Impact of global warming on the productive and reproductive efficiency of goats

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Abstract

Global warming is the rise in the average temperature of Earth's atmosphere and oceans. Climate change has had an enormous impact on domestic animal production system. Thermal stress is the most prominent impact of global warming in goat production resulting in a range of physiological, metabolic and production disorders. Negative energy balance due to poor food quality and heat stress cause endocrinal disturbances: increased frequency of LH-waves (anovulatory cycles), increased diameter of dominant follicle (lower concentration of oestradiol)) and increased system or intrafollicular level of insulin–like growth factor-I (IGF-I). Glucocorticoids inhibit the release of gonadotrope hormones, which reduces fertility probably due to ovulation failure and reduced growth and maturation of follicles. A high temperature several days prior to and after mating was found to reduce conception rate, since heat stress may negatively affect oocytes, spermatozoa and embryos. Increased ambient temperature also affects animal health, reproduction and nutrition, resulting in poor reproductive performance, low product quality and quantity, or the possible outbreak of new diseases. The indirect impact of global warming is manifested in the reduced production of fodder used to feed animals due to long-term droughts or floods. In addition to decreased quantity of animal feed, the quality of fodder grown during droughts or floods is also questionable. As a result of feeding with poor quality feed and insufficient quantities, numerous metabolic and endocrine disorders occur that can significantly affect fertility and sexual performance in goats. .

Key words: *global warming; goat; heat stress; production; reproduction*

Introduction

Global warming is an increase in the average temperature of the Earth's atmosphere and oceans. The increase in environmental temperature due to global warming directly and indirectly affects many natural, economic and social systems, including ecosystems, agriculture, health and natural water resources. In the

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20th century, the temperature of the Earth's atmosphere rose by 0.74 ± 0.18°C, and a further rise of 1.8 to 3.5°C is predicted by the end of the 21st century (Forster et al., 2023). A temperature increase of more than 2°C could lead to drastic changes in global ecosystems. Desertification has increased in the past 30 years, with 0.35% more deserts, *i.e.*, 13.56% in relation to the total land area (Faye, 2024). Climate change also affects livestock production systems: through limited food and water supplies, disruption of thermoregulatory mechanisms, heat stress and the emergence and spread of new diseases (e.g., vector borne diseases such as bluetongue disease).

Global warming affects livestock production systems in two ways. The direct impact manifests in health, breeding and nutrition and leads to poor breeding ability, poor production under new environmental conditions, and also to poor product quality. Indirect effects of global warming and climate change include reduced availability of grazing land, reduced soil fertility, growth of poorer quality crops, reduction of arable land, reduction of grazing land (Nair et al., 2021; Sejian et al., 2021), expansion of deserts, and emergence of new exotic, unusual tropical diseases (e.g., expansion of vector district boundaries, etc.). When the temperature of the environment in which the animal resides increases, the body attempts to maintain optimal body temperature (within the species-specific physiological range) by initiating numerous physiological and metabolic functions (Ribeiro et al., 2018a). Thermal stress is one of the main challenges in adapting to climate change faced by domestic animals, as it causes various metabolic and production disorders.

Goats have numerous metabolic, biological, economic and social advantages compared to large ruminants (early sexual maturity, short gestation period, short generation interval and high rates of twinning), but also a stronger ability to survive in difficult environmental conditions (Castro Lima et al., 2022; Lu, 2023). Compared to dairy cows, goats are more tolerant to heat stress as they have a higher sweating rate, high water conservation capacity, and more favourable body weight to surface area ratio than cattle (Silanikove, 2000; Serradilla et al., 2017). The wide geographical distribution of goats can be attributed to various physiological, behavioural and morphological adaptation mechanisms that allow them to survive in different conditions. Nevertheless, goats are also exposed to the negative effects of climate in terms of reduced production, reproduction, resistance and adaptation (Serradilla et al., 2018). Goats are less sensitive to heat stress and therefore require few biological mechanisms of thermoregulation, which may be related to greater efficiency in water use and fibre digestion (Farias Machado et al., 2020). In arid and semi-arid areas of the world, indigenous goat breeds are more resistant to high heat stress, water shortage and fodder scarcity than other imported or exotic breeds with high productivity (Silanikove, 2000; Daramola and Adeloye, 2009; Silanikove and Koluman, 2015; Nair et al., 2021).

Dairy goats under heat stress had a 20–35% of reduction in feed intake and produced a lower quantity of milk (3–10%) of lower quality (lower fat, protein and lactose content). In addition to milk production (Sano et al., 1985; Brown et al., 1988; Salama et al., 2014), elevated ambient temperatures affect growth (Pragna et al., 2018) and meat production by at least 4% (Archana et al., 2018), and also affect the immune response (Dangi et al., 2015; Madhusoodan et al., 2019; Sejian et al., 2021).

Physiological and morphological adaptation mechanisms of goats to global warming

During respiration, animals cool down as they dissipate excess heat through evaporation. Goats exposed to a high temperature-humidity index (THI) >77 or extremely high heat stress increased the respiratory rate (RR) from the basal 15–30 breaths/min to 80–120 or more than 200 breaths/min (Dangi et al., 2015; Hamzaoui et al., 2012). Vasodilation leads to increased blood flow in the periphery of the skin, where heat is exchanged between the body and the environment. The decrease in skin temperature in goats exposed to heat stress is attributed to evaporative heat loss through sweating (Nijland and Baker, 1992; Al-Tamimi, 2007). Under resting conditions, the heart rate of goats fluctuates between 60 and 80 beats per minute, while during heat stress it increases to around 90 beats per minute or more (Gupta et al., 2013; Okoruwa, 2014). The skin mechanism of evaporative cooling by increasing peripheral blood flow and pulse rate (PR) leads to faster heat exchange (Rocha et al., 2009; Souza et al., 2014; Dangi et al., 2015; Ribeiro et al., 2018a). Goats can also lower body temperature by increasing rectal temperature (RT).

There are significant individual and breed-related genetic differences between goats in terms of response to heat stress and differences in adaptability. Higher expression of the genes HSP70, HSF1, HSP20 and HSP90 as well as TLR2, TLR8, growth hormone (GH), growth hormone receptor (GHR), insulin-like growth factor-1 (IGF-1), leptin (LEP) and leptin receptor (LEPR) are considered potential biomarkers for heat stress (Angel et al., 2018; Carabaño et al., 2019; Sejian et al., 2021; Abioja et al., 2023; Kaushik et al., 2023).

The influence of an increase in ambient temperature is manifested by significant changes in the hormonal profile of ruminants due to the adaptation and acclimatisation process of the endocrine system, mainly the thyroid and adrenal glands (Ribeiro et al., 2018b). One of the most important endocrine stress responses and regulators is the hypothalamic-pituitary-adrenal axis (HPA axis) via corticotropin-releasing hormone (CRH), adrenocorticotropic hormone (ACTH) and adrenal hormones. Cortisol is a hormone synthesised by the adrenal cortex and is considered one of the most important hormones involved in the stress response. It is responsible for gluconeogenesis and promotes the breakdown and release of glucose, amino acids and fats in the liver, muscles and adipose tissue (Sejian et al., 2021). Cortisol levels are not only subject to daily fluctuations, but can also vary depending on the season, photoperiod, dietary composition and stress depth from various causes. During heat stress, cortisol promotes the breakdown of proteins into amino acids (Sejian et al., 2021) and regulates the immune response, reproduction, metabolism and behaviour.

The concentrations of the thyroid hormones thyroxine (T4) and triiodothyronine (T3) in the serum fluctuate considerably during the season, but also with changes in the ambient temperature. In some goat breeds (such as Azul, Graúna, Boer, Savana, Saanen), these changes are much more pronounced than in other breeds (Berbigier and Cabello, 1990; Uribe-Velasquez et al., 1998; Todini et al., 2007; Menéndez-Buxadera et al., 2012; Ribeiro et al., 2018). When the thyroxine concentration decreases and the triiodothyronine concentration in blood plasma increases, intestinal motility slows down, which prolongs the passage time and nutrient absorption (Berbigier and Cabello, 1990; Todini et al., 2007).

In dehydrated goats due to heat stress, the secretion of antidiuretic hormone (ADH) increases due to activation of the renin-angiotensin-aldosterone system, which leads to the excretion of more concentrated urine due to increased water uptake in the kidneys (Kaliber et al., 2016). When goats have constant access to water, plasma aldosterone levels are increased (Shilja et al., 2016). There is an increased secretion of the hormone aldosterone from the adrenal glands, which causes an increased reabsorption of sodium from the renal tubules, leading to an imbalance of electrolytes in the body. Levels of catecholamines (adrenaline and noradrenaline) and glucocorticosteroids (hydrocortisone) have been found to rise sharply in ruminants when exposed to high ambient temperatures above 40°C (Aleena et al., 2020; Gupta and Mondal, 2021).

Possible effects of global warming on the reproductive system of goats

In the temperate climate belt, goats are seasonal polyoestrous animals whose season is related to short days (Šavorić et al., 2024). Numerous climatic factors (e.g., ambient temperature, relative humidity, radiant heat, wind speed, altitude and other factors), management factors (e.g., housing, ventilation, provision of shade, and others) and animal species factors (e.g., age, genotype, coat characteristics, degree of acclimatisation, state of health, physical activity, reproductive state, etc.) are crucial for the organism's timely response to environmental influences and adaptation to new unfavourable conditions (Salama et al., 2014). Air temperature and rainfall during different seasons could affect the reproductive efficiency in different sheep breeds, and positive or negative correlations have been shown between climate variables and reproductive performance (Đuričić et al., 2019a; 2019b), while in goats (Boer and French Alpine) there was no correlation between those climatic variables and reproductive efficiency in northwestern Croatia (Djuricic et al., 2010, 2012, 2020). Reproductive and productive traits in small ruminants are affected by genetic and non-genetic factors (Vlahek et al., 2023). Indicators of reproductive success in goats are the number of kids born, body weight of kids at birth and at weaning, kidding interval, percentage of kids born and weaned, age at first kidding, abortion rate, and the length of the goat's reproductive life (Šavorić et al., 2024).

High ambient temperatures have negative effects on the tissues or organs of the reproductive system in both sexes (Adjassin et al., 2022). A higher THI index (high humidity and ambient temperature) negatively affects the ability to exhibit natural mating behaviour by decreasing the duration and intensity of oestrus in females, decreasing spermatogenesis and libido in males, resulting in significantly reduced reproductive performance in goats. It is known that for the genetic improvement of the goat population, males are responsible for 60 to 80% of genetic progress and have a significant selection pressure, so preserving the quality and quantity of semen and libido is important in a long-time stressful condition (Herrera Vargas et al., 2023).

In bucks, sperm production, sperm quality and quantity, sperm motility and sperm count, and testosterone levels all decrease, leading to a decrease in libido (de La Salles et al., 2017). Problems with spermatogenesis and testicular degeneration have also been observed in males exposed to heat stress (Pérez-Crespo et al., 2008; Gupta and Mondal, 2021). In females, follicular growth, egg maturation (Ozawa et al., 2005), embryonic development and pregnancy rates are slowed (Aboul-Naga et al., 1987; Marai et al., 2006; Rojas-Downing et al., 2017; Gupta and Mondal, 2021; Danso et al., 2024). Glucocorticoids inhibit the secretion of gonadotropic hormones, which further reduces fertility due to absent or reduced formation and maturation of follicles and failure of ovulation to occur. Heat or thermal stress leads to endocrine disruption: reduced LH wave frequency (anovulatory cycle), reduced diameter of the dominant follicle (lower oestradiol levels) and reduced systemic and intrafollicular levels of insulin-like growth factor I (Gupta and Mondal, 2021).

When goats are exposed to high ambient temperatures for a relatively long-period, follicular growth is suppressed until ovulation due to decreased LH receptor levels and follicular oestradiol synthesis (Ozawa et al., 2005), leading to follicular involution and failure to ovulate. Oestradiol regulates follicular development and ovarian atresia, inhibits granulosa cell apoptosis, and promotes granulosa cell division and growth. A reduced amount of oestradiol leads to a suppression of oestrus signs (oestrus is absent or weakly expressed), reduced gonadotropin levels, the absence of ovulation and gamete transport, and a reduced fertilization rate (Ozawa et al., 2005). The harmful effects of high environmental temperatures on the embryo are most evident in the early stages of development. Low progesterone secretion limits endometrial function and embryo development in the blastocyst stage, after implantation (during early organogenesis) and in the foetal stage, which can lead to various teratologies and early embryonic mortality (Wolfenson et al., 2000);

In conclusion, goats are a species of domestic animal that is more resistant to global warming and changes in climate factors compared to other types of livestock, so preserving indigenous and resilient breeds of goats, their genetic potential and diversity will increase the chances for a better selection of more resistant breeds or hybrids that will have to face global climate change in the future.

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Utjecaj globalnog zatopljenja na proizvodnu i reproduktivnu učinkovitost koza

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Globalno zatopljenje je porast prosječne temperature Zemljine atmosfere i oceana. Klimatske promjene imaju ogroman utjecaj na sustav uzgoja domaćih životinja. Toplinski stres je najizrazitiji utjecaj globalnog zatopljenja na uzgoj koza koji rezultira različitim fiziološkim, metaboličkim i proizvodnim poremećajima. Negativna energetska ravnoteža zbog loše kvalitete hrane i toplinski stres prouzroče endokrine poremećaje: povećanu učestalost LH-valova (anovulatorni ciklusi), povećani promjer dominantnog folikula (nižu koncentraciju estradiola) te povećanu sustavnu ili intrafolikularnu razinu faktora rasta sličnog inzulinu-I (IGF-I). Glukokortikoidi inhibiraju oslobađanje gonadotropnih hormona koji smanjuju plodnost vjerojatno zbog izostanka ovulacije, usporenog rasta i sazrijevanja folikula. Utvrđeno je da visoka temperatura nekoliko dana prije i nakon parenja smanjuje uspjeh koncepcije jer toplinski stres može negativno utjecati na jajne stanice, spermije i zametke. Povećana temperatura okoliša utječe i na zdravlje, reprodukciju i hranidbu životinja, što dovodi do slabijeg reproduktivnog učinka, niske kvalitete i količine proizvoda ili mogućeg izbijanja novih bolesti. Indirektni utjecaj globalnog zatopljenja očituje se u smanjenoj proizvodnji krmiva koja služe u hranidbi životinja zbog dugotrajnih suša ili poplava. Osim što je hrane za životinje znatno manje, upitna je i kvaliteta tih krmiva uzgojenih za vrijeme suše ili poplava. Zbog hranjenja krmivom loše kvalitete i nedovoljnim količinama dolazi do brojnih metaboličkih i endokrinih poremećaja koji mogu znatno utjecati na plodnost i spolnu učinkovitost u koza.

Ključne riječi: *globalno zatopljenje, koza, toplinski stres, proizvodnja, rasplodnja*