



Review article

Heat Stress in Water Buffaloes: A Review. I. Effects of Climate in Cuba and Morphological Particularities of the Skin

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ABSTRACT

Background: Of the many environmental effects that impact animals, those related to climate occupy a predominant place due to the changing nature of the climate and the physiological characteristics of each species to cope with it. Among these issues, temperature sensations are one of the main factors representing the influence of climate on animal production. Water buffaloes are animals resistant to different environments; however, they experience stress when exposed to direct solar radiation or on days with high environmental temperatures. **Aims.** To describe the climatic characteristics in Cuba and the anatomical peculiarities that cause heat stress (HS) in buffaloes. **Development:** The climate outlook for the coming years, its impact on production, and the morphological particularities of the skin that influence the occurrence of HS in water buffaloes in Cuba are reported. **Conclusions:** The water buffalo is a resilient animal with specific anatomophysiological characteristics of the species that make it sensitive to HS due to the combined impact of high environmental temperature and relative humidity.

Keywords: buffaloes, climate, heat stress, skin, morphological traits of the skin (Source: *AIMS*)

INTRODUCTION

The genetic breeding program carried out in Cuba (Prada 1984) was based on the introduction of genotypes. The buffalo species was the second in terms of food production in Cuba. By the end of 2022, 6 million 984 thousand liters of milk and 2 thousand 104.5 tons of live weight meat were obtained. For this purpose, a total of 553 facilities were available, of which 257 were dairies (MINAG, 2023). Most of these units were designed for highly specialized cattle, with characteristics for high-input systems, in soils of very low farming quality, and little shade in the

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pastures. Currently, these facilities do not provide the conditions that meet the physiological needs and prevent the impact of heat stress (HS) for buffalo breeding.

The growing interest in this species leads to the transition towards more sustainable production systems, a change that represents a challenge due to the complexity of agroecosystems, especially in places where agroecological sustainability has not yet been fully achieved (Navas, 2023), as is the case with Cuban livestock farming.

HS is one of the greatest challenges facing the livestock industry in tropical conditions. The increase in environmental temperature (ET) and relative humidity (RH) compromises animal production with devastating economic consequences (Chauhan et al., 2021). Raising water buffalo under extreme ET and RH conditions leads to HS, which shows the inability of the thermoregulation system to respond in this species (Rai et al., 2023; Tomar et al., 2024).

Due to climate changes and the recognition of HS occurrence in buffaloes, the international community has raised the need for scientific management to achieve optimal productive efficiency in buffalo breeding (Arunpandian et al., 2021). A series of articles will be published detailing other aspects of the effects of HS on the species, following extensive literature reviews.

The aim of this review is to describe the climate characteristics in Cuba and the anatomical peculiarities that cause heat stress (HS) in buffaloes.

DEVELOPMENT

Climatic variables: a source for predicting heat stress in animals

The environmental factors that influence animal performance are, ET and RH, high radiation, precipitation, atmospheric pressure, low wind speed, and their interactions (Krishnan *et al.*, 2023). In tropical and subtropical regions, prolonged summers are characterized by high ET and RH, which produce HS in animals (Wankar *et al.*, 2021; Nasr, 2022).

Impact of climate change in Cuba

The impact of climate change on livestock directly affects the welfare, health, reproduction, and productivity of animals and indirectly, due to the low availability of food, in their welfare, health, reproduction, and productivity (del Prado et al., 2020).

The First Nationally Determined Contribution (Updated), indicated that Cuba's climate is transitioning from humid tropical to dry tropical, with average temperatures above 30°C, approximately 1000 mm of annual average rainfall, and 70 days of precipitation, conditions that will lead to the displacement of dry landscapes from the eastern region to other areas of the country. Air temperature will continue to rise, potentially reaching 4.5°C. The greatest warming will occur mainly during the warmest period of the year, a trend that will become more evident over time (Cubano, 2020).

Fonseca Rivera *et al.* (2024) reported that the annual average temperature during 2023 (Figure 1) was the third highest since 1951, with a value that exceeded the historical average of the 1961-1990 period (25.6°C) by 1.38°C.

The average accumulated rainfall (248.6 mm) represented a standardized anomaly of 1.28. The rainy season (May-October 2023) concluded with a stark contrast in its behavior between the western side, which was classified as moderately dry (average of -169.9 mm), and the eastern part of the country, which was extremely wet (Fonseca Rivera *et al.*, 2024).

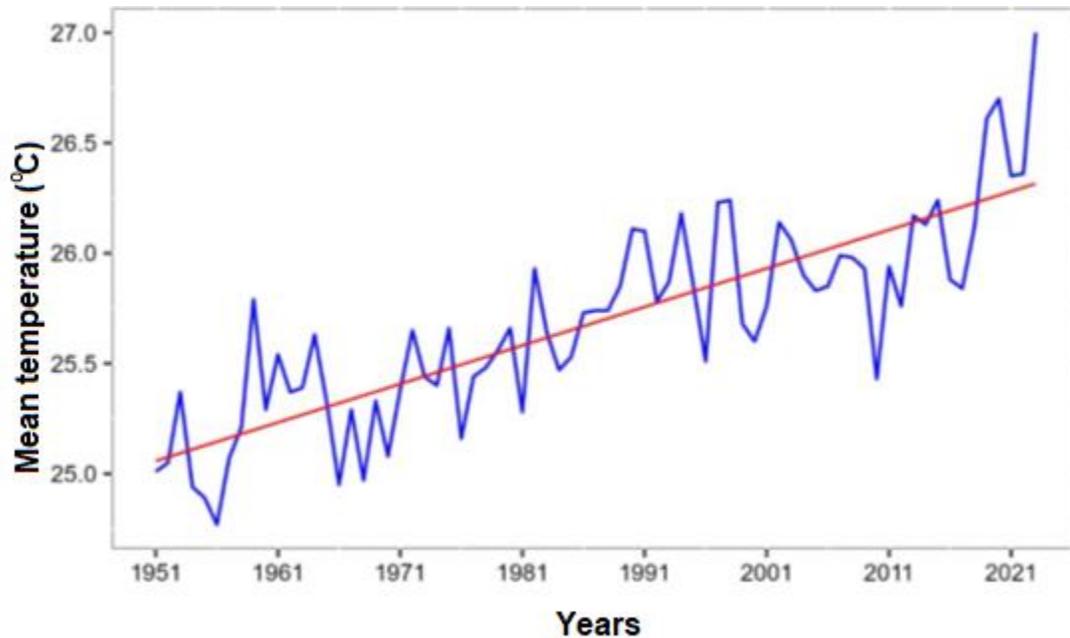


Figure 1. Annual average temperature in Cuba during the 1951-2022 period, the red line represents the linear trend (Fonseca Rivera *et al.*, 2024)

Heat Stress in Buffaloes

Heat stress (HS) is defined as a set of conditions arising from overexposure to the aforementioned environmental factors, where the animal is unable to dissipate enough heat to maintain homeothermy, conspiring against animal welfare and leading to economic losses resulting from reduced reproductive performance, productivity, and health (Mafruchati *et al.*, 2023).

When buffaloes are exposed to direct sun radiation, they show signs of great discomfort, with changes in their biological and productive functions (Purohit *et al.*, 2020), increased susceptibility to diseases, and in extreme cases, higher mortality (Godde *et al.*, 2021; Wankar *et al.*, 2021).

The ways in which an animal will respond to heat stress and the point at which production losses begin to occur vary widely and depend on the species, breed, age, genetic potential, physiological status, nutritional status, animal size, and previous exposure; high-yielding breeds and individuals are more susceptible (Godde *et al.*, 2021).

Adaptability, thermoneutral zone of the water buffalo, and temperature-humidity index values

Water buffaloes, as homeothermic animals, are heat-tolerant (Costa *et al.*, 2020) and adapt well to hot and humid climates where they can withstand temperatures above 46°C (Marai and Haebe, 2010). However, given their anatomical and physiological particularities, they are more susceptible to heat stress (Purohit *et al.*, 2020).

The environmental temperature at which an animal's body is in equilibrium, meaning it neither gains nor loses heat, is called the "Thermoneutral Zone" (TNZ). To achieve maximum productivity, animals need to be within this range (Rai *et al.*, 2022); when the ET exceeds it, livestock are exposed to HS conditions (Mishra, 2021).

For water buffaloes, the TNZ is between 13.0 and 24°C, with RH between 55 and 65%, and the body temperature of buffaloes ranges from 37.8°C to 38.0°C (Marai and Haebe, 2010). However, when it exceeds 37.5°C to 39°C, physiological and behavioral responses are triggered to restore thermoneutrality and prevent the consequences of HS (Zhang *et al.*, 2020).

To achieve this, they use some physiological and behavioral adjustments that help maintain body temperature, especially when they are outside their TNZ (Pereira *et al.*, 2020). In Trinidad and Tobago, the average skin temperature of the flank and back of Buffalypso females, which gave rise to the Cuban herd, was 34.50±0.23°C and 34.64±0.19°C, respectively (Dunn *et al.*, 2013).

In the livestock context, some indexes were developed to determine the influences resulting from production systems, such as the Temperature-Humidity Index (THI), which represents the intensity of heat load (Kalyan *et al.*, 2022).

Given the anatomical particularities of buffaloes, Umar *et al.* (2021) suggested recalibrating the THI to measure HS. They proposed, according to the physiological, hematological, and biochemical parameters they recorded, the following: THI 68-72 for mild heat stress, THI 73-76 for moderate stress, and THI ≥77 for severe heat stress with extreme alteration of homeostasis. In this regard, Sharmam *et al.* (2024) considered the optimal THI for buffalo well-being to be 74.37.

Not all buffalo breeds exhibit the same adaptive potential; native animals are the most resistant due to their ability to face and maintain productivity in hostile environments. Saravanakumar and Thiagarajan (1992) found that Murrah buffaloes had a lower heat tolerance index (74.52) compared to Surti (76.90) and a non-racial group (82.47), which turned out to be the most tolerant.

In the Philippines, Maylem *et al.* (2023), when analyzing the adaptability of native buffaloes compared to breeds imported from Italy, Brazil, and Bulgaria, observed that during periods of extreme environmental temperatures, native animals showed less physiological variability with a significant difference ($p < 0.001$) in pulse rate but not in rectal temperature ($p > 0.001$). The expression of the HSP70 gene was significantly higher ($p < 0.05$) in imported breeds, so the authors advocated for the participation of native buffaloes as a priority for the genetic improvement of the national herd, aiming to increase production, even though other imported breeds had adapted to the tropical Philippine climate to a lesser extent.

Morphological particularities of buffalo skin

Skin layer and hair

Unlike *Bos taurus* or *Bos indicus* cattle, buffalo skin has characteristics that may represent advantages/disadvantages in certain climates. In this species, there is an intense physiological response to direct solar radiation, and its structure plays a key role in thermoregulation due to the sympathetic nervous system (including thermoreceptors), which perceives and transmits stimuli to the preoptic area (Mota-Rojas *et al.*, 2021a).

The anatomical features of the skin that cause these physiological responses are black color, epidermis thickness, hair density, and a lower number of sweat and sebaceous glands (Bhakat, 2020). Figure 2 shows the main differences in the skin of buffaloes and cattle.

Black skin color: They have a high concentration of melanin in the basal cells of the skin and hair. In Taiwanese water buffaloes, the averages were $0.407 \pm 0.306 \mu\text{g}/\text{mg}$ and $2.734 \pm 2.409 \mu\text{g}/\text{mg}$, respectively, which absorbs heat causing an increase in body temperature (Pi-Hua *et al.*, 2009). Ibrahim and Hussin (2018) stated that melanocytes are larger ($10\text{-}10.5 \mu\text{m} \pm 0.2$) than in cattle ($8\text{-}8.5 \mu\text{m} \pm 0.1$).

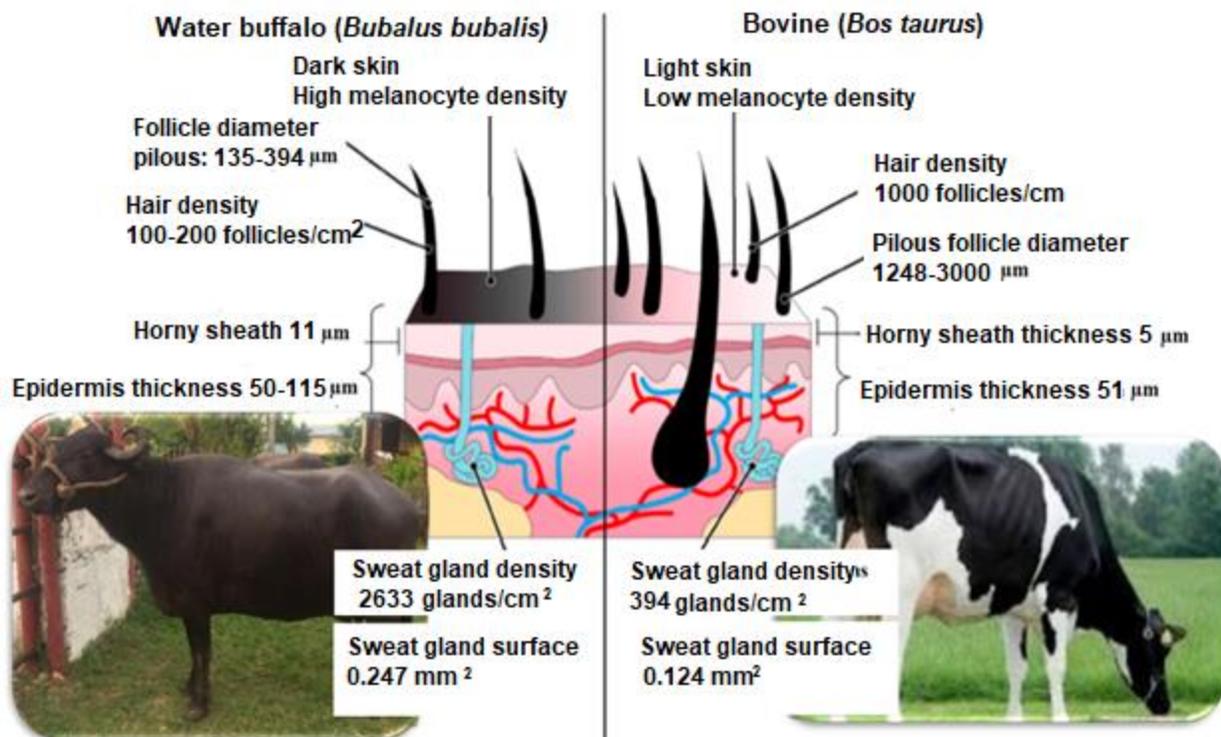


Figure 2. Differences in the structure of buffalo and cattle skin (Mota-Rojas *et al.*, 2023)

In tropical regions, while black skin color protects them by catching ultraviolet rays and preventing them from penetrating through the dermis to deeper tissue layers, it also makes them more

susceptible to HS because dark-colored skin and coat absorb higher concentrations of ultraviolet radiation (Marai and Habeeb, 2010; Bertoni *et al.*, 2019ab).

Skin thickness: In buffaloes, the average skin thickness, main epidermis, papillomatous epidermis, and stratum corneum were 6.5 mm, 50, 115, and 11 μ , respectively, while in cattle, the measurements of these variables were 4.3 mm, 51, and 5 μ in the same order (Hafez *et al.*, 1955). El-Shafey *et al.* (2017) stated that the thickness of the epidermis, papillomatous epidermis, and reticular layers of Egyptian buffaloes were 178.06 μ m, 831.86 μ m, and 3304.9 μ m, respectively. In Murrah females, the skin thickness was 6.03 ± 1.16 mm (Vilela *et al.*, 2022).

Skin thickness is not the same in all buffalo breeds. Saravanakumar and Thiagarajan (1992), in Murrah, Surti, and non-racial buffaloes, stated that it was 8.0740, 8.9185, and 8.6650 mm, while the epidermis measured 144.06, 117.74, and 144.11 μ m, respectively. According to Muralidharan and Ramesh (2005), in Murrah breed animals, the layers of the dermis, papillary and reticular, were larger than in crossbred buffaloes of this breed, measuring 1.18 ± 0.06 mm and 4.91 ± 0.06 mm, compared to 1.15 ± 0.03 mm and 3.74 ± 0.06 mm for crossbred animals.

Number of Hair Follicles, Sparse Hair Coat: Depending on the age, differences were observed in the number of hair follicles per cm^2 of skin, in a five-month-old embryo (10560), a newborn calf (1248), and an adult buffalo (400). Each hair follicle was accompanied by two large lobulated sebaceous glands in buffaloes (Hafez *et al.*, 1955).

Unlike the *Bos* genus, which has approximately 1000 hairs/ cm^2 , water buffaloes have between 100 and 200 hairs/ cm^2 (Upadhyay and Chaiyabutr, 2017). The hair density in Murrah females was 2.0 ± 0.26 mm^2 (Vilela *et al.*, 2022). The average number of hair follicles in buffaloes was 135-145 follicles/ cm^2 , lower than in Zebu animals, where 3000 follicles/ cm^2 were observed. This characteristic facilitates heat dissipation but reduces the reflective hair layer in the epidermis, making them more susceptible to visible and infrared radiation, which is more absorbed and transmitted due to the black color of the epidermis (Mota-Rojas *et al.*, 2021a).

Shafie and Omran (2018) reported that buffalo calves under two different artificial thermal conditions (A: 40°C) and (B: 25°C) had a total number of hairs per cm^2 of 449.50 and 915.00, respectively. This decrease in the number of hairs under HS of 457.5/ cm^2 occurred to easily distribute heat and reduce the higher temperature load.

Accessory Glands

Sweat Glands: Marai and Haeeb (2010) mentioned that buffaloes have a less efficient evaporation mechanism to dissipate heat due to their reduced sweating capacity, making them susceptible to heat stress. To dissipate the received heat and regulate their temperature, they initiate different behavioral responses, such as seeking shade or immersion in water or mud.

The number of sweat glands per cm^2 of skin was 394 in buffaloes and 2633 in cattle, highly correlated with the number of hair follicles (García *et al.*, 2022). For this reason, heat loss through the skin is greater in cows and through respiration in buffaloes (Aggarwal and Upadhyay, 2013).

The dimensions of sweat glands in buffaloes are twice the size of those in cattle (0.247 cm² and 0.124 cm², respectively), possibly compensating for the lack of functional glands (Upadhyay and Chaiyabutr, 2017). The length, circumference, and surface area of these glands in buffaloes were 0.58; 0.47 and 0.276 mm², and in cattle, 0.47; 0.26 and 0.124 mm². The glandular surface area in buffaloes was 1.07 cm² per skin and 3.08 cm² per skin in cattle.

Sweating rate can be modified according to environmental temperature, as demonstrated in a study where Mediterranean buffaloes exposed to HS increased it (control group: 320.18 g/m²/h; heat stress group: 493.13 g/m²/h) (Pereira *et al.*, 2020).

The comparison of the mean number of sweat glands between Murrah, Surti, and non-racial buffaloes provided figures of 254.3; 163.9 and 224.5/cm² of skin area and differed significantly. Raghav *et al.* (2022) reported that they were significantly higher ($p < 0.05$) in buffaloes (123±3.15 µm) and smaller in goats (50.33±2.85 µm). According to Vilela *et al.* (2022), the active tissue of sweat glands in adult Murrah females was 1.57±0.38%.

Sebaceous Glands: Water buffaloes have well-developed sebaceous glands with greater activity than in cattle (Shafie and El-Khair, 1970). The sebum secreted is a fatty substance that emerges on the skin's surface and covers it as a lubricant, making it slippery to water and mud.

In turn, when liquefied during heat, it becomes shinier and radiates many of the sun's rays, causing the elimination of excess heat in buffaloes. Additionally, the product of sebaceous glands, along with the thick and horny upper layer of the skin, prevents the absorption of water and solutes, providing protection to the animals from the possible harmful effects of chemical compounds that may be present in the water (Marai and Habeeb, 2010).

The number of sebaceous glands/mm² was lower in buffaloes (2.47/mm²) than in cattle (5.13/mm²) (Ibrahim and Hussin, 2018) but with a richer supply of blood vessels and capillaries (Shafie and El-Khair, 1970).

Raghav *et al.* (2022) stated that the diameter of sebaceous glands was significantly higher ($p < 0.05$) in buffaloes (109.83±6.14 µm) than in goats (61.16±2.42 µm) and that the number of these glands/mm² was lower in buffaloes (0.76 ±0.05) than in horses (3.10±0.24), while Vilela *et al.* (2022) reported that the active tissue of sebaceous glands in Murrah females was 1.08±0.39%.

Global warming is a current challenge for livestock systems in Cuba and the rest of the world, including buffalo breeding. It is necessary to maintain climatic indicators such as ET, RH, lighting, and ventilation in production units according to each species' characteristics, as it is estimated that 10-30% of animal productivity is determined by the microclimate (Kiktev *et al.*, 2021).

Understanding animal anatomy is a crucial skill that involves comprehending the physiological structure and function of animals used in the food production industry. Skin traits explain why buffaloes need shade, flood zones, puddles, and wetlands as additional preferential thermoregulation mechanisms (Mota-Rojas *et al.*, 2021b). (Mota-Rojas *et al.*, 2021b).

The consensus knowledge in the literature about the impact of HS on this species, based on its anatomical characteristics, will allow understanding the impact of climate change on its thermoregulation processes, as a basis for optimizing its production in Cuba.

CONCLUSIONS

In Cuba, the impact of global warming, the behavior of climatic factors, vulnerability to heat stress due to the species' morphophysiological particularities, and the production systems used—extensive without control and semi-intensive—constitute a challenge for water buffalo breeding.

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AUTHOR CONTRIBUTION STATEMENT

Research conception and design: AMV, ALV, HPE; data analysis and data interpretation: A AMV, ALV, HPE; redaction of the manuscript: AMV, ALV, HPE.

CONFLICT OF INTEREST STATEMENT

The authors state there are no conflicts of interest whatsoever.