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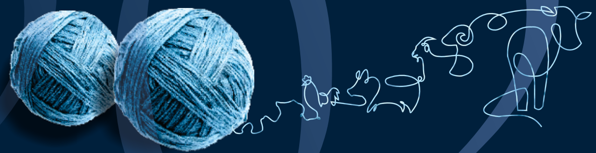

PROCEEDINGS

4 - 6 October 2023, Belgrade, Serbia

Institute for Animal Husbandry
Belgrade - Zemun, SERBIA

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GOATS AND CLIMATE RESILIENCE

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Invited paper

Abstract: Climate change poses a major global concern and is therefore an ongoing topic. World's population is expected to reach 9.7 billion people by 2050 and 10.4 billion by 2100, which means that the food resources will become crucial. In that respect, animal protein is considered a vital nutrient for growing human population. However, in the light of ever-changing climate events food and water sources for both animals and humans can become scarce in certain areas. The impacts of higher temperatures, changes in precipitation and extreme weather events pose the most risk on agricultural systems such as livestock. Direct and indirect influence of heat and drought caused by global warming is harmful to livestock. Small ruminants and particularly goats are considered more resilient and better adapted to hot and dry environments compared to other livestock. These animals require less in terms of feed, water and labor than large ruminants and are also more thermo-tolerant. They have certain physiological, behavioral and anatomical advantages aiding their survival during heat and drought. Goats are less of a competition to humans in terms of available food as they can thrive on plants unusable for human nutrition. The review discusses advantages of goats as species in terms of adaptation to changing climate.

Key words: goats, climate, heat, adaptation, thermotolerance

Introduction

The climate has been constantly changing and consequently impacting agricultural systems, both plant and livestock. These changes, which include higher temperatures, changes in precipitation and extreme weather events, have direct as well as indirect impact on animal breeding. These effects, which can vary by region, animal species, level of adaptability and production type, may be favourable or unfavourable *(Sejian et al., 2017)*. In northern Europe, warmer and wetter climate might favour crop and pasture growth, as well as higher yields of forage in central Europe, although quality will vary according to water availability and soil characteristics *(Gauly et al., 2013; Stagge et al., 2017)*. However, negative effects are most likely to be felt in tropical and subtropical areas *(Henry et al., 2018)*. Animals are directly impacted by heat stress caused by increased air temperatures and indirectly by reduced water and feed availability and quality, as well as increased exposure to pests and pathogens *(Gauly et al., 2013)* and the end effects are the same for both impacts, as they lead to impaired welfare, health and productivity.

Goats are regarded as the perfect domestic animal model for climate change due to their great resistance to disease, high resilience to heat and drought, and capacity to subsist on scarce pastures *(Reshma Nair et al., 2021)*. Compared to other domestic animal species, they have an advantage in thriving in harsh environments, as evident from African countries. As the climate change unfolds, environmental conditions globally are becoming more heat and drought prone. Even countries with temperate climate are experiencing more heat and drought during summer months as well as milder and drier winters. In some areas of Central Europe, such as Hungary, the percentage of days that cause heat stress, defined as days with a temperature humidity index (THI) value above a specific comfort threshold, increased by 4.1% between 1973 and 2008 *(Solymosi et al., 2010)*. Goats require less care compared to other livestock and don't need a lot of initial housing or equipment investment. Additionally, goats are tough and much more likely to withstand a prolonged dry spell and they even consume failed crops. They can walk longer distances and harsher terrains in search for forages and are disease resistant and drought tolerant, especially those of native breeds. When given low quality feed goats are better at digesting dry matermatter, utilizing nutrients and converting them into milk and meat compared to cattle or sheep.

Differences between species, as well as breeds, in adaptation to heat stress can be attributed to three main factors: ability of adaptation to elevated temperature and radiation, ability of adaptation to water restriction and ability of adaptation to periods of feed scarcity, all of which are found in goats through their efficient behavioural and physiological thermoregulation, capacity to withstand severe dehydration, low metabolic requirements supported by small body size, efficient digestive capacity and skilful grazing behaviour *(Nyamushamba et al., 2017)*.

In this review, we present what is known about the adaptation and production in goats as species under harsh environments caused by climate change.

Goats as the most climate-adapted animal model

Through the years population of goats increased in hot and dry areas whilst suppressing other ruminant species, especially in tropical continents such as Asia and Africa *(Scherf et al., 2009; FAO, 2018)*. Goats have distinctive morphological, behavioural, biochemical, cellular, and molecular characteristics which allow them to survive in various tropical environments *(Reshma Nair et al., 2021).*

Such behavioural, physiological and anatomical advantages aid their survival during drought. During the periods of water shortage, the voluntary intake of dry matter, i.e., feeding, decreased in an effort to maintain equilibrium with the available body water *(Maloiy et al., 2008; Alamer 2009).* Also, feeding frequency can be modified in terms of more frequent and shorter meals to reduce heat production caused by rumen fermentation or nocturnal feeding can be implemented to avoid high temperatures during the daytime *(Morand-Fehr, 2005).* Goats also have the ability to desiccate their faeces and can concentrate the urine thereby reducing water loss through waste matter discharge when faced with limited water availability *(Jaber et al., 2013; Kaliber et al., 2016).* As a part of physiological response, the heart rate was found to decline in water-restricted goats, therefore reducing their metabolism to conserve water and to compensate for the reduction in feed intake. This ability to reduce metabolism allows goats to survive even when faced with prolonged periods of severe limited food availability *(Silankove, 2000; Brosh, 2007).* They also have the ability to repress the evaporative water loss pathways both through the respiratory tract and skin surface, by reducing the water turnover when faced with water deficiency and this is considered as one of the key aspects of goat adaptation as compared to other farm animals *(Robertshaw and Dmi'el, 1983)*. Rumen, which can serve as water tank, also contributes to ability of goats to withstand drought. Some studies found that the rumen has the capacity to store water for some time, thus preventing hemolysis and osmotic shock to tissues, and also allowing animals to walk longer distances in search of feed (*Silankove, 2000; Jaber et al., 2013).* Rumen of goats allows the intake of large volumes of water upon rehydration which is then temporarily stored in the rumen and this is more pronounced in goats as opposed to sheep *(Giger-Reverdin and Gihad, 1991).*

Goats are well adaptable and opportunistic feeders, as they can consume almost anything in order to survive. There is no specific feed requirement for goats and they can utilize forages not consumed by other ruminants. Goats can survive even on thorns and spines *(Decandia et al., 2008).* Goats also have some anatomical distinctions that contribute to their specific feeding behaviour such as the ability to assume a bipedal position, which makes them capable of browsing higher vegetation that is beyond the reach of sheep, as well as specific anatomy of the mouth with mobile upper lip, which enables them to make the maximum use of attainable vegetation, as opposed to sheep which have a cleft upper lip. In addition to this browsing behaviour goats can also travel long distances in search of food and water.

Morphological attributes such as body shape and size help in reducing heat loads and minimizing water losses *(Silankove, 2000)*. When compared to other ruminants, goats are small with low body weight which helps them through periods of feed scarcity. Smaller animals also benefit from a relatively larger surface area which allows them to better dissipate heat from the body to the environment *(Jaber et al., 2013)*.

Goats also have some digestive advantages making them more potent to survive on limited pastures. These animals are believed to have better digestive efficiency than other ruminant species as they have longer mean retention time of digesta in rumen and better feed conversion efficiency because of the microflora inhabited in rumen *(El-Tarabany et al., 2017)*. It was found by *Daramola and Adeloye (2009)* that in goats fed with low-quality forages, lignin undergoes modification, degradation, and absorption from the gastrointestinal tract. This was recognized as one reason for the enhanced microbial activity in rumen.

In addition to their exceptional adaptation abilities to heat and drought stress goats also have high feed conversion efficiency resulting in lower enteric methane emission per unit of feed. Numerous studies demonstrated the least enteric CH_4 emission in goats as compared to other ruminant species *(Görgülü et al., 2009; Moeletsi et al., 2017; Darcan and Silanikove, 2018)* thus highlighting the advantage of goat rearing amidst the deteriorating environmental conditions *(Reshma Nair et al., 2021)*.

Among the domestic ruminants, goats are considered to be the most disease resistant. In the review by *Daramola and Adeloye (2009)* it was reported that goats tend to have more lymphocytes than neutrophils in their circulation suggesting a well-developed immune system in this species. Disease resilience under thermal stress conditions depends, among other things, on physiological adaptation and responses on cellular and molecular level of animals, so the thermal-stress adapted animals will be in better health in general.

Variations in heat tolerance among breeds

Goats are often praised as heat resistant species, but just like other species they too have temperature comfort zone in which their homeostasis is best regulated. Outside this comfort zone goats also undergo changes in their energy and basal metabolism even though they are generally more resistant to the effects of temperature variations compared to other ruminant species *(Gupta and Mondal, 2019)*. The resilience of goats to heat and drought varies according to genotype, genetic potential, life stage, management or production system and nutritional status.

Indigenous breeds of goats, as well as of other species, are considered to be more able to cope with high heat load and water and feed deficiency than their exotic counterparts in dry rangelands *(Alamer, 2003; Silanikove, 2000; Cooke et* *al., 2020)*. Selection for higher productivity in animal breeding often leads to reduced fitness of animals, disease resistance and tolerance caused by climate changes *(McManus et al., 2020)*. On the other hand, indigenous breeds have few unique adaptive mechanisms that help them to survive in a specific and often times harsh environment *(Wheelock et al., 2010)* and are more easily adapted to sudden environmental fluctuations and disease outbreaks than other exotic or crossbred breeds *(Alamer, 2003)*. Therefore, not all goats are created equal and breed contributes a lot to adaptive capacity. *Offoumon et al. (2019)* compares reproductive traits of Red Maradi, Saanen and crossbred Saanen x Red Maradi goats in sub-humid tropical Sudano-Guinean region and finds a rustic breed of Red Maradi to have better reproductive performances under constant heat load than pure Saanen or their crosses.

There are more than 600 goat breeds worldwide and the capability to adapt to the thermal challenges differs between the breeds *(Joy et al., 2020)*. *Gandhi and Arjava (2016)* state that tropical breeds can be comfortable in the environment with the temperatures as high as 38 ºC, while temperate breeds need temperatures in the range from 5 to 25 ºC for optimal performance. *Lallo et al. (2012)* note that tropical breeds have higher thermal tolerance thanks to low metabolic heat production and high heat dissipation.

However, even indigenous breeds that evolved in different regions of one country can also vary in their adaptive capacity to stressful conditions as shown in some previous studies *(Aleena et al., 2018; Pragna et al., 2018)*. An animal's ability to endure environmental challenges is determined by its genetic potential *(Silankove and Koluman, 2015)*. As a result of the interaction between numerous genes and traits, the genetic foundation of thermo-tolerance involves complex processes. Some researchers including *Yakubu et al. (2017)* and *Khan et al. (2019)* studied the SNP markers of MHC class II DRB gene and SOD3 gene and were able to identify association between certain number of SNPs and the heat stress response variables.

Recent studies *(Aleena et al., 2018; Madhusoodan et al., 2019)* report variations in goats' tolerance to heat stress and the effectiveness of their adaptation based on molecular alterations in terms of changes in heat shock protein 70 (HSP70), TLR2, TLR8. Heat shock proteins (HSPs) are a group of proteins synthesized by all living organisms as a response to heat stress. They help sustain cellular homeostasis and cellular adaptation to changing environment *(Hoffmann et al., 2003; Roti, 2008)*. One of the most prevalent and well-studied members of the HSP family, which is made up of highly conserved stress proteins, is heat shock protein 70 (HSP70), which is essential for environmental stress tolerance and adaptation *(Banerjee et al., 2014)*. Such research enables the identification and quantification of heat stress biomarkers, which may further support long-term breeding objectives to create breeds unique to agroecological zones *(Sejian et al., 2021)*.

Climate change and milk production

Dairy industry is negatively impacted by elevated ambient temperatures, which has been well documented *(Salama et al., 2014; Silankove and Koulman, 2015; Contreras-Jodar et al., 2018)*. Goats are generally considered more tolerant to heat stress compared to dairy cows because of their low body mass, and low metabolic requirements, as well as greater sweating rate and relatively larger surface area allowing greater heat dissipation. Their main advantage, unlike other ruminants, is their grazing strategy and efficient digestive system, which enable goats to attain maximal food intake and utilization in a given feeding situation. Because goats can consume browse (tree leaves and shrubs), there is a consistent and stable supply of food throughout the year. However, lactating dairy goats are not heatproof as they also exhibit several changes in performance due to thermal stress, including reductions in feed intake, milk yield and milk composition *(Hamzaoui et al., 2013)*. *Contreras-Jodar et al. (2018)* report that heat stress not only negatively affects milk production in dairy goats, but also results in impairment in the functionality of immune cells, making the immune system of heat-stressed goats less capable of resisting diseases. Their research shows reduced feed intake, milk yield, protein, and fat content in heat stressed goats. Also, microarray analysis of blood reveals that 55 genes are up-regulated, whereas 88 are down-regulated by heat stress and bioinformatics analysis reveals that 31 biological pathways are impacted by heat stress as well. Research by *Sano et al. (1985)* as well as that of *Brasil et al. (2000)* demonstrates depression in milk yield by 3 to 13% in Saanen and 6% in Alpine goats, respectively, after being exposed to moderate or severe heat stress. *Silankove (2000)* and *West (2003)* state that under equivalent conditions of elevated THI, the reduction in milk yield in Holstein dairy cows would be much greater than in these Saanen and Alpine goats.

Lactating dairy animals generate substantial metabolic heat and also accumulate additional heat from radiant energy *(Coppock, 1985; West, 2003)*. High yielding cows are especially at risk of suffering from heat stress. As stated by *Coppock (1985)* the proportion of heat that gets produced through the metabolic processes of milk production in high yielding cows can exceed 50% of total heat generation. The built up heat load can cause disruptions in thermoregulation, which might result in increased body temperature and a general thermal stress *(Gauly et al., 2013)*, as well as cow mortality *(Vitali et al., 2009)*.

Hamzaoui et al. (2013) found heat stressed Murciano-Granadina dairy goats in late lactation to show dramatic physiological changes during the first week of exposure to elevated air temperature (climatic chamber treatment) and then to partially recover thereafter. They are able to sustain milk yield by losing body mass, but milk protein content and protein yield decrease.

So, no doubt that the heat stress causes depression in milk quantity and quality in dairy animals, goats included. But, even though goats are located in all types of ecology zones, their concentration is the highest in dry and tropic zones of developing countries *(Escareno et al., 2013)* and this is due to their higher resilience to heat and drought, as well as better adaptation to poor rearing conditions compared to other domestic animal species. Dairy industry in temperate zones hasn't been so far directly affected to the higher degree by elevated air temperature, however major concern is indirect impact through grain production. It is expected that there will be a conflict of interest between humans and animals as higher proportions of grains will be used for human instead livestock nutrition, as well as question of using high-quality forages that can be used as edible food for humans will arise *(Silankove and Koulman, 2015)*. In such scenarios, intensive production systems based on large ruminants like high producing dairy cows that rely on high concentrate diets, will no longer be possible.

Some previous studies demonstrated that milk production by local breeds of goats herding on natural pasture was not affected by heat stress *(Brown et al., 1988; Lallo et al., 2012; Di Rosa et al., 2013)* which suggests that milk yield in breeds adapted to hot environment are less affected by heat stress.

So, in the case of worsening of climate change the proportion of milk production from goats could be increased by exploiting the advantageous physiological traits of goats and thus lessening the overall impact of climate change on dairy production.

Mitigation strategies

When it comes to mitigation strategies, there are basically three available approaches to sustain survival and the productivity of animals in hot environment: through physical modifications of environment, nutritional management and genetic development of breeds less sensitive to heat stress *(Collier et al., 2006)*. These mitigation strategies can be used alone or in combination to assure better productive environment.

Physical modification of environment usually involves provision of shade and evaporative cooling techniques. Provision of shade is important when animals are kept outside, on pasture, as shade provides protection from direct solar radiation. Shades can be natural from trees or artificial (eaves/canopy). Trees are considered better option as they are cost-effective and also capture radiation by evaporation of humidity in the leaves. A good-designed shade structure can reduce heat output by 30 - 50% *(Muller et al., 1994)*. *Habeeb et al. (2018)* suggests that the adequate surface area from shade for small ruminants should be 1.86 - 2.79 m^2 per animal in order for animals to be kept loose.

Provision of artificial ventilation in facilities is another strategy to reduce the heat load on animals. Preferably, buildings should be built from natural materials that ″breathe″ and airflow can be increased by fans or coolers if possible. Spraying the roof and walls of the barns helps in cooling of the surroundings and consequentially animals *(Brouk et al., 2003)*. Also, fully enclosed facilities are not recommended for hot climates because of the restricted natural air flow, therefore, partially enclosed shelters are preferred *(Sejian et al., 2015)*.

Nutritional management strategies include: feeding animals during the cooler periods of the day, providing enough fresh water, providing diet with high quality forages (i.e. grass–legume mixtures have higher crude protein concentration and lower fibre concentration than pure grass stands), increasing concentrate to forage ratio which improves the efficiency of nutrients utilization in animals under heat load, implementing fat supplementation which increases net energy intake in heat stressed animals due to its higher energy density and its lower metabolic heat, when compared to fibre or starch, supplementing with certain minerals, vitamins, amino acids and plant extracts *(Sivakumar et al., 2010; Hamzaoui et al., 2012; Hamzaoui et al., 2013; Kholif et al., 2016; Conte et al., 2018; De Lima et al., 2019)*.

Autochthonous goats are considered more capable of coping with harsh environments bringing on high heat load, water, and energy deficit compared to their exotic breeds. Goat production in such environments should be based either on rearing purebred autochthonous goats accustomed to specific environmental conditions, or using this locally adapted breeds in crossbreeding programmes. Also, selecting individual animals based on adaptive/fitness traits and/or heat stress biomarkers in breeding programs can be a good mitigation strategy. In small ruminants, genes with significant roles in metabolic, immune, and thermoregulatory pathways may serve as potential biomarkers for genetic selection. Identification and mapping of the individual genes responsible for better adaptation features is necessary for the incorporation of specific genes to improve thermo tolerance, which paves the way for an improved breeding program using marker-assisted selection and transgenics *(Henry et al., 2018)*. Prospective selection should balance productivity, health and thermal adaptability *(Joy, 2020)*. Keeping animals in good health and condition is also very important as healthy individuals will better resist heat than ailing animals.

Conclusion

Climatic changes will undoubtedly impact future supply of meat, milk, fibre and other products from ruminant animals. Increased temperatures, altered precipitation patterns, and extreme weather events will have varying effects on different geographic regions, animal species, and socioeconomic adaptation capability. Developing countries are by far the most vulnerable to climate change and elevated ambient temperatures since their agriculture is almost completely weather dependent. All ruminant livestock production systems will inevitably have to adapt to climate change. Some of the climate change negative outcomes could be mitigated through nutritional and breeding management, which will yield fast aid, but also through much slower genetic selection, which is more of a long-term approach.

All species of livestock will undoubtedly experience heat stress to some extent under the scenario of climate change, which will negatively influence their ability to produce and reproduce. However, goats are considered the most climate-adapted domestic animals and are expected to perform better than other livestock species, particularly in terms of feed and fodder shortage. Their physiological, anatomical and behavioural features allow them advantage in this demand. This is especially true for autochthonous and locally adapted breeds whose survival and protection should be imperative for all concerned. However, even though goats possess some advantages over other species in reducing the effects of climate change, they have consistently been a neglected species. Goats should gain far more attention in scientific community as they can be a go-to species when it comes to protecting economy of farmers through overcoming climate change–associated adversities.

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