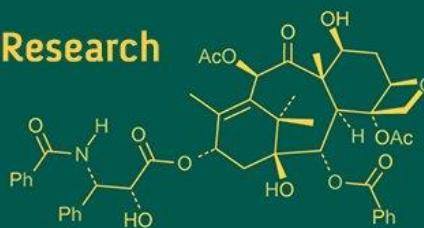


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Role of infrared thermography in animal reproduction

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Abstract

Reproductive efficiency is a backbone of livestock production. Traditional methods for monitoring reproductive status such as rectal palpation are often invasive, labor intensive or subject to human error. Infrared thermography has emerged as a promising Precision Livestock Farming (PLF) technology offering a non-invasive, contactless method to quantify surface temperature variations associated with physiological and pathological states. The application of IRT describes its importance in animal reproduction covering biophysical principles, diagnostic utility in male and female fertility and the critical influence of environmental and technical factors on data accuracy.

Keywords: Infrared thermography, inflammation, thermograph, scrotal thermoregulation, pregnancy diagnosis

Introduction

The modernization of animal husbandry has driven a demand for technologies that enable real-time, accurate and automated monitoring of animal physiology (Zheng *et al.*, 2022) [28]. Infrared thermography (IRT) is a non-ionizing, passive technology that detects infrared radiation emitted by an object and converts it into a radiometric image, or thermogram (Borah *et al.*, 2022) [1]. Because all objects with a temperature above absolute zero emit infrared radiation, allows IRT for the quantification of surface temperatures based on the Stefan-Boltzmann law (Usamentiaga *et al.*, 2014) [25].

In the context of reproduction, IRT is valued for its ability to detect microcirculatory changes driven by hormonal fluctuations, metabolic activity and inflammatory processes (Mota-Rojas *et al.*, 2021) [15]. Unlike invasive techniques which can induce stress-related hyperthermia and skew diagnostic results, IRT permits remote monitoring and thereby improving animal welfare (Stewart *et al.*, 2005) [23]. IRT is helpful in detecting estrus, diagnosing pregnancy, assessing male fertility and identifying reproductive pathologies across various livestock species including bovines, buffaloes, small ruminants, equines and swine.

Biophysical Principles and Thermal Windows

The clinical application of IRT relies on the evaluation of “thermal windows”. These are specific anatomical regions characterized by a high density of blood vessels, presence of arteriovenous anastomoses and often lack of thick hairs or fur (Mota-Rojas *et al.*, 2021) [15]. These features facilitate heat exchange between body core and environment.

Vascular Dynamics and Heat Transfer: The surface temperature of an animal is largely determined by the core body temperature and the blood flow to the periphery (Borah *et al.*, 2022) [1]. Vasodilation controlled by the autonomic nervous system increases blood flow to the skin facilitating heat dissipation and appearing as “hotspots” on a thermogram (Ghezzi *et al.*, 2024) [6]. Conversely, vasoconstriction reduces blood flow resulting in cooler surface temperatures (Mota-Rojas *et al.*, 2021) [15]. In reproductive physiology, these vascular changes are often modulated by hormones such as estrogen and progesterone (Skliarov *et al.*, 2023) [22].

Key Reproductive Thermal Windows

- **Vulva or Perineum:** A critical window in females where surface temperature correlates with blood flow changes driven by the estrous cycle (Talukder *et al.*, 2014) ^[24].
- **Scrotum:** In males, the scrotal surface is the primary window for assessing testicular thermoregulation which is essential for spermatogenesis (Kastelic *et al.*, 1996) ^[8].
- **Mammary Gland:** The udder surface reflects vascular changes related to lactation and inflammatory responses such as mastitis (Colak *et al.*, 2008) ^[3].
- **Ocular/Muzzle:** While not reproductive organs, these zones are often used as proxies for core temperature and stress assessment during reproductive procedures (Mota-Rojas *et al.*, 2021) ^[15].

Applications in Female Reproduction

Estrus detection

Accurate detection of estrus is pivotal for optimizing timing of insemination. Traditional visual detection is inefficient particularly in species like buffaloes that exhibit “silent heat” (Riaz *et al.*, 2023) ^[18].

- **Cattle and Buffalo:** Research indicates that the temperature of the vulvar skin (regio urogenitalis) increases significantly during the follicular phase due to increased vascularity (Skliarov *et al.*, 2023) ^[22]. Studies have shown that vulvar surface temperature rises by approximately 0.5 °C to 1.2 °C during the 24 to 48 hours preceding ovulation (Talukder *et al.*, 2014) ^[24]. In Murrah buffaloes, a strong inverse correlation ($r^2 = 0.70$) has been observed between vulvar temperature and plasma progesterone levels; as progesterone drops during estrus, vulvar temperature rises (Ruediger *et al.*, 2018) ^[19]. Thermograms of cows in estrus display “hot” color palettes (red/white) in the external genitalia, contrasting with the “warm” (orange) colors seen during diestrus (Skliarov *et al.*, 2023) ^[22]. Automated IRT systems utilizing Support Vector Machine (SVM) and logistic models have achieved estrus detection rates exceeding 81% by monitoring ocular and vulvar temperatures (Wang *et al.*, 2023) ^[26].
- **Swine:** In sows, the vulva is a reliable thermal window. Thermographic monitoring has demonstrated significantly higher vulvar temperatures during estrus compared to diestrus with a temperature difference of 2-3 °C often observed (Scolari *et al.*, 2011; Skliarov *et al.*, 2023) ^[20, 22]. This hyperthermic response is attributed to the estrogen-dependent increase in blood supply to the external genitalia (Simões *et al.*, 2014) ^[21].
- **Small Ruminants:** In goats and sheep, IRT has been effectively used to differentiate phases of the estrous cycle with vulvar temperatures rising by over 1 °C during estrus (Skliarov *et al.*, 2023) ^[22].
- **Mares:** In Mares, the external genitalia can be 3-4 °C hotter than the surrounding croup tissue during estrus due to hyperestrogenemia (Skliarov *et al.*, 2023) ^[22].

Pregnancy Diagnosis

The application of IRT for pregnancy diagnosis yields mixed results depending on species-specific anatomy.

- **Equines:** IRT has demonstrated success in diagnosing pregnancy in mares, particularly during late gestation (Bowers *et al.*, 2009) ^[2]. Pregnant mares exhibit higher

surface temperatures in the flank and abdominal regions compared to non-pregnant mares attributed to the metabolic demands of the fetus and increased uterine blood flow (Bowers *et al.*, 2009) ^[2].

- **Ruminants:** In dairy cattle, abdominal IRT is generally ineffective for pregnancy diagnosis because the metabolic heat generated by the large, physiologically active rumen masks the thermal signals of the fetus (Knížková *et al.*, 2007) ^[10]. However, some studies suggest that vulvar temperature may offer indirect diagnostic support by reflecting the maintenance of high progesterone levels (Radigonda *et al.*, 2017) ^[17].
- **Exotic Species:** IRT has been successfully used to detect pregnancy in giraffes, zebras and giant pandas, likely due to anatomical differences that make the fetal heat signature more detectable than in domestic ruminants (Benesch and Hilsberg, 2003; Durrant, 2006) ^[7, 5].

Mammary Glands Health: Mastitis is a major cause of economic loss and reproductive inefficiency. IRT is highly effective for the early detection of mastitis, identifying temperature elevations (1.0-2.3 °C) associated with inflammation often before clinical signs appear (Colak *et al.*, 2008; Korelidou *et al.*, 2024) ^[3, 11]. Udder surface temperature correlates positively with somatic cell counts (SCC) and California Mastitis Test (CMT) scores (Polat *et al.*, 2010) ^[16].

Applications in Male Reproduction

Testicular Thermoregulation and Semen Quality

Mammalian testes typically require a temperature 2-6 °C lower than the body core for effective spermatogenesis (Kastelic *et al.*, 1996) ^[8]. The scrotum functions as athermoregulator and IRT is an ideal tool for assessing this function.

- **Thermal gradients:** A healthy bull scrotum exhibits a distinct thermal gradient, decreasing in temperature from the scrotal neck (top) to the fundus (bottom) (Kastelic *et al.*, 1995) ^[9]. The vascular cone cools arterial blood before it enters the testes (Skliarov *et al.*, 2023) ^[22].
- **Semen Quality Correlation:** Disruptions in this gradient, such as warmer fundus or “hot spots”, indicate compromised thermoregulation and are associated with poor semen quality (Yadav *et al.*, 2019) ^[27]. In buffalo bulls, a scrotal temperature gradient of ≥ 6.5 °C was linked to higher sperm concentration and motility while gradients ≤ 4.0 °C correlated with poor quality (Yadav *et al.*, 2019) ^[27]. Abnormal thermograms are also associated with higher percentages of sperm morphological defects (Menegassi *et al.*, 2015) ^[14].

Diagnosis of Pathologies

IRT is useful for detecting inflammatory and degenerative conditions in the male reproductive tract.

- **Inflammation:** Conditions such as orchitis, epididymitis and balanoposthitis (inflammation of glans penis and prepuce) present as hyperthermic zones on thermograms (Kozumplik *et al.*, 1989; Skliarov *et al.*, 2023) ^[12, 22].
- **Varicocele:** Scrotal thermography is noted for diagnosing varicocele (enlargement of veins) which

disrupts normal cooling mechanisms and appears as localized heating (Comhaire *et al.*, 1976) ^[4].

- **Degeneration:** Conversely, testicular dystrophy and hypogonadism often present with reduced temperature gradients and “cold” spots due to decreased blood flow and metabolic activity (Skliarov *et al.*, 2023) ^[22].

Factors Influencing Thermographic Data

To ensure accuracy, several influencing factors must be managed during IRT data collection.

Technical factors

- **Emissivity(ε):** Accurate temperature calculation requires the correct emissivity setting. Biological tissue generally has high emissivity (0.98) but this can vary (McManus *et al.*, 2022) ^[13]. Inaccurate emissivity values can lead to significant measurement errors (Borah *et al.*, 2022) ^[1].
- **Distance and Angle:** The distance between the camera and the animal, as well as the shooting angle can affect temperature readings; standardizing these parameters is crucial for reproducibility (McManus *et al.*, 2022) ^[13].

Environmental Factors

- **Solar Loading:** Direct sunlight can artificially increase surface temperature readings making it a critical confounder (Mota-Rojas *et al.*, 2021) ^[15].
- **Wind and Humidity:** Wind velocity can decrease surface temperature via convective cooling (e.g., wind speeds of 12 km/h can lower eye temperature by nearly 0.8 °C) while high humidity affects evaporative cooling (Mota-Rojas *et al.*, 2021) ^[15].

Animal Specific Factors

- **Coat Characteristics:** Thick hair or wool acts as an insulator blocking infrared radiation from the skin. Therefore, glabrous regions like eye, muzzle and vulva are preferred (Mota-Rojas *et al.*, 2021) ^[15].
- **Pigmentation:** Darker hair coats absorb more solar radiation than lighter coats, potentially skewing data (Mota-Rojas *et al.*, 2021) ^[15].
- **Behavior and Stress:** Physical activity or stress prior to imaging can cause stress-induced hyperthermia altering surface temperatures (Stewart *et al.*, 2005) ^[23].

Conclusion

Infrared thermography represents a valuable, non-invasive tool for monitoring animal reproduction. It offers significant advantages in detecting estrus, assessing male fertility, and diagnosing inflammatory conditions like mastitis without the stress associated with invasive methods. While highly effective in specific applications such as scrotal thermoregulation assessment and mastitis detection, its utility in pregnancy diagnosis is species-dependent showing limitations in ruminants due to rumen heat. The accuracy of IRT is contingent upon strict control of environmental and technical variables. Future integration with artificial intelligence and automated systems promises to enhance the reliability and practical application of IRT in commercial livestock production and breeding.

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