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HEAT STRESS IMPACT ON SHEEP PRODUCTION

UTICAJ TOPLOTNOG STRESA NA PROIZVODNJU OVACA

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ABSTRACT

Research on the impact of heat stress on animals has mainly been related to cattle, while sheep have been neglected and the impact of heat stress on sheep production is still insufficiently researched. There are numerous stressors related to the procedures and methods of breeding sheep in barns and pastures among them ambient temperature is the most important variable because its effect is exacerbated in the presence of high humidity. Thermal indices are useful for assessing the influence of weather parameters in a certain agroecological area, of which the temperature-humidity index proved to be the best thermal index for assessing the harmful effect of heat stress on the productive performance of animals. Sheep have good adaptability and they are resistant to harsh environmental conditions, still in addition to a certain tolerance to heat stress, high temperatures can negatively affect sheep, which most often leads to dehydration, reduced appetite, reduced milk production and increased risk of disease. Mechanisms that help sheep to survive the challenge of heat stress include morphological, behavioural, physiological, blood biochemistry and genetic bases of adaptation. Sheep can combat heat stress by seeking shade, drinking enough water, and properly ventilating the barn. Increasing the productivity of sheep by adapting various management strategies including housing and animal management and climate monitoring may enhance production capacity of the herd. Therefore, heat stress has a negative effect on sheep, temperatures will increase year by year, and therefore it is necessary to investigate the relationship between sheep production and heat stress in time, to improve sheep farming and make life easier in the days ahead.

Keywords: climate change, temperature-humidity index, sheep production, adaptation, sheep management

SAŽETAK

Istraživanja uticaja toplotnog stresa na životinje su se uglavnom odnosila na goveda, pri čemu su ovce ostale zapostavljene i još uvek je nedovoljno istražen uticaj toplotnog stresa na ovčarsku proizvodnju. Brojni su stresori vezani za postupke i metode uzgoja ovaca u štalama i pašnjacima, među kojima je temperatura okoline najvažnija varijabla jer se njeno dejstvo pogoršava u prisustvu visoke vlažnosti. Termalni indeksi su korisni za procenu uticaja vremenskih parametara na određenom agroekološkom području, od kojih se indeks temperature i vlažnosti pokazao kao najbolji termalni indeks za procenu štetnog uticaja toplotnog stresa na produktivne performanse životinja. Ovce poseduju dobru prilagodljivost i otporne su na oštre uslove životne sredine, ali i pored određene tolerancije na toplotni stres, visoke temperature mogu negativno uticati na ovce, što najčešće dovodi do dehidracije, smanjenog apetita, smanjenja proizvodnje mleka i povećanja rizika od bolesti. Mehanizmi koji pomažu ovcama da prežive izazov toplotnog stresa uključuju morfološke, bihejvioralne, fiziološke, biohemijske i genetske osnove adaptacije. Ovce se mogu boriti sa toplotnim stresom tražeći hladovinu, pijući dovoljno vode i pravilnom ventilacijom staje. Povećanje produktivnosti ovaca prilagođavanjem različitih strategija upravljanja uključujući smeštaj i upravljanje životinjama i praćenje klime može poboljšati proizvodni kapacitet stada. Dakle, toplotni stres ima negativan uticaj na ovce, temperature će iz godine u godinu sve više rasti i zato je neophodno na vreme istražiti odnose između ovčarske proizvodnje i toplotnog stresa, unaprediti ovčarstvo i olakšati život u danima koji nam dolaze.

Ključne reči: klimatske promene, indeks temperature i vlažnosti, ovčarska proizvodnja, adaptacija, menadžment ovaca

1. Introduction

Climate change can have a significant impact on animals. Increases in temperature, changes in rainfall and other factors can affect their feeding, reproduction, migration and survival. Animals must adapt to new conditions in order to survive. The impact of climate change on livestock production will depend on the magnitude and nature of the changes and can be mediated through direct effects on animals and indirect impacts on their environment; for example, through the quantity and quality of food. Among the environmental variables that affect animals, heat stress is a major factor that makes animal production challenging in many parts of the world. Heat stress is one of the most harmful factors that contribute to reduced growth, production, reproduction, quantity and quality of milk, as well as natural immunity, making animals more vulnerable to disease and even death. However, small ruminants have successfully adapted to this extreme environment and possess some unique adaptive traits due to behavioral, morphological, physiological and mostly genetic bases. However, complete information is lacking on how these animals can adapt and survive in new and changing environments (1).

In general, sheep have good adaptability and they are resistant to harsh environmental conditions. Sheep adapt to extreme weather conditions through behavioral, morphological, physiological and mostly genetic bases (2,3). However, physiological and behavioral changes in response to hot environments affect the production of small ruminants (4). In general, sheep are raised on pastures in relatively large groups that rely on low inputs in terms of feed, water and labour, and possess a high thermotolerance compared to large ruminants. Globally, the number of sheep is increasing the most compared to other livestock, considering the problem of global warming and climate change, sheep can be crucial for maintaining the production of animal proteins, which will ensure the existence of mankind. Research on the impact of heat stress on animals has mainly been related to cattle, while sheep have been neglected and the impact of heat stress on sheep production is still insufficiently researched. In addition to a certain tolerance to heat stress, high temperatures can negatively affect sheep, which most often leads to dehydration, reduced appetite, reduced milk production and increased risk of disease. Sheep can combat heat stress by seeking shade, drinking enough water, and properly ventilating the barn. Therefore, heat stress has a negative effect on sheep, temperatures will increase year by year, and therefore it is necessary to investigate the relationship between sheep production and heat stress in time, to improve sheep farming and make life easier in the days ahead.

This review paper aims to provide an insight into the state of sheep production in conditions of heat stress, look at different mechanisms of sheep adaptation and strategies for improving sheep production in order to successfully deal with the global problem called heat stress.

2. CLIMATE CHANGE AND LIVESTOCK PRODUCTION

The climate has changed several times in the geological past of the planet, which was influenced by various factors, from the composition of the atmosphere, through volcanic eruptions, reactions in the sun, etc. However, since the agricultural revolution 10,000 years ago, climatic conditions have not changed much. However, in the second half of the last century, it became clear that the climatic conditions were beginning to change too quickly. Since the beginning of the industrial revolution, in 150 years the average temperature on earth has

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increased by 1°C (Figure 1.), which causes numerous changes in the climate.

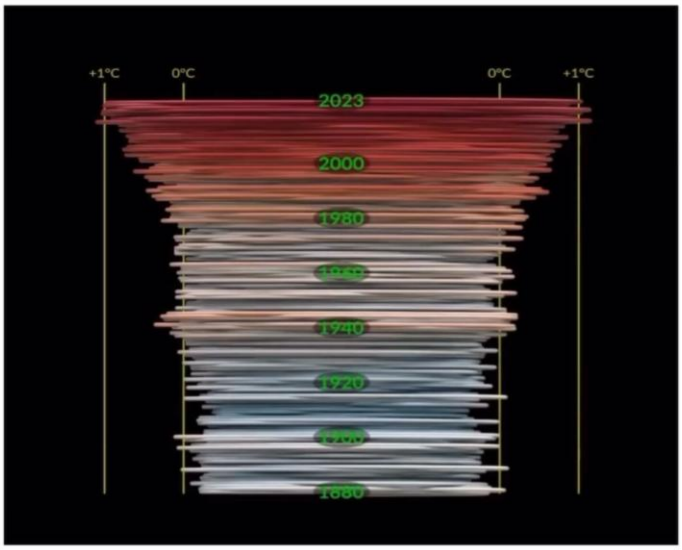

Figure 1. Changes in temperature since the beginning of the industrial revolution.

Scientists have proven that this does not happen naturally, but that humans are responsible for the increase in temperature. As much as 80% comes from the burning of fossil fuels, coal, oil and gas for the production of electricity, industry, heating and transport. Livestock contributes to almost 18% of total anthropogenic greenhouse gas emissions. If we do not stop burning fossil fuels, our planet will continue to heat up, which in the future will cause more frequent and powerful heat waves, more frequent droughts, melting of polar caps and glaciers, then rising sea levels, stronger and more destructive storms and more frequent floods. The confounding of greenhouse gas emissions by anthropogenic activities on climate change has fueled global research efforts regarding the contribution of livestock to global warming. Further efforts are needed to comprehensively assess the multiple impacts of climate change on different ecosystem components to gain a thorough understanding of this topic.

Climate change is defined as a long-term imbalance in the normal weather conditions such as temperature, wind and precipitation characteristics of a particular region and is likely to be one of the major challenges facing humanity during the current century (5). Livestock production plays an important role in the global economy. The effects of climate change are not limited to crop production, but also affect livestock production. Therefore, livestock-based food security is at risk in many parts of the world. Livestock react to environmental changes by changing their phenotypic and physiological characteristics. Therefore, the survival of an animal often depends on its ability to cope with or adapt to existing conditions. Therefore, in order to sustain livestock production in a climate-induced environment, animals must be genetically fit and have the ability to survive in diverse environments. (6).

2.1. TYPES OF ENVIRONMENTAL STRESS IN SHEEP

There are numerous stressors related to the procedures and methods of breeding sheep in barns and pastures. The most significant stressors on farms and pastures come from unfavorable housing conditions, improper handling, veterinary and zootechnical measures and procedures (treatment, vaccinations, blood tests, operations, marking, weaning, grouping, clipping, tail trimming, hoof care), inadequate climatic conditions (extremes of heat and cold) and nutrition (7). The effect of these stressors is manifested in all life periods of sheep, but there are periods when they are subjected to additional loads and the animals are more susceptible to these stressors, such as partus, soon after birth, juvenile period, puberty, estrus, advanced pregnancy and puerperal period. Some stressors may be qualitatively physical components, such as

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climate, while others involve certain procedures in handling procedures, such as manipulation of animals, introduction of new diet, new environment or new animals in the herd, etc. (7) Components that can cause stress in sheep are ambient temperature, humidity, air flow, solar radiation, etc., among which ambient temperature is the most important (8). In the livestock environment, ambient temperature is the most important variable because its effect is exacerbated in the presence of high humidity. Heat stress is defined as any combination of environmental parameters that create conditions that are higher than the temperature range of the animal's thermoneutral zone (TNZ). (9).

2.2. SHEEP PRODUCTION IN THE CHANGING CLIMATE SCENARIO

Climate change affects sheep production both directly and indirectly. The production losses incurred for climate change in sheep could be attributed to the low pastures, low water availability and disease outbreaks (10). In general, sheep are raised in extensive farming systems, with a small percentage of intensive sheep farming. Much of the production is in extensive pastures where inputs are low and feed production and water supply vary with seasonal climate. Intensive ruminant production is more vulnerable to welfare and health impacts of climate changes through heat stress and there is a threat to both intensive and extensive systems of new or expanded exposure to pests and disease (11). The adaptive profiles of sheep have been well studied in different farming systems (12,13). Heat stress affects performance and productivity of small ruminants in all phases of production. The degree to which these stress impacts on productivity will differ between the agroecological regions and between production systems (14). Sheep possess superior ability to convert more fibrous and low-quality feed to meat than cattle. Native sheep breeds of arid and semiarid regions have higher adaptability to harsh environmental conditions compared to exotic breeds (15). Hence, appropriate breed selection is an effective tool to sustain production in the changing climatic conditions (16).

Even though sheep show higher adaptation to harsh environment, the fast-changing climate could affect the sustainable production through low feed intake, variation in energy and mineral metabolism, alterations in water and protein balances, etc. (8,17). The key constraints such as thermal-, nutritional- and water-related stresses reduce productivity of the sheep in hot and dry regions (18, 19). In addition, the indirect effects of increased incidence of disease and parasite infection and reduced pasture availability also contribute to additional stress and produce decreased wool, milk and meat production in sheep (20). Since most of the sheep population are owned by poor sections of the society, loss of production may lead to severe poverty in rural areas (15). Loss of production and reproduction in sheep during heat exposure can be partially explained by lower feed intake, but is also influenced by altered endocrine and metabolic status. Performance strongly affected by high temperatures includes a range of neuroendocrinological, physiological and behavioral responses, which affect the balance of animal functions (8). Such responses can promote alterations in the level of blood metabolites and metabolic hormones (21, 22, 23). Based on stated, among the various climatic factors, heat stress appears to be the main intriguing factor hindering modern sheep production.

3. MEASUREMENTS OF SEVERITY OF HEAT STRESS IN SHEEP

Heat stress is defined as a condition in which the organism is exposed to ambient temperatures that are outside the biological optimum, which leads to the amount of heat produced in the body being greater than the amount consumed. In a state of heat stress, energy is spent on cooling, i.e. maintaining homeothermy, instead of maintaining productive traits. The animals perform efficiently in their thermoneutral zone. The zone above or below the critical temperature constrains the animal’s productivity as they undergo stress. Exposure of sheep to severe heat stress demands the metabolic system of body to dissipate the excess heat by increasing respiratory rate, sweat rate, rectal temperature and pulse rate (15). Various thermal indices like temperature-humidity index (THI), black globe-humidity index (BGHI), equivalent temperature index (ETI), environmental stress index (ESI), heat load index (HLI) and respiratory rate predictor (PRR) have been assessed for livestock considering the local weather condition including all cardinal weather parameters based on physiological adaptability (24). BGHI and THI is by far the best assessment tool to evaluate the effect of heat stress.

Black global humidity index (BGHI) refers to daily temperatures, relative humidity, degree of radiation and wind speed. BGHI is expressed as total solar radiation as a function of direct solar rays and the angle at which they fall on a certain surface (25). Temperature and humidity index (THI) is the simplest approach, which combines ambient temperature and relative humidity to assess the response of livestock productivity as a function of climate (26). As temperature and humidity are often readily collected, the minimal inputs make THI an easy tool for retrospective studies in most regions (27). The most reliable THI values for assessing the thermal load of sheep are described by Marai et al. (28): normal < 27.8, moderate 27.8–28.8, severe 28.9–29.9 and very severe (emergency) ≥ 30.0. It is important to recognise that thermal stress is not initiated by ambient temperature alone, and that there are a variety of cardinal weather variables that can assist in the assessment or prediction of high heat load (17).

It is assumed that an animal's core temperature reflects the temperature of the main internal organs such as the heart, brain and viscera (29). Rectal temperature has long been used to evaluate core temperature and to quantify the heat stress response in livestock (30). Another common location for measuring core temperature is the vagina, which is well insulated and characterised by thermal gradients (31). Over the past decade, intra-ruminal insertion of temperature sensors has emerged as a non-invasive alternative to the surgical implantation of devices (32), but research shows the potential impact of hyperthermia on rumen function in sheep (33). Measuring the heat emitted by the body is becoming more and more popular, and the thermal imaging camera has found its wide application. The thermal imaging camera represents a modern and non-invasive assessment of thermal status. Thermo-graphic images can be used to demonstrate an increase in body temperature and changes in blood flow related to stressful environmental conditions such as high heat load (34). In our previous research (35) carried out on sheep during the summer, the body surface temperature was measured by collecting images in different parts of the body-thermal window: eye temperature (ET), nose (NT), front leg (LT) and abdomen temperature (AT). Results shown that the abdomen and legs are good thermal windows because LT and AT are good summative responses to external ambient THI and internal metabolic changes in sheep under heat stress, with significant correlation with almost all examined blood parameters and with the THI, so it could be a suitable method in the non-invasive assessment of stress load in sheep. A range of subcutaneous microchips and other implantable devices are also being developed for the continuous measurement of body temperature in livestock (36, 37). However, all require surgical procedures for implantation. In addition to their invasive nature, subcutaneous temperature is influenced by environmental conditions and physiological state as this directly effects the flow of blood to the skin (38). The development of predictive model software which facilitates ease of data collection, management and integration would be a key milestone in adopting this technology at an industry level. The associated costs of these technologies and their comparable relationship to core temperature is likely to be a key determinant in which technologies provide the most helpful information in preventing and managing heat stress (27).

4. DIFFERENT MECHANISMS OF SHEEP ADAPTATION

Among species, sheep and goats are considered less sensitive to heat stress than cattle (39, 40). In brief, the adaptation is the level of tolerance to survive and reproduce under extreme living conditions (41). Sheep are very rustic animals that can cope with such an environment. However, full information on how these animals can adapt and survive to the novel and transforming environments are lacking. The adaptation of sheep breeds to different locations/climates depends upon temperature, humidity, vegetation and wool cover and resistance/susceptibility to various diseases. Sheep breeds can tolerate a wide range of climate and convert poor-quality forage into quality animal protein. These characters favour their rearing under extensive system among poor rural people in harsh climate (42). There are several phenotypic and genotypic characters which impart the adaptive potential to an animal, thereby allowing it to cope with harsh conditions. Basically, adaptation involves morphological, behavioral and genetic capacity of the animal for change (6). The adaptive process can be expanded to include: 1) morphological, 2) behavioural, 3) physiological, 4) blood biochemistry and 5) genetic bases of adaptation (Figure 2). These mechanisms help sheep to survive the heat stress challenges. Morphological adaptations are physical changes that occur over many generations of animals that enhance its fitness in a given environment. Body size and shape, coat and skin color, hair type, and fat storage are among the main morphological adaptation in sheep (43). Body size and shape are the most dominant morphological characteristics influencing the thermoregulatory mechanisms of farm animals in extremely hot environments. The authors stated that animals with larger body size have lower metabolic rate than that of smaller animals and gain heat at a slower rate (44, 45). The coat and skin color characteristics of sheep that have evolved in tropical and desert areas are different from those that evolved in temperate climates. For instance, the loose, open fleece of hair and wool of Awassi sheep enhances heat loss via convection (46). Wool is a natural indicator of short-term stress exposure within the sheep's natural environment. Wool fibres reduce in microns at the point of stress caused by individual events or through a combination of factors (nutrition, disease or pregnancy) (9). Most of the time, fat tails and rump fat are considered as an adaptive response of animals to extreme environments and are used as a valuable energy reserve for the animal during migration and winter. About 25% of the world's sheep population comprises fat-tailed breeds (47).

Behavioral adaptation is recognized as the first and foremost response adopted by animals to reduce heat load (48). One of the most quick and profound behavioral changes seen in heat stressed animals is shade seeking. The stressed animals attempt to ameliorate the negative effects of direct heat load by using shade whenever they can access to it (6). When animals are exposed to high temperatures, reduction of feed intake will occur. Reducing feed intake is a method of adaptation to decrease heat production in the warm environment as the heat increment of feeding is an important source of heat production in ruminants (49). Generally, heat stressed animals tend to spend more time standing so that they can reorient themselves in different directions to avoid direct solar radiation and ground radiation. In addition, the standing position also obstructs the conductive heat transfer into the animal body due to the presence of a layer of air adjacent to the skin, and also facilitates the dissipation of body heat load to the surroundings by increasing the amount of skin exposed to air flow or wind (6). Higher drinking frequency and increased water intake were reported for various livestock species during summer (48). Breeds adapted to desert regions compensate higher water loss during periods of high heat load by concentrating urine (50).

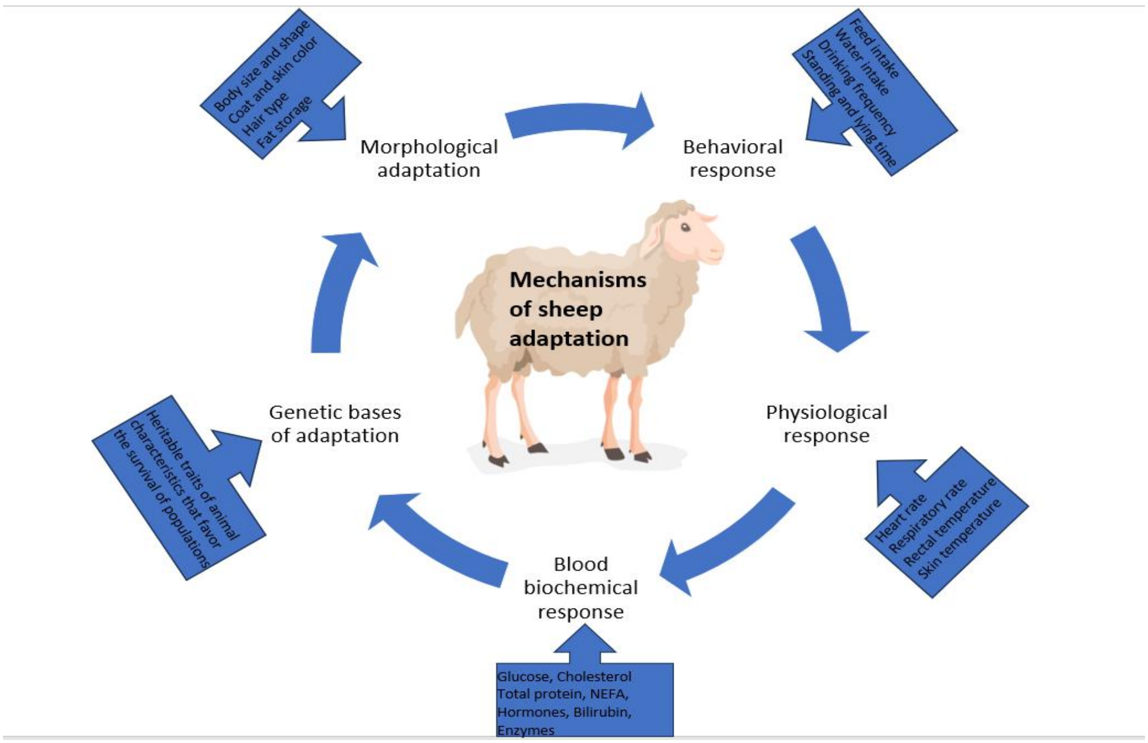

Figure 2. Different adaptive mechanisms of sheep to heat stress.

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Animals possess a variety of physiological adaptation mechanisms in the reduction of heat load. Change in heart rate, respiration rate, skin temperature and rectal temperature are the key parameters that indicate the mechanism of physiological adaptation in sheep. Rectal temperature is a good index of body temperature even though there is a considerable variation in several parts of the body score at different times of the day. In heat-stressed environments, respiratory rate is the first thermoregulation mechanism used by sheep to help them maintain their body temperature (51). Exposure of sheep to hot environment also increased skin temperature. This higher skin temperature could be directly attributed to the vasodilatation of skin capillary bed to enhance the blood flow to the skin periphery for facilitating heat transfer to the surroundings (48). When the physiological mechanism fails to alleviate the effect of heat load, the body temperature may increase to a point at which animal well-being is compromised. Body temperature is a good measure of heat tolerance in animals, as it represents the result of all heat gain and heat loss processes in the body (51).

Blood metabolite concentrations are one of the main regulators of animal adaptation to HS challenges. HS significantly changes glucose homeostasis in animals, the results of the effect of high ambient temperature on the blood glucose (GLU) content of sheep are conflicting. Maraii et al. (52) found in Ossimi sheep that blood GLU levels were significantly higher in summer than in winter. Some other studies showed that blood GLU decreased significantly with different percentages (in Chios sheep and crossbred Chios x Ossimi) (53). Srikandakumar et al. (54) examined the effect of HS on the metabolism of Omani and Merino sheep, where they observed that HS increased GLU in Merino but decreased it in Omani sheep. Which means that a variety of variables can affect GLU metabolism, including breed, age, breeding, hormones, physiological state (i.e. pregnancy, lactation, malnutrition and disease), and the most important nutritional influences. Total lipid concentration significantly decreases in ruminants with prolonged exposure to high ambient temperature, especially cholesterol values. The concentration of total proteins increases in HS. Salem et al. (53) observed that serum total proteins levels were higher during hot summer than winter in Chios lambs and crossbred Chios x Ossimi in Upper Egypt. Another important metabolic regulator is non-esterified fatty acids (NEFA) in plasma and serum (55). Endocrine responses are one of the main regulators of animal adaptation to HS challenges. Cortisol, the main glucocorticoid, is mainly produced in the adrenal cortex, is considered an important stress marker, and participates in various bodily functions, including immune responses and protein, carbohydrate, and fat metabolism (56). Under conditions of HS, it is common to observe a decrease in the levels of thyroid hormones T3 and T4, both responsible for mediating animal metabolism, as a mechanism to reduce metabolic heat production (57). Indicators of the functional state of the liver are the concentration of bilirubin and the activity of enzymes in the blood, which can also indicate metabolic stress. The effects of HS on blood metabolite concentrations vary widely across studies, making it difficult to explain the metabolic adaptations made by sheep to survive and adapt to hot climates (35).

The adaptive capability of sheep is determined by their genetic potential. The research findings from one type of sheep may not be necessarily applicable to the other kind of sheep. Another limitation is that most of the studies were for short term and conducted in laboratories located in the temperate zone on British/Merino breeds (15). Adaptation in terms of genetics refers to the heritable traits of animal characteristics that favor the survival of populations (58). Adaptation traits are usually characterized by low heritability. Genetic variation in a population provides flexibility to adapt to the changing environment and it is crucial for the survival of the population over time (51). The genetic basis of heat adaptation is poorly understood. Evidence from different researchers indicated that the role of genetics in determining an individual’s capability to adapt to the stressed environment is very complicated. As a result, in the cellular energy, mitochondria play a central role as a facilitator of energy metabolism (59). Genome and genomic studies help to investigate thermo-tolerance genes and genomic regions that play a significant role for regulation of body temperature in small ruminants (60).

5. MANAGEMENT STRATEGIES TO COUNTER HEAT STRESS IN SHEEP

Substantially increasing the productivity of these animals by adapting various management

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strategies including housing and animal management and climate monitoring may enhance production capacity of the flock, and hence better output can be expected from the animals in terms of meat, wool, milk and number of offspring (15). Simultaneously efforts are also needed to identify the most appropriate strategies for a particular location and the other factors that influence the genetic merits of animals that question their survival in a particular environment (61). The management strategies can be categorized as: housing management, nutritional modifications, genetics and breeding, and health management (Figure 3).

The housing must reduce the quantum of stress during adverse environmental condition and provide a suitable environment for the animals to survive and produce optimally. Under housing management, the type of shelter, availability of shade, ventilation and light availability inside the shed are considered as the major factors affecting the productivity of the animal. At times of heat stress during summer, water and shade availability around the shed are crucial factors (15). Supplementation of sheep diets with vitamin and mineral, especially with Vit E and Se at supranutritional levels successfully reduced heat-induced oxidative stress. Chauhan et al. (62) study suggests that supranutritional levels of antioxidants (specifically Vit E and Se) are needed to alleviate the negative effects of heat stress on redox homeostasis in sheep. Also, seasonal specific feeding is one of the factors to be considered in nutrition management. Apart from these factors, selection of breed is given primary importance as sheep farming nowadays is production oriented. So selecting the genetically superior breeds for a given trait like meat, wool, milk and adaptation capability is advisable to get desirable income (30). A key component of adaptation, however, is the genetic ability of an organism to survive under stressful conditions. Genetic selection for heat tolerance would provide a sustainable means of augmenting feeding and/or housing modifications (63). In a review of such strategies, Gaughan (64) suggests to identify existing local breeds that are already adapted to production under environmental stresses and to allocate stress-adaptive genes in these breeds would provide a way forward. Subsequently, selection signatures for thermotolerance can be identified through functional genomics and productive breeds improved through cross-breeding with resilient genotypes and incorporation of stress-tolerant genes (65). Health and also disease status has to be monitored regularly. Animal management itself is another important factor to be considered. Way of handling the animal that include transport, shearing and sorting imparts a major effect on the productivity of the animal.

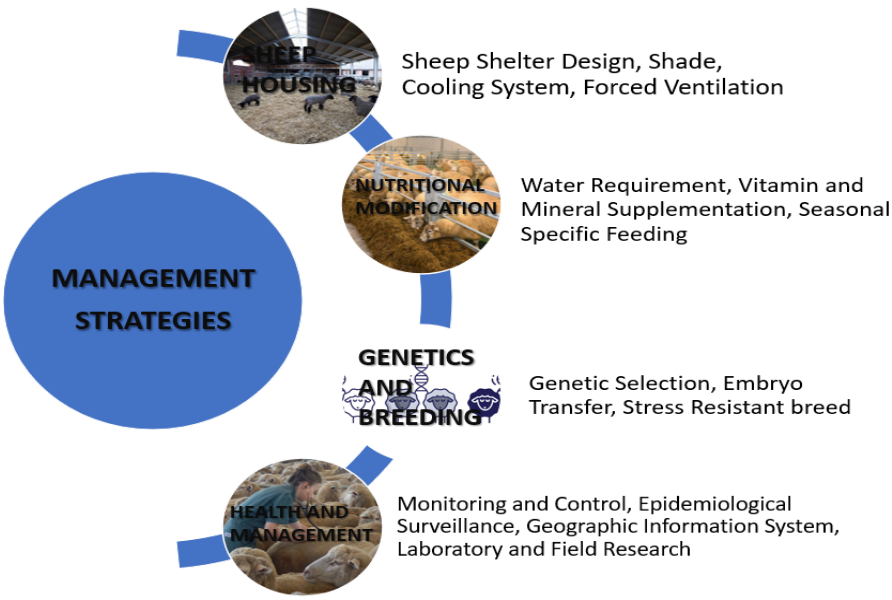

Figure 3. Management strategies to improve sheep production

6. CONCLUSIONS

Ruminant production systems will need to adapt as the climate continues to change, in line with the expectation that they will also contribute to the goals of reducing greenhouse gases and minimizing other negative environmental impacts. The projected increase in extreme weather events and changes in the availability, composition and quality of food, as well as in animal nutrition will affect the availability of animal products and the food supply. These effects are likely to be greatest in developing countries where population and food demand are greatest. Given that sheep are more resistant to heat stress than cattle, it is inevitable that they will represent the main source of animal protein in the coming days. Accordingly, it is necessary to understand to what extent and in what way heat stress affects sheep production, examine adaptive mechanisms in detail and work on strategies to improve sheep production. This review will provide researchers with a basis for predicting when sheep is under heat stress. The only conditions modern humans have ever known so far, are changing, and changing fast. What we do now, and in the next few years will profoundly affect the next few thousand years.

REFERENCES

1. *Berihulay, H.; Abied, A.; He, X.; Jiang, L.; Ma, Y. Adaptation Mechanisms of Small Ruminants to Environmental Heat Stress. Animals 2019, 9 (75), 1–9. https://doi.org/10.3390/ani9030075.*
2. *Seixas, L.; De Melo, C.B.; Tanure, C.B.; Peripolli, V. Heat Tolerance in Brazilian Hair Sheep. Asian-Australas. J. Anim. Sci. 2017, 30, 593–601.*
3. *José, C.; Manuel, A.; Pereira, F.; De Mira, A.; Morita, L.; Antonio, E.; Titto, L. Thermoregulatory Response in Hair Sheep and Shorn Wool Sheep Cristiane Gonc. Small Rumin. Res. 2016, 144, 341–345.*
4. *Li, F.K.; Yang, Y.; Jenna, K.; Xia, C.H.; Lv, S.J.; Wei, W.H. Effect of Heat Stress on the Behavioral and Physiological Patterns of Small-Tail Han Sheep Housed Indoors. Trop. Anim. Health Prod. 2018, 50, 1893–1901. https://doi.org/10.1007/s11250-018-1642-3*
5. *Bernabucci U.; Lacetera N.; Baumgard L.; Rhoads R.; Ronchi B.; Nardone A. Metabolic and hormonal acclimation to heat stress in domesticated ruminants. Animal. 2010, 4(07), 1167-1183. DOI: 10.1017/s175173111000090x*
6. *Sejian, V.; Bhatta, R.; Gaughan, J. B.; Dunshea, F. R. & Lacetera, N. Review: Adaptation of animals to heat stress. Animal 2018, 1–14. doi:10.1017/s1751731118001945.*
7. *Hristov, S.; Maksimović, N.; Stanković, B.; Žujović, M.; Pantelić, V.; Stanišić, N. & Zlatanović, Z. The most significant stressors in intensive sheep production. Biotechnology in Animal Husbandry 2012, 28(4), 649-658. http://dx.doi.org/10.2298/BAH1204649H*
8. *Marai M.F.I.; El-Darawany A.A.; Fadie A.; Abdel-Hafez M.A.M. Physiological traits as affected by heat stress in sheep—A review. Small Rumin. Res. 2007, 71, 1–12.*
9. *Sawyer, G., & Narayan, E. J. A review on the influence of climate change on sheep reproduction. Comparative endocrinology of animals 2019, 10.*
10. *Sejian V.; Bahadur S. and Naqvi S.M.K. Effect of nutritional restriction on growth, adaptation physiology and estrous responses in Malpura ewes. Anim Biol 2014, 64:189–205.*
11. *Henry, B. K.; Eckard, R. J.; Beauchemin, K. A. Review: Adaptation of Ruminant Livestock Production Systems to Climate Changes. Animal, 2018, 12 (s2), S445–S456. https://doi.org/10.1017/S1751731118001301.*
12. *Kochewad, S. A.; Traghunandan; Rao, K.; Reddy, K. K.; Kumari, N.; Ramana, D.; Kumar, S.; Meena. L.R.; Singh, S. P. Reproductive Performance and Body Condition Score of Deccani Sheep during Various Physiological Stages in Different Farming Systems. Indian J. Anim. Sci. 2018, 88 (12), 1379–1382. https://www.researchgate.net/publication/330310367*
13. *Kochewad, S. A.; Raghunandan, T.; Sarjan Rao, K.; Kondal Reddy, K.; Nalini Kumari, N.; Ramana, D.B.V.; et al. Productive Performance, Body Condition Score and Carcass Characteristics of Deccani Lambs Reared under Different Farming Systems. Indian J Anim Res 2018, 52 (3), 444–448. https://doi.org/10.18805/ijar.B-3478.*
14. *Shekhawat, I.; Pareek, A. A Review: Growth and Physiological Adaptability of Sheep to Heat Stress under Semi-Arid Environment. Int. j. emerg. trends sci. technol. 2015, 02 (09), 3188–3198. https://doi.org/10.18535/ijetst/v2i9.09.*
15. *Sejian, V.; Bhatta, R.; Gaughan, J.; Malik, P.K.; Naqvi, S.M.K. and Lal, R. 2017. Adapting Sheep Production to Climate Change. In: Sejian, V., Bhatta, R., Gaughan, J., Malik, P., Naqvi, S., Lal, R. (eds) Sheep Production Adapting to Climate Change. Springer, Singapore. https://doi.org/10.1007/978-981-10-4714-5_1*
16. *Iniguez L. Characterization of small ruminant breeds in West Asia and North Africa, vol 1. ICARDA 2005, Aleppo*
17. *Finocchiaro R.; Van Kaam J.B.C.H.M.; Portolano B.; Misztal I. Effect of heat stress on production of Mediterranean dairy sheep. J Dairy Sci 2005, 88(5), 1855–1864. https://doi.org/10.3168/jds.S0022-0302(05)72860-5*

18. *Kandemir C.; Kosum N.; Taskin T. Effects of heat stress on physiological traits in sheep. Maced J Anim Sci 2013, 3:25–29.*
19. *Sejian V. Climate change: impact on production and reproduction, adaptation mechanisms and mitigation strategies in small ruminants: a review. Indian J Small Rumin 2013, 19(1):1–21.*
20. *Singh S.K.; Meena H.R.; Kolekar D.V.; Singh Y.P.; Climate change impacts on livestock and adaptation strategies to sustain livestock production. J Vet Adv 2012, 2(7):407–412.*
21. *Marai, I.; El-Darawany, A.; Fadiel, A.; Abdel-Hafez, M. Reproductive performance traits as affected by heat stress and its alleviation in sheep. Trop. Subtrop. Agroecosyst. 2008, 8, 209–234.*
22. *Sejian, V.; Maurya, V.P.; Naqvi, S.M. Adaptive capability as indicated by endocrine and biochemical responses of Malpura ewes subjected to combined stresses (thermal and nutritional) in a semi-arid tropical environment. Int. J. Biometeorol., 2010, 561 54(6), 653–661. doi: 10.1007/s00484-010-0341-1.*
23. *Macias-Cruz, U.; Alvarez-Valenzuela, F.D.; Correa-Calderon, A.; Diaz-Molina, R.; Mellado, M.; Meza-Herrera, C.A.; Thermoregulation of nutrient-restricted hair ewes subjected to heat stress during late pregnancy. J. Therm. Biol., 2013, 38, 1–9. 564 doi: 10.1016/j.jtherbio.2012.09.002.*
24. *Hahn G.L.; Mader T.L.; Eigenberg R.A. Perspective on development of thermal indices for animal studies and management. EAAP Technic Ser 2003, 7:31–44.*
25. *Buffington, D.E.; Collier, R.J.; Canton, G.H. Shade man- cattle agement systems to reduce heat stress for dairy cows in hot humid climates. Trans. Am. Soc. Agric. Eng. 1983, 26, 1798–1803.*
26. *Lallo, C.; Cohen, J.; Rankine, D.; Taylor, M.; Cambell, J.; Stephenson, T. Characterizing heat stress on livestock using the temperature humidity index (thi)—Prospects for a warmer caribbean. Reg. Environ. Change 2018, 18, 2329–2340. https://doi.org/10.1007/s10113-018-1359-x*
27. *Lewis Baida, B.E.; Swinbourne, A.M.; Barwick, J. et al. Technologies for the automated collection of heat stress data in sheep. Anim Biotelemetry 2021, 9, 4. https://doi.org/10.1186/s40317-020-00225-9*
28. *Marai, I.; Ayyat, M. & Abd El-Monem, U. Growth Performance and Reproductive Traits at First Parity of New Zealand White Female Rabbits as Affected by Heat Stress and Its Alleviation under Egyptian Conditions. Trop. Anim. Health Prod. 2001, 33, 451–462. https://doi.org/10.1023/A:1012772311177*
29. *Sellier N.; Guettier E.; Staub C. A review of methods to measure animal body temperature in precision farming. Am J Agric Sci Tech. 2014, 2:74–99. https://doi.org/10.7726/ajast.2014.1008.*
30. *Alhidary I.; Shini S.; Al Jassim R.; Gaughan J. Physiological responses of australian merino wethers exposed to high heat load. J Anim Sci. 2012, 90:212–20. https://doi.org/10.2527/jas.2011-3972.*
31. *Taylor N.A.; Tipton M.J.; Kenny G.P. Considerations for the measurement of core, skin and mean body temperatures. J Therm Biol. 2014, 46:72–101. https://doi.org/10.1016/j.jtherbio.2014.10.006.*
32. *Godyn D.; Herbut P.; Angrecka S. Measurements of peripheral and deep body temperature in cattle—a review. J Therm Biol. 2019, 79:42–9. https://doi.org/10.1016/j.jtherbio.2018.11.011.*
33. *Hyder I.; Ravi Kanth Reddy P.; Raju J.; Manjari P.; Srinivasa Prasad C.; Aswani Kumar K. et al. Alteration in rumen functions and diet digestibility during heat stress in sheep. In: Sejian V, Bhatta R, Gaughan J, Malik PK, Naqvi SMK, Lal R, eds. Sheep production adapting to climate change Singapore: Springer Nature; 2017. p. 235–65.*
34. *McManus, C.; Tanure, C.B.; Peripolli, V.; Seixas, L.; Fischer, V.; Gabbi, A.M.; Costa, J.B.G., Jr. Infrared thermography in animal production: An overview. Comput Electron. Agric. 2016, 123, 10–16. https://doi.org/10.1016/j.compag.2016.01.027*
35. *Čukić, A.; Rakonjac, S.; Djoković, R.; Cincović, M.; Bogosavljević-Bošković, S.; Petrović, M.; Savić, Ž.; Andjušić, L.; Andjelić, B. Influence of Heat Stress on Body Temperatures Measured by Infrared Thermography, Blood Metabolic Parameters and Its Correlation in Sheep. Metabolites 2023, 13, 957. https://doi.org/10.3390/metabo13080957*
36. *Lee Y.; Bok J.D.; Lee H.J.; Lee H.G.; Kim D.; Lee I. et al. Body temperature monitoring using subcutaneously implanted thermo-loggers from holstein steers. Asian-Australasian Association of Animal Production Societies; 2016. Report No.: 1011–2367 Contract No.: 2.*
37. *Torrao N.A.; Hetem R.S.; Meyer L.C.; Fick L.G. Assessment of the use of temperature-sensitive microchips to determine core body temperature in goats. Vet Rec. 2011, 168:328–34. https://doi.org/10.1136/vr.c6200*
38. *Kellogg D.L. In vivo mechanisms of cutaneous vasodilation and vasoconstriction in humans during thermoregulatory challenges. J Appl Physiol. 2006, 100:1709–18. https://doi.org/10.1152/japplphysiol.01071.2005*
39. *Silanikove N. The physiological basis of adaptation of goats to scarcity of food and water in harsh environments. Small Rumin. Res. 2000, 35:181-193. DOI: 10.1016/S0921-4488(99)00096-6*
40. *Khalifa H.H.; Shalaby T.; Abdel- Khalek T.M.M. An approach to develop a biometeorological thermal discomfort index for sheep and goats under Egyptian conditions. In: Proceeding of the 17th International Congress of Biometeorology (International Society of Biometeorology). Garmisch-Partenkirchen, Germany: Offenbach am Main; 2005. pp. 118-122*
41. *Nejad, J.G.; Sung, K.-I. Behavioral and Physiological Changes during Heat Stress in Corriedale Ewes Exposed to Water Deprivation. J. Anim. Sci. Technol. 2017, 59, 13 DOI 10.1186/s40781-017-0140-x*
42. *Shinde A.K.; Sejian V. Sheep husbandry under changing climate scenario in India: an overview. Indian J Anim Sci 2013, 83(10):998–1008*
43. *Chedid, M.; Jaber, L.S.; Giger-Reverdin, S.; Duvaux-Ponter, C.; Hamadeh, S.K. Water Stress in Sheep Raised under Arid Conditions. Can. J. Anim. Sci. 2014, 94, 243–257. https://doi.org/10.4141/cjas2013-188*

44. *Silanikove, N. The Physiological Basis of Adaptation in Goats to Harsh Environments. Small Rumin. Res. 2000, 35, 181–193. https://doi.org/10.1016/S0921-4488(99)00096-6*
45. *Cain, J.W., III; Krausman, P.R.; Rosenstock, S.S.; Turner, J.C. Mechanisms of Thermoregulation and Water Balance in Desert Ungulates. Wildl. Soc. Bull. 2006, 34, 570–581. https://doi.org/10.2193/0091-7648(2006)34(570:MOTAWB)2.0.CO;2*
46. *Gootwine, E. Mini Review: Breeding Awassi and Assaf Sheep for Diverse Management Conditions. Trop. Anim. Health Prod. 2011, 43, 1289–1296 https://doi.org/10.1007/s11250-011-9852-y*
47. *Moradi, M.H.; Nejati-javaremi, A.; Moradi-shahrbabak, M.; Dodds, K.G. Genomic Scan of Selective Sweeps in Thin and Fat Tail Sheep Breeds for Identifying of Candidate Regions Associated with Fat Deposition. BMC Genet. 2012, 13, 10. https://doi.org/10.1186/1471-2156-13-10*
48. *Shilja S.; Sejian V.; Bagath M.; Mech A.; David C.G.; Kurien E.K.; Varma G. and Bhatta R. Adaptive capability as indicated by behavioural and physiological responses, plasma HSP70 level, and PBMC HSP70 mRNA expression in Osmanabadi goats subjected to combined (heat and nutritional) stressors. International Journal of Biometeorology 2016, 60, 1311–1323.*
49. *Attia, N.E.-S. Physiological, Hematological and Biochemical Alterations in Heat Stressed Goats. Benha Vet. Med. J. 2016, 31, 56–62.*
50. *Chedid M.; Jaber L.S.; Giger-Reverdin S.; Duvaux-Ponter C. and Hamadeh S.K. Water stress in sheep raised under arid conditions. Can. J. Anim. Sci. 2014 94, 243–257.*
51. *Berihulay, H.; Abied, A.; He, X.; Jiang, L.; Ma, Y. Adaptation Mechanisms of Small Ruminants to Environmental Heat Stress. Animals 2019, 9, 75. https://doi.org/10.3390/ani9030075*
52. *Marai, I.F.M.; Daader, A.H.; Makkawy; M.Y., Gabr, H.A.; Ibrahim, H. Effect of housing system, season of year and age on some physiological parameters and blood constituents of Ossimi sheep. J. Arid Environ. 1992, 22, 277-285.*
53. *Salem, J.A.; Kobeisy, M.A.; Zenhom, M.; Hayder, M. Effect of season and ascorbic acid supplementation on some blood constituents of suckling Chois lambs and its crosses with Ossimi sheep in Upper Egypt. Assiut Journal of Agricultural Science 1998, 29, 87–100.*
54. *Srikandakumar, A.; Johnson, E.H.; Mahgoub, O. Effect of heat stress on respiratory rate, rectal temperature and blood chemistry in Omani and Australian Merino sheep. Small Rumin. Res. 2003, 49 (2), 193–198. https://doi.org/10.1016/S09214488(03)00097-X*
55. *Aleena J.; Pragna P.; Archana P.R.; Sejian V.; Bagath M.; Krishnan G.; Manimaran A.; Beena V.; Kurien E.K.; Varma G. and Bhatta R. Significance of metabolic response in livestock for adapting to heat stress challenges. Asian J. Anim. Sci 2016, 10, 224–234.*
56. *Tadesse, D.; Patra, A.K.; Puchala, R.; Goetsch, A.L. Effects of High Heat Load Conditions on Blood Constituent Concentrations in Dorper, Katahdin, and St. Croix Sheep from Different Regions of the USA. Animals 2022, 12(17), 2273. https://doi.org/10.3390/ani12172273*
57. *III, J. W. C.; Krausman, P. R.; Rosenstock, S. S.; Turner, J. C. Mechanisms of thermoregulation and water balance in desert ungulates. Wildl. Soc. Bull. 2006, 34 (3), 570-581. https://doi.org/10.2193/0091-7648(2006)34(570:MOTAWB)2.0.CO;2*
58. *Abdul Niyas, P.A.; Chaidanya, K.; Shaji, S.; Sejian, V.; Bhatta, R.; Bagath, M.; Rao, G.S.L.H.V.P.; Kurien, E.K.; Girish, V. Adaptation of Livestock to Environmental Challenges. J. Vet. Sci. Med. Diagn. 2015, 4, 1–7. http://dx.doi.org/10.4172/2325-9590.1000146*
59. *Xu, S.; Luosang, J.; Hua, S.; He, J.; Ciren, A.; Wang, W.; Tong, X.; Liang, Y.; Wang, J.; Zheng, X. High Altitude Adaptation and Phylogenetic Analysis of Ti- Betan Horse Based on the Mitochondrial Genome. J. Genet. Genom. 2007, 34, 720–729. https://doi.org/10.1016/S1673-8527(07)60081-2*
60. *Kim, E.; Elbeltagy, A.R.; Aboul-naga, A.M.; Rischkowsky, B.; Sayre, B.; Mwacharo, J.M.; Rothschild, M.F. Multiple Genomic Signatures of Selection in Goats and Sheep Indigenous to a Hot Arid Environment. Heredity 2016, 116, 255–264. https://doi.org/10.1038/hdy.2015.94*
61. *Kosgey I.S.; Okeyo A.M. Genetic improvement of small ruminants in low-input, smallholder production systems: technical and infrastructural issues. Small Rumin Res 2007 70(1):76–88*
62. *Chauhan, S. S.; Celi, P.; Leury, B. J.; Clarke, I. J. & Dunshea, F. R. Dietary antioxidants at supranutritional doses improve oxidative status and reduce the negative effects of heat stress in sheep. Journal of Animal Science 2014 92(8), 3364-3374.*
63. *Friggens, N.C.; Blanc, F.; Berry, D.P.; Puillet, L. Review: Deciphering animal robustness. A synthesis to facilitate its use in livestock breeding and management. Animal 2017, 11, 2237–225.*
64. *Gaughan, J.B.; Sejian, V.; Mader, T.L.; Dunshea, F.R. Adaptation strategies: ruminants. Anim. Front. 2019, 9, 47–53.*
65. *Osei-Amponsah, R.; Chauhan, S.S.; Leury, B.J.; Cheng, L.; Cullen, B.; Clarke, I.J.; Dunshea, F.R. Genetic Selection for Thermotolerance in Ruminants. Animals 2019, 9, 948. https://doi.org/10.3390/ani9110948*