Chapter 2

THERMOTOLERANCE OF RUMINANTS

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INTRODUCTION

Global climate change on our planet is accompanied by an increase in temperature, changes in photoperiod and the quantity and quality of precipitation, which causes a decrease or change in the structure of animal diets, the quality and quantity of available feed in most regions, a decrease in the availability of water and a greater susceptibility to diseases[1].

Ruminant animals are an important component of agricultural production and are of great importance to the economy in terms of the production of meat, milk and wool. However, they also face challenges from climate change and extreme weather conditions, which can negatively impact their well-being and productivity. One of the key aspects that should be studied is the thermotolerance of ruminants, that is, their ability to adapt to changes in temperature and stressful conditions.

In recent years, numerous studies have been carried out to study the physiological and molecular mechanisms of thermotolerance in ruminants. These studies have expanded our understanding of their adaptive responses to high temperatures and identified factors influencing their thermotolerance.

The problem of challenge of better understanding and studying thermotolerance in ruminants reinforces the need to ensure animal resistance to high-temperature stress conditions, which is an important aspect for increasing productivity and ensuring their well-being in a variable climate. Therefore, solving the problem of thermotolerance in ruminants is an urgent task of modern science and practice of animal husbandry.

The purpose of the research is to study and analyze the thermotolerance of ruminant animals with a specialization in their adaptation to different temperature conditions.

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[1] Angel S. P., Amitha J. P., Rashamol V. P., Vandana G. D., Savitha S. T., Afsal A., ... & Sejian V. Climate Change and Cattle Production-Impact and Adaptation. *Journal of Veterinary Medicine and Research*. 2018. *5*(4). 1134.

1. Concept of thermotolerance in living nature

The thermotolerance of living organisms to increased temperature is divided into basal and acquired. While basal thermotolerance refers to the ability to withstand high temperatures, acquired thermotolerance refers to the ability to cope with deadly high temperatures after a period of acclimation[2]. Moreover, thermotolerance concerns not only flora and fauna, but also microorganisms, so zoonotic thermotolerant species of Campylobacter (C. iejuni and C. coli) are recognized throughout the world as important pathogens of human diarrhea[3].

Identification of traits in thermotolerant animals will allow producers to optimize the selection of replacement young animals that are better adapted to unfavorable environmental conditions[4].

The concept of animal thermotolerance appeared relatively recently. A thermotolerant animal is one that maintains heat balance under conditions of heat stress. However, from the point of view of livestock production, the ability to maintain productive and reproductive functions in hot conditions is important. An animal's performance under heat stress is a way of measuring the animal's overall ability to cope with excess heat. Characteristics of skin and its derivatives and body surface to mass ratio related to the animal's ability to dissipate internal heat[5].

In the literature, three main types of studies of thermotolerance are found: 1) study of associations of polymorphisms of specific genes and genome-wide analysis of associations[6, 7]; 2) comparison of the genomes

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[2] Zongliang Chen, Mary Galli, Andrea Gallavotti, Mechanisms of temperature-regulated growth and thermotolerance in crop species. *Current Opinion in Plant Biology*. 2022. Vol. 65. 102134. https://doi.org/10.1016/j.pbi.2021.102134.

[3] Fernandez H., Vergara M., Tapia F. Dessication resistance in thermotolerant Campylobacter species. *Infection.* 1985. T. 13. №. 4. C. 197.

[4] Zully E. Contreras-Correa, Héctor L. Sánchez-Rodríguez, Mark A. Arick, Gladycia Muñiz-Colón, Caleb O. Lemley, Thermotolerance capabilities, blood metabolomics and mammary gland hemodynamics and transcriptomic profiles of slick-haired Holstein cattle during mid-lactation in Puerto Rico. *Journal of Dairy Science*. 2024. https://doi.org/10.3168/jds.2023-23878.

[5] Carabaño M. J., Ramón M., Menéndez-Buxadera A., Molina A., & Díaz C. Selecting for heat tolerance. *Animal Frontiers*. 2019. 9(1). 62–68.

[6] Macciotta N. P. P., Biffani S., Bernabucci U., Lacetera N., Vitali A., Ajmone-Marsan P., & Nardone A. Derivation and genome-wide association study of a principal component-based measure of heat tolerance in dairy cattle. *Journal of Dairy Science.* 2017. 100(6). 4683–4697.

[7] Lemal P., May K., König S., Schroyen M., Gengler N. Invited review: From heat stress to disease – Immune response and candidate genes involved in cattle thermotolerance. *Journal of Dairy Science*. 2023. Volume 106. Issue 7. P. 4471–4488. https://doi.org/10.3168/jds.2022-22727.

of adapted and unadapted breeds/species to strict conditions[8, 9] and 3) differential expression analysis[10, 11, 12].

Single nucleotide polymorphism c.136G>T is a candidate biomarker for thermotolerance traits in Bali cattle[13].

Recent advances in molecular genetics have provided significant advances in breeding allowing the identification of molecular markers in both beef and dairy cattle production, including marker-assisted selection (MAS) as a tool in selecting the best thermotolerant animals. Single nucleotide polymorphisms (SNPs), which can be detected by DNA sequencing, are desirable DNA markers for MAS due to their abundance in coding and noncoding regions of the genome. Many SNPs in some genes (eg HSP70, HSP90, HSF1, EIF2AK4, HSBP1, HSPB8, HSPB7, MYO1A and ATP1A1) in different cattle breeds have been analyzed to play a key role in many cellular activities during stress, making them potential candidate genes for molecular markers of thermotolerance[14].

The skin plays an important role in thermoregulation. Identifying genes in the skin that promote heat tolerance could be used to select animals that perform best in warm environments[15]. Thus, the thermotolerance of fibroblasts from cows and sheep to acute hyperthermia (45 °C for 4 hours) may differ. Bovine cells showed greater resilience than sheep cells in terms

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[8] Chan E. K., Nagaraj S. H., & Reverter A. The evolution of tropical adaptation: comparing taurine and zebu cattle. *Animal Genetics.* 2010. 41(5). 467–477.

[9] de Andrade Pantoja M. H., de Novais F. J., Mourão G. B., Mateescu R. G., Poleti M. D., Beline M., ... & Titto, C. G.). Exploring candidate genes for heat tolerance in ovine through liver gene expression. *Heliyon.* 2024.

[10] Chauhan S. S., Celi P., Fahri F. T., Leury B. J., & Dunshea F. R. Dietary antioxidants at supranutritional doses modulate skeletal muscle heat shock protein and inflammatory gene expression in sheep exposed to heat stress. *Journal of Animal Science*. 2014. 92(11). 4897–4908.

[11] Hariyono D. N. H., & Prihandini P. W. Association of selected gene polymorphisms with thermotolerance traits in cattle–A review. *Animal bioscience.* 2022. 35(11). 1635.

[12] Sadid Al Amaz, Md Ahosanul Haque Shahid, Ajay Chaudhary, Rajesh Jha, Birendra Mishra, Embryonic thermal manipulation reduces hatch time, increases hatchability, thermotolerance, and liver metabolism in broiler embryos. *Poultry Science*. 2024. Volume 103. Issue 4. 103527. https://doi.org/10.1016/j.psj.2024.103527.

[13] Suhendro I, Rachman Noor R, Jakaria J, Priyanto R, Manalu W, Andersson G. Association of heat-shock protein 70.1 gene with physiological and physical performance of Bali cattle. *Vet World*. 2024. 17(1). 17–25. doi: 10.14202/vetworld.2024.17-25.

[14] Hariyono DNH, Prihandini PW. Association of selected gene polymorphisms with thermotolerance traits in cattle – A review. *Anim Biosci*. 2022. 35(11). 1635–1648. doi: 10.5713/ab.22.0055.

[15] de Andrade Pantoja M. H., Poleti M. D., de Novais F. J., Duarte K. K. S., Mateescu R. G., Mourão G. B., ... & Titto C. G. Skin transcriptomic analysis reveals candidate genes and pathways associated with thermotolerance in hair sheep. *International Journal of Biometeorology*. 2024. 68(3). 435–444.

of cell viability, proliferation and migratory activity, and maintenance of HSP90 and HSP70 expression to overcome the deleterious effects of hyperthermia[16].

It has been established that the thermotolerance index depends on age[17] and can vary significantly within the same breed [18] Genetic variation for thermotolerance exists within a breed, which allows genetic selection to improve thermotolerance and can improve animal stability and welfare[19]. Today, genetic selection of beef and dairy cattle is aimed at such productive traits as growth rate, meat productivity, milk yield and milk quality. However, constant selection for productive traits, ignoring heat resistance, leads to a decrease in heat resistance[20].

Moreover, the thermophilicity of the species and its thermotolerance may differ slightly[21].

Genetic selection or development of thermotolerant breeds, environmental modification and regulation of animal nutrition are key strategies to consider when marketing their genetic resources in hot environments[22, 23].

In cattle and sheep cells, thermotolerance is greater in breeds adapted to warm climates than in animals with moderate heat stress. This persistence may be mediated by heat shock protein (HSP)-related mechanisms[24].

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[16] Saadeldin, Islam M., Ayman Abdel-Aziz Swelum, Adel M. Zakri, Hammed A. Tukur, and Abdullah N. Alowaimer. Effects of Acute Hyperthermia on the Thermotolerance of Cow and Sheep Skin-Derived Fibroblasts. *Animals.* 2020. 10. no. 4. 545. https://doi.org/10.3390/ani10040545.

[17] Krebs R. A. A comparison of Hsp70 expression and thermotolerance in adults and larvae of three Drosophila species. *Cell Stress & Chaperones*. 1999. Т. 4. №. 4. С. 243.

[18] Pantoja M. H. A., Mourão G.B., Ferreira M. C. S., Titto E. A. L., Strefezzi R. F., Gallo S. B., Titto C.G., Heat tolerance in hair sheep: individual differences on physiological, endocrine, and behavioral responses. *Animal – Open Spac.* 2024. Volume 3. 100067. https://doi.org/10.1016/j.anopes.2024.100067.

[19] Ansari-Mahyari S., Ojali M. R., Forutan M., Riasi, A., & Brito L. F. Investigating the genetic architecture of conception and non-return rates in Holstein cattle under heat stress conditions. *Tropical Animal Health and Production.* 2019. 51. 1847–1853.

[20] Boonkum W., Misztal I., Duangjinda M., Pattarajinda V., Tumwasorn S., & Buaban S. Genetic effects of heat stress on days open for Thai Holstein crossbreds. *Journal of dairy science.* 2011. 94(3). 1592–1596.

[21] Adrian Langarica-Fuentes, Pauline S. Handley, Ashley Houlden, Graeme Fox, Geoffrey D. Robson, An investigation of the biodiversity of thermophilic and thermotolerant fungal species in composts using culture-based and molecular techniques. *Fungal Ecology*. 2014. Volume 11. Pages 132–144. https://doi.org/10.1016/j.funeco.2014.05.007.

[22] Johnson J. S. Heat stress: impact on livestock well-being and productivity and mitigation strategies to alleviate the negative effects. *Animal Production Science.* 2018. 58(8). 1404–1413.

[23] Osei-Amponsah, Richard, Surinder S. Chauhan, Brian J. Leury, Long Cheng, Brendan Cullen, Iain J. Clarke, and Frank R. Dunshea. Genetic Selection for Thermotolerance in Ruminants. *Animals.* 2019. 9. no. 11. 948. https://doi.org/10.3390/ani9110948.

[24] Saadeldin, Islam M., Ayman Abdel-Aziz Swelum, Adel M. Zakri, Hammed A. Tukur, and Abdullah N. Alowaimer. Effects of Acute Hyperthermia on the Thermotolerance of Cow

Productive animals that are the best producers under conditions of comfort may not generally be the best animals under heat stress. However, this approach has two serious drawbacks: 1) the inaccuracy of an individual assessment of an animal's ability to maintain its level of productivity under conditions of heat stress due to the scarcity of individual records on the heat load scale and 2) the antagonism between productivity and heat is a criterion of tolerance. Much knowledge is accumulating about the mechanisms underlying the heat stress response through "omics" research. Many candidate genes and potential biomarkers have been proposed from DNA, RNA and metabolomics studies, but work still needs to be done to integrate this accumulated knowledge to provide selection tools for improving heat tolerance in breeding schemes[25].

Thermal tolerance is a multifactorial polygenic trait influenced by genetic and epigenetic factors. Heat shock protein 70 (HSP70) is one of the major genes widely used as a biomarker of heat stress. Heat shock proteins are encoded by a conserved multigene family and are found in almost all organisms [26].

2. Heat stress in ruminants and its features

Management techniques such as environmental modulation, feeding patterns and selection of adapted breeds have been proposed to mitigate the adverse effects of heat stress on lactation ruminants[27].

The number of days with a temperature-humidity index (THI) above the comfort threshold (>72) is increasing in the northern United States, Canada, and Europe. Heat stress can affect the emotional state of dairy cows by causing feelings of hunger and thirst, hence the need for research efforts to examine the potential links between heat stress, frustration, aggression and pain[28].

The authors measured heat tolerance of 4-5 month old Dorper and second cross (Paul Dorset × (Border Leicester × Merino)) lambs by assessing feed intake, physiological activity, blood chemistry and prolactin. Heat stress reduced feed intake only in second-cross lambs, but not in Dorpers.

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and Sheep Skin-Derived Fibroblasts. *Animals*. 2020. 10. no. 4. 545. https://doi.org/10.3390/ani10040545.

[25] María J Carabaño, Manuel Ramón, Alberto Menéndez-Buxadera, Antonio Molina, Clara Díaz. Selecting for heat tolerance. *Animal Frontiers*. 2019. T. 9. V. 1. 62–68. https://doi.org/10.1093/ af/vfy033.

[26] Asea A. A., & Kaur P. Heat shock proteins in veterinary medicine and sciences. Cham: Springer International Publishing. 2017.

[27] Beede D. K., & Collier R. J. Potential nutritional strategies for intensively managed cattle during thermal stress. *Journal of animal science*. 1986. 62(2). 543–554.

[28] Polsky L., & von Keyserlingk M. A. Invited review: Effects of heat stress on dairy cattle welfare. *Journal of dairy science.* 2017. 100(11). 8645–8657.

As expected, heat stress also increased water intake, respiratory rate, rectal temperature, and skin temperature in both genotypes, but to a lesser extent in Dorpers. The lesser influence of thermal stress on the indicators of thermotolerance in Dorper breeds indicates the adaptability of this breed to heat minds[29].

It is known that sheep do not tolerate high temperatures with excess air humidity well, since the compensatory mechanism of releasing excess heat is blocked due to increased and accelerated breathing and evaporation of moisture from the lungs, respiratory tract and sweating.

We have researched some markers of thermotolerance in sheep of different blood types of the Texel breed. To determine them, body temperature, pulse rate and respiratory rate of lambs of various genotypes were studied under various conditions of temperature load (Table 1). It has been established that in the spring, at an air temperature of 19 ^{0}C, there is no significant difference between crossbreeds of different bloodlines, either among rams or ravines.

During the period of increased temperature load 27–30 ^{0}C, there was an increase in all indicators in both groups of experienced sheep. Thus, the body temperature of the sheep increased by 0.6–0.7 ^{0}C, the pulse rate by 38–43 beats, and the respiratory rate by 60–71 movements per minute.

In ewe lamb, with similar temperature exposure, body temperature increased by 0.1–0.3 ^{0}C, pulse by 7.6 beats, breathing rate by 32.5–35.2 movements.

With an increase in air temperature to 38^{0}C with an almost constant pulse rate, the body temperature of the rams of both groups increased by 0.3–0.5 ^{0}C, the breathing rate by 49.3–55.4 movements. In ewe lamb, the increase in body temperature was 1.1–1.2 ^{0}C, pulse rate by 10.–14.5 beats, breathing rate by 91.7–92.0 movement[30].

Models of response parameters to thermal load organisms using performance records (both productive and reproductive) and meteorological information have been widely used to measure heat tolerance in dairy or meat production[31].

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[29] Joy, Aleena, Frank R. Dunshea, Brian J. Leury, Kristy DiGiacomo, Iain J. Clarke, Minghao H. Zhang, Archana Abhijith, Richard Osei-Amponsah, and Surinder S. Chauhan. Comparative Assessment of Thermotolerance in Dorper and Second-Cross (Poll Dorset/Merino×Border Leicester) Lambs. *Animals*. 2020. 10, no. 12. 2441. https://doi.org/10.3390/ani10122441.

[30] Жарук П. Г., Атановська-Маслюк О. Й., Маслюк А. М. Природна резистентність та адаптаційна здатність ярок, одержаних від вівцематок асканійської м’ясо-вовнової породи та баранів породи тексель. *Вівчарство та козівництво*. 2020. Вип. 5. С. 28–37. https://doi.org/10.33694/2415-3958-2020-1-5-28-37.

[31] Bradford H. L., Fragomeni B. O., Bertrand J. K., Lourenco D. A. L., & Misztal I. Genetic evaluations for growth heat tolerance in Angus cattle. *Journal of Animal Science*. 2016. 94(10). 4143–4150.

Table 1

Clinical indicators of physiological functions of young animals of different genotypes

Genotypes	**Time of day, hours**	**Air temperature ^{0}C**	**n**	**Indicators**					
				body temperature, ^{0}C		**heart rate (pulse), beats/minute**		**respiration rate, movement/minute**	
				M±m	**C,%**	**M±m**	**C,%**	**M±m**	**C,%**
29.05.2020									
½ texel ♂	8	19	12	39,6±0,07	0,64	90,7±4,07	15,6	57,5±4,01	24,1
¾ texel ♂	8	19	12	39,5±0,54	0,47	95,0±3,0	10,9	63,8±4,33	23,5
½ texel ♀	8	19	19	39,8±0,09	0,95	116,8=3,85	14,4	71,6±3,86	23,5
¾ texel ♀	8	19	11	39,6±0,10	0,81	130,2±5,27	13,4	65,3±5,18	26,3
07.07.2020									
½ texel ♂	8	30	12	40,2±0,11	0,94	129,3±3,24	8,68	128,7±10,3	27,8
¾ texel ♂	8	30	12	40,2±0,05	0,40	138,0±4,79	12,0	123,7±9,31	26,1
½ texel ♂	14	38	12	40,9±0,10	0,85	127,3±4,61	12,6	186,7±3,62	6,74
¾ texel ♂	14	38	12	40,8±0,09	0,77	131,0±4,27	11,3	173,0±7,47	15,0
07.07.2020									
½ texel ♀	7	30	19	39,9±0,07	0,73	123,4±3,67	13,0	104,2±6,0	25,1
¾ texel ♀	7	30	11	39,9±0,07	0,54	125,8±5,16	13,6	102,5±7,7	24,9
½ texel ♀	15	38	19	41,1±0,05	0,53	133,7±3,27	10,7	198,5±4,23	9,29
¾ texel ♀	15	38	11	41,0=0,07	0,58	138,5±4,89	11,7	189,5±5,89	10,3

Genetic component of the heat stress response in performance using the so-called broken line model. The broken line model is determined by two parameters: 1) the thermoneutrality threshold and 2) the slope of the decline in production after passing this threshold as a result of heat stress[32].

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[32] Bernabucci U., Biffani S., Buggiotti L., Vitali A., Lacetera N., & Nardone A. The effects of heat stress in Italian Holstein dairy cattle. *Journal of dairy science.* 2014. 97(1). 471–486.

Table 2 presents the physiological features of the development of the body’s response to an increase in the heat load on the body of sheep, depending on the time of day and temperature. Table 2 presents the physiological features of the development of the body’s response to an increase in the heat load on the body of sheep, depending on the time of day and temperature. The authors researched some physiological markers of the adaptive ability of sheep of the Askanian selection, namely the Askanian fine-wool breed (AT), the Askanian meat-wool with cross-bred wool (AMB) and the Askanian Karakul breed (AK) (table 2).Thus, significant fluctuations in physiological indicators of temperature, pulse and respiration rate have been established depending on the period of day in the summer in different breeds of sheep of domestic selection.

Table 2

Physiological characteristics of rams of different genotypes during thermal overload

Indicators		**Breeds of experimental rams**		
		AT	**AMB**	**AK**
6.00 (21 ^{0}C)	body temperature, ^{0}C	39,9±0,05	39,9±0,08	39,5±0,04
	respiratory rate, movement/min	80,8±4,25	85,6±3,11	80,8±0,95
	heart rate (pulse), beats/minute rate	99,6±3,34	104,0±2,23	102,4±2,75
14.00 (33 ^{0}C)	body temperature, ^{0}C	40,6±0,05	40,4±0,10	40,1±0,13
	respiratory rate, movement/min	110,0±2,88	115,6±2,27	113,6±2,17
	heart rate (pulse), beats/minute rate	124,8±2,78	130,8±1,89	132,4±2,19

AT – Askanian selection, namely the Askanian fine-wool breed.

AMB- Askanian meat-wool with cross-bred wool.

AK – Askanian Karakul breed.

Thus, the beginning of the day, regardless of breed characteristics (21 ^{0}C), was characterized by slightly lower indicators of physiological activity of the circulatory and respiratory systems, however, an increase e in temperature load to 33 ^{0}C in rams, regardless of genotype, was found to increase rectal temperature and increase the functional activity of the circulatory and respiratory systems.

At the same time, polypous (shallow) breathing was observed in some animals from all groups. Consequently, mechanisms for increasing heat transfer are triggered due to the intensification of blood circulation and heat removal with exhaled air through the lungs. Moreover, sheep of the Askanian Karakul breed showed a higher level of thermotolerance due to a decrease in fluctuations in rectal temperature. The slightest thermotolerance was observed in Ascanian fine-wool sheep[33].

Other scientists' results showed that less heat-tolerant sheep had higher rectal and body surface temperatures, although there were no differences in skin morphology between groups. Less heat-tolerant sheep continued to sweat for a longer period after the end of the heat treatment to lose heat ($P<0.05$). Animals with less heat tolerance also had higher rectal temperatures during cool hours and took longer to dissipate excess heat. These results suggest that there are individual differences in thermoregulatory responses within the same breed under similar environmental conditions, and that breeding programs can be used to produce more heat-tolerant but still productive animals in tropical environments[34].

Heat stress in ruminants, regardless of their species, has a negative impact on digestion processes in the forestomach, absorption of feed nutrients, immune system, reproduction, animal productivity and can be accompanied by metritis, mastitis, and infectious diseases[35].

The hypothalamic-pituitary-mammary axis (HPM axis) plays an important role in regulating the stress response and lactation physiology in dairy cows experiencing heat stress. The researchers' results showed that a total of 13, 702, and 202 DE lncRNAs were identified in the hypothalamus, pituitary gland, and mammary glands, respectively. With lncRNAs 8, 209 and 45 were upregulated, and 5, 493 and 157 lncRNAs were downregulated. Analyzes gene ontology (GO) and Kyoto Encyclopedia of Genes and Genomes (KEGG) enrichments revealed that differentially expressed lncRNAs target genes that may play a role in hormone synthesis, secretion and action, apoptosis, mitogen-activated protein kinase (MAPK) (AMPK) signaling mechanical target of rapamycin (mTOR) pathway[36].

Some lncRNAs may be involved in the regulation of stress response and the physiological process of lactation. Changes in the expression profiles of lncRNAs and regulatory ceRNAs (lncRNA–miRNA–mRNA) in tissues associated with the hypothalamic-pituitary-mammary gland axis are key to influencing the stress response and lactation physiology of dairy cows

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[33] Яковчук В. С., Столбуненко С. Г. Ааптаційна здатність баранчиків порід асканійської селекції. *Науковий вісник «Асканія-Нова».* 2022. № 15. С. 136–158. https://doi.org/10.33694/2617-0787-2022-1-15-136-158.

[34] Pantoja M. H. A., Mourão G. B., Ferreira M. C. S., Titto E.A.L., Strefezzi R. F., Gallo S. B., Titto C.G., Heat tolerance in hair sheep: individual differences on physiological, endocrine, and behavioral responses. *Animal – Open Space*. 2024. Volume 3. 100067. https://doi.org/10.1016/j.anopes.2024.100067.

[35] Lacetera N. Impact of climate change on animal health and welfare. *Animal Frontiers*. 2019. T. 9. №. 1. C. 26–31.

under heat stress, providing a theoretical basis for the molecular mechanism in the stress response of HPM axis-related tissues in dairy cows under heat stress [36].

The effect of heat stress on milk production can be divided into 2 different causes: those effects that are mediated by a decrease in voluntary feed intake associated with heat stress, and direct physiological and metabolic effects of heat stress. Heat stress caused a decrease in the concentration of milk protein and caseins and increased the content of urea in milk[37].

It is traditionally believed that HS leads to decreased dry matter intake (DMI), which reduces milk production and protein content in the milk of dairy cows. Regulation of the metabolic rate in the mammary gland of a cow under heat stress occurs due to the influence on the intensity of protein synthesis. Thus, the results of recent studies indicate that a total of 213 genes in the mammary glands of cows have been identified as differentially expressed using functional analysis of differentially expressed genes. Of these, during heat stress of cows: 89 are activated; 124 – inactivated[38].

In vitro studies have shown that high ambient temperature decreases the expression of genes involved in cellular structure, biosynthesis and transport, whereas it increases the expression of genes involved in protein repair and degradation of bovine mammary epithelial cells[39].

Under heat stress conditions, 15,989 genes were expressed in sheep skin samples, of which 4 genes were differentially expressed (DE; FDR <0.05) and 11 DE (FDR 0.05–0.177) between two different groups. These genes are involved in cellular defense of sheep skin against heat stress (HSPA1A and HSPA6), ribosome compilers (28S, 18S and 5S ribosomal RNA) and immune response (IGHG4, GNLY, CXCL1, CAPN14 and SAA-4)[40].

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[36] Zeng, Hanfang, Shujie Li, Yunfei Zhai, Haomiao Chang, and Zhaoyu Han. Preliminary Transcriptome Analysis of Long Noncoding RNA in Hypothalamic-Pituitary-Mammary Gland Axis of Dairy Cows under Heat Stress. *Biomolecules.* 2023. 13. No. 2. 390. https://doi.org/10.3390/biom13020390.

[37] Cowley F. C., Barber D. G., Houlihan A. V., & Poppi D. P. Immediate and residual effects of heat stress and restricted intake on milk protein and casein composition and energy metabolism. *Journal of dairy science*. 2015. 98(4). 2356–2368.

[38] Yue S., Wang Z., Wang L., Peng Q., Xue B. Transcriptome Functional Analysis of Mammary Gland of Cows in Heat Stress and Thermoneutral Condition. *Animals.* 2020. 10. 1015. https://doi.org/10.3390/ani10061015.

[39] Cowley F. C., Barber D. G., Houlihan A. V., & Poppi D. P. Immediate and residual effects of heat stress and restricted intake on milk protein and casein composition and energy metabolism. *Journal of dairy science*. 2015. 98(4). 2356–2368.

[40] de Andrade Pantoja M.H., Poleti M.D., de Novais F.J. *et al.* Skin transcriptomic analysis reveals candidate genes and pathways associated with thermotolerance in hair sheep. *Int J Biometeorol.* 2024. 68. 435–444 https://doi.org/10.1007/s00484-023-02602-4.

Modern conditions of livestock farming, especially when creating new genotypes and gene pools, determine the need for constant and systematic monitoring of the health status of animals, including their adaptive ability.

Blood is the most accessible system for research, showing the entire complex of physiological and biochemical processes in the animal's body. It is known that blood combines the biochemical processes of various parts of the body into a single system and thereby ensures the connection of all organs and tissues, stipulating and maintaining the necessary conditions for their existence. It is the first to react to any external factor, adequately responding to changes in its composition[41]. Values of indicators blood make it possible to judge the direction of metabolism, the state of health of the animal and, within certain limits, the nature of productivity and adaptive ability.

It is currently known that heat stress can have a negative impact on immune system mechanisms, but this information is of limited use in the context of heat stress phenotyping. In addition, there is a lack of knowledge on the molecular mechanisms of thermotolerance that link the relevant genes to a given animal phenotype[42].

While most generally known consequences associated with production reactions, new evidence indicates that heat stress profoundly alters the immune response of calves and cows from prenatal period through lactation[43].

Concentrations of haptoglobin and serum amyloid. And in the blood of goats significantly depended on the intensity of the heat load on their body. The results suggest the possible use of Hp and SAA as potential indicators and sensitive markers in monitoring heat stress in goats[44].

Behavioral characteristics including locomotion time, mastication time and feeding time were recorded for 453 Holstein cows. Positive correlations of thermotolerance to physical activity and feed consumption with thermotolerance to milk production and negative genetic correlations of thermotolerance to physical activity with the content of somatic cells

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[41] Дергач І. В., Горбелік Р.В., Ященко М. Ф. Білки сироватки крові ягнят у постнатальному онтогенезі. *Вівчарство*. 1975. № 14. С. 118–122.

[42] Lemal P., May K., König S., Schroyen M., Gengler N. Invited review: From heat stress to disease – Immune response and candidate genes involved in cattle thermotolerance. *Journal of Dairy Science*. 2023. Volume 106. Issue 7. Pages 4471–4488. https://doi.org/10.3168/jds.2022-22727.

[43] Dahl GE, Tao S and Laporta J Heat Stress Impacts Immune Status in Cows Across the Life Cycle. *Front. Vet. Sci*. 2020. 7. 116. doi: 10.3389/fvets.2020.00116.

[44] Al-Dawood A. Acute phase proteins as indicators of stress in Baladi goats from Jordan. Acta Agriculturae Scandinavica. *Section A -Animal Science*. 2017. 67(1–2). 58–65. https://doi.org/10.1080/09064702.2017.1363815.

in milk were revealed. and protein: 59% and somatic cell estimate: 31% based on behavioral data[45].

Cows with low milk production have more consistent milk production under heat stress conditions. Key issues in avoiding heat stress in animals include the following: heat tolerance is not considered in most dairy animal breeding programs; heat resistance is negatively correlated with milk production potential; simultaneous breeding for heat resistance and milk production increases productivity[46].

CONCLUSIONS

A summary of the research article "Thermotolerance of ruminants" using the example of sheep indicates the importance of studying thermotolerance in animals to ensure their comfort and productivity in the face of climate change.

Research shows that thermotolerance plays a key role in the adaptation of ruminants, including sheep, to changing climatic conditions. This is especially true in the context of global warming.

Factors influencing thermotolerance: housing conditions, genetic characteristics and physiological mechanisms of thermoregulation affect the thermotolerance of ruiners (in particular sheep).

Genetic studies are a key element in understanding thermotolerance in ruminants; they help to identify genes and markers that influence this parameter and determine the heritability of thermotolerance, which is important for breeding work. Genetic studies confirm that individual genes can influence thermotolerance in sheep, opening the possibility of breeding breeds with greater tolerance to heat stress.

Understanding and improving thermotolerance in sheep is important for agriculture to improve their health, welfare and productivity in a changing climate.

Further research, including the analysis of genetic markers and the development of effective breeding methods, is needed to better understand thermotolerance in ruminants, including sheep.

Research findings highlight the importance of effective farm management to maintain thermotolerance in sheep and enable them to adapt

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[45] Lemal P., Tran M-N., Atashi H., Schroyen M., N. Gengler, Adding behavior traits to select for heat tolerance in dairy cattle. *JDS Communications*. 2024. https://doi.org/10.3168/jdsc.2023-0421.

[46] Oloo R.D., Ekine-Dzivenu C.C., Mrode R., Bennewitz J., Ojango J.M.K., Kipkosgei G., Gebreyohanes G., Okeyo A.M., Chagunda M.G.G. Genetic analysis of phenotypic indicators for heat tolerance in crossbred dairy cattle. *Animal*. 2024. 101139. https://doi.org/10.1016/j.animal.2024.101139.

to climate change and ensure flock resilience to stress conditions associated with high temperatures.

SUMMARY

The thermotolerance of ruminants depends on both the genetic and physiological characteristics of the species, breed, sex, age, level of productivity, their temperament, the tone of the nervous system, the intensity of metabolism in the forestomach and the functioning activity of the pathways for removing heat from the body. Thermal tolerance plays a key role in the adaptation of animals to extreme environmental temperatures, especially in a changing climate. In ruminant animals, the ability to effectively regulate their body temperature is essential for maintaining health and productivity. The study of thermotolerance in ruminants remains a relevant and important task, especially taking into account changing climatic conditions.

The conducted research on thermotolerance in ruminant animals is of great importance for agriculture and makes it possible to develop livestock management strategies aimed at improving thermotolerance and adaptation to changing climatic conditions. The overall conclusion of the paper highlights the importance of understanding and maintaining thermotolerance in ruminants to ensure their health, welfare and productivity in the face of climate change.

The authors highlight the importance of studying this issue in the changing light of climate and the need to develop effective livestock management strategies to ensure sustainable production. Analysis of scientific research allows us to determine priority areas for further research in this area.

Bibliography

1. Angel S. P., Amitha J. P., Rashamol V. P., Vandana G. D., Savitha S. T., Afsal A., ... & Sejian V. Climate Change and Cattle Production-Impact and Adaptation. *Journal of Veterinary Medicine and Research*. 2018. 5(4). 1134.

2. Zongliang Chen, Mary Galli, Andrea Gallavotti, Mechanisms of temperature-regulated growth and thermotolerance in crop species. *Current Opinion in Plant Biology*. 2022. Vol. 65. 102134. https://doi.org/10.1016/j.pbi.2021.102134.

3. Fernandez H., Vergara M., Tapia F. Dessication resistance in thermotolerant Campylobacter species. *Infection.* 1985. T. 13. №. 4. C. 197.

4. Zully E. Contreras-Correa, Héctor L. Sánchez-Rodríguez, Mark A. Arick, Gladycia Muñiz-Colón, Caleb O. Lemley, Thermotolerance capabilities, blood metabolomics and mammary gland hemodynamics

and transcriptomic profiles of slick-haired Holstein cattle during mid-lactation in Puerto Rico. *Journal of Dairy Science*. 2024. https://doi.org/10.3168/jds.2023-23878.

5. Carabaño M. J., Ramón M., Menéndez-Buxadera A., Molina A., & Díaz C. Selecting for heat tolerance. *Animal Frontiers*. 2019. 9(1). 62–68.

6. Macciotta N. P. P., Biffani S., Bernabucci U., Lacetera N., Vitali A., Ajmone-Marsan P., & Nardone A. Derivation and genome-wide association study of a principal component-based measure of heat tolerance in dairy cattle. *Journal of Dairy Science*. 2017. 100(6). 4683–4697.

7. Lemal P., May K., König S., Schroyen M., Gengler N. Invited review: From heat stress to disease – Immune response and candidate genes involved in cattle thermotolerance. *Journal of Dairy Science*. 2023. Volume 106. Issue 7. P. 4471–4488. https://doi.org/10.3168/jds.2022-22727.

8. Chan E. K., Nagaraj S. H., & Reverter A. The evolution of tropical adaptation: comparing taurine and zebu cattle. *Animal Genetics*. 2010. 41(5). 467-477.

9. de Andrade Pantoja M. H., de Novais F. J., Mourão G. B., Mateescu R. G., Poleti M. D., Beline M., ... & Titto, C. G.). Exploring candidate genes for heat tolerance in ovine through liver gene expression. *Heliyon*. 2024.

10. Chauhan S. S., Celi P., Fahri F. T., Leury B. J., & Dunshea F. R. Dietary antioxidants at supranutritional doses modulate skeletal muscle heat shock protein and inflammatory gene expression in sheep exposed to heat stress. *Journal of Animal Science*. 2014. 92(11). 4897–4908.

11. Hariyono D. N. H., & Prihandini P. W. Association of selected gene polymorphisms with thermotolerance traits in cattle–A review. *Animal bioscience*. 2022. 35(11). 1635.

12. Sadid Al Amaz, Md Ahosanul Haque Shahid, Ajay Chaudhary, Rajesh Jha, Birendra Mishra, Embryonic thermal manipulation reduces hatch time, increases hatchability, thermotolerance, and liver metabolism in broiler embryos. *Poultry Science*. 2024. Volume 103. Issue 4. 103527. https://doi.org/10.1016/j.psj.2024.103527.

13. Suhendro I, Rachman Noor R, Jakaria J, Priyanto R, Manalu W, Andersson G. Association of heat-shock protein 70.1 gene with physiological and physical performance of Bali cattle. *Vet World*. 2024. 17(1). 17–25. doi: 10.14202/vetworld.2024.17-25.

14. Hariyono DNH, Prihandini PW. Association of selected gene polymorphisms with thermotolerance traits in cattle – A review. *Anim Biosci*. 2022. 35(11). 1635–1648. doi: 10.5713/ab.22.0055.

15. de Andrade Pantoja M. H., Poleti M. D., de Novais F. J., Duarte K. K. S., Mateescu R. G., Mourão G. B., ... & Titto C. G. Skin

transcriptomic analysis reveals candidate genes and pathways associated with thermotolerance in hair sheep. *International Journal of Biometeorology*. 2024. 68(3). 435–444.

16. Saadeldin, Islam M., Ayman Abdel-Aziz Swelum, Adel M. Zakri, Hammed A. Tukur, and Abdullah N. Alowaimer. Effects of Acute Hyperthermia on the Thermotolerance of Cow and Sheep Skin-Derived Fibroblasts. *Animals*. 2020. 10. no. 4. 545. https://doi.org/10.3390/ani10040545.

17. Krebs R. A. A comparison of Hsp70 expression and thermotolerance in adults and larvae of three Drosophila species. *Cell Stress & Chaperones*. 1999. T. 4. №. 4. C. 243.

18. Pantoja M. H. A., Mourão G. B., Ferreira M. C. S., Titto E. A. L., Strefezzi R.F., Gallo S.B., Titto C.G., Heat tolerance in hair sheep: individual differences on physiological, endocrine, and behavioral responses. *Animal – Open Spac*. 2024. Volume 3. 100067. https://doi.org/10.1016/j.anopes.2024.100067.

19. Ansari-Mahyari S., Ojali M. R., Forutan M., Riasi, A., & Brito L. F. Investigating the genetic architecture of conception and non-return rates in Holstein cattle under heat stress conditions. *Tropical Animal Health and Production*. 2019. 51. 1847–1853.

20. Boonkum W., Misztal I., Duangjinda M., Pattarajinda V., Tumwasorn S., & Buaban S. Genetic effects of heat stress on days open for Thai Holstein crossbreds. *Journal of dairy science*. 2011. 94(3). 1592-1596.

21. Adrian Langarica-Fuentes, Pauline S. Handley, Ashley Houlden, Graeme Fox, Geoffrey D. Robson, An investigation of the biodiversity of thermophilic and thermotolerant fungal species in composts using culture-based and molecular techniques. *Fungal Ecology*. 2014. Volume 11. Pages 132–144. https://doi.org/10.1016/j.funeco.2014.05.007.

22. Johnson J. S. Heat stress: impact on livestock well-being and productivity and mitigation strategies to alleviate the negative effects. *Animal Production Science*. 2018. 58(8). 1404–1413.

23. Osei-Amponsah, Richard, Surinder S. Chauhan, Brian J. Leury, Long Cheng, Brendan Cullen, Iain J. Clarke, and Frank R. Dunshea. Genetic Selection for Thermotolerance in Ruminants. *Animals*. 2019. 9. no. 11. 948. https://doi.org/10.3390/ani9110948.

24. Saadeldin, Islam M., Ayman Abdel-Aziz Swelum, Adel M. Zakri, Hammed A. Tukur, and Abdullah N. Alowaimer. Effects of Acute Hyperthermia on the Thermotolerance of Cow and Sheep Skin-Derived Fibroblasts. *Animals*. 2020. 10. no. 4. 545. https://doi.org/10.3390/ani10040545.

25. María J Carabaño, Manuel Ramón, Alberto Menéndez-Buxadera, Antonio Molina, Clara Díaz. Selecting for heat tolerance. *Animal Frontiers*. 2019. T. 9. V. 1. 62–68. https://doi.org/10.1093/ af/vfy033.

26. Asea A. A., & Kaur P. Heat shock proteins in veterinary medicine and sciences. Cham: Springer International Publishing. 2017.

27. Beede D. K., & Collier R. J. Potential nutritional strategies for intensively managed cattle during thermal stress. *Journal of animal science*. 1986. 62(2). 543–554.

28. Polsky L., & von Keyserlingk M. A. Invited review: Effects of heat stress on dairy cattle welfare. *Journal of dairy science.* 2017. 100(11). 8645–8657.

29. Joy, Aleena, Frank R. Dunshea, Brian J. Leury, Kristy DiGiacomo, Iain J. Clarke, Minghao H. Zhang, Archana Abhijith, Richard Osei-Amponsah, and Surinder S. Chauhan. Comparative Assessment of Thermo-tolerance in Dorper and Second-Cross (Poll Dorset/Merino×Border Leicester) Lambs. *Animals*. 2020. 10, no. 12. 2441. https://doi.org/10.3390/ani10122441.

30. Жарук П. Г., Атановська-Маслюк О. Й., Маслюк А. М. Природна резистентність та адаптаційна здатність ярок, одержаних від вівцематок асканійської м’ясо-вовнової породи та баранів породи тексель. *Вівчарство та козівництво*. 2020. Вип. 5. С. 28–37. https://doi.org/10.33694/2415-3958-2020-1-5-28-37.

31. Bradford H. L., Fragomeni B. O., Bertrand J. K., Lourenco D. A. L., & Misztal I. Genetic evaluations for growth heat tolerance in Angus cattle. *Journal of Animal Science*. 2016. 94(10). 4143–4150.

32. Bernabucci U., Biffani S., Buggiotti L., Vitali A., Lacetera N., & Nardone A. The effects of heat stress in Italian Holstein dairy cattle. *Journal of dairy science.* 2014. 97(1). 471–486.

33. Яковчук В. С., Столбуненко С. Г. Ааптаційна здатність баранчиків порід асканійської селекції. *Науковий вісник «Асканія-Нова».* 2022. № 15. С. 136–158. https://doi.org/10.33694/2617-0787-2022-1-15-136-158.

34. Pantoja M. H. A., Mourão G. B., Ferreira M. C. S., Titto E. A. L., Strefezzi R. F., Gallo S. B., Titto C. G., Heat tolerance in hair sheep: individual differences on physiological, endocrine, and behavioral responses. *Animal – Open Space*. 2024. Volume 3. 100067. https://doi.org/10.1016/j.anopes.2024.100067.

35. Lacetera N. Impact of climate change on animal health and welfare. *Animal Frontiers*. 2019. T. 9. №. 1. C. 26–31.

36. Zeng, Hanfang, Shujie Li, Yunfei Zhai, Haomiao Chang, and Zhaoyu Han. Preliminary Transcriptome Analysis of Long Noncoding RNA

in Hypothalamic-Pituitary-Mammary Gland Axis of Dairy Cows under Heat Stress. *Biomolecules*. 2023. 13. no. 2. 390. https://doi.org/10.3390/biom13020390.

37. Cowley F. C., Barber D. G., Houlihan A. V., & Poppi D. P. Immediate and residual effects of heat stress and restricted intake on milk protein and casein composition and energy metabolism. *Journal of dairy science*. 2015. 98(4). 2356–2368.

38. Yue S., Wang Z., Wang L., Peng Q., Xue B. Transcriptome Functional Analysis of Mammary Gland of Cows in Heat Stress and Thermoneutral Condition. *Animals*. 2020. 10. 1015. https://doi.org/10.3390/ani10061015.

39. Cowley F. C., Barber D. G., Houlihan A. V., & Poppi D. P. Immediate and residual effects of heat stress and restricted intake on milk protein and casein composition and energy metabolism. *Journal of dairy science*. 2015. 98(4). 2356–2368.

40. de Andrade Pantoja M.H., Poleti M.D., de Novais F.J. *et al.* Skin transcriptomic analysis reveals candidate genes and pathways associated with thermotolerance in hair sheep. *Int J Biometeorol*. 2024. 68. 435–444 https://doi.org/10.1007/s00484-023-02602-4.

41. Дергач І. В., Горбелік Р.В., Ященко М. Ф. Білки сироватки крові ягнят у постнатальному онтогенезі. *Вівчарство*. 1975. № 14. С. 118–122.

42. Lemal P., May K., König S., Schroyen M., Gengler N. Invited review: From heat stress to disease – Immune response and candidate genes involved in cattle thermotolerance. *Journal of Dairy Science*. 2023. Vol. 106. Issue 7. Pages 4471-4488. https://doi.org/10.3168/jds.2022-22727.

43. Dahl GE, Tao S and Laporta J Heat Stress Impacts Immune Status in Cows Across the Life Cycle. *Front. Vet. Sci*. 2020. 7. 116. doi: 10.3389/fvets.2020.00116.

44. Al-Dawood A. Acute phase proteins as indicators of stress in Baladi goats from Jordan. Acta Agriculturae Scandinavica. *Section A -Animal Science*. 2017. 67(1–2). 58–65. https://doi.org/10.1080/09064702.2017.1363815.

45. Lemal P., Tran M-N., Atashi H., Schroyen M., N. Gengler, Adding behavior traits to select for heat tolerance in dairy cattle. *JDS Communications*. 2024. https://doi.org/10.3168/jdsc.2023-0421.

46. Oloo R. D., Ekine-Dzivenu C. C., Mrode R., Bennewitz J., Ojango J. M. K., Kipkosgei G., Gebreyohanes G., Okeyo A.M., Chagunda M.G.G. Genetic analysis of phenotypic indicators for heat tolerance in crossbred dairy cattle. *Animal*. 2024. 101139. https://doi.org/10.1016/j.animal.2024.101139.

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