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Thermal Tolerance of Horned and Polled Bali Cattle to High Ambient Temperature and Exercise Provision

Kirana Dara Dinanti Adiputra
Department of Animal Science, Faculty of Agriculture, Mulawarman University, Samarinda, Indonesia

Sukandi Sukandi
Livestock and Animal Health Service of South Sulawesi Selatan, Makassar, Indonesia

Herry Sonjaya
Department of Animal Production, Faculty of Animal Science, Hasanuddin University, Makassar, Indonesia

Hasbi Hasbi
Department of Animal Production, Faculty of Animal Science, Hasanuddin University, Makassar, Indonesia

Sudirman Baco
Department of Animal Production, Faculty of Animal Science, Hasanuddin University, Makassar, Indonesia

Nurliani Erni
Department of Animal Science, Faculty of Agriculture, Mulawarman University, Samarinda, Indonesia

Address: Jl. Pasir Balengkong, Samarinda, East Kalimantan
Corresponding author: kiranadaradinanti28@gmail.com

Abstract. *This study investigated the heat tolerance of horned and polled Bali cattle under high ambient temperatures and physical exercise using heat tolerance index parameters. Eight male Bali cattle (four horned and four polled) were observed in the morning and afternoon after walking exercises under direct sunlight. Measured parameters included the Iberian Heat Tolerance Coefficient (IHTC), Benezra's Coefficient (BC), and panting score (PS). A 2×2 factorial design (cattle type × measurement period) was used, and data were analyzed via two-way ANOVA, followed by Duncan's test for significant interactions (P < 0.05).Results showed no significant differences (P > 0.05) in heat tolerance indices between horned and polled cattle. IHTC (106.15 ± 9.89 vs. 102.40 ± 10.93), BC (2.22 ± 0.35 vs. 2.28 ± 0.39), and PS (0.88 ± 0.83 vs. 1.38 ± 1.06) were comparable, indicating similar physiological responses to heat. However, the measurement period significantly affected (P < 0.05) all parameters. IHTC decreased in the afternoon (96.78 ± 5.56) compared to the morning (114.78 ± 5.22), while BC (2.29 ± 0.76 vs. 1.91 ± 0.77) and PS (1.88 ± 0.64 vs. 0.38 ± 0.52) increased, suggesting cattle experienced heat stress as temperatures rose. significant interaction (P < 0.05) between cattle type and measurement period was observed. Horned cattle had the highest IHTC in the morning (117.70 ± 4.28), while polled cattle had the lowest in the afternoon (92.95 ± 4.25). Polled cattle also had the highest BC (2.64 ± 0.06) and PS (2.25 ± 0.50) in the afternoon, indicating greater heat stress susceptibility. In conclusion, while both types showed similar heat tolerance under normal conditions, polled cattle were more vulnerable to heat stress, particularly after physical exertion in the afternoon.*

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Keywords: *Adaptability, Bali cattle, Heat stress, Polled, Thermal tolerance*

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*Corresponding author, kiranadaradinanti28@gmail.com

INTRODUCTION

Genetic and environmental factors play a crucial role in livestock productivity, with genetic factors contributing approximately 30% and environmental factors accounting for 70%. Additionally, microclimatic conditions—such as temperature, humidity, radiation, and wind speed—significantly influence stress levels in cattle (Herbut et al., 2018; Assatbayeva et al., 2022; Davis et al., 2022; Asmarasari, 2023). Climate change presents one of the most pressing challenges for the global livestock industry (Herbut et al., 2019; Ganaie et al., 2013; Nardone et al., 2010). In many countries, cattle are a primary source of animal protein, supporting both meat and milk production. However, the impact of climate change on the livestock sector is substantial. Morgando et al. (2023) highlight that rising environmental temperatures adversely affect livestock productivity, welfare, and health. Furthermore, these changes pose significant financial risks to global food supply, food security, and the livestock industry as a whole (North et al., 2023; Godden et al., 2021)

Heat stress occurs when an animal's body temperature rises beyond its normal range due to external factors such as high ambient temperature and humidity. In response, animals attempt to maintain thermal homeostasis by activating thermoregulatory mechanisms that regulate heat production and dissipation (Sukandi et al., 2023; Mota-Rojas et al., 2021a; Renaudeau et al., 2012). The ability of an animal to maintain body temperature balance under extreme climatic conditions is referred to as thermal tolerance (Carabaño et al., 2016). This process relies on the animal’s capacity to dissipate metabolically generated heat (Pryce et al., 2022) and involves multiple biological systems, including cellular, morphological, behavioral, and physiological adaptations (Sejian et al., 2018).

Indonesia is home to indigenous cattle breeds, including Bali cattle, which have been domesticated for centuries and play a crucial role in local livelihoods. Bali cattle are known for their adaptability, as they can thrive on low-quality feed and survive in harsh environments (Purwantara et al., 2012; Baco et al., 2020a). They also exhibit strong physiological performance, making them well-suited to Indonesia’s climate (Nussa et al., 2018; Aritonang et al., 2017a; Aritonang et al., 2017b). However, within this breed, there exists a genetic variant of Bali cattle that naturally lacks horns, known as polled Bali cattle. Studies by Algra et al. (2023) and Parés-Casanova & Caballero (2014) suggest that horns, which contain a vascularized bony core covered by keratin, can aid in heat dissipation through vasodilation.

High ambient temperatures have a vasodilatory effect on superficial blood vessels in peripheral structures such as horns, enhancing radiant heat loss and aiding in heat dissipation. Anatomically, cattle horns align with the description of thermoregulatory organs (Knierim et al., 2023; Romanovsky et al., 2018). Evidence from goats indicates that blood circulation in the horns influences brain temperature (Algra et al., 2023). Functionally, horns contribute to heat exchange by retaining or dissipating heat through vasomotor changes in superficial blood vessels, a physiological process that can be visualized and quantified using infrared thermography (Mota-Rojas et al., 2021b). Despite these insights, there has been no scientific research specifically investigating the heat tolerance and adaptive capacity of polled Bali cattle.

Heat tolerance varies among individual animals, making it essential to assess their responses to hot environmental conditions. Several heat tolerance indices have been developed to evaluate livestock resilience to heat stress, including the Iberian Heat Tolerance Coefficient (Rhoad, 1944), Benezra's Coefficient (Benezra, 1954), and Panting Score (Mader et al., 2006). This study aims to compare the heat tolerance of horned and polled Bali cattle under high-temperature conditions and during exercise-induced heat stress. The findings are expected to contribute to improved livestock management strategies and provide a foundation for further research on heat adaptation in Bali cattle.

LITERATURE REVIEW

An animal's thermoregulatory system will perform to release heat in hot conditions to maintain a normal body temperature. The process of thermoregulation allows animals to maintain homeostasis in their body temperature by reacting to specific environmental factors, such as heat or cold, where this process requires considerable energy (Mota-Rojas et al., 2021). Terrien et al. (2011) state that thermoregulation is essential for maintaining homeostasis in mammals, including cattle.

The ability of living organisms to maintain body stability in the face of environmental changes is known as homeostasis. Respiratory, circulatory, excretory, endocrine, and neurological systems all contribute to this mechanism (Terrien et al., 2011; Seixas et al., 2017; Mota-Rojas et al., 2021). Moreover, to minimize the effects of heat stress, physiological, behavioral, and metabolic processes all contribute to the necessary balance of body temperature (Mota-Rojas et al., 2021). According to Renaudeau et al. (2012), thermoregulation is the process of maintaining a stable body temperature by balancing body heat production and loss.

When outside temperatures rise above the thermoneutral zone (TNZ), heat stress occurs. Livestock struggle to release body heat under these conditions, especially when there is slow airflow and high humidity (Rashamol et al., 2018; Wang et al., 2020). This inability demonstrates how poorly animals are able to adapt to or tolerate extreme climates. Collier et al. (2019) state that for animals to survive heat stress, their basal metabolism must increase.

Animals do not require activation of additional systems to regulate their body temperature in the thermal comfort zone, which lies between the lower critical temperature (LCT) and upper critical temperature (UCT). In this state, all available energy can be used for productive processes such as reproduction and production (dos Santos et al., 2021). However, extremely high or low temperatures are potentially lethal and disrupt the biological balance.

Heat tolerance is the resistance of animals to heat in the surrounding environment. The animal's body will respond to stress starting with sensing and sensing the presence of stress. This is followed by the activation of neurophysiological mechanisms to resist and prevent further disturbance. These animal responses can be in the form of behavioural, autonomic nervous system, neuroendocrine, and/or immunological responses (Rahardja & Lestari, 2019).

Bali cattle are one of the livestock species that have high adaptability to the tropical environment. In general, Bali cattle are known to have horns in both males and females. On the other hand, there are hornless (polled) Bali cattle in South Sulawesi. Baco et al. (2020b) stated that the polled variety of Bali cattle was initially identified in the early 1980s in Sidenreng Rappang Regency, where Brahman cross (BX) was used to breed Bali cattle (*Bos sondaicus*). An autosomal dominant inheritance pattern is seen in polled features (Medugorac et al., 2012; Glatzer et al., 2013; Gehrke et al., 2020). Horned and polled Bali cattle do not differ significantly in terms of morphology, body size, or mating behaviour (Zulkharnaim et al., 2017; Zulkharnaim et al., 2020). There are still very few studies that specifically address polled Bali cattle, although many studies have been conducted on Bali cattle in general.

RESEARCH METHODS

Location and Microclimatic Conditions

The study was conducted at a local farm Tanete Riaja Subdistrict, Regency of Barru, South Sulawesi (coordinates 4^{o}29'17 south latitude and 119^{o}38'50 east longitude, 10 meters above sea level) in July, which is one of the dry season months (May–November) in the region. During the study, microclimatic conditions were measured, including ambient temperature, humidity, and the temperature-humidity index (THI).

The recorded microclimatic conditions were as follows:

- Ambient temperature: morning 23.68–24.72°C, afternoon 31.82–33.98°C
- Humidity: morning 91.49–95.01%, afternoon 59.00–76.00%
- Temperature-humidity index (THI): morning 74.12–75.6, afternoon 84.48–85.90

Animals and Management

A total of 8 Bali cattle of cattle were used, consisting 4 horned and 4 polled Bali cattle aged 2.5 - 4.5 years with male sex. The cattle were kept in individual stalls measuring 1 x 1.5 m equipped with feed and water containers. The observations were conducted over four days, with measurements taken from two cattle per day (one horned and one polled) to facilitate data collection.

Measurements were taken twice a day for each animal:

- Morning (06:00–07:00 a.m.): before feeding and any activity.
- Afternoon (12:30–2:00 p.m.): after the cattle exercised by walking in direct sunlight for 5 minutes before measurement.

Parameters Measured

1. Iberian Heat Tolerance Coefficient (IHTC)

The Iberian Heat Tolerance Coefficient (IHTC) can be calculated using the formula from Rhoad (1944) as follows:

$$\mathrm{IHTC} = 100 - 10(\mathrm{Tr} - 101)$$

Description:

IHTC = Iberia Heat Tolerance Coefficient.

Tr = Rectal temperature (^{o}F) was measured in the morning from 6:00 am to 7:00 am and in the afternoon from 12:30 pm to 2:00 pm.

100 = Perfect coefficient value for Tr_1.

10 = Constant

2. *Benezra's Coefficient (BC)*

Benezra's Coefficient (BC) can be calculated based on rectal temperature and respiration frequency using the formula from Benezra (1954) as follows:

$$\mathrm{BC} = \frac{Tr}{38.3} + \frac{Rr}{23}$$

Description:

BC = Benezra's Coefficient

Tr = Rectal temperature (°C) was measured in the morning from 6:00 am to 7:00 am and in the afternoon from 12:30 pm to 2:00 pm.

Rr = Respiration rate (breaths/minute) was measured in the morning from 6:00 am to 7:00 am and in the afternoon from 12:30 pm to 2:00 pm.

3. *Panting Score*

Panting scores were measured during physiological data collection using the approach described by Mader et al. (2006). Each animal was scored according to the panting score criteria observed. The determination of panting score criteria is described in Table 1.

Table 1. Description of Panting Score Determination

Scores	Description
0	Normal respiration
1	Elevated respiration
2	Moderate panting and/or presence of drool or small amount of saliva
3	Heavy open-mouthed panting; saliva usually present
4	Severe open-mouthed panting accompanied by protruding tongue and excessive salivation; usually with neck extended forward

Statistical Analysis

The data on heat tolerance indices were analyzed using a 2 x 2 factorial. The first factor was Bali cattle (horned and polled) and measurement period (morning and afternoon). Then the interaction between Bali cattle and measurement period was followed by Duncan's test. The statistical analysis tool used in this study is IBM Statistics version 25.

RESULTS AND DISCUSSION

Tabel 2. Thermal Tolerance Parameters in Horned and Polled Bali Cattle

	n	IHTC	BC	PS
Overall	16	96.76±5.56	2.25±0.36	1.13±0.96
Bali Cattle				
Horned	8	106.15±9.89	2.22±0.35	0.88±0.83
Polled	8	102.40±10.93	2.28±0.39	1.38±1.06
Measurement Period				
Morning	8	$114.78±5.22^a$	$1.91±0.77^a$	$0.38±0.52^a$
Afternoon	8	$96.78±5.56^b$	$2.29±0.76^b$	$1.88±0.64^b$
Bali Cattle*Measurement Period				
Horned-Morning	4	$117.70±4.28^a$	$1.90±0.08^a$	$0.25±0.50^a$
Horned-Afternoon	4	$100.60±3.89^b$	$2.54±0.05^b$	$1.50±0.58^b$
Polled- Morning	4	$111.85±4.73^a$	$1.92±0.08^a$	$0.50±0.58^a$
Polled- Afternoon	4	$92.95±4.25^c$	$2.64±0.06^c$	$2.25±0.50^b$

Ket: IHTC = Iberian Heat Tolerance Coefficient; BC = Benezra's Coefficient; PS = Panting score
^{a,b,c}Different superscripts indicate significant differences (P < 0.05)

Iberian Heat Tolerance Coefficient (IHTC)

In this study, the IHTC of polled and horned Bali cattle was 102.40±10.93 and 106.15±9.89, respectively. According to statistical analysis, there was no significant difference between the two Bali cattle (P > 0.05), suggesting that their thermal tolerance levels are similar.

Based on the analysis of measurement period parameters, both types of Bali cattle showed lower thermal tolerance ability when exposed to afternoon sunlight and given exercise than in the morning. IHTC in Bali cattle measured during the day was 96.78±5.56, which is below the ideal thermal tolerance coefficient of 100 (Mandal et al, 2018). In contrast, measurements in the morning showed better results with an IHTC of 114.78±5.22, which was significantly higher than that in the afternoon. This decrease may be due to the increase in ambient temperature during the day, which increases the thermal load on Bali cattle, thus reducing the activity of body heat regulation mechanisms. Studies conducted by Kumari et al. (2018) and Tej et al. ((2020) showed that IHTC in summer was lower than heat in winter. Rai et al. (2022) also found in their study that buffalo adaptability was worse in summer than in winter. In addition, providing exercise during the day has the potential to increase the heat load of Bali cattle, which can negatively affect their physiological performance. Irmawanti et al. (2022) stated that providing exercise to cattle exposed to extreme heat can reduce the effectiveness of thermoregulatory mechanisms, and changes in environmental conditions cause heat stress, reduce productivity, and affect animal physiological responses such as increased body temperature, respiratory rate, and heart rate.

The IHTC measurement for each Bali cattle with different measurement times was 117.70±4.28 in the morning and decreased by 100.60±3.89 after being exposed to sunlight in the afternoon and given exercise. Meanwhile, in polled Bali cattle, the measured IHTC value was 111.85±4.73 in the morning and decreased by 92.95±4.25 after being exposed to the sunlight in the afternoon and given exercise. These results indicate that there is a decrease in IHTC values in both types of Bali cattle during the daytime. The decrease in IHTC value indicates the physiological response of Bali cattle to an increase in ambient temperature during the day, which is generally accompanied by higher heat intensity. However, when compared between the two types of Bali cattle, polled Bali cattle showed a deeper decrease in IHTC values than horned Bali cattle. This may be caused by several factors, including the role of horns in assisting heat dissipation or other physiological mechanisms that may be more developed in horned cattle. A study by Algra et al. (2023) on the thermal response of horns in dairy cows revealed that heat stress can affect the vascular system in horns. If temperature conditions are too high or heat stress lasts too long, the blood circulation process in the horn vasculature becomes ineffective, reducing heat dissipation ability.

Benezra's Coefficient (BC)

The study found that polled Bali cattle had a BC value of 2.28±0.39 while horned Bali cattle had a BC value of 2.22±0.35. The two Bali cattle did not differ significantly ($P > 0.05$), according to statistical analysis. This suggests that the way both Bali cattle react to heat endurance is similar.

BC values in both Bali cattle showed an increase and moved away from 2, from 1.91±0.77 to 2.29±0.76, when exposed to direct sunlight and given exercise. This indicates that both Bali cattle were unable to maintain their tolerance to the stressors. Hot environmental conditions combined with the giving of exercise made Bali cattle unable to maintain their heat tolerance. This condition was supported by a study conducted by Prasanna et al. (2022), which found that BC values in summer were higher than in the rainy season and winter. The animal's ability to adapt to hot environmental conditions can be predicted from rectal temperature and respiration rate (Sejian et al., 2018).

BC for horned and polled Bali cattle conducted in the morning and afternoon with exercise showed that horned Bali cattle increased from 1.90±0.08 in the morning to 2.54±0.05 in the afternoon. In contrast, polled Bali cattle showed a higher increase from 1.92±0.09 in the morning to 2.64±0.06 in the afternoon. This higher increase in BC indicates that polled Bali cattle are more susceptible to stress. During the heat of the day, polled Bali cattle have a low tolerance to ambient heat. The study by Irmawanti et al. (2022) showed that there was an increase in BC value during the day (2.11) compared to the morning (1.81) and then decreased again in the afternoon (1.88). Araujo et al. (2017) also reported the results of their research on Aglo-Nubian goats that every increase in ambient temperature, the BC value also increased. The higher the BC value obtained, the lower the heat resistance (Pribadi et al., 2021). Suhendro et al. (2024) also added that the BC value is influenced by genetic and epigenetic factors in each animal.

Panting Score (PS)

PS is a non-invasive observational method that serves as an alternative for assessing livestock responses to hot ambient conditions, both individually and across different types (Idris et al., 2020; Gaughan et al., 2010). A higher PS indicates that cattle are experiencing greater heat stress (Mader et al., 2006). Evaluated visually on a scale from 0 to 4 (Stumpf et al., 2021), PS is considered an easier and more quantifiable measure than respiratory rate, particularly for identifying cattle exposed to extreme heat stress (Tresoldi et al., 2016).

In polled Bali cattle, the average PS was 1.38 ± 1.06, whereas in horned Bali cattle, it was 0.88 ± 0.83. The difference between the two groups was not statistically significant ($P > 0.05$), suggesting that their responses to heat stress were similar. According to Osei-Amponsah et al. (2020), PS is determined by panting intensity, the presence of saliva, an open mouth, and an extended tongue.

In both types of Bali cattle, PS increased significantly in the afternoon compared to the morning ($P < 0.05$). The average PS in the morning was 0.38 ± 0.52, rising to 1.88 ± 0.64 in the afternoon. A higher PS corresponds to greater heat stress experienced by individual or group-housed cattle. The PS scale ranges from 0 to 4, where 0 indicates no stress (normal) and 4 represents severe stress (Mader et al., 2006).

PS is an early indicator of increased heat stress (Nienaber & Hahn, 2007; Marai et al., 2007). A significant increase in PS from morning to afternoon ($P < 0.05$) was observed in cattle, as daytime ambient temperatures exceeded their thermal comfort zone, triggering heat stress. Similarly, Lees et al. (2020) reported a rise in average PS in Brahman, Charolais, and Angus cattle when exposed to heat stress. This increase in PS was positively correlated with respiratory frequency (Marcone et al., 2021), suggesting that PS can serve as a reliable predictor of respiratory rate. Furthermore, managing the micro-environmental conditions around cattle pens such as controlling air temperature, humidity, and solar radiation—can help mitigate the impact of heat stress (Davis et al., 2022; Adrial et al., 2023)

CONCLUSION

Horned and polled Bali cattle exhibit similar levels of heat tolerance under normal environmental conditions. However, when exposed to sunlight during the day and subjected to exercise, polled Bali cattle demonstrate greater susceptibility to heat stress compared to their horned counterparts. Therefore, it is essential to consider environmental conditions and rearing management strategies to minimize heat stress in Bali cattle, particularly in polled individuals.

Further study is recommended to identify genetic markers associated with heat tolerance in Bali cattle, especially the differences between horned and polled individuals. Additionally, investigating variations in sweat gland density, metabolic rate, and the relationship between stress biomarkers—such as cortisol levels—and heat stress responses in horned and polled Bali cattle would be valuable.

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