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Research Article

Thermoregulatory Responses and Physiological Adaptability of Kacang Goats Under Smallholder Farms in the Islands Region of North Maluku, Indonesia

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Abstract | The objective of this study was to evaluate the thermoregulatory responses and physiological adaptability of Kacang goats under smallholder farms in the islands region of North Maluku, Indonesia. Ten does (2-2.5 years-old) were raised in a semi-intensive system and distributed in a completely randomized design with three treatments (morning, midday, and afternoon shift) and 10 replications per treatment. The environmental variables were collected through a digital thermo-hygrometer. The physiological variables such respiratory rate (RR), heart rate (HR), and rectal temperature (RT) were measured. Heat tolerance coefficient (HTC) and adaptability coefficient (AC) were also measured accordingly. The results indicated a significant effect of the day shift ($p<0.05$) on all environmental variables. During the experimental period, the temperature was relatively low in the morning (26.33±0.13°C), peaked at midday (32.45±0.32°C), and remained high in the afternoon (31.19±0.25°C). These temperatures, coupled with high relative humidity levels (averaging between 78.03% and 96.62%) throughout the study period, resulted in temperature-humidity index (THI) values of 78.65±0.22, 85.02±0.49, and 84.91±0.34 units for morning, midday, and afternoon, respectively. The THI values indicated that goats experienced mild stress in the morning and moderate stress both at midday and in the afternoon. There was a significant effect ($p<0.05$) of day shift on all physiological variables, with highest means found in the afternoon shift. The animals increased RR and HR during the day periods to be able to maintain the RT within the normal range for this species, which was confirmed by the HTC and AC tests.

Keywords | Ambient temperature, Goat farming, Physiological parameter, Thermal stress

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INTRODUCTION

Livestock is a significant contributor to Indonesia's agricultural gross domestic product by generating income, providing essential products like meat, milk, eggs, hides, and skins, and supporting livelihoods (Ditjenpkh, 2024). Goat farming plays a vital role in enhancing the family economy, promoting sustainable livelihoods, and reducing poverty in rural households through the income generated from sales. A recent report by Ditjenpkh (2024) indicates that around 15.71 million goats are distributed across 38 provinces in Indonesia. Among the various goat breeds, Kacang goat is recognized as an indigenous livestock breed, mainly kept by farmers for meat production (Fauzy *et al*., 2024). This breed thrives in a variety of agro-ecological conditions, particularly in the eastern part of Indonesia. Goat farming is predominantly conducted by small-scale farmers utilizing a range of production systems, from extensive and semi-extensive to intensive farms (Hariyono and Endrawati, 2023). In North Maluku, which consists of large and small islands in the eastern region of Indonesia, the Kacang goat dominated the population and is traditionally managed by smallholders. The rearing system applied is semi-intensive without offering any concentrate feeds, which has been practiced by breeders for many years.

Animal production is greatly influenced by climate, which is currently undergoing continuous changes. The recent challenges posed by global climate change present a serious threat to the agricultural sector, including goat production in tropical regions like Indonesia. This issue disrupts the physiological balance of the animals, resulting in suboptimal conditions and reduced performance compared to those in more temperate climates (Moula *et al*., 2024). Goats are typically considered to be more adaptable to varying climates compared to other ruminant animals; however, they are still susceptible to the negative impacts of high ambient temperatures. Additionally, breed-specific differences in sweating rates and coat thickness can influence the severity of heat stress experienced by goats (Bhateshwar *et al*., 2023). Elevated ambient temperatures have been proven to negatively impact both the production and reproductive capabilities of goats (Adjassin *et al*., 2022; Danso *et al*., 2024).

Several studies exploring the physiological responses of goats to environmental stress shows that seasonal heat and cold stress have a notable impact on thermoregulatory mechanism, body weight, and physiological parameters (Coloma-García *et al*., 2020; Danso *et al*., 2024). Studies have demonstrated that the key thermo-physiological parameters for assessing animal well-being in harsh environments are rectal temperature, respiratory rate, and blood indices (Araujo *et al*., 2017; Beyleto *et al*., 2022; Coloma-García *et al*., 2020). Hence, it is important to examine the capacity of goats to maintain heat adaptation in challenging environments. Additionally, physiological conditions can serve as a measure for tracking the health of animals (Nagasawa *et al*., 2022). Farmers can use this information to identify and manage physiological disorders or abnormalities in their animals. The health condition of the animals can be assessed through determining their capacity to adapt and tolerate variations in environmental temperature. So far, there has been no research examining the impact of air temperature and humidity changes on the adaptability of Kacang goats under smallholder farms in the islands region of North Maluku. Understanding the physiological response of animals to heat stress is important to select which animals are adaptable to a specific ecology, feed management, housing, and health. Therefore, this study aimed to evaluate the adaptability profile of Kacang goats raised under smallholder farms in the islands region of North Maluku, Indonesia, through changes in their physiological parameters.

MATERIALS AND METHODS

Study sites

The study was conducted in Bangko village, West Halmahera regency, North Maluku province, Indonesia, from April to June 2025. West Halmahera and the North Maluku region had a tropical climate, with temperatures ranging from 23.4 to 31.1°C. The average wind speed was 3.58 km/h, and the average air humidity was 83.92%, with an average sunlight exposure of 83.92%. Thus, as a general indication of tropical conditions, the region was greatly influenced by the maritime climate and had two seasons, namely north west and south east, which were each interspersed with two transitional periods each year.

Animals and experimental design

Ten females from Kacang goat breed, with an average age of 2-2.5 years and initial body weight of 23.12±0.35 kg, were raised in a semi-intensive system and allocated in a completely randomized design involving three treatments (morning, midday, and afternoon shift) with 10 replications per treatment. The goats were housed in a fold solely for data collection. A 15-day pre-experimental period was implemented to facilitate their adaptation to the management and data measurement processes. During the experimental phase, the goats had unrestricted access to graze in the paddock throughout the day and could enter the pen for water as needed. They were kept in pens overnight. The goats were provided with local grasses, as well as legumes such as *Leucaena leucocephala* leaves, *Gliricidia sepium* leaves, and jackfruit leaves, along with drinking water, available ad libitum in the pens. All procedures were approved by the Ethical Clearance Commission of the Faculty of Agriculture, Universitas Khairun (Ethical number 012/KEPH/PH/2025).

Data collection

The physiological variables recorded included respiratory rate (RR), heart rate (HR) and rectal temperature (RT). Observation was conducted in the morning from 06:00 to 07:00 hours, at midday from 11:00 to 12:00 hours, and the afternoon from 17:00 to 18:00 hours, every three days over a two-month period. This schedule was designed to minimize stress experienced by the animals during observation. RR (breaths/min) was determined by monitoring the left flank movements for one minute. HR (beats/min) was recorded using a flexible stethoscope positioned on the left side of the thoracic region. RT (°C) was measured by inserting a veterinary clinical thermometer into the animal's rectum for two minutes.

Relative humidity (RH) and air temperature (AT) were measured simultaneously with physiological status data using a digital thermohygrometer (HTC-2 with precision

1°C and 5% for temperature and humidity, respectively).

Statistical analysis

Data on physiological status were statistically analyzed with mean values presented alongside standard errors in a tabular format. Temperature-humidity index (THI) was calculated as per the formula described by Habeeb *et al.* (2018):

$$THI = (1.8 \times AT + 32) - ((0.55 - 0.0055 \times RH) \times (1.8 \times AT - 26))$$

Where: THI = Temperature humidity index, AT = Air temperature (°C), RH = Relative humidity (%).

Assessment of heat tolerance, which serve as measures of goat's adaptation to the environment were performed using the Ibéria (or Rhoad) test and the Benezra test. The Ibéria test was used to calculate the heat tolerance coefficient (HTC):

$$HTC = 100 - [18 \times (RT - 38.60)]$$

Where: HTC = heat tolerance coefficient, 100 = maximum efficiency in maintaining body temperature at 38.6°C, 18 = constant value, 38.60°C = normal average RT on goats in thermal comfort zone, RT = final RT.

In order to enhance the efficiency of the test in assessing the goat's adaptation, the Benezra test was also used to calculate the adaptability coefficient (AC) as per the following equation (Benezra, 1954):

$$AC = RT / 39.1 \pm RR / 19 \pm HR / 75$$

Where AC was the Benezra test's adaptability coefficient; RT was rectal temperature (°C); RR was respiratory rate (breaths/min); 19 was respiratory on goats; 39.1 was normal rectal temperature in goats; 75 was normal heart rate on goats; and HR was heart rate.

The experiment employed a completely randomized design with three treatments (morning, midday, and afternoon), each repeated 10 times. The data were statistically analyzed using SPSS version 25.0, and the means were compared using the Duncan's multiple range test at the 5% probability level.

RESULTS AND DISCUSSION

Environmental conditions

Comfortable environmental conditions are essential for livestock, as they significantly influence animal health, productivity, and welfare. Table 1 presents the AT, RH, and THI recorded in this study with reference to difference time of recording. The analysis of variance indicated a significant effect of the day shift ($p < 0.05$) on all environmental variables. The AT was relatively low in the morning (26.33±0.13°C), peaked at midday (32.45±0.32°C), and remained high in the afternoon (31.19±0.25°C). These temperatures, coupled with high RH levels (averaging between 78.03% and 96.62%) throughout the study period, resulted in THI values of 78.65±0.22, 85.02±0.49, and 84.91±0.34 units for morning, midday, and afternoon, respectively. Although the average AT remained within the normal range for the Indonesian environment, the results indicated a higher incidence of solar radiation during the midday and afternoon shift, which led to an increase in AT and THI, ultimately resulting in a decrease in RH during this period.

Table 1: Averages and standard error of the means of air temperature, relative humidity, and temperature-humidity index.

Environmental variable	Time of recording		
	Morning (07:00)	Midday (12:00)	Afternoon (17:00)
Air temperature	26.33±0.13^c	32.45±0.32^a	31.19±0.25^b
Relative humidity	96.83±0.50^a	78.03±1.55^c	86.73±1.28^b
THI	78.65±0.22^b	85.02±0.49^a	84.91±0.34^a

^{a,b,c} Means in the same row with different superscripts are significantly different ($p < 0.05$), THI: temperature-humidity index (THI).

Animals typically express their potential production most effectively under their thermoneutral zone. To assess whether the goats were under thermoneutral zone or under heat stress, we used the model proposed by Armstrong (1994). In this model, a THI of less than 72 indicates no stress, 72–78 indicates mild stress, 79–88 indicates moderate stress, and 89–98 indicates severe stress. According to the classification, goats in the present study experienced mild stress in the morning and moderate stress both in the midday and afternoon. This was due to the elevated AT and RH, leading to discomfort that affected their behavior and physiological responses. Animals must adapt to various environmental factors, and extreme changes in these conditions can disrupt homeostasis, resulting in heat or thermal stress (Yadav *et al.*, 2024). Heat stress has been reported to significantly impact goat production and reproduction, especially when temperatures exceed their thermoneutral zone. Consequences of this stress include decreased feed intake, lower growth rates, diminished reproductive performance, and increased susceptibility to diseases (Chen *et al.*, 2021; Mugoti *et al.*, 2025; Oke *et al.*, 2021). Therefore, the integration of trees and the use of artificial shading are essential strategies for mitigating thermal stress in animals managed under semi-extensive conditions.

Physiological status

Understanding the physiological status of livestock is essential in order to detect potential health problems early, optimize feeding strategies, and make informed decisions about breeding and management practices. Table 2 presents the variations in basic physiological variables [RR (breaths/min), HR (beats/min), and RT (°C)] of goats during the morning, midday, and afternoon. All physiological variables were significantly ($p < 0.05$) higher during midday and afternoon compared to the morning shift.

Table 2: Physiological status of goats recorded during the experiment, at morning, midday, and afternoon

Physiological trait	Time of recording		
	Morning (07:00)	Midday (12:00)	Afternoon (17:00)
Respiratory rate (breaths/min)	21.23±0.21[c]	29.83±0.21[a]	29.13±0.19[b]
Heart rate (beats/min)	93.32±0.50[c]	109.60±1.35[a]	100.64±1.86[b]
Rectal temperature (°C)	38.38±0.06[b]	39.22±0.06[a]	39.08±0.04[a]

[a,b,c] Means in the same row with different superscripts are significantly different ($p < 0.05$).

Respiration rate

The RR serves as an effective indicator of the health status of goats. The typical method of measurement involves counting the number of respiratory cycles per minute based on flank movements (Dißmann *et al*., 2022). In this study, the average RR was 21.23±0.21 breaths/min in the morning, 29.83±0.21 breaths/min at midday, and 29.13±0.19 breaths/min in the afternoon, respectively (Table 2). The normal RR range for goats is approximately 15-30 breaths/min (Sejian *et al*., 2021). Therefore, the average RR observed in this study falls within the normal range. However, the RR values were significantly ($p < 0.05$) higher at midday and in the afternoon compared to the morning shift, which aligned with the findings reported by Beyleto *et al*. (2022) and da Silva Borges and Rocha (2018). This increase in RR likely indicated the animals' effort to regulate their body temperature through enhanced respiratory evaporation.

Respiration is the process of inhalation of oxygen (O_2) and the subsequent elimination of carbon dioxide (CO_2), which is produced during cellular metabolisms. This process also contributes to evaporative moisture loss from the respiratory tract, essential for maintaining thermal balance in animals. It is critical for preventing hypothermia, especially under thermal/heat stress conditions (Shephard and Maloney, 2023). As temperatures exceed the thermal comfort zone for goats, a notable increase in RR indicates their attempt to maintain homeostasis by dissipating heat through evaporative cooling, resulting in increased moisture vaporization into the surrounding environment (Al-Dawood, 2017). Given this physiological adaptive response fails to mitigate the heat load, the goat's body temperature may rise to levels that compromise well-being and productivity (Berihulay *et al*., 2019), primarily due to decreased feed intake and additional energy loss during the heat dissipation process (Danso *et al*., 2024).

Heart rate

The HR is a vital indicator for assessing animal welfare, health status, process efficiency, and environmental impact. In this study, the average HR was recorded at 93.32±0.50 beats/min in the morning, 109.60±1.35 beats/min at midday, and 100.64±1.86 beats/min in the afternoon. The HR range observed was higher than that of male Kacang goats under intensive management condition in Yogyakarta Special Region province (HR= 75.00 – 87.00 beats/min (Suwignyo *et al*., 2018) and under semi-intensive management conditions in East Nusa Tenggara province (HR= 74.17 - 90.89 beats/min) (Beyleto *et al*., 2022). The variation in HR values across studies may be attributed to differences in sunlight exposure received by the animals. In this study, the goats were allowed to graze freely from 9 am to 5 pm, leading to longer grazing periods and higher sunlight exposure, resulting in a higher average HR compared to animals confined in pens.

The HR primarily indicates the homeostasis of the circulatory system (Olshansky *et al*., 2023). HR can change quickly due to external influences such as seasonal changes, time of day, elevated AT, RH, and physical activity (Siquier-Coll *et al*., 2023). Normally, HR for sheep and goats range from 90 to 95 beats/min (Al-Dawood, 2017). However, it increases under thermal stress to facilitate greater heat dissipation through enhanced blood circulation to the body's surface. Yousif (2019) noted that the HR in domestic goats increased with rising heat stress, from 77.06 beats/min in shaded animals to 84.78 beats/min in those exposed to sunlight. This aligned with the findings by Fithron *et al*. (2025), who reported an increase in HR due to heat exposure in goats.

Rectal temperature

RT serves as an indicator of thermal balance and can be used to evaluate the severity of heat stress. In the present study, the average RT recorded was 38.38±0.06°C in the morning, 39.22±0.06°C at midday, and 39.08±0.04°C in the afternoon (Table 2). The RT values were significantly higher ($p < 0.05$) at midday and in the afternoon compared to the morning shift, which aligned with the findings reported by Beyleto *et al.* (2022) and da Silva Borges and Rocha (2018). The normal RT range for goats under thermo-neutral conditions is between 38.3 and 40°C; however, exposure to heat stress (33-38.5°C) substantially increases RT, and surrounding temperatures exceeding 42°C pose a life-threatening risk to goats (Chedid *et al.*, 2014). The RT observed in the goats studied remained within the normal range, despite an increase in RT during the midday and afternoon periods. The rise in RT during these times may be attributed to various factors, including the animal's activity level, environmental temperature and humidity, and sun intensity (Habeeb *et al.*, 2023). An elevation in RT occurs only when the sweating and respiratory evaporation mechanisms are unable to maintain thermal homeostasis in goats (Berihulay *et al.*, 2019).

Heat tolerance coefficient (HTC) and adaptability coefficient (AC)

In this study, the HTC was estimated to measure the adaptability of animals during heat stress. The average HTC values were measured at 103.92±1.13 in the morning, 88.89±1.03 at midday, and 91.29±0.81 in the afternoon, respectively (Figure 1). The HTC values were significantly (p < 0.05) lower at midday and afternoon compared to the morning shift. The findings aligned with those reported by Beyleto *et al.* (2022) in Kacang goats raised in dry-land regions of Indonesia, where HTC values were also lower during midday and afternoon than in the morning. To understand the impact of heat stress on production, it is essential to assess climate effects on animal comfort. Heat tolerance is indicated by HTC values, with higher HTC reflecting greater heat tolerance in animals. This index is complemented by other indices such as the adaptability coefficient (CA) (Benezra, 1954), as an alternative to increase the efficiency of the test in detecting the animals' adaptation. The AC values for goats in this study are presented in Figure 2. A significant variation (p < 0.05) was observed in AC values based on the shift recorded. The AC values noted during the midday (4.03±0.02) and afternoon (3.87±0.03) shifts were greater than those recorded in the morning shift (3.33±0.01).

The AC values observed in this study were slightly higher than those reported by Beyleto *et al.* (2022) for the same breed in the dry-land areas of East Nusa Tenggara province, which recorded AC values of 2.77, 3.66, and 3.66 for morning, midday, and afternoon, respectively. Similarly, the recorded AC values were higher than those for local gotas on Madura Island, Indonesia, which had average AC value of 2.15 (Susilorini *et al.*, 2025). This indicated that the Kacang goats in this study exhibited lower adaptability compared to the same breed in other reports. Conversely, the Kacang goats in this study showed greater adaptability than the Anglo-nubian goats from Brazil, as reported by Araujo *et al.* (2017), with values of 3.40, 3.62, 4.92, and 7.85, for goats raised at AT of 20, 24, 28, and 32°C, respectively.

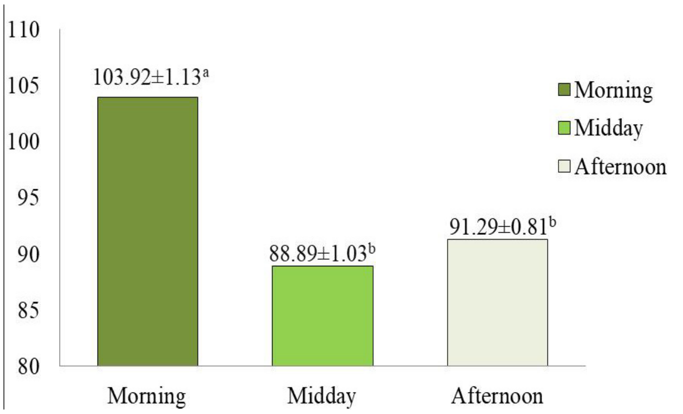

Figure 1: Mean and standard error of the means of heat tolerance coefficient (HTC) in Kacang goats under semi-intensive system. [a,b] Means with different superscripts are significantly different (p <0.05).

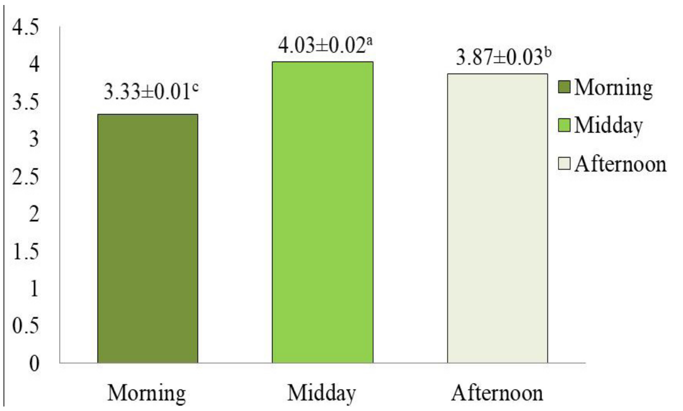

Figure 2: Mean and standard error of the means of Benezra adaptability coefficient (AC) in Kacang goats under semi-intensive system. [a,b,c] Means with different superscripts are significantly different (p <0.05).

The findings of this study revealed an increase in AC values for goats along with the increasing AT, consistent with previous findings (Araujo *et al.*, 2017; Beyleto *et al.*, 2022). The rising AT can lead to increased RR in animals, which serves as an effective mechanism for heat dissipation in environments classified as outside the thermal comfort zone (TCZ). The respiratory system and skin are the main routes for excessive heat dissipation in heat-stressed goats. The first sign of heat stress is an increase in RR, which is the most effective means of heat loss. This ultimately results in improved blood flow from the body's core to the periphery, accompanied by an elevated HR, resulting in greater heat dissipation. RT may increase when excess heat cannot be dissipated, causing a variety of morphological, hematological, and biochemical responses to regulate temperature (Zhou *et al.*, 2023).

CONCLUSIONS AND RECOMMENDATIONS

The THI value in this study indicated that the Kacang goats experienced mild stress in the morning and moderate stress at midday and in the afternoon. Although the animals increased their RR and HR during the day to maintain RT, the values remained within the normal range for this species, which was confirmed by the HTC and AC tests, suggesting a potential adaptation to tropical environments. Therefore, it is recommended that farmers in the study area allow their Kacang goats access to paddocks for feeding and watering throughout the day, while housing them at night under a semi-intensive management system.

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NOVELTY STATEMENTS

The present study employed HTC and AC to investigate the thermoregulatory responses and physiological adaptability of Kacang goats under smallholder farms. The findings offer new insights into the potential adaptation of Kacang goats to the tropical climates, especially in the eastern part of Indonesia where the majority of the farmers practiced the traditional semi-intensive farming system.

AUTHOR'S CONTRIBUTION

MAS designed conceptualization, resources and supervision. DNHH conducted conceptualization and writing original draft. EE performed methodology and reviewed the draft. NS conducted investigation and data analysis.

Data availability statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

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Ethical statement

The study was granted approval by the Ethical Clearance Commission of the Faculty of Agriculture, Universitas Khairun (012/KEPH/PH/2025).

Generative AI and AI-assisted technology statement

The authors confirm that the manuscript was prepared under the authors' responsibility, and any generative AI or AI-assisted tools, if used, were only for language improvement. The authors take full responsibility for the content.

Conflict of interest

The authors have declared no conflict of interest.

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