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AS Rajput
Livestock Production Management Section, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

MM Rafiq
Livestock Production Management Section, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

S Chouksey
Department of Veterinary Gynecology and Obstructers, NDVSU-Jabalpur, Madhya Pradesh, India

Dr. M Bhakat
Scientist, APR Division, ICAR-CIRG, Farah, Makhdoom, Mathura, Uttar Pradesh, India

TK Mohanty
ARGO Division, Artificial Breeding Research Centre, ICAR-National Dairy Research Institute, Karnal, Haryana, India

Corresponding Author:
Dr. M Bhakat
Scientist, APR Division, ICAR-CIRG, Farah, Makhdoom, Mathura, Uttar Pradesh, India

Infrared thermography an alternate supportive tool for Estrus detection in dairy animals: A review

AS Rajput, MM Rafiq, S Chouksey, M Bhakat and TK Mohanty

Abstract
Estrus detection is a significant concern in dairy cattle operations because of the multivariate influences of genetics, environmental, social, and individual factors. The main issue to be considered on a priority basis is the identification of Estrus because inefficient Estrus detection reduces the fertility status of the herd and causes an economic burden. Researchers have explored various Estrus detection techniques and are still studying new methods to improve Estrus detection efficiency. The present review defines the alternate method for Estrus detection by using non-invasive infrared thermography (IRT). During the Estrus, temperature change is a significant phenomenon that is contributed by increased physical activity, and the thermogenic effect of progesterone (P4) secreted during the luteal phase contributed to the rise in body temperature. IRT shows significantly higher temperatures of different body points during Estrus compared to the non-Estrus period. The IRT offers higher sensitivity than visual observation and activity meter. Therefore, IRT can be used as a supportive tool along with visual observation for accurately identifying Estrus in different species.

Keywords: Estrus, IRT, temperature, Estrus cycle

1. Introduction

Dairying is a primary livelihood for most landless or marginal farmers. The dairy farmer must follow scientific practices to make dairying a profitable and sustainable venture leading to improved productivity. India has the largest cattle population in the country (192.49 million), and it has contributed 36.04% to the total livestock population (535.78 million) of the country (Basic Animal Husbandry Statistics-2020-21; http://www.dahd.nic.in/about-us/divisions/statistics). In this vast population, the main issue to be considered on a priority basis is the identification of Estrus because inefficient Estrus detection reduces the fertility status of the herd and causes an economic burden (Kumar *et al*., 2013) [20]. Moreover, the success of artificial insemination (AI) depends on correctly identifying the Estrus. Missing one cycle incurs a loss of Rs 500 to 800 in a lactating cow (Kutty, 2000) and buffalo (Kumar and Mandape, 2005) [19]. It is also reported that improper Estrus detection leads to wrong-time insemination in 11.05% of cattle and 20.75% of buffaloes in India (Suthar and Dhami, 2010) [56]. There are several techniques available for Estrus detection efficiently and accurately in cows, which include visual observation, vaginal mucus resistance, changes in body temperature, and ultrasonography. The change in vaginal temperature during Estrus got the attention of the researchers, and various temperature monitoring sensors have been tried to measure it (Kumar *et al*., 2013) [20]. Invasive methods used for monitoring vaginal temperature cause discomfort and stress by restraining the animal's measuring body temperature higher than the actual. During stress, the hypothalamic-pituitary-adreno-cortical axis gets stimulated, leading to an increase in the concentration of catecholamine and cortisol, which is associated with heat production and loss (Schaefer *et al*., 2002) [47], which could be the reason for the measuring of higher body temperature than actual in invasive methods.

Recently, non-invasive IRT has focused on understanding the temperature-related changes during various physiological and pathological conditions of dairy animals for efficient and timely decisions in dairy animal management (McManus *et al*., 2022) [33]. The non-invasive nature of IRT attracts researchers from various fields to assess conditions where surface temperature change is essential (Hillen *et al*., 2020) [15].

IRT can precisely determine the body surface temperature without causing discomfort to the animals in normal or silent Estrus, thus improving pregnancy rates (Kumar *et al*., 2013) [20]. In the field of animal science, researchers are exploring the use of IRT for various purposes like disease diagnosis in dairy animals (Schaefer *et al*., 2012; Renn *et al*., 2014; Alsaaod *et al*., 2014) [43, 46, 2], body dimensions and weight measurements (Stajnko *et al*., 2008; Stajnko *et al*., 2010) [52, 53], quantification of cattle stress (Stewart *et al*., 2007) [54] and milking process (Kunc *et al*., 2007) [21] as well as identification of Estrus (Talukder *et al*., 2014; Simões *et al*., 2014; Lee *et al*., 2019) [58, 50, 24]. IRT has become an upcoming technology in diagnostics as a supportive tool (Roberto *et al*., 2014). Therefore, the present review focused on using IRT to identify Estrus in dairy animals.

2. Infrared thermography (IRT)

A thermographic camera is a device that generates an image using infrared radiation. Infrared cameras are susceptible to wavelengths from about 1000 nm (1 µm) to 14000 nm (14 µm). Infrared energy contributes to one part of the electromagnetic spectrum, which comprises radiation from lower wavelength to higher wavelength, *i.e*., gamma rays, x-rays, ultraviolet, a thin region of visible light, infrared, terahertz waves, microwaves, and radio waves. An infrared camera is a non-contact and remote temperature measuring tool. Infrared cameras locate the infrared power emitted, transmitted, or contemplated by all substances at a temperature above absolute 0^0 Kelvin and convert the energy factor into a thermogram. The precept of infrared thermography is based on the bodily phenomenon that any frame of a temperature above absolute zero (-273.15 °C) releases electromagnetic radiation. There is a clear correlation between the surface of a frame and the intensity and spectral composition of its emitted radiation. By determining its radiation and intensity, an object's temperature can be defined in a non-contact manner (Speakman and Ward, 1998) [51].

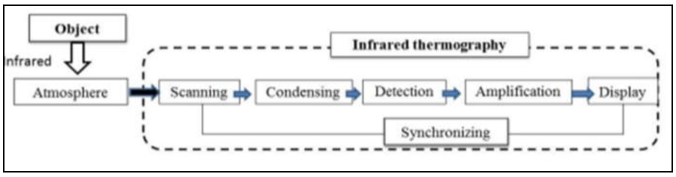

Fig 1: Working Principle of IRT

3. Estrous cycle in dairy animals

The estrous cycle in cattle is 21 days, ranging from 18 to 24 days. The period from one Estrus to the subsequent Estrus completes one estrous cycle (Odde & Holland, 2021) [36]. The four phases of the Estrus cycle are proEstrus, Estrus, metEstrus, and diEstrus. ProEstrus is the phase 1 to 3 days before Estrus (12 to 24 hours), and then metEstrus (3 to 5 days) and diEstrus (12 to 14 days) follow (Adams & Singh, 2021) [1]. In an estrous cycle, several follicular waves occur, and several small follicles develop, but only one follicle becomes the dominant follicle, which ovulates for the release of an egg; with the increase in follicular size, the estrogen from the ovary increases, leading to Estrus and uterine contraction for sperm transport. The estrogen also helps in the secretion of luteinizing hormone (LH) from the pituitary gland in a pulsatile manner. It is responsible for graffian follicle rupture and egg release (Das *et al*., 2023) [9]. Then, the corpus luteum (CL) is formed in the same place as the ovary, where the mature graffian follicle ruptures and starts producing progesterone hormone, responsible for pregnancy maintenance if the cow is conceived. In the normal estrous cycle, the CL starts regressing from day 16 to 18 under the influence of the prostaglandin hormone secreted from the uterus (Das *et al*., 2023) [9].

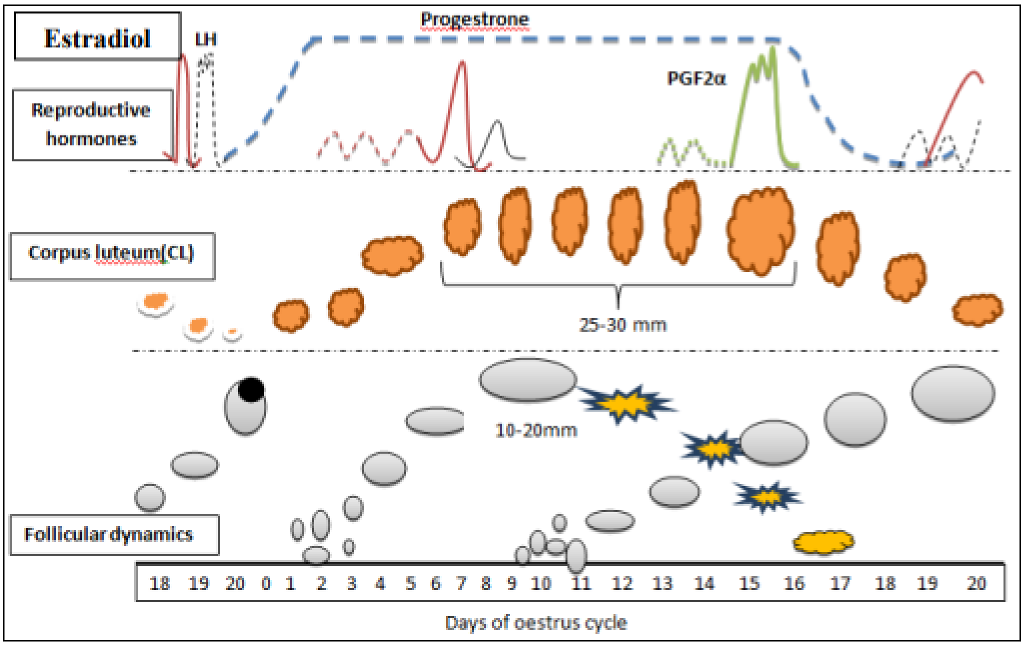

Fig 2: Pattern of Estrus cycle in dairy cattle

4. Temperature changes during various physio-pathological conditions

The temperature of the animal body can be determined using rectal, vaginal, rumen, subcutaneous skin, and ear canal. Dairy cows' body temperature indicates their physiological and health status (Liu *et al*., 2019) [28]. Variation in body surface temperature is associated with local metabolism, blood supply beneath the skin, and heat transfer between the body and the external environment; temperature differences on the skin surface can indicate physiological and pathological conditions. The increase in body surface temperature in animals during heat stress can be assessed using IRT (Stewart *et al*., 2007) [54]. Sexual status and rhythms, especially during Estrus, pregnancy, parturition, and lactation, also influence body temperature (Cooper-Prado *et al*., 2011) [8]. External conditions such as humidity, atmospheric temperature, heat, wind, rain, and air movement significantly affect body temperature (Lowe *et al*., 2019) [29]. During Estrus, the eye, cheek, neck, rump, flank, vulva area, and wither thermogram exhibited higher temperatures at 48 h and 24 h before ovulation than four days before ovulation (Marquez *et al*., 2019) [30]. The vaginal gluteal temperature increased during the pro Estrus, reaching a maximum mean value 24 hours before Estrus, after which it started decreasing markedly to achieve a minimum value 12 hours after Estrus. Moreover, vaccination against Q fever also caused a transient increase in body temperature that peaked in the first 12 to 24 hours and declined after that (Schulze *et al*., 2016) [49].

5. IRT in animal science

Sir William Herschel first discovered infrared in 1800 while exploring new optical materials (Hennessy *et al*., 2020) [14]. Infrared thermography has become multifarious, from industrial application to disease diagnostic of humans and animals (Schaefer *et al*., 2012; Martins *et al*., 2013) [46, 32]. Every region of the animal body radiates different amounts of infrared radiation. IRT images can monitor precise temperature changes over the body surface as the temperature change can be visualized by a shift in colour palates (Kníz˘ková *et al*., 2007) [18]. The change in body surface temperature helped to understand the thermoregulation and seasonal influence on livestock health (Kotrba *et al*., 2007) [18]. The use of noninvasive IRT technology is a recent interest in animal science, and it is explored less with temperature change, which may be an increase or decrease in a particular body surface area due to changes in blood flow to that specific area under various circumstances (Harper, 2000) [13]. Generally, heat is transferred to the affected area's skin in case of inflammation through increased capillary blood flow, which dissipates in the form of infrared radiation. IRT can act as a supportive tool to assess the inflammation associated with various conditions and further open up the avenues of more invasive diagnostic for appropriate therapies. IRT has been successfully used in the diagnosis of septic arthritis of the right metatarsophalangeal joint in Holstein Friesian heifer (Cockroft *et al*., 2000) [7] and bovine viral diarrhoea in calves. Even lameness has been detected based on the coronary band's IRT-based temperature monitoring (Nikkah *et al*., 2005) [35], and suitability of the various textures of the floors for cow resting areas based on the thermodynamic conductivities can also done by IRT (Lendelova *et al*. 2005) [26].

6. Temperature changes during Estrus

The use of a clinical thermometer to monitor temperature has its own set of challenges and drawbacks, including being stressful for the animal and the worker, the risk of zoonotic disease transmission, and the fact that handling can cause an increase in temperature (Schmid *et al*., 2021) [48]. Gradually researchers have used various techniques to assess the temperature change to evaluate multiple conditions to monitor core body temperature by temperature boluses in the reticulum (Bewley *et al*., 2008) [4], transmitters implanted in the abdominal cavity (Brown-Brandl *et al*., 2005) [5], thermistor embedded in the udder (Lefcourt *et al*., 1999) [25] and intravaginal radiotelemetry for Estrus identification (Kyle *et al*., 1998) [23]. Sometimes, using such sensors or transmitters also causes significant animal discomfort. The temperature monitoring of the skin, body, vagina, and milk was recorded to predict Estrus in cattle (Burnett *et al*., 2020). Sexually mature cows also displayed a robust body temperature pattern during Estrus. An increase in core body temperature around 1.3 °C on the day of Estrus was observed every 21 days (Piccione *et al*., 2007) [37]. The higher temperature in the vulva area is attributed to increased circulation and vasodilatation of the region, which results in high concentrations of circulating estrogen during Estrus, causing edema and vulvar hyperemia (Sumiyoshi *et al*., 2014) [55]. During Estrus, the temperature was measured by sensor-based intra-ruminal electronic radio-telemetric bolus, and an increase in the ruminal temperature was recorded (Grohn *et al*., 2000) [12]. The vaginal temperature was lowest on the day before Estrus and had increased by 1 °C on the day of Estrus, changed little during diEstrus, and then declined steadily from day seven until day one before Estrus (Lewis and Newman, 1984) [27]. The core body temperature of animals in Jersey and Shorthorn dairy cows was higher during Estrus (102.3°F) than mid-cycle (101.4 to 101.5° F) (Fallón, 1962). The body temperature reduced and reached a low point two days before the onset of Estrus. On the day of Estrus, the temperature rose very sharply. The body temperature of cows is low during ovulation. It increases gradually after ovulation, and the high temperature on the day of Estrus in cows indicates the increased activity of cows in Estrus (Wrenn *et al*., 1958) [62]. Prediction of Estrus based on vaginal temperature was excellent, and a peak vaginal temperature was observed with a maximum increase in 0.9 ± 0.3 °C with an efficiency of 85.7% during the Estrus caused by increased physical activity (Lewis and Newman, 1984; Walton and King, 1986) [27, 61]. Other studies suggested that the thermogenic effect of progesterone (P4) secreted during the luteal phase contributed to the rise in body temperature (Wrenn *et al*., 1958; Kyle *et al*., 1998) [62, 23]. Rajamahendran *et al*. (1989) [40] and Rajamahendran and Taylor (1991) [40] demonstrated a rise (>1 °C) in vaginal or rectal temperature after induced Estrus by using clinical thermometers. A microprocessor-controlled temperature logger inserted in the vaginal cavity in dairy cows found maximum body temperatures (39.0 ± 0.5 °C) during Estrus (Suther *et al*., 2011) [29]. In contrast, low body temperatures were observed from PGF2α injection to Estrus (38.6 ±0.3 °C) and around ovulation (38.5 ± 0.2 °C), respectively. Redden *et al*. (1993) [42] used transmitters inserted in the vagina of HF cows for monitoring of temperature during Estrus, and they found that an increase in vaginal temperature of 0.6 ± 0.3 °C at Estrus and remained elevated by at least 0.3 °C for 6.8 ± 4.6 h. Therefore, any noninvasive technology or tool that monitors the temperature change in the animals has an added advantage in the welfare and comfort of the animals (Mosher *et al*., 1990) [34].

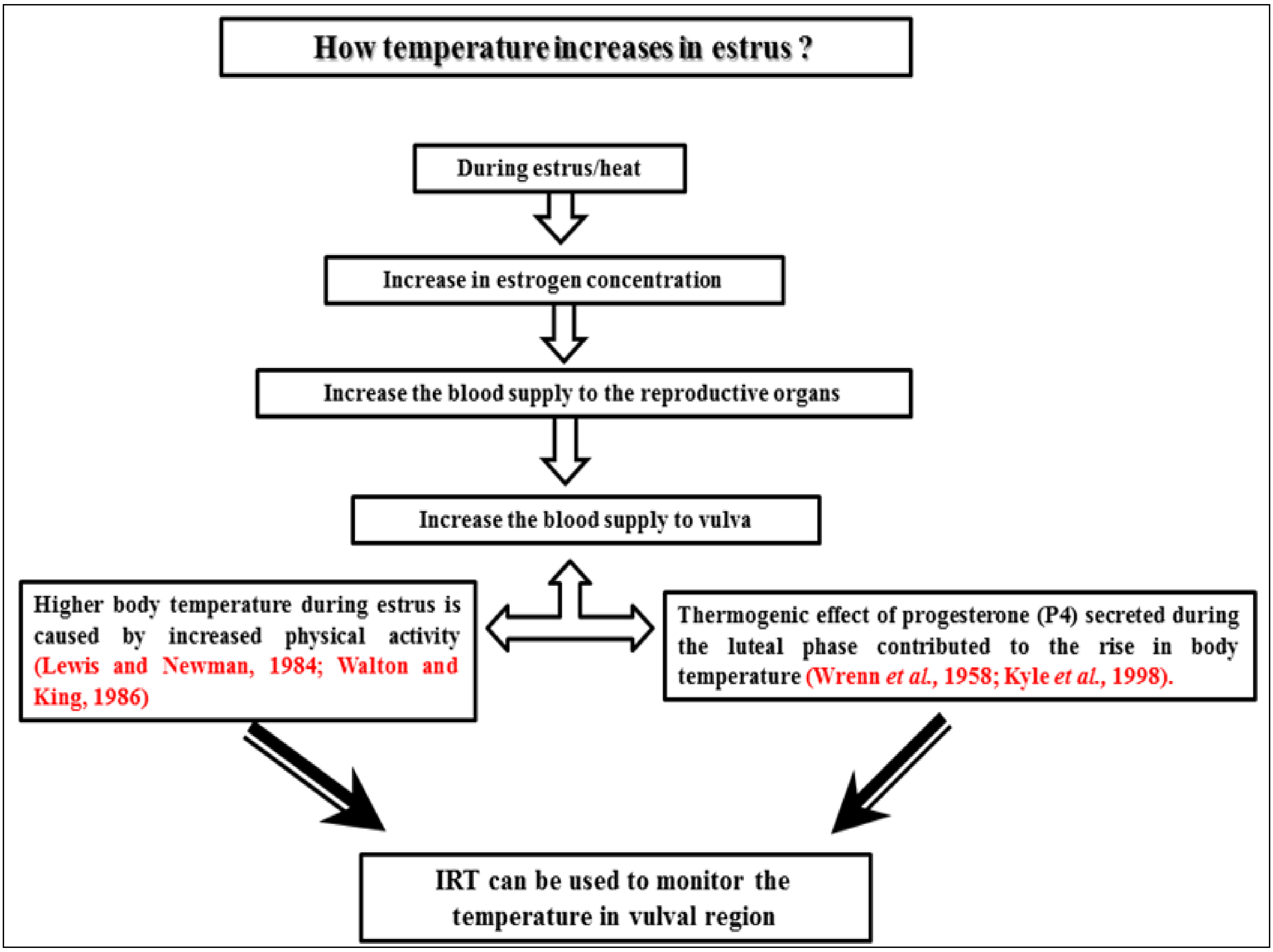

Fig 3: Temperature changes during Estrus

7. IRT for Estrus identification

Temperature change during Estrus and parturition was assessed using a clinical thermometer. IRT is catching the attention of researchers to use as a supportive diagnostic technique where body surface temperature change is quite evident. Estrus detection with higher accuracy and specificity is essential to achieve a higher conception rate for inseminated cows (Hockey, 2010) [16]. The increase and decrease of vaginal and vulvar temperature during Estrus and ovulation were recorded by various researchers (Wrenn *et al*., 1958; Redden *et al*., 1993; Kyle *et al*., 1998) [62, 42, 23]. The use of IRT monitor vulvar, muzzle, and eye temperature in Estrus synchronized cows reported that 73 percent of cows ovulated 24 to 47 hours from the initiation of the IRT Estrus (Talukder *et al*., 2014) [58]. IRT shows higher sensitivity than visual observation (67%) and Estrotect activation (67%). The IRT temperature of the eye, cheek, flanks, vulva region, neck, rump, and wither was also significantly higher 24 to 48 hours before ovulation compared to 4 days before ovulation. Suthar *et al.* (2011) [56] studied body temperature around induced Estrus in dairy cows. They found that higher body temperatures around (39.0 ± 0.5 °C) and low progesterone (P4) concentrations (<0.5 ng/mL) were observed during Estrus. Several studies have been conducted to assess the Estrus using IRT and reported that temperature increase was more common in pigs than cows. In pigs, vaginal gluteal temperature (3.8±1.9 °C) increases 24 hours before Estrus and decreases to a minimum value 12 hours after the Estrus (0.5 ± 1.5 °C) (Simões *et al*., 2014) [50]. Similarly, vulvar skin temperature slightly increases 32 to 24 hours before ovulation and significantly lowers during ovulation in the sow (Saara *et al*., 2011). In sows, higher vulvar temperature was recorded in Estrus compared to the non-Estrus phase (Lee *et al*., 2019; Sykes *et al*., 2012) [57, 24]. In ewes during the estrous cycle, maximum muzzle (35.4±1.0), ear (34.7±1.6), and vulvar surface temperatures (37.1±0.8) reported in Estrus as compared to post-ovulation (de Freitas *et al*., 2018) [10]. Vicentini *et al*. (2020) [60] used the IRT to reveal surface body temperature changes during the proEstrus and Estrus phases in Gyr heifers (Bos Taurus indicus). They found that a decrease in muzzle (29.2±0.57 °C), eye (37.7±0.21 °C), and vulva (36.5±0.24 °C) regions temperature during proEstrus and the higher temperature was recorded in muzzle (30.5±0.25 °C), eye (38.2±0.10 °C) and vulva (37.2±0.20 °C) during Estrus. Tiwari *et al.* (2021) [59] use the IRT differentiation of Estrus and non-Estrus stages of dairy animals, and they observed the significantly higher temperature of the muzzle (34.72±0.21 °C vs. 32.15±0.09 °C) and vulva (39.15±0.15 °C vs. 35.49±0.08 °C) during Estrus as compared to non-Estrus animals. The use of IRT in Sahiwal cows shows significantly higher temperatures of muzzle, eye, ear, and vulva during Estrus compared to the non-Estrus period (Rajput *et al*., 2022) [41]. Various authors have studied temperature change monitoring using IRT for Estrus identification in multiple species, and their observations have been documented in Table 1 below.

Table 1: IRT monitoring of different body points about Estrus in dairy animals.

Breed/Species	body part	Temperature changes during Estrus	References
Sow	Vulva	Increase 3.8±1.9 °C 24 hours before Estrus	Simões *et al*., 2014 [50]
Dairy cow	Vulva	The maximum vulva, muzzle, eye, and ear temperature was found 24 hours before ovulation.	Talukder *et al*., 2014 [58]
Sow	Vulva	Increased by 4 °C	Lee *et al*., 2019 [24]
	Body temperature	Increased by 2 °C	
Dairy cows	Eye, rump, flank, vulva and wither	0.5 °C and 1.20 °C increase in thermo gram at 48 h before ovulation	Marquez *et al*., 2019 [30]
Yorkshire/Landrace crossbred gilts	Vulva surface	A higher vulvar peak (36.6±0.2 °C) was found during Estrus as compared to di Estrus (35.6±0.3 °C)	Sykes *et al*., 2012 [57]
Cows	Vulva	Vulvar temperature showed an increase of 0.9 °C to 1.3 °C on the day of Estrus as compared to before Estrus	Talukder *et al*., 2014 [58]
Ewe	Vulva	The increase in vulvar temperature was 0.6 °C during Estrus	de Freitas *et al*., 2018 [10]
HF	Vulva	Higher vulvar temperature (35.35 ± 0.27 °C) was recorded in Estrus compared to day -5 before ovulation.	Marquaz *et al*., 2021
Gyr heifers (Bos Taurus indicus)	Muzzle, eye and vulva	Muzzle, eye, and vulva temperatures were higher during Estrus than pro Estrus.	Vicentini *et al*., 2020 [60]
Murrah	Muzzle, eye and vulva	Maximum muzzle, eyeball, and vulva temperature found on the day of Estrus as compared to 3 days before Estrus	Ragul, 2020
Sahiwal cow	Muzzle and vulva	Muzzle and vulva temperatures were significantly higher during Estrus than in non-Estrus cows.	Tiwari *et al*., 2021 [59]

8. Conclusion

Estrus detection is still a primary concern related to dairy farming because it causes a significant economic burden. Several methods are available for the accurate identification of Estrus in dairy animals so that they can be bred at the proper time to maintain the fertility status of the herd. Recently, researchers explored the use of non-invasive IRT for identifying Estrus, and they found that during Estrus, dairy animals show higher body temperature, which is contributed by increased physical activity and estradiol concentration. IRT can measure this temperature rise efficiently and help improve the herd's fertility status.

9. Reference

1. Adams GP, Singh J. Ovarian follicular and luteal dynamics in cattle. Bovine reproduction; c2021. p. 292-323.
2. Alsaaod M, Syring C, Dietrich J, Doherr MG, Gujan T, Steiner A. A field trial of infrared thermography as a noninvasive diagnostic tool for early detection of digital dermatitis in dairy cows. The Veterinary Journal. 2014;199(2):281-285.
3. Basic Animal Husbandry Statistics-2020-21. Available from: http://www.dahd.nic.in/about-us/divisions/statistics.
4. Bewley JM, Grott MW, Einstein ME, Schutz MM. Impact of intake water temperatures on reticular temperatures of lactating dairy cows. Journal of Dairy Science. 2008;91(10):3880-3887.
5. Brown-Brandl TM, Eigenberg RA, Nienaber JA, Hahn GL. Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, part 1: Analyses of indicators. Biosystems Engineering. 2005;90(4):451–462.
6. Burnett TA, Kaur M, Polsky L, Cerri RL. Rumen-reticular temperature during Estrus and ovulation using automated activity monitors in dairy cows. Frontiers in Veterinary Science. 2020;7:597512.
7. Cockcroft PD, Henson FM, Parker C. Thermography of a septic metatarsophalangeal joint in a heifer. The Veterinary Record. 2000;146(9):258–260.
8. Cooper-Prado MJ, Long NM, Wright EC, Goad CL, Wettemann RP. Relationship of ruminal temperature with parturition and Estrus of beef cows. Journal of Animal Science. 2011;89(4):1020-1027.
9. Das PK, Mukherjee J, Banerjee D. Female Reproductive Physiology. In Textbook of Veterinary Physiology. Singapore: Springer Nature Singapore; 2023. p. 513-568.
10. de Freitas ACB, Vega WHO, Quirino CR, Junior AB, David CMG, Geraldo AT, Dias AJB. Surface temperature of ewes during estrous cycle measured by infrared thermography. Theriogenology. 2018;119:245-251.
11. Fallon GR. Body temperature and fertilization in the cow. Reproduction. 1962;3(1):116-123.
12. Grohn YT, Rajala-Schultz PJ. Epidemiology of reproductive performance in dairy cows. Animal Reproduction Science. 2000;60:605–614.
13. Harper DL. The value of infrared thermography in the diagnosis and prognosis of injuries in animals. Proceedings of Inframation. 2000;115-122.
14. Hennessy O, Potter SM. Use of infrared thermography for the assessment of free flap perforators in autologous breast reconstruction: A systematic review. Journal of Surgical Reconstruction. 2020;23:60-70.
15. Hillen B, Pfirrmann D, Nägele M, Simon P. Infrared thermography in exercise physiology: the dawning of exercise radiomics. Sports Medicine. 2020;50(2):263-282.
16. Hockey CD, Morton JM, Norman ST, McGowan MR. Evaluation of a neck-mounted 2-hourly activity meter system for detecting cows about to ovulate in two paddock-based Australian dairy herds. Reproduction in Domestic Animals. 2010;45(5):107-117.
17. Knížková I, Kunc P, Gürdil GAK, Pinar Y, Selvi KC. Applications of infrared thermography in animal production. Journal of the Faculty of Agriculture. 2007;22(3):329-336.
18. Kotrba R, Knízˇková I, Kunc P, Bartos L. Comparison between the coat temperature of the eland and dairy cattle by infrared thermography. Journal of Thermal Biology. 2007;32(6):355–359.
19. Kumar H, Mandape MK. Techno-economics of reproductive disorders among bovines in Tarai zone of Uttar Pradesh. In National Seminar on Enterpreneurship Development for livelihood security–experiences,

prospects and strategies for rural India,[IVRI, Izatnagar, 2005, pp: 88].
20. Kumar P, Shankar Rao TK, Kumar N, Chaurasia S, Patel NB. Heat detection techniques in cattle and buffalo. Veterinary World. 2013;6(6):363-369.
21. Kunc P, Knížková I, Přikryl M, Maloun J. Infrared thermography as a tool to study the milking process: a review. Agricultura Tropica et Subtropica. 2007;40(1):29-32.
22. Kutty CI, Ramachandran K. Reproductive performance of crossbred cattle reared by small holders under artificial insemination programme in two districts of Kerala. Proceedings of the International Conference on Small Holder Livestock Production Systems in Developing countries. Kerala. 2000. p. 19.
23. Kyle BL, Kennedy AD, Small JA. Measurement of vaginal temperature by radiotelemetry for the prediction of Estrus in beef cows. Theriogenology. 1998;49(8):1437–1449.
24. Lee JH, Lee DH, Yun W, Oh HJ, An JS, Kim YG, Cho JH. Quantifiable and feasible Estrus detection using the ultrasonic sensor array and digital infrared thermography. Journal of Animal Science and Technology. 2019;61(3):163.
25. Lefcourt AM, Huntington JB, Akers RM, Wood DL, Bitman J. Circadian and ultradian rhythms of body temperature and peripheral concentrations of insulin and nitrogen in lactating dairy cows. Domestic animal endocrinology. 1999;16(1):41-55.
26. Lendelova J, Pogran S, Knizkova I, Kunc P. The influence of top-layer structure quality on thermal properties of dairy cubicle floors. In: Proc., Aktuální otázky bioklimatologie zvířat, Brno, Czech Republic. 2005. p. 48-52.
27. Lewis GS, Newman SK. Changes throughout estrous cycles of variables that might indicate Estrus in dairy cows. Journal of Dairy Science. 1984;67(1):146–152.
28. Liu J, Li L, Chen X, Lu Y, Wang D. Effects of heat stress on body temperature, milk production, and reproduction in dairy cows: A novel idea for monitoring and evaluation of heat stress - a review. Asian-Australasian Journal of Animal Sciences. 2019;32(9):13-32.
29. Lowe GL, Sutherland MA, Waas JR, Schaefer AL, Cox NR, Stewart M. Physiological and behavioral responses as indicators for early disease detection in dairy calves. Journal of Dairy Science. 2019;102(6):5389-5402.
30. Marquez HP, Ambrose DJ, Schaefer AL, Cook NJ, Bench CJ. Infrared thermography and behavioral biometrics associated with Estrus indicators and ovulation in Estrus-synchronized dairy cows housed in tie-stalls. Journal of Dairy Science. 2019;102(5):4427-4440.
31. Marquez HP, Ambrose DJ, Schaefer AL, Cook NJ, Bench CJ. Evaluation of infrared thermography combined with behavioral biometrics for Estrus detection in naturally cycling dairy cows. Animal. 2021;15(7):100-205.
32. Martins RFS, do Prado Paim T, de Abreu Cardoso C, Dallago BSL, de Melo CB, Louvandini H, McManus C. Mastitis detection in sheep by infrared thermography. Research in Veterinary Science. 2013;94(3):722-724.
33. McManus R, Boden LA, Weir W, Viora L, Barker R, Kim Y, Yang S. Thermography for disease detection in livestock: A scoping review. Frontiers in veterinary science. 2022;1163.
34. Mosher MD, Ottobre JS, Haibel GK, Zartman DL. Estrual rise in body temperature in the bovine II. The temporal relationship with ovulation. Animal Reproduction Science. 1990;23(2):99-107.
35. Nikkhah A, Plaizier JC, Einarson MS, Berry RJ, Scott SL, Kennedy AD. Infrared thermography and visual examination of hooves of dairy cows in two stages of lactation. Journal of Dairy Science. 2005;88(8):2749-2753.
36. Odde KG, Holland MD. Synchronization of Estrus in cattle. In: Factors affecting calf crop. CRC Press; 2021. p. 251-262.
37. Piccione G, Caola G, Refinetti R. Annual rhythmicity and maturation of physiological parameters in goats. Research in Veterinary Science. 2007;83(2):239-243.
38. Ragulraj S. Application of infrared thermography for identification of Estrus, calf health and tick infestation in murrah buffalo. Thesis. NDRI, Karnal, Haryana, India; 2020.
39. Rajamahendran R, Taylor C. Follicular dynamics and temporal relationships among body temperature, oEstrus, the surge of luteinizing hormone and ovulation in Holstein heifers treated with norgestomet. Reproduction. 1991;92(2):461-467.
40. Rajamahendran R, Robinson J, Desbottes S, Walton JS. Temporal relationships among Estrus, body temperature, milk yield, progesterone and luteinizing hormone levels, and ovulation in dairy cows. Theriogenology. 1989;31(6):1173-1182.
41. Rajput AS, Bhakat M, Mohanty TK, Baithalu RK, Mir AA, Lal GS, Shah N. Identification of Estrus using infrared thermography in indigenous dairy animals. Pharm Innov J. 2022;1571-1575.
42. Redden KD, Kennedy AD, Ingalls JR, Gilson TL. Detection of Estrus by radio telemetric monitoring of vaginal and ear skin temperature and pedometer measurements of activity. Journal of Dairy Science. 1993;76:713–721.
43. Renn N, Onyango J, McCormick W. Digital infrared thermal imaging and manual lameness scoring as a means for lameness detection in cattle. Veterinary Clinical Science. 2014;2(2):16-23.
44. Roberto JVB, de Souza BB, Furtado DA, Delfino LJB, Marques BDA. Thermal gradients and physiological responses of goats in the Brazilian semi-arid using thermography infrared. Journal of Animal Behaviour and Biometeorology. 2014;2(1):11-19.
45. Saara CS, Clark SG, Knox RV, Tamassia MA. Vulvar Skin Temperature Changes Significantly During Estrous in Swine as Determined by Digital Infrared Thermograph. Journal of Swine Health and Production. 2011;19(3):152.
46. Schaefer AL, Cook NJ, Bench C, Chabot JB, Colyn J, Liu T, Webster JR. The noninvasive and automated detection of bovine respiratory disease onset in receiver calves using infrared thermography. Research in Veterinary Science. 2012;93(2):928-935.
47. Schaefer AL, Matthews LR, Cook NJ, Webster J, Scott SL. Novel noninvasive measures of animal welfare. In: Animal Welfare and Behaviour, from Science to Solution Joint NAWAC/ISAE Conference, Hamilton, New Zealand; c2002.
48. Schmid SM, Büscher W, Steinhoff-Wagner J. Suitability of different thermometers for measuring body core and

skin temperatures in suckling piglets. Animals. 2021;11(4):1004.
49. Schulze LC, Borchardt S, Ouellet V, Heuwieser W. Effect of a phase I Coxiella burnetii inactivated vaccine on body temperature and milk yield in dairy cows. Journal of Dairy Science. 2016;99(1):541-550.
50. Simões VG, Lyazrhi F, Picard-Hagen N, Gayrard V, Martineau GP, Waret-Szkuta A. Variations in the vulvar temperature of sows during proEstrus and Estrus as determined by infrared thermography and its relation to ovulation. Theriogenology. 2014;82(8):1080-1085.
51. Speakman JR, Ward S. Infrared thermography: principles and applications. Zoology-Jena. 1998;101:224-232.
52. Stajnko D, Brus M, Hočevar M. Estimation of bull live weight through thermographically measured body dimensions. Computers and Electronics in Agriculture. 2008;61(2):233-240.
53. Stajnko D, Vindiš P, Janžekovič M, Brus M. Noninvasive estimating of cattle live weight using thermal imaging. New Trends in Technologies: Control, Management, Computational Intelligence and Network Systems. 2010:243-256.
54. Stewart M, Webster JR, Verkerk GA, Schaefer AL, Colyn JJ, Stafford KJ. Noninvasive measurement of stress in dairy cows using infrared thermography. Physiology & Behavior. 2007;92(3):520-525.
55. Sumiyoshi T, Tanaka T, Kamomoae H. Relationships between the appearances and changes of estrous signs and the estradiol-17β peak, luteinizing hormone surge and ovulation during the periovulatory period in lactating dairy cows kept in tie-stalls. Journal of Reproduction and Development. 2014;60(2):106-114.
56. Suthar VS, Burfeind O, Patel JS, Dhami AJ, Heuwieser W. Body temperature around induced Estrus in dairy cows. Journal of Dairy Science. 2011;94(5):2368-2373.
57. Sykes DJ, Couvillion JS, Cromiak A, Bowers S, Schenck E, Crenshaw M, Ryan PL. The use of digital infrared thermal imaging to detect Estrus in gilts. Theriogenology. 2012;78(1):147-152.
58. Talukder S, Kerrisk KL, Ingenhoff L, Thomson PC, Garcia SC, Celi P. Infrared technology for Estrus detection and as a predictor of time of ovulation in dairy cows in a pasture-based system. Theriogenology. 2014;81(7):925-935.
59. Tiwari S, Singh Y, Sirohi R, Yadav B, Singh DN, Gurung A, Shakya P. Infrared thermographical differentiation of Estrus and non-Estrus stages of dairy animals. The Pharma Innovation. 2021;10(4):24-28.
60. Vicentini RR, Montanholi YR, Veroneze R, Oliveira AP, Lima ML, Ujita A, El Faro L. Infrared thermography reveals surface body temperature changes during proEstrus and Estrus reproductive phases in Gyr heifers (Bos taurus indicus). Journal of Thermal Biology. 2020;92:102662.
61. Walton JS, King GJ. Indicators of Estrus in Holstein cows housed in tie stalls. Journal of Dairy Science. 1986;69(11):2966-2973.
62. Wrenn TR, Bitman J, Sykes JF. Body temperature variations in dairy cattle during the estrous cycle and pregnancy. Journal of Dairy Science. 1958;41:1071–1076.