro-ecological zones. The impact of these stresses on productivity depends on production systems and agro-ecological zone, and the capability of a genotype to produce at a certain level in a harsh environment depends on the contribution and expression of a variety of traits that can be divided into those that are directly related to the production and adaptability. Therefore, one of the most important characteristics is that the birth weight of lambs, the growth of the animals including body weight, physiological function, milk production and reproductive performance are affected by hyperthermia. Thus, animals become more dependent on evaporative cooling in the form of sweating and panting, as the primary non-evaporative methods of cooling small ruminants (radiation, conduction, convection) all become less effective as environmental temperatures increase.
***Key Word**: heat stress, ewes, THI, heart rate, rectal temperature milk production, reproduction.*

Date of Submission: 05-11-2022 Date of Acceptance: 20-11-2022

I. Introduction

The importance of understanding the impact of environmental change on animals and their arsenal of coping mechanisms is crucial within the context of the current debate on global climate change. Within the tropics, one of the important agro-ecological zones is the semi-arid environment[1], whereas, climate change is expected to have a significant negative impact on the Middle East and North Africa (MENA) region, shifting the current hot and arid natural conditions of the area[2,3,4,5]. This will result in noticeably higher day and night temperatures. Therefore, today's maximum heat wave temperatures in the Middle East and North Africa are about 43°C, but are projected to increase to 46°C by 2050 and 50°C by the end of the century[6].In addition, by 2050, the demand for livestock products globally is projected to double, due mainly to the rising standard of living throughout the world. However, through its effects on forage and crop quality, water availability, milk production, livestock diseases, animal reproduction, and biodiversity, a changing climate poses a global risk to the livestock sector[7]. Thus, the sensitivity of livestock to heat stress is influenced by temperature, humidity, species, genetic potential, life stage, and nutritional status. Considering that livestock in subtropical regions are typically better acclimated to high temperatures and drought, livestock in higher latitudes will be more affected by increased temperatures than livestock in lower latitudes[8]. Adding to that, climatic change will have a smaller impact on confined livestock production systems that have more control over climate exposure[9]. In the case of sheep exposed to temperature extremes, body weight, average daily gain (ADG), growth rate, and total solid mass will decrease, resulting in decreased reproduction[10,11], as a result, according to the study. It is therefore important to note that the impact of climate change[12]on sheep production is not limited to those systems that have more control over climate exposure. All the physiologic and cellular processes of the organism are disrupted when an animal is subjected to stress, either because of the stress itself (such as a drop in body temperature due to heat stress) or due to physiologic adaptations made by the animal to counteract the stress. Additionally, metabolic and digestive processes are often impaired when animals are subjected to heat stress, due to altered or impaired feeding behavior[13,14].

Both physiological characteristics and some of the production performance (reproduction, milk production and lamb growth) exhibited by sheep which are affected by heat stress are addressed in this article.

II. Consequences of heat stress on sheep

1. Physiological adaptability to heat stress

One of the important animal species in tropical areas with arid and semi-arid climate are sheep, also high temperature and solar radiation in tropical areas are known to have a negative impact on animal productivity[15]. Thus, the recognition and measurement of stress has been done using a variety of behavioral and physiological changes, depending on the stressor, these alterations may differ qualitatively or quantitatively, hence the need to use a variety of indices to determine the severity of stress. According to the stressor, these alterations may differ qualitatively or quantitatively, hence the need to use a variety of indices to determine the severity of stress. Among the most crucial factors in assessing the adaptation of animals to the dynamic environment are rectal temperature (RT), heart rate (HR), and respiratory rate (RR)[16]. Moreover, both environment and animal work together as a single and interrelated system[17]. Hence, sheep combine the production of metabolic heat, heat storage, as well as heat exchange within the environment to maintain a constant body temperature. If the environmental temperature increases, homeostatic processes that stimulate heat dissipation and decrease metabolic heat production are activated[18]. Thus, homeostatic processes that stimulate heat dissipation and decrease metabolic heat production become activated as the environmental temperature rises. The vasodilatation of peripheral blood vessels near the surface and in areas of low subcutaneous fat (e.g., ears, legs), as well as in the upper respiratory tract, allows metabolic heat to be transferred from the sheep's core to the surface, thereby increasing sensible heat loss (convection, conduction, radiation)[19]. The primary evaporative cooling mechanism available to sheep is respiration. During respiration, sheep lose 60-90% of their body heat and only 10% through transpiration. As temperatures increase, evaporative heat exchange, such as transpiration and respiration, becomes more important, with the percentage of heat lost through respiration increasing from 20% to 60% when the ambient temperature increases from 12°C to 35°C[14]. The thermal gradient between an animal and its environment reduces and eventually reverses as outside temperatures approach and then exceed skin temperature[14]. In the case of an increase in ambient temperature from 24°C to 40°C, heat exchange through respiration and, to a lesser extent, sweating, becomes the only efficient method for cooling the body. At these temperatures, the respiratory rate increases by a factor of 2.6.

The typical mammalian homeostatic responses to heat stress encompass decreased water loss in feces and urine[20], decreased food intake in both pregnant[21,22]and non-pregnant females[23,24], and an increase in sweating[18]and an early increase in respiratory and heart rates[25,26,27]. However, these responses are not necessarily the same as those observed in pregnant animals. Numerous adjustments in physical, biochemical, and physiological processes are occurring in response to the stress to mitigate the adverse consequences of heat stress and maintain thermal homeostasis. The majority of these changes are aimed at decreasing metabolic heat production and dissipating body heat to the environment[19].

The result of heat stress can impact physiological parameters such as heart rate (HR), respiratory rate (RR), and rectal temperature (RT), which can be used as indicators of stress[28,29].

1.1. Heart rate

HR reflects blood flow homeostasis in relation to overall metabolic state. For example, the effects of several variables, including season, day, time of day, ambient temperature, humidity, and exercise, have been extensively studied on the cardio respiratory system[14]. Therefore, the heart rate has a circadian rhythm, and exposure to heat stress leads to a decrease in the magnitude of change during the hottest part of the day. Exhaling of Naimey sheep to heat stress reduced ($P<0.05$) The exposure of Naimey sheep to heat stress reduced ($P<0.01$) the daily average HR (115.7 and 85.8 beats/min for the control and heat stress groups, respectively)[30]. Thus, several breeders have reported that a correlation exists between HR and metabolic heat production[31,32]. On the other hand, exposure to heat stress is widely known to reduce metabolic heat production and to minimize heat loss, in order to maintain a constant body temperature

An insight into the results of several researchers, who found that HR is accelerated during exposure to heat stress, is shown in Table 1. The study of Bharat Merino breed revealed 73.30 ± 2.60 beats/min during thermo-neutral (TN) and 96.80 ± 1.30 beats/min during heat stress (HS)[33]. In other experiments, lower values were found in the Malpura breed (57.61± 0.61 beats/min versus 57.61 ± 0.61 beats/min)[25]. While in other experiments, HR values during non-stress (90 and 91 beats/min for Morada Nova and Santa Ines breed) and stress (98.9 and 100 beats/min for Morada Nova and Santa Ines breed)[26]. However, similar values were found by the Indian teamfor three breeds bred in India which are the Chokla breed (84.51 ± 0.70 beats/min in TN period and 96.96 ± 0.55 beats/min in HS period), the Magra breed (95. 71 ± 0.38 beats/min in the NT period and 99.90 ± 0.38 beats/min in the HS period) and the Mrawari breed (91.46 ± 0.81 beats/min in the NT period and 99.90 ± 0.45 beats/min in the HS period)[34]. Finally, with Blackbelly ewes and under tropical conditions in southern

Mexico, HR varied from 91.99 ± 18.08 beats /min under TN conditions to 108.58 ± 20.38 beats/min under HS conditions[35].

1.2.Respiratory rate

The frequency of respiration is a mechanism for thermolysis and maintenance of homeothermy to cope with increased body temperature[15]. Additional researchers have indicated that respiratory rate can be used to assess heat stress in sheep, while other experiments have reported that high prolactin circulation during respiration can be used to assess heat stress in sheep[36]. In addition to the respiratory rate,can also be used to evaluate heat stress in sheep. The respiratory rate can also be used to assess heat stress in sheep, while for other experiments have reported that high prolactin circulation during a period of heat stress has the effect of reducing heat stress in the sheep. Whereas other experiments have reported that high prolactin circulation during a period of heat stress modulates some heat dissipation mechanisms as well as oriented heat production to support homeothermy[37]. Such an indicator, respiratory rate, provides an opportunity to assess the effect of elevated temperatures on animals. Environmentally controlled chamber studies have developed models to monitor the effect of heat stress on the respiratory rate of animals[38,39,40]. There are various temperature conditions (thermal neutral zone or optimal zone) under which animals are able to maintain a relatively stable body temperature without affecting animal welfare and physiological function[41].

Sheep respond to elevated temperatures by accelerating thebreathing rate, which increases evaporation through the respiratory tract, also, animals' increase their breathing rate (breaths/min), which increases the respiratory evaporation (Wm^{-2}) required for thermal balance. The rise in RR is an attempt to increase respiratory evaporation and skin temperature that can be attributed to being exposed to heat stress can result in altered blood, blood flow and redistribution of blood flow across surfaces. Recently, similar results have been reported by several authors[30,42,43].

Table 1: Physiological parameters: respiration rate (RR), heart rate (HR) and rectal temperature

Breed	Ambiant temperature °C	THI (units)	Respiration rate (RR) breaths/min	Heart rate (HR) beats/min	Rectal temperature (TR) en °C	References
Bharat Merino	TN 19.1 to 34.6 °C HS 40 °C for 6 hours	********** **********	42.90 ± 3.40 126.50 ± 2.80	73.30 ± 2.60 96.80 ± 1.30	38.5 ± 0.00 39.1 ± 0.00	[33]
Malpura	TN 35.6 to 36.2 °C HS 39.5 to 41.0 °C	29.55 ± 0.32 35.40 ± 0.20	22.45 ± 0.41 60.79 ± 1.07	57.61 ± 0.61 66.00 ± 0.46	38.34 ± 0.00 39.07 ± 0.00	[25]
Morada Nova Santa Inès	TN 22.75 ± 0.83 °C HS 33.68 ± 1.66 °C TN 22.75 ± 0.83 °C HS 33.68 ± 1.66 °C	72.46 ± 0.31 79.50 ± 1.94 72.46 ± 0.31 79.50 ± 1.94	31.20 ± 12.70 51.40 ± 14.20 51.40 ± 15.20 69.50 ± 10.10	91.40 ± 14.60 98.90 ± 14.50 90.40 ± 15.30 100.10 ± 14.30	37.60 ± 0.90 38.60 ± 1.10 38.10 ± 0.80 38.70 ± 0.50	[26]
Chokla Magra Marwari	TN 20 °C HS 38.5 °C TN 20 °C HS 38.5 °C TN 20 °C HS 38.5 °C	65 84 65 84 65 84	36.31 ± 0.52 59.58 ± 0.67 49.81 ± 0.33 58.11 ± 0.29 45.13 ± 0.80 57.93 ± 0.39	84.51 ± 0.70 96.96 ± 0.55 95.71 ± 0.38 99.90 ± 0.38 91.46 ± 0.81 99.90 ± 0.45	39.02 ± 0.00 39.78 ± 0.00 39.61 ± 0.00 39.75 ± 0.00 38.95 ± 0.00 39.62 ± 0.00	[34]
Lacaune	TN 15 to 20 °C HS 35 °C	59 à 65 83	42.00 ± 2.00 132 ± 2.00	************ ************	38.86 ± 0.04 39.63 ± 0.04	[27]
Blackbelly	TN 29.3 ± 3.1 °C HS 34.2 ± 2.9 °C	79 88	42.15 ± 18.12 116.73 ± 33.59	91.99 ± 18.08 108.58 ± 20.38	38.18 ± 1.68 38.93 ± 0.87	[35]

TN: Thermoneutral zone; HS: Heat stress

In some Egyptian studies, researchers have also described that in sheep, during the summer season, RR is higher than during the winter season[44,45], in other studies, researchers have observed a trend of increased RR in the Egyptian Rahmani sheep breed, the Ossimi breed and Ossimi x Suffolk crosses, they observed that RR was lower at 8 am compared to 12 pm and 4 pm[45,46,47]. However, in Indian studies, a team of researchers found accelerated RR in the afternoon compared to the morning in the Malpura sheep breed raised in a semi-arid region. An overview of the results of several investigators who confirmed that RR is always higher during the period of high heat (RR ranging from 51.40 breaths/min for Morada Nova ewes[26]to132 breaths/min for Lacaune ewes[27]) compared with the results found during mornings with milder temperatures (RR ranging from 22.45 breaths/min for Malpura ewes[25]to 51.40 breaths/ min for Santa Ines ewes[26]under thermal comfort conditions) is shown in Table 1.

1.3.Rectal temperature

The most commonly used parameter to get an idea of the internal body temperature of animals[48]is rectal temperature, thus, Increases of one degree or less in rectal temperature are sufficient to reduce the performance of livestock[49]. In addition, rectal temperature is widely associated with changes in physiological function under heat stress[15], and, when exposed to high ambient temperatures, animals are encouraged to balance the excessive heat load by using various means to dissipate the latent heat. If all these means fail, rectal body temperature increases[50]. During exposure to heat stress, hyperthermia results from a decrease in the thermal gradient between the animal and the surrounding environment, and therefore heat loss through the sensible pathway becomes less efficient[51,52]. However, during the winter season, animals are exposed to low temperatures, especially at night, and because of this, animals are unable to maintain their internal body temperature and thereby RT decreases. Meanwhile, during the summer season, the THI has high values in the afternoon, which leads to an increase in RT in summer compared to other seasons. As animals are being exposed to high environmental temperatures, the rectal temperature will increase[30,52]. Some other researchers have indicated that RT is generally considered one of the best indicators to get a sense of internal temperature variations throughout the day. Though, RT can range from 38.3°C to 39.9°C under thermo-neutral conditions[43]. Raising ambient temperature from 18°C to 35°C is accompanied by an increase in RT in sheep[10,25,45]. In a review study, it was found that the RT of sheep was higher than that of humans. Moreover, a synthesis study by an Indian team indicated that a temperature of 42°C or higher is dangerous for animals[16], while an Egyptian research team indicated that sheep are homeotherms and are able to maintain thermal balance by dissipating excess body heat[14]. Therefore, the assessment of rectal temperature during the summer season is relevant because it allows us to see if animals are adapted to high temperatures or whether heat tolerance is explained by the loss of body temperature[53,54]. In fact, several researchers have found that in order to assess the adaptation of animals to high temperatures, the use of rectal temperature, respiratory rate and physiological variables are not sufficient to express heat stress[55,56,57].

For instance, according to Table 1, the rectal temperature of ewes under heat neutral condition ranged from 37.60°C in Morada Nova ewes[26]to 39.61°C in Magra ewes[34]. While these same temperatures under heat stress condition they ranged from 38.60 °C for Moada Nova[26]ewes to 39.78 °C for Chokla[34]ewes.

1.2. The effect of heat stress on sheep production

High environmental temperature has a negative impact on production performance, reproduction, immunity and udder health of ewes and goats, even though they are considered to be among the most heat tolerant species[58].

1.2.1. Ewe reproduction

Sheep are considered among the most reproductive species despite the fact that most breeds have a seasonal reproductive cycle. In addition, they reported that during the breeding season (winter), sexual activity is intense while in summer, ewes do not exhibit heat behavior. When ewes were exposed to high temperatures, they exhibited heat stress 5 hours later and the heat period was shorter by 6 hours[59].

Excessively high temperature causes a delay in the onset of heat in Bharat Merino ewes. This may reflect altered pulsatile LH secretions and decreased estrogen secretion. In addition, estrus intensity is greater in ewes sheltered from the sun compared to ewes kept in a 40°C climate chamber, hence, elevated temperature does not affect ovulation in ewes that are exposed to heat stress before and during superovulation treatment, nor does it affect their fertility. For ewes that are exposed to heat stress before and during superovulation treatment, high temperature does not affect ovulation or fertility. However, this is attributed to the adaptation of these ewes to stressful temperature conditions[33].

When ewes are exposed to high ambient temperature, poor-quality embryos result, even if they are kept under shelter during embryonic development. Thus, the alteration in embryo quality comes from the poor quality of the oocytes[33], since heat stress during the follicular phase reduces the oocyte's developmental capacity. Investigation of the effect of the humid tropical climate on the reproductive performance of Santa Ines ewes shows that 60.6% of the ewes return to heat during the wet/dry transition period[60]. In another research team, it was shown that the exposure of Aragonesa ewes to a temperature higher than 30°C during the two days before artificial insemination causes a decrease in fertility and consequently in the probability of pregnancy[61].

During the mating season, the number of days per week with ambient temperatures below 32.0°C was inversely related to ewe fertility (number of lambs per 100 ewes mated) in both surveys. There was also a negative correlation between the number of lambs born per 100 ewes bred and heat stress during mating[62]. There was also a correlation between the number of days with temperatures below 32.0°C during the mating period and the fraction of ewes returning to estrus/service, a sign of fertilization failure[63]. In addition, data from more than 150 flocks of artificially inseminated (AI) sheep in Spain provide further evidence that heat stress influences fertilization rates in the field[61].

1.2.2. Heat stress during gestation on lamb birth weight

Thermal stress during the late gestation period has a significant effect on the birth weight of lambs[64]. Likewise, exposure of ewes to a high temperature source during the last month of gestation results in delayed fetal growth (birth weight 2.3 Kg Vs 3.4 Kg; $P<0.05$)[65].

Severe climatic conditions and infrequent rainfall throughout the year are common features of sheep farming in arid regions, with negative effects on the quantity and quality of forage produced, while animals face severe supply shortages throughout the year, though reduced MSI in pregnant females is a common feature of all small ruminant production systems in drylands. In response, nutritional supplementation at the end of gestation is a good practice to improve the nutritional level of pregnant females. In addition to heat stress[14,66]and undernutrition[67,68]during gestation causes placental dysfunction and fetal growth retardation. Certainly, low birth weight affects not only perinatal and peri-weaning viability, but can also compromise functional and metabolic abilities in adulthood[69,70].

The Katahdin x Pelibuey crossbred ewes supplemented during the last third of gestation with different heat stress scenarios develop physiological and anatomical adaptations of the placenta to counteract such environmental insults. Based on this biological strategy, energy-protein supplementation was redirected to activate thermoregulatory mechanisms and to be able to compensate for the effect of heat stress while ensuring nutritional requirements for fetal growth[71]. When ewes are exposed to a temperature of 30-40°C with a RH of 40% in late gestation, the total number of embryonic cells and the size of the placenta are reduced, which in turn reduces fetal development[14]. In a similar way, with the Assaf dairy sheep breed[72], it was found that the birth weight of the lambs was affected by heat stress (4.93 Kg versus 4.53 Kg). Increased temperature during gestation negatively affects fetal growth and increases the abortion rate[73].

An overview of the effect of heat stress at different periods of ewe gestation on lamb birth weight and placental weight, when ewes are exposed to heat stress throughout gestation, birth weight is significantly affected (3.67 Kg Vs 3.03 Kg). The most remarkable effect (a 36% decrease in birth weight) is recorded for ewes that are exposed to heat stress during the last two thirds of gestation (3.96 Kg Vs 2.55 Kg)[74].

1.2.3. Milk production

Throughout the Mediterranean basin, the increase in temperature coincides directly with the last stage of gestation in dairy ewes. Both heat stress and the advancement of the lactation stage reduce the mobilization of body reserves for milk synthesis, which has negative effects on the quantity and quality of milk produced[75].

Lactating ewes under high temperature with THI>80 units, reduces production and changes milk composition, indeed for milk performance they found significant differences(2.9 kg/day for non-stressed ewes vs. 2.7 kg/day for the control group) and they also noted a significant effect on milk composition, namely: fat proportion (55.6 g/Kg vs. 49.4 g/Kg), protein content (50.1 g/kg vs. 48.6 g/kg) and amount of dry matter produced/ewe/day (0.46 kg/d vs. 0.42 kg/d)[72].

Although the Merino de Grazalema sheep is considered to be a hardy breed of sheep, well adapted to the mountainous conditions of southwestern Andalusia, its results show that the dairy performance of these animals is affected by temperature and humidity levels. In the case of high humidity, measured by the index (THI), the comfort zone where there is no thermal stress is between THI = 28 and THI = 47[76].In addition, the same authors with the method of linear least squares regression of milk yield for each value of THI shows that there is an average loss of 16.6±2.9 g/day of milk yield per ewe and per unit of THI after the critical threshold of THI (value = 47). Similarly, they indicate that there is no effect for THI values between 28 and 47; however they observed deterioration in the amount of dry matter and the amount of protein and fat produced/ewe/day.

In addition, the decrease in milk production in ewes subjected to high ambient temperature is due to inhibition of prolactin secretion by the pituitary gland due to dopamine release from the hypothalamus[77]. Furthermore, the milk performance of the Sardinian breed decreases by 20% from a THI of 60-65 to 72-75[78]. Besides the deterioration observed in the performance and quality of the milk produced, solar radiation has a negative effect on the hygienic quality of the milk[72].

1.2.4. Heat stress and lamb growth

The process of growth, i.e., increase in live weight, mass and cell multiplication, is genetically and environmentally controlled. Both of nutrient availability, hormone and enzyme secretion, and elevated temperatures are considered factors that can influence ADG[14,36,79].In fact, other researchers have reported that increased temperature also reduces animal weight, average daily gain (ADG), growth rate and total solid conten[10,11,77]. Adding to that, the decrease in growth of lambs subjected to elevated temperature is the result of increased catabolism and decreased anabolism due to reduced feed intake and the ADG values recorded for lambs (Suffolk lambs) demonstrate a lower ADG in summer than in winter[14]. Similarly, body weight, ADG, total body dry matter and body dry matter ADG (g) were altered as a result of exposure to high temperatures[10,14,80]. Furthermore, in an Italian experiment, the effect of exposure to solar radiation for 10 weeks on the growth of lambs of two breeds (Comisana and Sardinian) was studied and it was concluded that there is a drop in ADG from -11.9 to -12.7 g/week for Comisana breed and from -8.5 to 9.7 g/week for Sardinian breed lambs[81].

In effect, other experiments have confirmed the negative effect of stressful temperatures on the growth of lambs among them:

- Using Cukurova Assaf lambs, researchers found a negative effect on lamb growth (206 g/d for the TN group versus 169 g/d for the HS group)[82].

- Texel X Santa Ines crossbred lambs are more sensitive than both Ile de France X Santa Ines crossbred lambs and Santa Ines breed lambs. Nevertheless, it should be noted that the crossbred lambs had the best ADGs compared to the Santa Ines lambs[83].

- When studying the effect of heat stress on the growth parameters of Afshari lambs, Iranian researchers found a decrease in ADG (210 g/d for heat stressed lambs versus 467 g/d for the control group)[84,85].

- The negative effects of stressful temperatures on the growth of Dorper × Katahdin crossbred lambs (302 g/d for the control group versus 226 g/d for the heat stress group)[86,87].

II. Conclusion

Based on the study, heat stress affects sheep as evidenced by changes in their growth, physiology and production traits. However, their metabolic functions and growth are compromised as they attempt to adapt to heat stress. In order to better understand how climate change affects animal growth, the studies of many scientists were reviewed in depth and summarized in the current article.

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Mâaoui W, et. al. "A review of the effects of heat stress on physiology, growth, milk and reproduction in ewes." *IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS)*, 15(11), 2022, pp. 01-08.