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Utilization of air-cooled ventilation to reduce heat stress in Nuami sheep in Saudi Arabia

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Abstract

Tropical and temperate countries experience significant economic losses in summer due to heat stress. It is possible to mitigate thermal stress through advances in environmental management, for instance, better accommodations, improved cooling systems, and improved feeding strategies. We examined the influence of ventilation on Nuami ewes in hot climates to determine their physiological efficiency and thermoregulation. Ten dry, non-cycling Nuami sheep were allocated to two treatments (n=5): The control (C) group was kept at ambient temperature, while the treatment (AC) group was kept at air-cooled temperature. Respiratory rate, rectal temperature, and infrared images of representative body regions were recorded weekly. There was a significant difference in climatic conditions between the two rooms. In comparison to the C group, AC sheep gained weight. Dry matter intake (kg/day) increased, water consumption (l/day) decreased, WI/DMI ratios fell, and respiratory rates fell 1.5 times in AC sheep compared to C sheep. AC group showed lower rectal, rump, and leg temperatures than the C group. Regardless of climate variations, the temperatures of the eyes and belly stayed pretty constant due to their physiological, anatomical, and coat characteristics. Therefore, cooled-air ventilation is the best method to reduce heat stress in livestock in the summer.

Keywords: Heat stress; Sheep; Thermoregulation; Ventilation; Thermography

1. Introduction

Global animal production has increased in the past two decades, particularly in tropical and subtropical regions. By 2050, there is a possibility that global temperatures will rise between 1.88 and 4.08 °C; due to population growth and increased food demand in tropical and subtropical regions [1]. Development countries generated most of this growth due to increased meat and milk production, mainly in semi-arid and arid regions. Increasing consumption of animal products, increasing household gain, and demography contributed to the high demand. Considerable aspects can impact livestock production (accessibility and costs of imports, feed quality, sanitary conditions, etc.). Environmental factors have a significant impact on determining the efficiency of production. It is common for livestock and poultry to experience heat stress during feeding, which negatively impacts their health. Desert and arid regions were affected directly and indirectly by heat stress, such as reduced performance, mortality, and economic output. Several adverse effects of thermal stress have been reported in livestock and poultry, including decreased food intake, slower growth, intestinal disequilibrium, reduced reproduction, immune disturbances, and endocrine dysfunction. Heat stress is caused by several factors, including oxidative stress, hormonal imbalances, cytokine imbalances, apoptosis, autophagy, and altered cellular structures [2]. In addition to the reduction of the metabolic rate and changes in the cardiovascular system, as well as changes to the efficiency of heat loss by latent and sensible pathways (evaporation, conduction, convection, and radiation), behavioral changes, and morphological changes, among others, over the life of the animal [3, 4]. Animals can lose heat through radiation, conduction, convection, and evaporation. Even though humidity is the main driving force behind radiation, convection, conduction, and evaporation are affected mainly by the temperature

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gradient between the animal and its environment [4]. It is also crucial for the efficacy of heat loss to have the body surface area in contact with the environment. With increasing ambient temperature, heat transfer by convective, radiative, and conductive exchanges becomes less efficient due to the reduced temperature variation between the skin and air temperatures needed for heat transfer [4]. Animals live in complex climatic conditions, especially when they are outdoors. The ambient temperature can't be used solely as an indicator of the thermal environment in these situations as weather factors such as solar radiation, relative humidity, and air movement all play a part in determining the environment's thermal state. In scientific terms, it is an index of heat exchange between an animal and its environment, including sensible and latent heat exchanges. It is possible to measure how well animals are able or unable to tolerate acute or chronic hot conditions directly (core, and surface temperatures, respiration rate, panting, and heat output) or indirectly (growth, eggs, and milk), which are indicators of the animals' capability to handle the heat [5, 6, 7].

Animals can evaporate water through their skin and respiratory tract. A first response involves increased respiratory ventilation and, consequently, increased respiratory evaporative heat loss, known as thermal polypnea [8]. As a result of this polypnea, a slower, deeper panting phase (thermal hyperpnea) occurs, characterized by increased alveolar ventilation. During evaporation, heat is lost from the body, resulting in the lungs' minute volume and pulmonary alkalosis in the blood, resulting in moderate to severe dehydration [8]. When heatwaves occur, managing the animals can be critical to their survival. An efficient and cost-effective method of combating climate-related heat stress may be to breed heat tolerance. It is possible to reduce the impact of hot climates using a variety of environmental and technical solutions. In this context, the design of animal facilities must adhere to fundamental and straightforward guidelines (shaped, oriented, thermally sound construction materials, ventilation, opening, etc.). Farm animals may not be relieved of heat stress through environmental treatments if nutrition, disease control, and breeding factors are not optimal. According to Krishnan et al., [9], you can reduce adverse environmental effects on dairy and livestock production by physically modifying the environment or genetically selecting heat-tolerant livestock. For outdoor animals, shade (natural or artificial) is the easiest and most effective means of reducing the heat generated by solar radiation [10]. Those measures that reduce solar radiation or ambient temperatures around the animal should be taken to reduce the possibility of heat stress. It is recommended to build a semi-open, high and well-isolated roof on a well-oriented semi-open building to maximize natural ventilation with extra fans that can be added if natural airflow is insufficient [11].

Saeed et al. [12] report significant improvements in the performance rates of broilers, turkeys, and laying hens when using optimal ventilation. In order to improve the performance of heat-stressed animals, fresh air can be used directly over them. Providing adequate ventilation is a crucial component of controlling the barn's environment. An adequately ventilated environment allows for a fair exchange of fresh air to the external climatic conditions at that particular time and the requirements of any animals housed within it. Using proper ventilation systems will ensure that clean, fresh air is provided to the animals, drafts will be prevented, moisture will be emitted from the stable, and heat will be removed in hot climates, as well as eliminating other issues like odors, dust, airborne pathogens, gas emissions, and dust from animal waste. Generally, fan ventilation cools the animal by removing metabolic heat and replacing it with cooler external air and convection when the air is moved close to the animal.

Nuami sheep are well adapted to subtropical and hot climates. These sheep are considered good walkers and can cover vast distances for food and water. In addition to their ability to endure high temperatures, they can survive, grow, and reproduce under poor diet and disease pressure conditions. Compared with other breeds and commercial lines, local desert breeds exhibit higher heat toleration due to their small size, low production levels, and unique morphological characteristics (e.g., fleece properties, tissue insulation, and special appendages). Indigenous breeds are likely to improve production levels under extreme circumstances (hot climate, insufficient nutritional resources, or poor livestock management). In order to improve performance levels, it is possible to use local breeds with high thermal tolerance to crossbreed them with exotic breeds with unique characteristics [13].

Selecting animals under stress or introducing heat-adapted genes into a breed can improve adaptation to climatic stress that matches current and future market specifications. Consequently, we hypothesize that Nuami sheep housed during heat-stress conditions will benefit from air-cooled ventilation compared to non-cooled ventilation.

2. Material and methods

Ten dry, non-cycling Nuami sheep were randomly allocated to two treatments (n=5): The control (C) group (61.22±2.41 kg) was kept under natural ambient temperature conditions in summer with 33.38±0.24 °C and 15.02±0.02 %, and the air-cooled (AC) group (60.09±3.91 kg) was kept in the air-cooled climatically controlled temperature with (18.32±0.16 °C and 34.22±0.23%), average daily temperature (Ta), and percentage relative humidity, respectively.

Sheep were kept in individual pens (1.5 x 2.0 m) to observe an individual feed and water intake presented ad libitum during the whole experimental period of 21 days conducted at Rief Alomodon Farming Station, Taima, Tabuk Region, Saudi Arabia.

On day 1, wool length averaged 4.5 ± 0.6 cm (mean ± SD) and 5.2 ± 0.8 cm in control and treatment ewes, respectively. Daily, the amount of alpha (Medicago sativa L.) and water consumed by each ewe was directly measured by re-weighing the remaining feed and water with an electronic scale, approximately at the same time in the morning (10:00 h). In order to correct water evaporation, a bucket containing water (10 l) was placed in a nearby area to measure the loss of water by evaporation. Calculating the amount of water consumed by the animals was made by subtracting the evaporated water from the total amount consumed. Throughout the trial, each room's ambient temperature and relative humidity

A respiratory rate (RR) was calculated by measuring flank movement for one minute between 15:00 and 15:30 h daily. Rectal temperature was recorded weekly at 11:00 h to the nearest 0.1 ºC using an electronic digital thermometer and bodyweight. The animals' surface temperature was determined by measuring the infrared radiation by infrared thermography equipment. Several representative body regions (eye, rump, front and rear belly) were selected to evaluate the infrared images of the animal once every week

2.1. Statistical Analysis

The MIXED model procedure of SAS [14] was used to analyze data from the randomized design. We analyzed variance with repeated measures. There were fixed effects for treatment and period and a random effect for the animal in the model. The model consisted of the following:

$$Y_{ijk} = \mu + TP_i + A_j + e_{ijk}$$

Where:
Y_{ijk}: observation value; μ: overall mean;
TP_i: combined treatment and period effect;
A_j: random effect of the animals and
e_{ijk}: random error. An integrated Tukey test detected differences between means with a 5 % significance level. All values are in the form of means ± SE unless otherwise mentioned.

3. Results and discussion

Significant climatic conditions existed between the two experimental rooms (Figure 1), with the average ambient temperature and relative humidity being 33.38± 0.24 °C and 18.32 ± 0.16 °C, and 15.02 ±0.02 and 34.22± 0.23 % for the control (C) and air-cooled (AC) rooms, respectively.

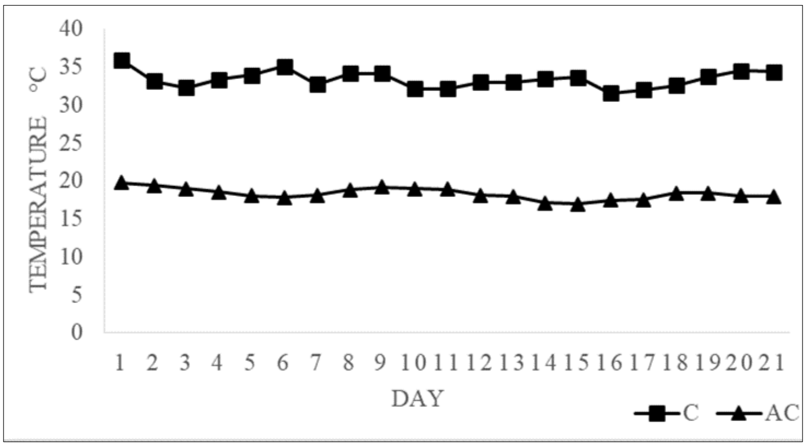

Figure 1 Average daily temperature in control (C) and air-cooled (AC) room during the entire experimental period (21 days).

On average, sheep under air-cooled gained weight during the trial, with (P < 0.001) a treatment X period effect on either initial or final body weight over time, compared to control group sheep that lost body weight with time (Figure 2).

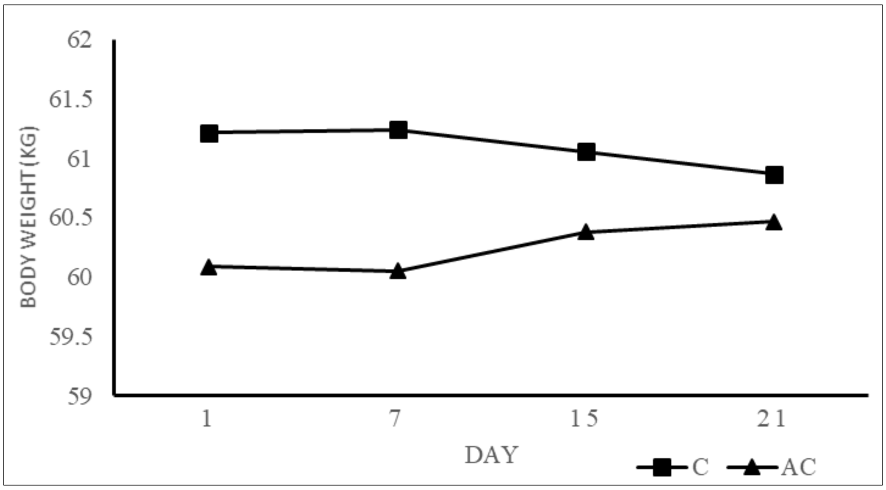

Figure 2 Average body weight (kg) in the control (C) and air-cooled (AC) group during the experimental period on days 1, 7, 15, and 21

This study's several variables were significantly impacted by exposure to heat stress conditions. Throughout the trial, the average daily water consumption in the control group was consistently higher (P<0.001) than in the air-cooled group, either expressed as water drunk per day or relative to the body or metabolic body weight (Table 1). Due to heat stress, animals consumed less daily feed (1.08 vs. 1.15 ± 0.27 kg) in the control and air-cooled groups, respectively.

It was observed that dry matter intake increased (kg/day), lower water consumption (l/day), lower WI/DMI ratios, and 1.5 times lower respiratory rates (37.13 ±0.87 vs. 56.05 ±1.81 N / min) in sheep that had been air-cooled compared with heat-stressed control sheep (Table 1).

Table 1 Average body weight, water drunk, dry matter intake, water intake to dry matter ratio in Nuami sheep in average ambient temperature (control) versus air-cooled group. Values are means ± SE

Trait	Control (C) N=5	Air-cooled (AC) N=5	P-value		
			Trt	Week	Trt*Wk
Body weight (kg)	61.09 ± 0.44	60.25 ± 0.80	0.673	0.887	<0.001
Metabolic body weight (kg$^{-0.75}$)	21.85 ± 0.12	21.62 ± 0.22	0.668	0.884	<0.001
Water drunk (l d^{-1})	3.3 ± 0.10	2.8 ± 0.93	0.327	0.002	<0.001
Water drunk (g kg BW)	54.26 ± 1.60	47.16 ± 1.4	0.360	0.002	<0.001
Water drunk (g kg BM$^{-0.75}$)	151.83 ± 4.51	131.32 ± 4.13	0.348	0.002	<0.001
Dry matter intake (kg d^{-1})	1.08 ± 0.27	1.15 ± 0.27	0.279	0.001	0.737
Dry matter intake (kg BW^{-1})	17.65 ± 0.42	19.05 ± 0.43	0.072	<0.001	0.745
Dry matter intake (g kg BM$^{-0.75}$)	49.37 ± 1.20	53.02 ± 1.21	0.101	<0.001	0.744
WD / DMI*1	3.14 ± 0.09	2.52 ± 0.07	0.040	0.333	<0.001

*1WD/DMI: Water drunk per dry matter intake

Thermoregulation regulates body temperature by balancing heat generation and dissipation through changes in the body's vascular system and sweat evaporation. According to the environment, location, vascularity, and metabolic activity in each part of the body, every part has its temperature range. Table 2 shows significant differences in rectal temperature between the two groups due to the treatment effect (P<0.001) and rump and leg surface temperatures between control and treatment animals. There was a very close correlation between the surface temperatures of the legs and the rump, while the temperatures of the eyes, front and rear bellies remained pretty stable irrespective of climate variations. Over the entire measurement period, there was no discernible difference between treatment groups for eye temperature.

Table 2 Average rectal, eye, rump, front and rear belly in Nuami sheep in average ambient temperature (control) versus air-cooled group. Values are means ± SE

Trait	Control (C) N= 5	Air-cooled (AC) N=5	P-value		
			Trt	Week	Trt*Wk
Rectal Temperature (°C)	39.18 ± 0.08	38.55 ± 0.04b	<0.001	0.846	0.708
Eye Temperature (°C)	33.80 ± 0.22	33.89 ± 0.16	0.748	0.432	0.692
Rump Temperatrure (°C)	29.05 ± 0.31	22.52 ± 0.56	<0.001	<0.001	<0.001
Leg Temperature (°C)	28.62 ± 0.29	26.95 ± 0.44	0.003	0.023	<0.001
Front Belly Temperarture (°C)	33.84 ± 0.24	33.49 ± 0.21	0.256	0.013	0.645
Rear Belly Temperarture (°C)	34.28 ± 0.244	33.64 ± 0.24	0.065	0.006	0.220

[a, b]: values in rows with different letters differ significantly (P≤ 0.05)

The impacts of heat stress on animal productivity are becoming more significant globally. Global warming emphasizes biological mechanisms for controlling cold and heat tolerance in livestock. Food consumption, digestion, and absorption decrease when animals undergo heat stress, providing fewer nutrients for animal maintenance, growth, and reproduction. Additionally, sweating, respiration, and heart rate are influenced, thereby decreasing internal heat production and increasing heat loss. A fat-tailed sheep's superiority is due to its heat tolerance, ability to cope with poor nutrition, and resistance to parasites and diseases. Several factors include differences in body conformation, skull and tail size, skin thickness, subcutaneous fat, and fleece features. The unique characteristics of sheep's fleece are critical in increasing their ability to adapt to harsh environments. Wool serves as a defensive layer and makes water evaporation from the skin more complex, decreasing sweating and heat loss. It has been shown that sheep are less stressed following shearing [5], indicating that wool cover limits sheep's ability to perform in hot conditions. There was a higher surface temperature observed in control groups in this study than on air-cooled ewes, indicating more excellent heat absorption due to higher ambient temperatures. The increased heat in these animals could be transmitted via conduction, convection, radiation, and increased evaporative heat loss that could be used more effectively. According to Maia et al., [15], an animal's thermal regulation requires that its coat surface temperature (Ts) be kept at a relatively constant temperature relative to the environment's temperature (Ta) to minimize heat flow. The color, length, structure, coat structure, and condition of the animal's hair influence the amount of radiant heat absorbed by its coat. Studies have demonstrated that different colored coats are influenced by the sun's radiation, with more heat being absorbed by black areas in strong sunlight than by white areas. In their study, Scharf [16] mentioned that a black coat has an absorbability of roughly 1.00, white fur has an absorbability of 0.37, and red fur has an absorbency of 0.65. Thus, animal surface area characteristics are considered the most critical factor determining overall thermoregulation performance. They are linked to heat load and the temperature range within which thermoregulation is possible.

Heat stress causes animals to sweat and pant; due to the wool coat, sheep sweat less than they evaporate due to respiratory cooling. Nevertheless, sheep can also dissipate heat through insensible perspiration and sweating. As indicated by Avendano-Reyes et al. [17], animals with warm surroundings maintain their body temperature by increasing their body temperature through heat diffusion through their bodies. The study by Piccione and his colleagues [18] concluded that lactating ewes could not maintain their thermal equilibrium under extended exposure to air temperatures exceeding 30 °C.

Temperature measurements with infrared (IR) thermography are noninvasive, noncontact, and non-disturbing methods that do not alter surface temperatures while providing real-time surface temperature distributions.

Using radiation energy emitted from the animal surface provides real-time information and an accurate description of animal temperature patterns [19]. Usually, the amount of Infrared radiation emitted from bare-skinned animals is regulated by the skin surface temperature. Still, for most mammals, the radiation may originate from the skin or the hairs themselves, depending on how well the hair covers the skin [20]. According to Peng et al. [21], body surface temperatures are more sensitive to environmental factors than rectal temperatures.

The respiratory rate has been regarded as a physiological variable particularly sensitive to heat stress. Changes in respiratory rate occur before changes in other physiological variables (rectal temperature, sweating, pulse, or heart rate) during heat stress [22]. In addition to decreasing metabolic rates, heat stress alters the post-absorption metabolism without affecting feed intake, indicating that heat-stressed animals do not prioritize growth, production, reproduction, and health [23]. Silanikove [3] and Todini et al. [24] describe hypothyroidism as reducing thyroid hormone levels, metabolic activity, feed intake, growth, and milk production. Generally, animals exposed to high temperatures should have lower thyroid activity, metabolism, and endogenous heat production. However, this abnormal decline in metabolic processes can negatively affect the product's performance, such as growth and fat deposition [25]. Cortisol levels are elevated in ewes exposed to heat stress and reduced ventilation rates. Cortisol secretion may increase as a result of reductions in immune system functioning.

4. Conclusion

In light of genetic variation within and between breeds, there is no doubt that a selection for heat stress tolerance can occur, even if practical issues have not yet been solved. It is still necessary to conduct further research to predict the impact of heat stress on animal productivity more accurately. Understanding animal responses to thermal challenges is imperative to implement strategies to improve production levels in warm climates successfully. Moreover, much effort has been directed toward identifying genes associated with heat tolerance and stress resistance. It is well known that sheep are among the best heat-resistant farm animals. It has been found that supplying livestock with cooled-air ventilation during the hot season is the most practical method of reducing heat stress. This application improved animals' physiological and welfare responses, including a decrease in body and core temperatures, a reduction in respiration rate, and many others.

Compliance with ethical standards

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Statement of ethical approval

All procedures contributing to this work comply with the ethical standards of the Saudi Animal Welfare committees.

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Author contributions

The investigation, conceptualization, methodology, data analysis, manuscript writing, and editing done by Diya AL-Ramamneh.

Data and model availability statement

All Data are available on request by the Corresponding Author.

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