Application of infrared thermography technology for estrus detection in beef cattle raised on smallholder farms

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Abstract. Infrared thermography (IRT) is a non-invasive imaging method used to measure body surface temperature and detect variations in body temperature during physiological and pathological conditions, making IRT a potential tool for estrus detection. This study evaluated the accuracy of IRT in detecting estrus in smallholder beef cattle raised in smallholder farming systems. The measured parameters included environmental parameters (ambient temperature and relative humidity), physiological responses (rectal temperature, pulse rate, and respiration rate), and body surface temperatures in four regions (eye, muzzle, ear, and vulva). Data were collected from eight estrous and eight non-estrus cows of two breeds (Limousin-cross and Simmental-cross). The physiological responses did not differ significantly ($p > 0.05$) between the two breeds. Additionally, although the estrus Limousin-cross cows had higher body surface temperatures at all body regions, no differences were statistically significant ($p > 0.05$). The body surface temperatures of the eye, muzzle, ear, and vulva regions of Simmental-cross cows in estrus were higher ($p<0.05$) than those of non-estrus cows. Weak associations with ambient temperature indicate that the eye and vulva are reliable regions for IRT readings. In summary, IRT is a non-invasive, reliable, and accurate method for detecting estrus in cows.

1 Introduction

Beef cattle are a major source of animal protein in Indonesia and a significant factor in the agricultural economy of the country. According to the National Livestock and Animal Health Statistics (2024), beef production grew by 8.51% in 2024, which does not satisfy the domestic demand [1]. Although the importation of live animals and beef products has gradually reduced in recent years, it still highlights the necessity of better production of beef products in the country. One strategy for increasing the national beef cattle population is improved reproductive management. Among the other assisted reproductive technologies, artificial insemination (AI) is the most affordable and popular, and can enhance the genetics of the

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herd while saving on breeding costs [2]. Nevertheless, proper estrus detection is vital to the success of an AI program because estrus refers to the period of sexual receptiveness in female bovines. In the case of smallholder farmers, the detection of estrus is hindered because it is based on the subjective assessment of cattle behaviour. Previous studies have found that an estimated 50% of Bos indicus and Bos taurus cows are in estrus during the nocturnal hours of 6:00 PM and 6:00 AM, resulting in the failure of farmers to recognize estrus signs [3, 4]. Inaccurate estrus detection may decrease conception rates by 20–30%, reduce calving intervals, decrease reproductive performance, and increase costs due to repeated AI, veterinary treatment, and premature culling. These gaps are the reason why more objective, easier-to-use, and technology-driven estrus detection methods are in great demand [5].

Several technological improvements have been developed to overcome such difficulties and improve the accuracy of estrus detection without involving extra human factors and unnecessary stress. Wrenn *et al.* (1958) first described the changes in body temperature during the estrus cycle. It was found that body temperature during estrus was higher than that during pre-estrus and ovulation, which forms the basis for developing heat-sensing tools for estrus detection [6]. Infrared thermography (IRT) has become a multifunctional instrument in veterinary medicine and is used to detect lameness, postpartum disorders, and mastitis, as well as to monitor welfare, behaviour, and reproductive health [7, 8]. IRT is also a promising alternative for the accurate detection of estrus in cattle, as it is a non-invasive, contactless imaging technique used to detect the heat emissions of the surface and visualize temperature distribution.

The application of IRT in reproductive management should be given serious attention to various factors that can influence the accuracy of measurements, including the animal, environmental conditions, and the operator. Animal factors include colouration on the surface of the skin, hair density, and involuntary movements that are monitored when collecting data. Hairs are also used to provide insulation to the skin surface; hence, they affect the thermal emissivity of the skin [9]. Consequently, the muzzle, ocular area, and vulva are hair-free areas that should be used for thermographic measurements [8]. From an environmental perspective, the ambient temperature and humidity during the observation period are the most important factors, that may affect the accuracy of the IRT measurements. It has been reported that IRT readings are also prone to diurnal fluctuations that can be attributed to meteorological factors such as solar radiation, ambient temperature, and humidity, as well as the physical activity of an animal [10].

Therefore, this study aimed to evaluate the application of IRT in detecting estrus in beef cattle kept in smallholder farms, where technical facilities are limited, and identifying estrus mainly depends on visual inspection. Specifically, it seeks to analyze temperature variations between estrus and non-estrus cows, assess the relationship between environmental factors and body surface temperature, and compare thermal responses among different cattle breeds to determine the accuracy and reliability of IRT as a precise and noninvasive estrus detection tool for resource-limited farming systems.

2 Material and method

2.1 Animal and place of study

The study was conducted from August to December 2023, involving 16 cows (Limousin-cross and Simmental-cross breeds) aged 1.5 to 8 years, weighing 290 to 580 kg, and divided into two groups: estrus and non-estrus. The animals used in this study were owned by members of the Karnadi Jaya Abadi farmer group in the Terbanggi Besar Subdistrict, Lampung Tengah Regency, Lampung Province. All the selected cows were healthy (no clinical symptoms of disease), had regular estrus cycles, and showed estrus behaviours such as frequent vocalization, tail swishing, mounting other cows, and the release of a small amount of thick whitish fluid from the vagina. A field veterinarian validated the health and estrus state of the cows through physical examination and rectal palpation. The Animal Ethics Committee of the School of Veterinary Medicine and Biomedical Sciences, IPB University (No. 149/KEH/XII/2023) approved all the experimental protocols.

2.2 Data collection

2.2.1 Physiological responses measurement of cattle

The physiological responses measured in each cow included the rectal temperature, respiration rate, and pulse rate. Rectal temperature was measured using a digital thermometer (ThermoOne, Indonesia). The thermometer was inserted approximately 5 cm into the rectum for about a minute, until a sound indicated a stable reading. The respiration rate was counted from the flank movements or exhaled air out of the nostrils for one minute. The pulse rate was measured by palpating the coccygeal artery at the tail base.

2.2.2 Infrared thermography measurement of cattle

A FLIR One Pro Thermal Camera (FLIR Systems Inc., USA) was coupled with a Redmi 9T smartphone (Xiaomi, China) to measure the body surface temperature. Thermal images were obtained from four body regions: the eyes, muzzle, ears, and vulva. The camera was positioned 50–100 cm from the body surface. Before image collection, the FLIR One acquisition software (FLIR Systems Inc., USA) was used to calibrate the camera and align the pointer. After the connection, the target area was focused, and the capture function was used to collect and save the thermal images. The obtained thermal images were reviewed in the FLIR One Pro gallery (FLIR Systems Inc., USA) and then clipped to ensure consistency across all thermal measurements [8]. While measuring the body surface temperature, an HTC-1 thermohygrometer (OneMed, Indonesia) was used to measure environmental parameters, including temperature and relative humidity within the barn. During the study, the ambient temperature ranged from 27.1 to 33.5 °C, and the relative humidity varied between 56% and 99%.

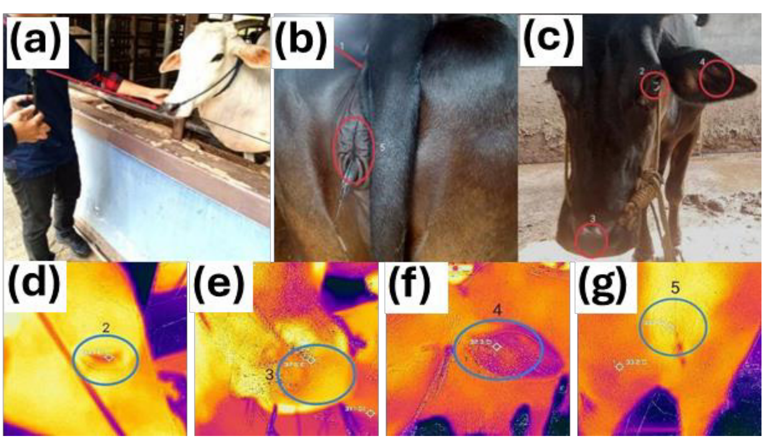

Fig. 1. Distance and body regions for thermal imaging of cattle. (a) Measurement distance used to capture the body surface temperature. (b) Vulva region showing the imaging site for body surface temperature measurement. (c) The head region, including the eyes, muzzle, and ears, was the target area for thermal imaging. (d–g) Thermal images of the eyes, muzzle, ears, and vulva.

2.3 Data analysis

Physiological responses (rectal temperature, pulse rate, and respiration rate) and body surface temperatures (eye, muzzle, ear, and vulva) were compared between estrus and non-estrus cows of Limousin-cross and Simmental-cross breeds using an unpaired t-test in GraphPad Prism version 8 (GraphPad Software, USA). Statistical significance was set at $p < 0.05$. The relationships between environmental parameters and cattle body temperatures, as well as between rectal and surface temperatures, were evaluated using Pearson's correlation test. Correlation strength was categorized as very weak (R = 0–0.199), weak (R = 0.2–0.399), moderate (R = 0.4–0.599), strong (R = 0.6–0.799), or very strong (R = 0.8–1.0).

3 Results and discussion

3.1 Physiological responses

The physiological parameters measured in this study, including rectal temperature, pulse rate, and respiratory rate, are shown in Figures 2A–C. In general, both Limousin-cross and Simmental-cross cows exhibited observable differences between estrus and non-estrus states; however, none of these differences were statistically significant ($p > 0.05$). Both Limousin-cross and Simmental-cross cows showed a slight increase in rectal temperature during estrus, with mean values of 38.26 ± 0.25°C and 38.62 ± 0.62°C, respectively. In non-estrus cows, the mean values were 38.03 ± 0.37°C and 38.16 ± 0.65°C. These slight increase in temperature correspond with hormonal cycles, particularly increases in estrogen and luteinizing hormone (LH), which enhance metabolic activity and blood flow before ovulation [11]. As shown in Figure 2B, the pulse rate tended to increase during estrus, with Limousin-cross cows averaging 96.00 ± 8.00 bpm and Simmental-cross cows averaging 93.60 ± 11.52 bpm, respectively. In non-estrus cows, the averages were 90.67 ± 6.11 bpm and 84.80 ± 8.67 bpm in Limousin-cross and Simmental-cross cows, respectively. This effect could be linked to the vasodilatory and thermogenic effects of estrogen, which increase cardiac output to meet the oxygen and energy needs of the body [9].

As shown in Fig. 2C, the respiration rate was a physiological mechanism for thermoregulation and heat dissipation, although the pattern differed between breeds. Limousin-cross cows had a higher respiration rate during the non-estrus state (40.00 ± 6.93 breaths min^{-1}) than in the estrus state (26.67 ± 6.11 breaths min^{-1}). In contrast, the estrus Simmental-cross cows had a higher respiration rate (42.40 ± 16.40 breaths min^{-1}) than the non-estrus Simmental-cross cows (30.40 ± 8.29 breaths min^{-1}). Such breed-specific differences suggest that there are differences in thermoregulatory responses and metabolic sensitivity to hormonal changes during the estrous cycle. The increased respiration rate observed in estrous Simmental-cross cows indicates a compensatory mechanism for increased metabolic heat production, facilitating heat loss through enhanced evaporative cooling [12]. Although the differences were not statistically significant, these findings suggest that estrus activity is associated with minor physiological changes reflecting hormonal state, metabolic rate, and thermoregulation, consistent with previous reports in beef, dairy cattle, and buffalo [13].

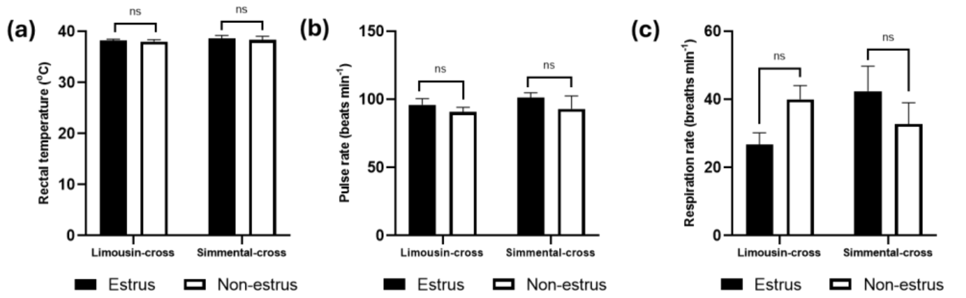

Fig. 2. Physiological parameters of Limousin-cross and Simmental-cross cows during estrus and non-estrus states. (A) Rectal temperature (°C), (B) pulse rate (bpm), and (C) respiration rate (breaths min^{-1}). Error bars represent the standard error of the mean (SEM). No significant differences (ns) were observed ($p > 0.05$).

3.2 Infrared thermography

The body surface temperatures measured at the eyes, muzzle, ears, and vulva of Limousin-cross and Simmental-cross cows are shown in Figures 3A–D. Generally, Estrus cows showed higher surface temperatures than non-estrus cows at all body regions, although the degree of change varied by region and breed. As shown in Figure 3A, the eye temperature increased in both Limousin-cross and Simmental-cross cows, and the difference was statistically significant ($p < 0.05$) only in the Simmental-cross cows. Similar patterns were found in the muzzle region (Figure 3B), where an increased temperature was recorded in estrus cows in both breeds. However, the muzzle showed higher variation owing to exposure to environmental factors, such as moisture, airflow, and surface contamination, which can influence infrared emissivity and reduce measurement accuracy [14]. The area with the greatest difference between both cow breeds was the ear region (Figure 3C), which had a statistically significant increase in temperature ($p < 0.001$) in Simmental-cross cows, but a smaller, though non-significant increase in temperature in Limousin-cross cows. The vulva temperature (Figure 3D) also increased, from 34.33 ± 0.81 °C to 36.10 ± 1.47 °C in Limousin-cross cows, and from 31.54 ± 2.22 °C to 34.64 ± 1.16 °C in Simmental-cross cows ($p < 0.05$). These results are in line with previous research that showed that the rise in surface temperature during estrus is more pronounced in highly vascularized regions, such as the vulva and eyes [9].

Hormonal and circulatory changes are the main factors that can explain the observed increase in surface temperature during estrus in cows. High blood estrogen levels cause vasodilation, which in turn increases peripheral blood flow to the periphery and results in localized hyperaemia in the reproductive and peripheral tissues. This effect is most noticeable in the vulvar area, where vascularization induced by estrogen triggers oedema, swelling, and an increase in surface temperature [13]. Increases in eye and vulva temperatures indicate that systemic thermogenic activities are activated by the endocrine system, especially the fall in progesterone levels and the pre-ovulatory luteinizing hormone (LH) surge. On the other hand, the muzzle area is more sensitive to extrinsic factors such as humidity, feed residue, and respiratory airflow, which could be the reason why the measurements are inconsistent [14]. Breed-related differences are also a source of thermal variability, as Simmental-cross cows exhibited greater changes than Limousin-cross cows, probably because of differences in hair density, skin pigmentation, and thermoregulatory efficiency [15]. Overall, the results support that the use of IRT is a valid non-invasive estrus detection method in beef cattle, with eye and vulva temperature measurements being the best indicators under smallholder farm conditions.

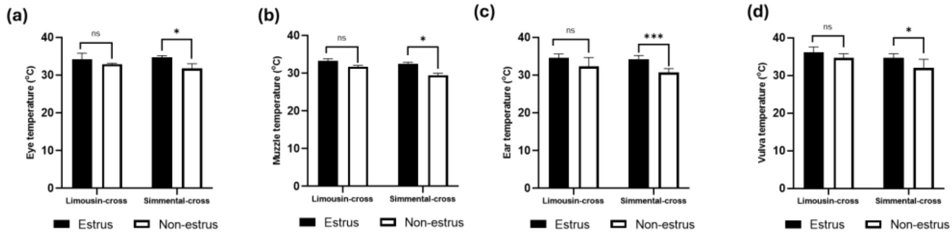

Fig. 3. Body surface temperatures of Limousin-cross and Simmental-cross cows during estrus and non-estrus states. (A) Eyes, (B) muzzle, (C) ears, and (D) vulva. Error bars represent the standard error of the mean (SEM). Asterisks indicate statistically significant differences (*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$).

3.3 Influence of environmental temperature and humidity

The relationship between environmental factors, physiological responses, and surface temperatures of cows in estrus and non-estrus is shown in Table 1. The correlation strength varied across breeds and estrus phases. Overall, ambient temperature was more strongly correlated with the physiological responses of Simmental-cross cows, whereas humidity was more strongly correlated with the physiological responses of Limousin-cross cows. The rectal temperature showed a moderate to strong correlation with ambient temperature in non-estrus cows of both breeds. However, this correlation was weaker in estrus Simmental-cross cows. Conversely, humidity had a strong to very strong correlation with rectal temperature in Limousin-cross cows, indicating that this breed is more responsive to the amount of water vapour in the barn. These findings align with those of a previous study, suggesting that Limousin cattle, despite their partial adaptation to tropical environments, show greater sensitivity to humidity-induced heat stress owing to strong thermoregulatory compensation [12]. The pulse and respiratory rates were moderately affected by humidity, but were not affected by humidity in both cattle breeds. This trend reflects adaptive thermoregulatory responses to greater physiological efforts to dissipate heat through evaporative mechanisms.

Surface temperature correlations also vary according to anatomical site and environmental factors. Muzzle and ear temperatures had a very strong and strong correlation with ambient temperature in Limousin-cross and Simmental-cross breeds, respectively. Conversely, the muzzle and ear temperatures were weakly correlated with humidity in both cattle breeds. The strong correlation between ambient temperature and both muzzle and ear temperatures is associated with the limited insulation and direct exposure of these regions to external air and sunlight. Therefore, temperature measurements in these regions are not as stable as those in more insulated or vascularized body areas, such as the eye and vulva. The correlations of eye and vulva temperatures with ambient temperature in Limousin-cross and Simmental-cross cattle were very weak and weak, respectively. This implies that these areas are likely to be relatively thermally stable under changing environmental conditions and, therefore, would be good targets for using IRT to detect estrus in cows.

In contrast, these areas had very strong and strong correlations with humidity in the Limousin-cross and Simmental-cross breeds, respectively. The data suggest that high levels of water vapour in the barn may block heat loss and increase the temperature on the body surface due to localized tissue heat retention [13]. Therefore, to ensure that IRT measurements are accurate and reliable, barn humidity must be controlled.

Table 1. Correlation of environmental factors (temperature and humidity) with physiological parameters and surface temperatures in Limousin-cross and Simmental-cross cows.

Parameter	Enviromental factor	Limousin-cross		Simmental-cross	
		Estrus	Non-estrus	Estrus	Non-estrus
Rectal temperature	T (°C)	Strong	Very strong	Very weak	Strong
	RH (%)	Strong	Strong	Strong	Strong
Pulse rate	T (°C)	Very weak	Very weak	Very weak	Very weak
	RH (%)	Strong	Strong	Strong	Strong
Respiration rate	T (°C)	Very weak	Very weak	Very weak	Very weak
	RH (%)	Moderate	Moderate	Moderate	Moderate
Eye temperature	T (°C)	Very weak	Very weak	Very weak	Very weak
	RH (%)	Strong	Strong	Strong	Strong
Muzzle temperature	T (°C)	Very strong	Very strong	Very strong	Very strong
	RH (%)	Weak	Weak	Weak	Weak
Ear temperature	T (°C)	Strong	Strong	Strong	Strong
	RH (%)	Weak	Weak	Weak	Weak
Vulva temperature	T (°C)	Weak	Weak	Weak	Weak
	RH (%)	Very strong	Very strong	Very strong	Very strong

Notes:
T: Ambient temperature, RH: Relative humidity
Correlation strength is categorized as very weak (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

4 Conclusion

Eye and vulva temperatures are reliable target areas for IRT measurement and remain stable under fluctuating ambient temperatures compared to other surface temperatures and physiological parameters. Infrared thermography (IRT) is an effective non-invasive method for estrus detection in cows, thereby supporting improved reproductive management and productivity in smallholder beef cattle farms.

The authors express gratitude to the Indonesian Ministry of Education, Research, and Technology for its financial support of this research project via the Matching Fund Program 2023 [Grant number: 18970/IT3.L1/HK.07.00/P/T/2023], and to the Animal Health and Livestock Service in Lampung Tengah District and the Karnadi Jaya Abadi farmers group in Karangendah Village, Lampung Tengah Regency for providing facilities and resources.

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