Infrared Thermography for Non-invasive Temperature Monitoring in Smallholder Beef Farm

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Abstract. Infrared thermography (IRT) can quickly, easily, and non-invasively measure the quantity of radiation that a thing releases. This study aims to find an alternative to rectal temperature measurement in beef cattle by comparing surface temperatures measured by IRT with rectal temperature under different environmental stress index conditions. Body surface temperatures were measured contactless using IRT at ten different regions, including the forehead, eyes, cheeks, muzzle, ears, neck, legs, costae, flank, and rump. A total of five Simmental-cross (SC) and five Limousin-cross (LC) cows, raised on a local farm in Central Lampung regency, were examined twice a day—once in the morning at 07:00 AM, mild environmental stress index) and once in the afternoon at 12:00 PM, severe environmental stress index). The comparison of rectal and surface temperatures between morning and afternoon showed no statistically significant difference in both SC and LC cows. All body surface temperatures were statistically significantly lower than rectal temperature. Among the body regions studied, the eye region exhibits the strongest correlation with rectal temperature, while showing a very weak correlation with the ambient temperature. We conclude that IRT-measured ocular temperature might be an alternative to rectal temperature in beef cattle.

1 Introduction

Infrared thermography (IRT) has developed into a promising technology in beef cattle farming by providing a non-invasive approach to monitoring the health and welfare of beef cattle. IRT employs thermal imaging to detect changes in body surface temperature, which indicate suspect diverse pathophysiological conditions impacting cattle. IRT can be utilized in beef cattle farming for health monitoring, stress evaluation, reproductive management, and enhancement of production [1]. One example of IRT's application is their ability to precisely detect the onset of Bovine respiratory disease complex (BRD) in calves by identifying the respiratory symptoms, allowing fast intervention before the manifestation of clinical symptoms [2]. Besides respiratory diseases, IRT is advantageous for evaluating heat stress

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in cattle which can adversely impact their welfare and productivity by reducing feed intake, diminishing reproduction rates, and increasing disease susceptibility [3]. By monitoring the body surface temperature, farmers can devise measures to alleviate heat stress, particularly in tropical regions with high ambient temperature and humidity. Furthermore, IRT can assist the evaluation of animal welfare in cattle during transportation and handling. The stress response elicited by these activities is marked by an elevation in body temperature as physiological response of high ambient temperature. By employing IRT, farmers can evaluate the animal welfare during transportation and make requisite adjustments to minimize stress.

IRT provides several applications that enhance health, well-being and production in beef cattle farming. Its non-invasive characteristics provide continuous monitoring without inducing stress in the animals, making it a valuable instrument in modern cattle management for both cattle and farmers [4]. Rectal temperature measurement has long been regarded as the definitive method for measuring the core body temperature in cattle. Nonetheless, it exhibits numerous constraints. Firstly, the procedure is invasive and stressful for the animals, potentially resulting in behavioural changes that could impact their overall welfare. Measuring rectal temperature requires handling, which is a stressful process that might induce transient physiological changes, including elevated heart rate and body temperature, which may not accurately represent the actual animal's health condition. Moreover, rectal temperature measurement is impractical for prolonged continuous monitoring, as it requires physical restraint and can only be conducted at designated intervals [5].

Despite its promising capabilities, several gaps limit the application of IRT, including the accurate correlation of surface temperature with rectal temperature and the effectiveness of IRT across various cattle breeds and environmental conditions. Environmental variables, such as ambient temperature, humidity, wind velocity, and the timing of data acquisition, can significantly affect thermal readings from cattle and complicate data interpretation [6]. Comprehending the influence of these factors on IRT readings is crucial for the development of reliable and precise monitoring systems. Moreover, additional research is necessary to assess the applicability of IRT across various cattle breeds and production systems. Incorporating diverse cattle populations and production conditions, including smallholder farms that raise several breeds in uncontrolled environments, into research is important. This study aimed to assess the viability of IRT's application in smallholder farming systems by analysing body surface temperature dynamics across several environmental conditions and breeds and identifying the body regions that correlate with rectal temperature. The findings will provide valuable insights into expanding the IRT applications for various farming conditions.

2 Material and method

2.1 Animals and place of study

The study was conducted from August to December 2023 and involved ten bulls, comprising five Simmental-cross and five Limousin-cross cows. The animals used in this study originated and were managed by the Karnadi Jaya Abadi farmer group members in Karangendah Village, Terbanggi Besar Subdistrict, Lampung Tengah Regency, Lampung Province. The cattle pen is in a lowland area at 32 meters. Cattle selection was conducted randomly based on the following criteria: age between 2 and 3 years, body weight ranging from 450 to 650 kg, verified health through physical examination, and no history of Foot and Mouth Disease (FMD) or Lumpy Skin Disease (LSD) infections. All experimental protocols received approval from the animal ethics committee of the School of Veterinary Medicine and Biomedical Sciences, IPB University (149/KEH/XII/2023).

2.2 Data collection

2.2.1 Microclimate profile

The temperature and humidity within the pens were recorded using the HTC-1 thermohygrometer (OneMed®) positioned inside the pen. The measurements were conducted thrice daily: morning (07.00 AM), afternoon (12.00 PM), and evening (04.00 PM). The temperature humidity index (THI) was calculated using the formula

$$THI = (1.8 \times T + 32) - (0.55 - 0.0055 \times RH) \times (1.8 \times T - 26) \quad (1)$$

where T represents the ambient temperature within the pen (°C) and RH is the relative humidity (%). Environmental stress levels based on THI values are classified as follows: comfort (THI < 68), mild discomfort (68 < THI < 72), discomfort (72 < THI < 75), alert (75 < THI < 79), danger (79 < THI 84) [7].

2.2.2 Temperature measurement of cattle

The rectal and surface temperatures were recorded twice daily: morning (07.00 AM) and afternoon (12.00 PM), corresponding to moderate heat stress (morning) and severe heat stress (afternoon) levels. Rectal temperature was measured by inserting a digital thermometer (ThermoONE®, Indonesia) into the rectum and maintaining it in place until the displayed temperature stabilized, or an audible beep was emitted. Body surface temperature was measured by the infrared thermal camera (FLIR One Pro Thermal Camera, Teldyne FLIR) at ten regions (Figure 1a): ear, eye, neck, muzzle, cheek, forehead, flank, limb, rump, and ribs. These regions were captured individually from each cattle inside the pen. The IRT pictures were captured roughly 1.0 m from each anatomical location. Pictures were analysed with acquisition software (FLIR Tools, FLIR Systems AB, Figure 1b) and unfocussed images were rejected. The adaptability of beef cattle to their environment is measured by calculating their Rhoad heat tolerance coefficient (HTC) using the formula

$$HTC = 100 - 10\,(BT_1 - BT_0) \quad (2)$$

where BT_1 is the body temperature in the afternoon, and BT_0 is the body temperature in the morning .

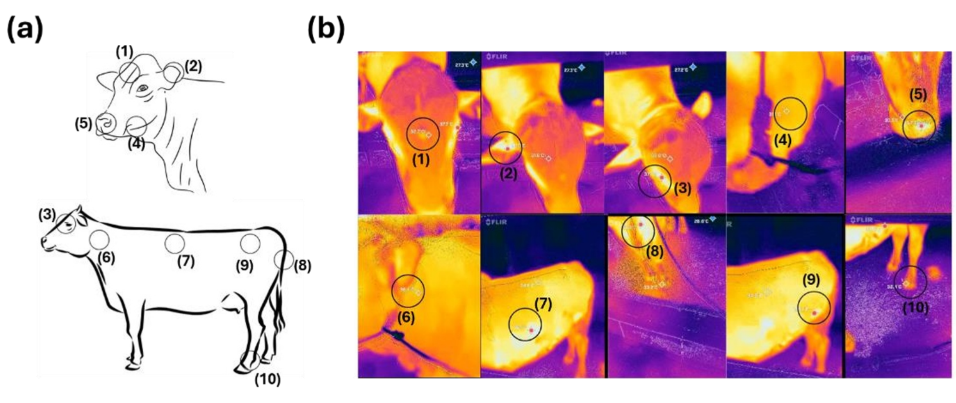

Fig. 1. (a) Illustrative images depicting the anatomical regions from which the IRT images were acquired (b) IRT images of (1) forehead, (2) ear, (3) eye, (4) cheek, (5) muzzle, (6) ear, (7) ribs, (8) rump, (9) flank, and (10) limb.

2.3 Data analysis

Rectal and surface temperature data were compared based on time of collection (morning and afternoon) and cattle breed (Limousin-cross and Simmental-cross) using an unpaired T-test, with $p < 0.05$ being statistically significant. The correlation between the microclimate profile and the cattle temperature and between rectal temperature and surface temperature was measured by the Pearson correlation test. The correlation is categorized as very weak (correlation coefficient/R: 0–0.199), weak (R: 0.2–0.399), moderate (R: 0.4–0.599), strong (R: 0.6–0.799), and very strong (R: 0.8–1).

3 Result and discussion

3.1 Microclimate profile

The ambient temperature within the pen exhibits a statistically significant difference (p<0.05) across morning, afternoon, and evening (Figure 2a). The mean afternoon temperature (34.66±0.75°C) and evening temperature (31.34±0.72°C) exceeded the thermoneutral zone for cattle living in a tropical climate [7]. The afternoon temperature was markedly increased than that of the evening and morning, while the evening temperature was markedly increased than the morning temperature. In contrast, the afternoon humidity was markedly decreased compared to the evening and morning, while the evening humidity was markedly decreased compared to the morning humidity (Figure 2b). The THI value is an essential indicator for assessing the level of heat stress. The THI value (Figure 2c) indicates that cattle experienced severe heat stress (danger) in the afternoon (83.71±1.66) and in the evening (82.47±1.27). In contrast, moderate heat stress (alert) occurred in the morning (78.46±0.67).

Heat stress is when an animal's body temperature exceeds normal levels due to environmental factors, including high ambient temperatures and humidity. As homeothermic animals, cattle regulate their body temperature by enhancing heat dissipation through evaporation and decreasing metabolic rate through behavioural adaptations, such as minimizing eating and rumination times [8]. The thermoregulatory response results in a decrease in feed intake and nutrient absorption efficiency. Consequently, the cattle will reduce chewing duration and saliva secretion, along with diminished rumination and rumen peristalsis [9]. This negative energy balance condition will reduce average daily feed intake and average daily gain, critical indicators for evaluating production performance. Moreover, sustained heat stress may lead to severe consequences, such as increased susceptibility to diseases and reduced reproductive performance. Heat stress also causes metabolic disorders, such as ketosis and acidosis, which further compromise the health and productivity of the cattle [10].

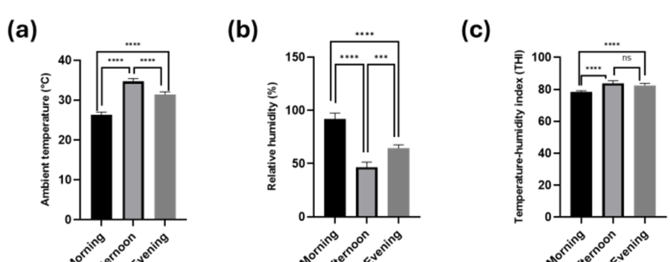

Fig. 2. (a) Average ambient temperature, (b) Average temperature-humidity index within the pen in the morning (07.00 AM), in the afternoon (12.00 PM), and in the evening (04.00 PM) throughout the study period (****: p<0.0001, ns: not significant).

3.2 Temperature measurement of cattle

The comparison of rectal and surface temperature in both Simmental-cross cattle (Figure 3a) and Limousin-cross cattle (Figure 3b) showed no significant differences between morning and afternoon measurements despite their significant differences in ambient temperature and THI values (Figure 2a and 2b). Rectal temperature is commonly utilized as a measure of core body temperature in humans and animals because of its proximity to the core, where metabolic processes predominantly take place. Rectal temperature also strongly correlates closely with core body temperature measured via invasive methods, such as pulmonary artery catheterization [11]. In a hot environment, the heat transfer from the environment to the body by radiation, convection, and conduction is increased. Heat stress will occur in animals when the cumulative heat load surpasses their capacity for heat loss. The initial response to regulate body temperature involves enhancing heat loss to the environment by increasing heart rate, respiration rate, and evaporative cooling, such as painting and sweating [8]. This mechanism results in no significant changes in rectal and surface temperature despite a significant increase in ambient temperature.

The heat tolerance coefficient (HTC) indicates the ability of animals to adapt to a high-temperature environment. The ideal value of HTC is 100, indicating no change of body temperature between the morning and afternoon. The average HTC values for Simmental-cross and Limousin-cross cattle are 89.56±9.38 and 94.60±7.74, respectively (Figure 3c), with no significant difference observed among them. Their value is below the ideal HTC value because of a slight increase in rectal and body temperature between afternoon and morning (Figure 3a and 3b), indicating a moderate level of heat tolerance as they exhibit several physiological responses to maintain the body temperature.

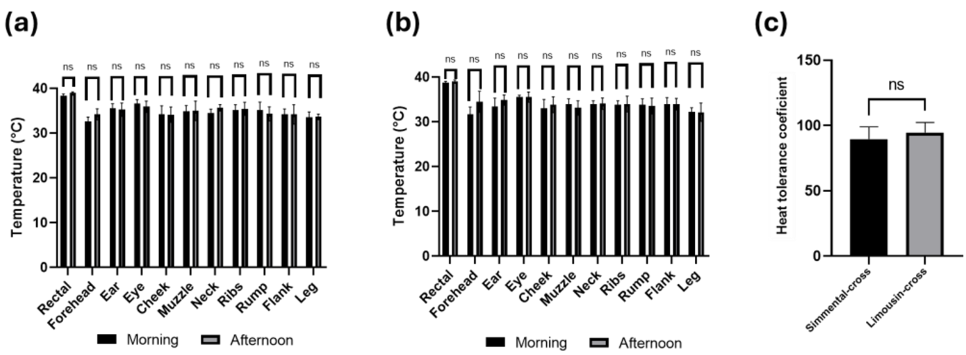

Fig. 3. (a) Comparison of rectal and surface temperatures in Simmental-cross cattle between morning (07.00 AM) and afternoon (12.00 PM), (b) comparison of rectal and surface temperature in Limousin-cross cattle between morning (07.00 AM) and afternoon (12.00 PM), (c) Heat tolerance coefficient in Simmental-cross and Limousin-cross cows, ns: not significant.

While IRT offers several advantages, such as rapid and non-invasive measurement of body temperature, its accuracy is limited by environmental factors, dirt on the skin, and hair thickness [12]. Furthermore, all body surface temperatures remained below rectal temperature during the morning and afternoon (Figure 3a and 3b). In both breeds of cattle breeds, the forehead and foot regions exhibit the lowest mean temperatures due to the thick hair covering the forehead and the accumulation of debris on the surface of the foot region. Conversely, the eye exhibited the highest temperature than other regions and is the only region that has a strong correlation with rectal temperature in both cattle breeds (Table 1). Other regions, such as forehead, muzzle, rump, and leg, also showed a moderate to strong correlation with rectal temperature. However, their result is not consistent in both cattle breeds. This variability is caused by some dirt attached to the skin or the thickness of the hair. Skin temperature varied depending on the number of vascularized blood vessels. With more vascularization to the skin, more metabolic heat is transferred to the skin. The dense hair on the forehead and the dirt on the rump and leg serves as an insulating layer, affecting the thermal conductivity of the skin surface and blocking infrared emission to the thermal camera sensor. The accuracy and validity of IRT measurements are significantly affected by ambient temperature. A previous report showed that the environmental temperature affected the precision and reliability of the infrared measurements obtained from cattle's hooves, with the greatest variability observed at lower ambient temperatures [13]. Moreover, excessive exposure to sunshine may alter the conductivity of IRT measurement due to short-wave reflection.

Table 1. Correlation coefficient of surface temperature with rectal and ambient temperature

Surface temperature	Rectal temperature		Ambient temperature		Relative humidity	
	SC	LC	SC	LC	SC	LC
Forehead	0.684*	0.107	0.110	0.762*	-0,567	-0,555
Ear	-0.137	0.230	0.051	0.598	0,447	-0,535
Eye	0.849**	0.783**	0.118	0.004	0,323	-0,358
Cheek	-0.239	0.284	0.094	0.986**	0,066	-0,124
Muzzle	0.518	-0.021	0.003	0.798*	-0,027	-0,354
Neck	0.230	0.182	0.522	0.141	-0,539	0,343
Ribs	-0.116	-0.040	0.125	0.259	-0,055	-0,238
Rump	0.234	-0.452	0.595	0.221	0,131	-0,0208
Flank	0.391	-0.251	0.030	0.221	0,079	0,202
Leg	0.355	-0.444	0.008	0.005	0,011	-0,037

*P<0.05, **P<0.005
SC: Simmental-cross, LC: Limousin-cross
The correlation is categorized as very weak (correlation coefficient/R: 0–0.199), weak (R: 0.2–0.399), moderate (R: 0.4–0.599), strong (R: 0.6–0.799), and very strong (R: 0.8–1).

The eye is the only area exhibiting a strong correlation with rectal temperature and is not affected by ambient temperature and relative humidity in both cattle breeds (Table 1). The linear regression equation between eye temperature and rectal temperature showed an R^2 of 0.7204 (Figure 4b) in Simmental-cross cows and an R^2 of 0.4920 in Limousin-cross cows (Figure 4b). It means that the 72.04% and 49.20% variation of rectal temperature in Simmental-cross and Limousin-cross cows, respectively, is accounted for from the eye temperature variation. The eye possesses extensive vascularization and is not covered by hair, resulting in a low correlation with the environment. A significant association among eye and rectal temperature was also observed in Angus cross steer, however the accuracy of IRT reading is affected by sunlight and wind speed [14].

IRT offers a promising approach for non-invasive cattle health monitoring, especially in evaluating stress levels and detecting early signs of disease based on febrile response. IRT is capable of detecting changes in eye temperature associated with bovine respiratory disease (BRD) several days before the appearance of clinical symptoms, indicating its potential for early disease detection [2]. Furthermore, the correlation between eye temperature and other physiological parameters, such as respiration rate, has been established, thereby reinforcing the utility of IRT in monitoring animal welfare and stress response [15].

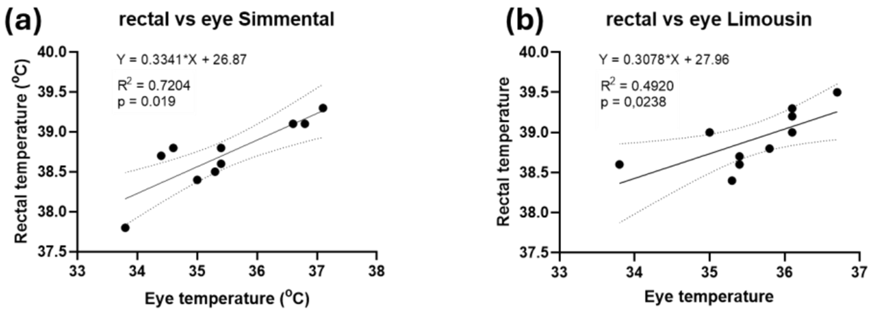

Fig. 4. (a) Relationship of rectal and eye temperature in Simmental-cross cattle using the linear regression equation, (b) Relationship of rectal and eye temperature in Limousin-cross cattle using the linear regression equation

4 Conclusion

Amongst other body regions studied, the eye region exhibits the strongest correlation with a very weak correlation with the ambient temperature, suggesting ocular temperature measured by IRT was capable of substituting rectal temperature in beef cattle.

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