COPING WITH CLIMATE CHANGE; IS WHITE SHEEP MORE FAVORABLE THAN BLACK?
A REVIEW

PUTRI KUSUMA ASTUTI – GEORGE WANJALA – ZOLTÁN BAGI – SZILVIA KUSZA

SUMMARY

Climate change and its impact on livestock production are a point of discussion nowadays. The impact of climate change, heat stress mainly, is negatively correlated to livestock production. In sheep, heat stress causes disruptions in the biological and physiological activities inside the body, resulting in hormonal imbalance, lower body growth and production, and reproduction impairment. Furthermore, the stress caused by the thermal condition does not promote animal welfare in the sheep population. Genetic factors determine coat color, and numerous genes have been identified as associated with it, including TRYP, MC1R, MLANA, OCA2, and others. Numerous studies indicate that light coat colors promote adaptation to hot environments owing to their ability to reflect sunlight more effectively than dark coat colors. Regardless, other research found no difference in adaption to a hot environment between light and dark coat colors. In the present work, authors summarized the effect of light and dark coat colors.

ÖSSZEFOGLALÓ

Astuti, P. K. – Wanjala, G. – Bagi, Z. – Kusza, S.: SZEMBENÉZNI AZ ÉGHAJLATVÁLTOZÁSSAL: KEDVEZŐBB A FEHÉR BÁRÁNY A FEKETÉNÉL? - IRODALMI ÁTTEKINTÉS

Az éghajlatváltozás és annak az állattenyésztésre gyakorolt hatása manapság vita tárgyát képezi. A klímaváltozás hatása, elsősorban a hőstressz negatívan hat az állattenyésztésre. A juhokban a hőstressz megzavarja a szervezeten belüli biológiai és élettani tevékenységeket, ami hormonális egyensúlyhiányt, kisebb testnövekedést és termelést, valamint szaporodási zavarokat okoz. Továbbá a termikus állapot okozta stressz hátrányosan hat az állatjólétre is. Genetikai tényezők határozzák meg a gyapjú színét, és számos gént azonosítottak, amelyek kapcsolatba hozhatóak annak kialakulásával, köztük a TRYP, MC1R, MLANA, OCA2 stb. A gyapjúszín kialakulása a bőr epidermiszében található melanociták által termelt kétféle pigmenttől függ. Számos tanulmány kimutatta, hogy a világos szőrszínek elősegítik a meleg környezethez való alkalmazkodást, mivel hatékonyabban verik vissza a napfényt, mint a sötét színek. Ettől függetlenül más kutatások nem találtak különbséget a forró környezethez való alkalmazkodásban a világos és a sötét szőrzet színei között. Sajnos jelenleg nem ismert, hogy a sötét és világos gyapjú miben tér el hőszabályozási mechanizmusaiban a hőstressz hatására. A szerzők jelen tanulmányukban összegezni kívánták a világos és sötét gyapjú hatását.

INTRODUCTION

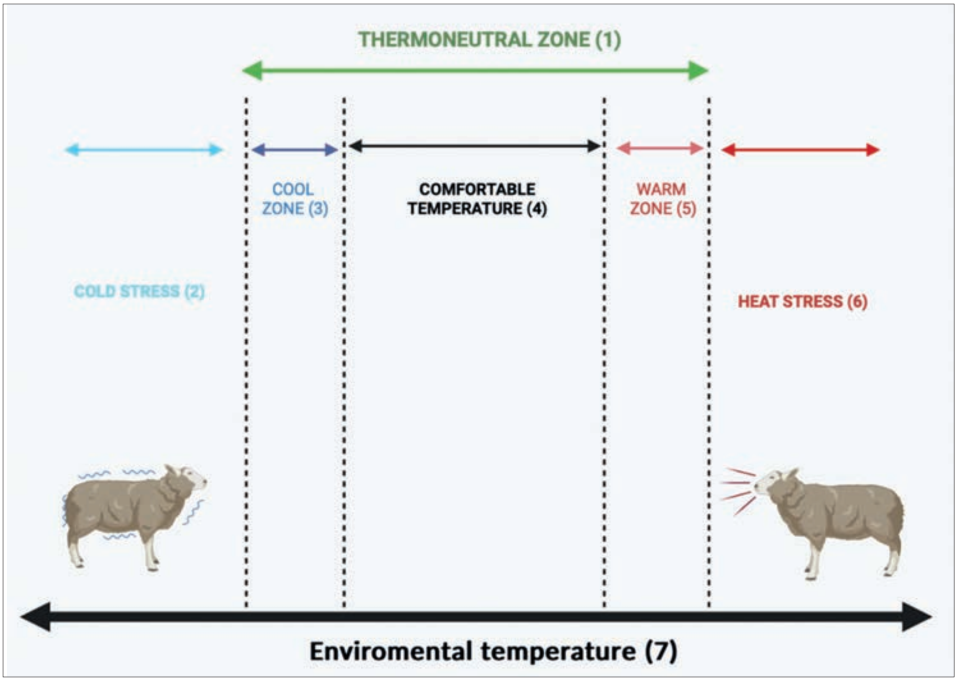
As the world is getting hotter, climate change is also becoming a hot topic that threatens humans and livestock. The rising global temperature is one of the significant components of climate change. Since 1975, the average global temperature has risen at an average rate of 0.15–0.20 °C per decade (*Malhi et al.,* 2021), and probabilistic calculations of the IPCC's range of climate sensitivity suggest that it will rise by 2 °C by 2100 and 4.2 °C by 2400 (*IPCC,* 2013) which enforce our attention to look for an adaptation measurement. Many studies have been done to understand how climate change, particularly heat stress, can affect livestock. According to *Sawyer and Narayan* (2018), heat/thermal stress is defined as any combination of environmental variables resulting in temperatures higher than the temperature range of the animal's thermoneutral zone and the urge to mitigate the heat stress effects has been widely discussed. Heat stress affects livestock farming in various ways; reduction in production efficiency (*West*, 2003; *Mader et al*., 2006), disruption of physiology, development, and reproductive function through complex hormonal changes (*Kapoor et al.,* 2008; *Fabris et al*., 2019), and many more that definitely lead to economic loss for farmers.

Each animal has a thermoneutral zone to maintain its normal body temperature without compromising its behavioral or physiological functioning. Thermoregulatory mechanisms to heat stress differ by species, and hence the extent of decrease in production performance varies between livestock animals. One of the primary regulators of animal adaptation to heat stress situations is endocrine responses. The Hypothalamic-Pituitary-Adrenal (HPA) axis is essential for homeostasis (*Niyas et al.,* 2015).

Figure 1. shows three thermal zones: thermoneutral, heat stress zone, and cold stress zone. According to *dos Santos et al.* (2021), when the animals are in the thermal comfort range, their metabolic rate is low because they are limited between the lower critical temperature (LCT) and the upper critical temperature (UCT) in the thermoneutral zone. Under this state, the animal does not activate physiological functions to release heat to the environment or generate endogenous heat, resulting in a body temperature that is balanced with the environment and all available energy being allocated to optimal performance (production, reproduction, among others). In this case, perceptible heat exchange methods are sufficient to maintain thermal balance. Suppose the environmental situation exceeds the UCT, the condition under heat stress. In that case, animals may attempt to adapt their behavior, such as seeking shade, increasing water intake, rapid breathing, increasing pulse rate, and decreasing feed intake, in addition to resting next to colder surfaces to try to balance the temperature change. The range of thermoneutral zone in sheep varies based on the type of sheep. Wool sheep produced constant metabolic heat at ambient temperatures ranging from 15 to 35°C, whereas hair coat sheep produced constant metabolic heat at temperatures ranging from 20 to 30°C (*de França Carvalho Fonsêca et al.,* 2019). This difference is related to the sheep's physiological ability to dissipate excessive heat.

Many efforts have been made to minimize the economic loss in livestock farming due to heat stress, as the consequences of climate change are unavoidable and seem to be becoming more severe; one that might be worth considering is

Figure 1. *Illustration of sheep's thermoneutral zone*



1. ábra Juhok termoneutrális zónájának bemutatása

termoneutralis zóna (1); hideg okozta stressz (2); hűvös zóna (3); kényelmes zóna (4); meleg zóna (5); hőstressz (6); környezeti hőmérséklet (7)

selecting an animal breed based on its coat color. Choosing tropical breeds that are more resistant to heat stress has been practiced for quite a long time, but what about having a different breed preference according to their coat color? This review will discuss heat stress in sheep and the relationship between coat color and heat tolerance in sheep.

DISCUSSION

Heat stress in sheep

Not excluding sheep, heat stress has a negative impact on sheep, despite the fact that sheep are thought to be the most robust livestock that can survive harsh conditions. The hot environment is the most significant single stressor affecting the efficiency of animal production systems, which has an impact on sheep performance and well-being. Many studies have proven the negative manifestation of heat stress in every stage of sheep life.

Gestation period

In the early-stage development of sheep life, exposure to excessive heat can inhibit normal prenatal growth. In oocyte development, *Gharibzadeh et al.* (2015) investigated ovine oocyte maturation in vitro after a 12-hour heat shock at 41°C. Heat stress during the early stages of maturation had a negative impact on oocyte maturation and the meiotic apparatus of the oocyte, which could have severe implications for pre- and post-implantation development. Furthermore, heat stress increased the dissolution time of the zona pellucid, which may be connected to premature cortical granule exocytosis. The overall embryo cell quantity and placentome size are dramatically reduced when a pregnant ewe is exposed to warm ambient temperatures during mid and late gestation (*van Wettere et al*., 2021). Aside from that, the incidence of embryo mortality in short term heat-stressed ewes is 12.7 higher than in thermoneutral ewes, followed by higher unfertilized ova found (*Sartori et al.,* 2002; *Kandemir et al*., 2013; *Romo-Barron et al.,* 2019). From the beforementioned findings, it can be concluded that heat stress impairs oocyte maturation, resulting in decreased fertility rates and independent effects on embryo wastage.

Lamb growth

In terms of growth, heat-exposed lambs had a reduced growth rate and feed efficiency without changing dry matter intake compared to thermoneutral lamb ($p<0.01$). Heat stress altered lambs' postabsorptive metabolism, specifically producing a metabolic environment of hyperinsulinemia, which hindered adipose tissue catabolism, boosted lipid anabolism, and increased cellular glucose availability. Blood biochemical disruption was also found; lower ($p<0.01$) serum concentrations of glucose, cholesterol, total protein, urea, potassium, thyroid hormones, erythrocyte and platelet counts, hemoglobin, and hematocrit were also identified, as were higher ($p<0.01$) serum triglyceride values, chlorine values, erythrocyte size, and leucocyte count, which could be a sign of reducing immune function (*Nicolás-López et al.,* 2021). Heat stress also had a deleterious impact on lamb antioxidant status and immunological response via complicated pathways, including body temperature change, behavioral and hormonal adaptation, circulatory adjustment, and oxidative stress, as evidenced by several previous research by *Rathwa et al.* (2017) and *Shi et al.* (2020).

Ewes and ram fertility

As is the case with heat-stressed animals, when nutrient insufficiency is discovered as a result of an imbalanced energy supply within the body, heat stress also disrupts hormonal balance, a critical aspect of reproduction. *Indu et al.* (2014) explained that heat stress significantly decreased plasma estradiol and progesterone levels in sheep due to decreased Gonadotrophin-releasing hormone (GnRH) production and feed intake. Further described by *Wakayo et al.* (2015), reduced estrogen concentrations may result from impaired ovarian follicular development caused by a reduced peripheral gonadotrophin concentration in response to heat stress. This condition might lead to estrous delay and alteration of estrous manifestation and behaviors.

Moreover, in ewes, when ambient temperatures were 32°C, ewe fertility and lambing rate were negatively correlated with the number of days per week during the mating period. Ewe fertility and lambing rate declined by 2.7 and 3.5 %, respectively, for each additional day of 32 °C during the mating week. High temperatures during the mating season harm fertility; heat-stressed ewes are 2.4 times less likely to become pregnant than thermo-neutral ewes (*Kleemann and Walker*, 2005; *Romo-Baron et al*., 2019).

Fertility disruption is also found in ram. Semen from rams with high testicular and scrotal temperatures are linked negatively with pregnancy rates due to lower semen quality, a higher presence of defective sperm, and a lower percentage of motile sperm. Germ cell death, DNA damage, and sperm maturation disruption can all be caused by elevated testicular temperature due to the environment condition. This damage to the sperm may result in infertility, impaired embryonic development, genetic disorders in the offspring, disturbance of postnatal growth, and litter longevity (*Hamilton et al.,* 2018; *van Wettere et al.,* 2021). Similar findings were also reported by *Marai et al.* (2008) and *Kastelic et al*. (2017).

Meat and milk production

The heat stress manifested in a live animal will affect the quality of their products, milk production, and meat after slaughtering. As the body needs more energy to maintain the homeostasis, in contrast, livestock tends to reduce feed intake and increase water consumption in anticipation of more heat accumulating inside the body, as another thermoregulation mechanism to reduce fermentative heat production at the rumen level and thus the body heat load created endogenously (*Hill and Wall*, 2017). In that case, to enhance the availability of needed nutrients without affecting the feed intake, sheep lower anabolic activity while increasing the catabolism of fat and muscle tissue (*Macías-Cruz et al.,* 2020). According to *Gregory* (2010) and *Xing et al.* (2019), heat-stressed sheep produce meat that is darker, dryer, and harder, attributed to a high post-mortem final pH (>6.0), which is attained by increased muscle glycogenolysis and anaerobic metabolism. Furthermore, these hormones are connected with metabolic changes decrease in post-sacrifice muscle glycogen content, and as a result, lactic acid production levels are insufficient to lower the ultimate pH below 6.0.

Many physiological responses are induced by heat load to maintain the core temperature constant, such as increasing blood circulation to transfer heat from the core to the periphery and also increasing respiration rate as an act of heat dissipation outside the body. *Kitajima et al.* (2021) investigated heat rate variability (HRV) in sheep, which was used as a sensitive indicator of the functional regulatory properties of the autonomic nervous system in sheep. HRV of sheep was reduced under high Heat Humidity Index (THI) circumstances, which could be attributed to an increase in sympathetic nervous system activity on heart rate regulation. This physiological adjustment and changing biochemical regulation inside the livestock body consume higher energy and increase inefficiency in livestock growth, leading to a slow growth rate, low feed efficiency, lower carcass yield, and many deprivations of meat quality aspects. Some findings evidencing the reduction in body weight were found in Dorset cross and Dorper cross sheep (*Zhang et al.,* 2021) and in Dorper x Katahdin male lamb but without feed intake change observed (*Macías-Cruz et al.,* 2020).

Because sheep milk is solely used for cheese manufacturing, it is required to include a high fat and protein content to manufacture high-quality cheese. According to *Caroprese et al.* (2012), heat stress can alter the composition of milk by lowering fat and protein levels. High ambient temperatures can also cause a mineral imbalance in the plasma, most notably by decreasing sodium, potassium, calcium, and phosphorus concentrations and increasing in chloride concentrations. *Sevi et al. (*2002) discovered that exposure to direct solar radiation had a deleterious effect on the fatty acid composition of sheep milk, resulting in a decrease in unsaturated fatty acids and an increase in saturated fatty acids, with the ratios of long to short chain and unsaturated to saturated fatty acids were 4 and 13% greater in the milk of shaded ewes compared to those of unshaded animals, respectively. Addition by *Sevi and Caroprese* (2012), exposure to sun radiation at high ambient temperature increased milk concentrations of neutrophils and capillary permeability, leading to an increase in milk lipolytic and proteolytic enzymes. While in term of milk production, a study in Sarda ewes by *Peana et al.* (2007) showed up to 15% milk yield reduction occurred if the minimum temperature reached 21°C, while in Valle del Belice sheep and Italian tropical breed, 3.9% decreasing milk production was observed when the THI is exceeding 23 (*Finocchiaro et al.,* 2005).

Disease occurrence and immunity

The disruption of biological processes inside animals' bodies as a response to stress due external factors, which here is defined as due to climate change or heat shock, has a deleterious impact on the sheep's immunity increasing susceptibility to some diseases. According *to Inbaraj et al.* (2016), stress is the biological response induced when an animal perceives a threat to its equilibrium, which could be in the form of metabolic alteration. When an animal experiences a stressor, the central nervous system sends signals to any of the body's systems to alleviate or compensate for the threat, then compensating the animal's immune system. In addition, by *Chauhan et al.* (2021), heat stress enhances the generation of reactive oxygen species and/or the depletion of antioxidants, resulting in an imbalance between oxidants and antioxidants and oxidative stress, which makes animals more prone to pathogens and production disease.

In sheep, Ewes exposed to heat stress had elevated cortisol levels; the increase in cortisol release may be responsible for weakening their cellular immune response following intradermal mitogen injection and their IgG production following antigen injection (*Caroprese et al.,* 2012). In the case of dairy sheep, one of the important aspects is udder health. It was observed that the frequency of environmental pathogens among the microbial species isolated from bacteriologically positive milk samples from ewes exposed to direct solar radiation suggests that heat stress can reduce mammary defense capacity, resulting in increased bacterial colonization of sheep udders, threaten the udder health and deprivation of milk quality (*Sevi et al.,* 2001). Many studies have also suggested the cellular disruption in genes related immune system and inflammatory, such as TNF-α and NF-κB (*Chauhan et al.,* 2014) also IL1R1, IL1R2, and HSPA2 (*Lu et al.,* 2019)

Skin and hair color of sheep
Coat color genes

When addressing heat stress, the skin and hair are crucial factors to consider because it is the exterior layer of an organism's body that functions as a defense layer against thermal stressor exposure. As explained by *Maćias-Cruz et al.* (2018), sheep exposed to high temperatures engage evaporative thermoregulation mechanisms. In contrast to other ruminants, where sweating is essential for avoiding hyperthermia, sheep can dissipate between 60 and 90 % heat load by raising the respiratory rate and less than 10% via sweating. The exterior qualities of animals' coats, such as coat color and physical hair characteristics, influence their adaptive potential. Coat traits can be considered essential phenotypic indicators that can be used as a criterion for animal selection; also, these qualities have a relationship with the thermoregulatory capacity and homeostasis of the animals.

According to *Yin et al.* (2019), the formation of coat color is dependent on two types of pigments produced by melanocytes in the epidermis of the skin. Melanocytes are skin cells that may create melanin, namely pheomelanin and eumelanin. The quality and ratio of these two kinds of pigment result in different skin and hair colors; pheomelanin is yellow to reddish, and eumelanin is black

Table 1.

Gene associated to skin color in sheep

Genes (1)	Sheep breed (2)	Reference (3)
Dopachrome tautomerase (DCT), tyrosinase (TYR), tyrosinase related protein 1 (TYRP1), melanin corpuscle protein (PMEL), solute carrier family 45 member 2 (SLC45A2), and melan-A (MLANA)	Bashibai, Yemule white, and Tulufan black.	*Yao et al.* (2019)
Melanosomal transmembrane protein (OCA2), dopachrome tautomerase (DCT), tyrosinase (TYR) and tyrosinase related protein (TYRP1), melanocortin 1 receptor (MC1R), and premelanosome protein (PMEL)	Minxian black fur and Small-tail Han.	*Shi et al.* (2021)
Lengsin (LGSN), melanosomal transmembrane gene (OCA2), and E3 ubiquintin protein ligase (HERC2)	Indian Changthangi, Deccani, and Garole.	*Saravanan et al.* (2021)
Melanocortin 1 receptor (MC1R), melanogenesis associated transcription factor (MITF)	Sarda and the Sardinian Ancestral Black.	*Cesarani et al.* (2019)
Platelet derived growth factor receptor alpha (PDGFRA), receptor tyrosine kinases (KIT), Sry-related HMg-Box gene 10 (SOX-10), Protein interacting with PEKCA1 (PICK1), endothelin 3 (EDN3), zinc finger protein 831 (ZNF831)	Black Noire de Thibar and Queue fine de l'ouest.	*Baazaoui et al.* (2019)

1. táblázat Bőrszínt befolyásoló gének juhban

gének (1); juhfajták (2); forrás (3)

to brown. Melanin is produced by melanocytes and accumulates because of hereditary and environmental influences. Several genes have been found that influence coat color in sheep, some of them are presented in *Table 1*.

Coat and adaptability

The morphological feature of animals determines their adaptability to nature. According to *Gebremedhin et al.* (2008), skin type and color are essential factors in heat stress adaptation. The sweat gland density, function, morphology, and the hair coat's density, length, and color determine the effectiveness of heat evaporation from the skin surface.

Hair density is significantly connected with the number of apocrine glands. Denser coats may make it more challenging to eliminate latent heat by cutaneous evaporation. In sheep, primary follicles give rise to hairs where heterotypic strands form first, followed by secondary follicles that give rise to wool. As a result, wool is not associated with a sweat gland (*do Prado Paim et al.,* 2012). Wool acts as a protective barrier, but it also makes water evaporation from the body more difficult, resulting in less heat loss through perspiration. Wool sheep have a lower thermoregulatory capacity. Despite the lower insulating effect of slightly thick wool, it also has characteristics that reduce thermoregulation by convection. Even with thinner wool, there is air stability on the inside of the fleece, resulting in less heat loss by convection (*McManus et al.,* 2020).

In addition to the hair type, color is also determinant in sheep's adaptability to the hot environment. Several research has been conducted to confirm the assumption that light colors reflect sunlight better than dark colors in terms of livestock coat color. A study in West African Dwarf male sheep by *Okourwa* (2015) implied that a higher risk of heat stress was observed in black coat color with low coat depth and short hair length sheep group due to the absorption of solar radiation by the dark pigmentation, low coat depth and short hair length that could not help the sheep to protect itself, especially from direct sunlight. A similar finding was found in Brazilian Santa ines, Bargamasca, and the crossbred animals by *McManus et al.* (2011). The white color coat is superior because it enhances epidermal protection by absorbing short-wave ultraviolet rays, which is critical due to epidermal depigmentation, which causes animals to be prone to erythema, burns, and neoplasms (*Leite et al.,* 2020).

A different discovery was found in Indian sheep breeds. The comparison of hemato-physio-biochemical traits of Chokla, Marga, and Marwari sheep with varied coat colors revealed no significant difference; all of these sheep are similarly adaptable under hot conditions (*Singh et al.,* 2016). Likewise, the Morada Nova Ewes with varying coat colors were observed by *Leite et al.* (2020). Regardless of color, there was no variation in the animals' rectal temperature, and all animals were able to maintain homoeothermic settings; nonetheless, each group activated different heat loss pathways. The most striking difference was seen in the entirely white coat, which displayed altered thermoregulatory responses as well as the highest sweating rate. The research on Saudi sheep by *Al-Haidary et al.* (2021) showed that Naemi, the white coat-colored breed had a considerably higher rectal temperature ($p<0.001$) than Najdi, the black coat-colored breed. Meanwhile, no significant (p>0.05) changes in skin temperature, packed cell volume, or plasma albumin levels were seen between the two breeds. However, plasma globulin and total protein levels in the black coat-colored breed were considerably (p=0.05) more remarkable than in the white coat-colored breed. The calculated heat tolerance coefficient in the black coat-colored breed was significantly (p=0.001) higher than in the white coat-colored breed. The findings revealed that light coat color did not increase heat tolerance in sheep grazing in a hot desert region.

CONCLUSION

This review highlights the adaptation of sheep to a heat-stressed environment. Heat stress has a negative impact on sheep productivity in various aspects; reproduction, body growth, milk production, and meat quality. Choosing animals based on coat color can be a mitigation strategy to minimize the effects of heat stress in sheep. Prior studies' findings either confirm the hypothesis that white coat sheep can outperform black coat sheep under heat stress conditions or disprove the superiority of the two types of sheep coat. None of the studies can prove the distinction between black-coat sheep and white one. Unfortunately, it is unknown how the thermoregulatory mechanism of heat stress differs in the bodies of these two types of sheep. More comprehensive research on the differences in thermoregulation in sheep with black or white skin and coat color is required in the future, which will undoubtedly strengthen and clarify the advantages between them and be very beneficial for farmers in deciding which sheep to keep in this era of unavoidable global warming.

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Szerzők címe: *Astuti P. K. – Wanjala G.*
Debreceni Egyetem Állatenyésztési Tudományok Doktori Iskola, Agrár Genomikai és Biotechnológiai Központ
Authors' address: Doctoral School of Animal Science, Centre of Agricultural Genomics and Biotechnology, University of Debrecen
H-4032 Debrecen, Egyetem tér 1.

Bagi Z. – Kusza Sz.
Debreceni Egyetem Agrár Genomikai és Biotechnológiai Központ, Centre for Agricultural Genomics and Biotechnology, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen
H-4032 Debrecen, Egyetem tér 1.
kusza@agr.unideb.hu