Exploring the multifaceted applications of Infrared Thermography in Livestock Management

A. Ghanghas[a*], D.S. Bidhan[b], D.C. Yadav[b], K. Jaglan[a], S. Yadav[c], A.K. Balhara[c], M. Singh[b], A. Boora[c]

[a]Department of Animal Husbandry and Dairying, Government of Haryana; [b]Lala Lajpat Rai University of Veterinary and Animal Sciences, [c]ICAR-Central Institute for Research on Buffaloes, Hisar-125001, India
[*]Corresponding Author Email ID: aghanghas1231@gmail.com

Journal of Livestock Science (ISSN online 2277-6214) 16: 270-280
Received on 03/01/25; Accepted on 19/3/25; Published on 22/3/25
doi. 10.33259/JLivestSci.2025.270-280

Abstract

Infrared Thermography (IRT) has emerged as a valuable tool in livestock management due to its non-invasive, on site, portable, real time nature and ability to detect thermal variations in animal bodies. This technology utilizes infrared radiation emitted by an object to create thermograms that represent its temperature distribution, offering insights into physiological processes and potential health issues. In the field of veterinary sciences, IRT finds applications across various domains, including animal health assessment, lameness detection, injury diagnosis, and monitoring of physiological responses to treatments or environmental conditions. By detecting subtle temperature changes, IRT can aid in the early detection of musculoskeletal injuries, inflammation, and infections, facilitating timely intervention and improving animal welfare. Moreover, its non-contact nature minimizes stress for animals, making it particularly suitable for monitoring exotic or wild species too. Despite its advantages, standardization of protocols and interpretation of thermal patterns remain among challenges. Nevertheless, ongoing research and advancements in technology continue to enhance the utility of IRT as a valuable adjunctive tool in wide area of livestock management.

Keywords: imaging; livestock; management; thermal; thermography

Introduction

IRT imaging, initially used in military equipments for most of the last century, has rapidly gained civilian use in last two decades. During COVID-19 outbreak, researchers applied the IRT principle to examine temperature rise for screening human at various public places during mass gatherings. This being a fast, real time, remote and non-invasive technique, its applications in animal health and welfare are demand of the hour. The advanced software and high-resolution infrared detectors and integrated artificial intelligence algorithms has opened new ways for developing automation of specific activities such as automated IR thermal camera-based mastitis screening in a dairy farm.

Infrared (IR) waves occupy a range of the electromagnetic spectrum larger than visible light but smaller than microwaves. This segment encompasses wavelengths from approximately 0.7 micrometers (700 nanometers) to 1000 micrometers. The IR spectrum is commonly categorized into near, mid, and far infrared. Near-infrared (NIR) extends from 0.7 μm and goes upto up to around 3 μm. Mid-IR spans wavelengths from approximately 3 to 15 micrometers and includes the region known as thermal infrared. All hot bodies emit IR, having temperature above absolute zero (-459.67 °F, or 0 Kelvin, or - 273.15 °C) result in vibration and rotation of molecule within the material. More is the temperature of the body, the higher is the frequency and shorter the wavelength. Hence thermal radiation becomes the primary source of IR radiation.

The journey of IRT started with the advent of IR radiation by William Herschel in 1800 AD. It works on the principle of emission of IR radiation by all objects proportionate to their temperature (Stefan-Boltzmann law) by means of conduction, convection, and radiation (Poikalainen et al., 2012). With time new generations of thermographic equipments were developed in the 1960s and 1970s by Japan, Europe and America. IRT is a relatively novel, user-friendly, non-intrusive method (Figure 1) that provides graphic images of animals without exposing users to radiation and measures the body's surface temperature due to change in blood flow (Figure 2) depending upon the environmental and physiological condition (Mcmanus et al., 2015). As a result, IRT has paved the way for advancements in livestock management. Effective quality management is very crucial for profitability in livestock rearing (Ugorets et al., 2021). IRT facilitates insights into areas such as feed efficiency, disease detection, environmental stress monitoring, inflammation identification, male and female reproductive health, and the detection of ectoparasite infestations (Paim et al., 2013; Mcmanus et al., 2016). IRT has some restrictions, including the possibility that factors like sunshine, moisture, dirt, and weather will affect how accurate the IRT is. It also depends on the object's stability, the handler's expertise, and the distance between the object and the tool. Because of its technological progress, IRT may be utilized to measure body surface temperature alterations both ways locally as well as across time.

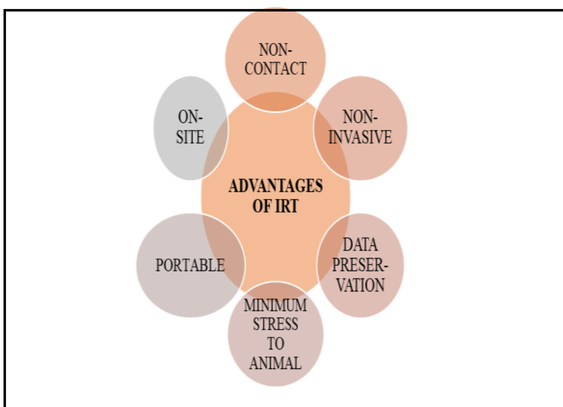

Fig 1: Advantages of IRT

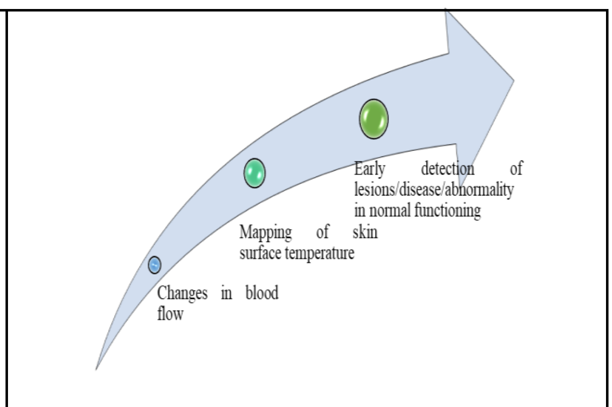

Figure 2: Functioning of IRT

Factors influencing IRT

During thermal imaging, a variety of factors, including biological, technological, and environmental ones, can impact IRT. The true temperature that thermography measure in mammals and birds is lower than the exterior physical surface. Thus, IRT takes a temperature reading of skin surface. Body surface where hair is absent, emits radiation and the superficial blood circulation—vasoconstriction and vasodilation in response to physiology, activity and environment is reflected in the surface temperature. Both solar energy and reflected IR rays have a remarkable impact on the temperature of body surfaces. The surface's emissivity needs to be known for accurate estimation. With emissivities ranging from 0.94 to 1.0, the majority of animal coats are thought to be blackbody emitters; however, emissivities can be altered by water and/or dirt. As we know dark colour has higher solar absorption as compared to light colour, therefore for better thermal pattern study animals should be preferably in shaded/dark area or in an area free from direct sunlight. Water and water vapor absorb far more infrared light. Therefore, in dense fog or cloud, as well as on wet animals, results of thermal imaging will be less reliable. Water evaporation cools the surface and can persist for a considerable amount of time, depending on the surroundings. According to Tattersall et al. (2009) surface temperature changes are greatly dependent upon blood flow to the underlying tissue, as well as the strength of vasodilation/constriction and activity. Since IR radiations are isotropic, meaning from a curved surface they radiate evenly in all directions, measurements taken from a distance cannot capture all of the radiations released at large viewing angles. According to Montanholi et al. (2015), temperature measurements generally increased as the IR camera's distance from the target or animal increased. Wind-induced increases in convective heat loss will cause cattle's surface body temperature to change. Once wind flow was stopped on the skin's surface, there was a direct association between temperature readings on the image and metabolic rate (Schutz et al., 2010). For this reason, in order to prevent the body's surface from cooling, the IR pictures must be taken in calm air. Increased blood flow results in localized rise in heat at the scratching location. Dark coats bearing animals tend to absorb more solar radiation than those having lighter coats (Maloney et al., 2009). An adjustment period should be allowed before the IR imaging after any physical activity and if the animal's feet are tucked beneath the body for longer periods (Gloster et al., 2011). Therefore, these aspects need to be taken into account while performing thermal imaging.

Application in livestock management

Udder health

Even before the mastitis symptoms appear IRT is capable of monitoring the rise in local surface temperature caused due to inflammation process going on underlying local part. Polat et al. (2010) compared IRT with conventional mastitis tests for SCM detection in Brown Swiss cows (n=62) and revealed that the udder skin surface temperature (USST) had a positive correlation with both CMT (r = 0.86) and Somatic Cell Count (SCC) (r = 0.73). Additionally, when the CMT score grew, it was shown by the receiver operating characteristics curve that SCC increased exponentially while USST increased linearly. Negative association between averages temperatures at quarter (-0.12℃) ($p<0.05$) and teat (-0.28℃) ($p<0.01$) level and SCC was observed by Bortolami et al. (2015). They concluded that IRT was unable to distinguish between positive and negative cattle indicating poor diagnostic value of thermal imaging in dairy cows.

Metzner et al. (2014) analyzed pre and post-inoculation thermograms of caudal udder surface of cows in good health by inoculating *E. coli* into the right hind quarter by using geometric analysis shapes such as polygons, rectangles, lines etc. There was increased temperature of quarter in images along with elevated SCC as compared to healthy quarter. Significant detection of changes in caudal udder surface was obtained in polygon shape. Paim et al. (2013) reported physiological response of animals in mammary gland disorders can be evaluated via IRT. In a study conducted by Sathiyabarathi et al. (2016) it was found that SCM-affected quarter had higher temperature than rectal body temperature by 1.51℃ showing a positive linear relation with SCC and EC ($R^2>0.95$). Similar results were obtained in Karan Fries cows (Sathiyabarathi et al., 2018). The USST of CM and SCM affected quarters was 1.1 and 0.8°C higher than the healthy quarter and body temperature. The increase in USST of SCM quarters showed a positive correlation with the SCC. Martins et al. (2012) also corroborated similar findings in sheep. Sensitivity and specificity of IRT for udder health in dairy cows were obtained as 78.6% and 77.9%, respectively. These results were obtained based on values of SCC at different levels classifying mild mastitis at a threshold of 2,00,000 cells/mL. However, when a threshold of 4,00,000 cells/mL was used for classification of mild mastitis, the sensitivity and specificity values declined to 71.4% and 71.6%, respectively. Sarubbi et al. (2020) stated significantly positive correlation between temperature and different categories of SCC in buffaloes. Such results shows that thermal imaging can be utilized as sensitive screening measure indirectly for detection of sub-clinical mastitis in bovines. Machado et al. (2021) observed that left fore udder temperature (R^2=0.92), rear udder temperature (R^2=0.86) and average udder temperature (R^2=0.94) were good in predicting udder infection based on SCC, respectively in crossbred cows. The most promising region for imaging was anterior udder quarters showing stronger correlations (r) of 0.87 and 0.88 between LFUT and RFUT with SCC, respectively.

Gayathri et al. (2024) stated significant increase in short milking tube surface temperature in SCM and CM quarters in contrast to healthy quarters, respectively in Murrah buffaloes. Also, the USST for pre-milking, milking, and post-milking of SCM and CM as opposed to healthy quarters showed an increase ($p<0.05$) of 2.17, 1.96, and 1.61ºC and 3.11, 2.88, and 2.73ºC, respectively. Their results showed a strong positive correlation of CMT and SCC with IRT. Gayathari et al. (2023) documented similar outcomes in Sahiwal cows. Some studies regarding application of IRT in udder health are mentioned in Table 1.

Hoof health

For the early and efficient identification of a variety of foot problems, including corns, laminitis, abscesses and navicular disease, IRT might be an useful aid for detecting contralateral temperature differences in foot. Due to arteriovenous plexus, warmest part of the normal limb thermogram comes out to be the coronary band. In comparision to conventional diagnostic aids such as radiography, ultrasonography etc, IRT had good amount of practicality if combined with thorough clinical examination. Rainwater-Lovett et al. (2009) suggested that IRT can serve as efficient tool in minimizing sample load required for diagnostic confirmation during FMD outbreak. A cut-off value of 25.25˚C was developed with 72% sensitivity and 73% specificity to detect hoof lesions by Main et al. (2012). Higher coronary band temperature with sensitivity of 89.1% and specificity of 66.6% was recorded by Alsaaod et al. (2014) in detection of digital dermatitis using IRT. Oikonomou et al. (2014) discovered that the temperature of the sole increased as the lameness score increased and dropped as the thickness of the digital cushion grew in dairy cows. Increased CBT was observed in white line disease, sole ulcer and digital dermatitis as compared to healthy foot in dairy animals (Orman and Endres, 2016). On monitoring foot thermograms of Holstein cows, Bobic et al. (2018) reported highly significant difference ($p<0.001$) in mean, maximum and minimum temperature of coronary band between healthy and affected foot which is also affected by stage of lactation as well as parity. Thus, without physical and clinical inspection of foot, IRT can be utilized for early detection and management of lameness in livestock (Leach et al., 2012; Alsaood et al., 2015). Table 2 depicts various studies conducted using IRT.

Female reproduction

Bowers et al. (2009) explained the applicability of IRT for confirmation of mid to late gestation in mares. Increased pre and post ovulation vaginal temperature can be used as an indicator for improving heat detection in cows and sows (Sykes et al., 2012). Findings of Talukder et al. (2014) revealed that thermal imaging had higher sensitivity of estrus alert than visual observation thus, can be IRT used as a potential estrus detection aid. In contrary to these findings, Olğaç et al. (2017) stated that to assess skin surface temperature changes, thermal imaging can be a valuable aid but they denied it as a tool for routine heat detection in Anatolian Shepherd bitches.

Male reproduction

IRT may serve as a tool to assess various seminal parameters by measuring scrotal surface temperature in dairy animals. Negative correlation was reported between vascular cone diameter of testis and surface temperature of scrotum by Brito et al. (2012). Thermal imaging is having potential as an examination tool in andrological evaluations in stallion (Ramires-neto et al., 2012) as well as a non-invasive indicator tool of sub-clinical testicular factors possibly affecting fertility of stallion (Janet et al., 2015). During spermiogenesis, testicular gradient (TG) was highly negatively correlated to ocular and rectal temperature as per results reported by Menegassi et al. (2016) who therefore stated that IRT technique can be applied indirectly to assess the effect of environmental changes in testicular gradient (TG) and Ocular temperature (OcT) of Brangus bulls. Ruediger et al. (2016) reported that scrotal surface temperature (SST) influences the sperm motility and concentration in bulls positively. Yadav et al. (2019) evaluated the effect of SST on semen quality from five different centres of Haryana and Punjab in Murrah bulls using the IR camera. On the basis of TG, bulls were grouped into three (I- 3.11±0.10 ºC, II- 4.91±0.09 ºC and III- 8.03±0.26 ºC) categories. A negative correlation was observed among TG and sperm abnormalities and positive correlation with mass activity and sperm concentration. Buffalo bulls' SST and semen quality were assessed by Silva et al. (2017) using IRT and reported that minimum SST and OcT were inversely connected with volume and progressive motility ($P<0.01$). A rise in the lowest SST had a negative effect on the integrity of the sperm membrane (P<0.01). Additionally, there was a significant association (P<0.01) between the temperature of the OcT and rectal, spermatic cord and epididymal tail. Ahirwar et al. (2018) reported high correlation among proximal, mid and distal scrotal temperatures and THI in Murrah buffaloes. The THI, TG and OcT had significant influence on acrosomal integrity, sperm abnormalities, and plasma membrane integrity of fresh and post-thawed semen. The TG significantly influenced live sperm % and sperm concentration.

Disease investigation

Inflammation in muscles can be seen as hot spots on the thermograms along with oedematous swelling in the affected muscle leading to reduced blood flow to the muscle generating a cold spot. Cook et al. (2015) gave a concept that thermal images of swine herd can be used for detecting the febrile responses at lower level of prevalence, and therefore have ability for detection of disease and a tool for surveillance in swine barns. IRT was described by Islam et al. (2015) as a method for detecting heat emissions from pig skin in order to detect salmonella and E. coli infections early.

Table 1: Application of IRT in udder health of livestock

Reference	Species	Camera	Salient Findings
Polat et al. (2010)	Cattle	IR FlexCam S	As the severity of mastitis increased in terms of SCC, USST also increased (n=62)
Metzner et al. (2014)		Flir B20 HSV	For automated mastitis monitoring, Polygons are the best shape (n=5)
Machado et al. (2021)		Fluke® model TiS10	Anterior quarters of udder was the best region for IRT (n=28)
Bortolami et al. (2015)		P25	Inverse relation between SCC and quarter as well as teat temperature (n=98)
Sathiyabarathi et al. (2016)		Flir i5	ROC curve analysis revealed 37.61℃ as cut off value for SCM (n=19)
Sathiyabarathi et al. (2017)		Flir i5	SCM affected quarter has rise of 1.51°C as compared to body temperature (n=14)
Sathiyabarathi et al. (2018)		Flir i5	Rise of 0.8°C and 1.1°C in USST of SCM and CM as compared to temperature of the body and healthy quarter (n=50)
Gayathri et al. (2024)	Buffalo	Darvi DTL007	Rise of 2.19℃ and 3.72℃ in SCM and CM quarter respectively as compared to healthy ones (n=30-45)
Sarubbi et al. (2020)		Flir i7	Exponential rise in udder temperature and SCC (n=192)
Martins et al. (2012)	Sheep	FLIR System Série-i	Maximum udder temperature was higher in SCM animals as compared to healthy and CM animals (n=37)

Table 2: Application of IRT in hoof health

Reference	Species	Camera	Salient Findings
Alsaaod and Buscher (2012)	Cattle	Jenoptik VarioCAM	Hoof lesions led to increase of 0.64-1.09 °C rise in surface temperature of coronary band (n=24)
Stokes et al. (2012)		ThermaCAM E2	5.3°C change in clean feet's temperature on surface area was observed in cows affected with digital dermatitis as compared to healthy (n=82)
Renn et al. (2014)		FLIR e40bx	Change of 3.10 °C in surface temperature of lame feet as compared to healthy (n=150)
Wilhelm et al. (2014)		ThermaCam E300	In case of sole hemorrhages, there was rise of 1.2 °C in claw temperature of hind limbs (n=123)
Siddalingaiah et al. (2022)	Buffalo	FLIR i5	Baseline thermographic information reported for the first time on CBT, BT, HSST and ΔT differentials for buffalo (n=15)
Cetinkaya and Demirutku (2012)	Horse	Flir P45	Surface temperature of the affected region increased by 0.5-1.5 °C (n=47)
Amezcua et al. (2014)	Swine	Flir T300	In lame animals, surface temperature of upper metatarsus and phalanges rose by 1.32°C and 2.43°C (n=297)
Talukder et al. (2015)	Sheep	Flir T620	1.3 °C change in surface temperature of affected foot (n=15)
Byrne et al. (2019)		Flir T430sc	Hoof lesions led to a change of 8.5 °C in hoof temperature (n=40)
Gelasakis et al. (2021)		Flir E8-XT	In case of footrot, surface temperature of coronary band rose by 2.2 °C (n=600)

Welfare and stress assessment

IRT can be applied for characterizing the effects of air movement on heat transfer and thermoregulation in pigs as new born piglet mortality is major cause of concern for swine industry recorded ear temperature using IRT in pigs and reported a significant rise in ear base temperature after two hours of transport. Paim et al. (2013) reported physiological response of animals in high temperature can be evaluated via IRT. IRT can be utilized to evaluate the thermal stress experienced in exercising horses when they were exposed to high temperature (Moura et al. 2011). IRT was utilized by Balhara et al. (2023) to study the natural diurnal behavior of the Banni buffalo which is best expressed when there is minimum disturbance in animal surroundings. Hence, IRT proved useful in studying nighttime behavior of buffaloes.

Core body temperature

Correlating with rectal or other recognized techniques of core body temperature determination, surface temperature measurement using IRT can also be used. Eye temperature has been employed in cattle (Abreu et al. 2010) to estimate deep body temperature using thermal imaging. Traulsen et al. (2010) showed that thermography of specific body surface areas like teats and vulva in sows can be a trustworthy alternate for predicting core temperature. Kammersgaard et al. (2013) concluded that maximum infrared temperature from full body thermograms can be utilized as an effective tool for assessing the thermal status in new born piglets, but not as similar substitute for rectal temperature. Balhara et al. (2024) revealed the utility of IRT as an efficient diagnostic tool for prediction of core body temperature in buffaloes.

Methane production

Results published by Gabbi et al. (2022) in Holstein, Gyr and Holstein X Gyr CB cows stated that left and flank thermographic temperature was substantially correlated with methane emission during entire study period. In order to study whether IRT is correlated to heat production and methane emission in Gyrolando F1 and Holstein breeds of cattle, Guadagnin et al. (2023) revealed IRT significantly positively correlated to Methane emission along with heat production, however the parts of body to which correlation was present varied between breeds.

Studies on birds and other mammals

Thermal imaging can be utilized to assess the insulation loss due to poor feather cover and quantitative measurement of feather cover or bare skin is possible by thermography Along with estimating total and regional heat loss obtained from thermography may be correlated to physiological function and adaptation to thermal challenges which is reported in studies on woodchuck, otters, vultures, elephants, camels and harbor seals as reported by Kuhn and Meyer (2009), Weissenbock et al. (2010), Abdoun et al. (2012) and Nienaber et al. (2010) respectively. Administration of gonadotropin releasing hormone and elevated testosteronemia in Alpacas were associated with elevated scrotal temperature that can be measured by thermography (Stelletta et al. 2012). In case of small animals, there are very few studies reported on healthy dogs limbs by especially on the stifle joint carried out by Infernuso et al. (2010). Thermal imaging has given the idea regarding thermoregulatory capacity and physiological responses in Camelids of South America and the benefit of thermal windows and coat structure in the face is of the thermal challenge (Gerken, 2010). IRT was utilized to identify temperature variations associated with different experimental FMD infection sites in mule deer (*Odocoileus hemionus*). Researchers found that eye temperature did not substantially change with body temperature in well-focused thermograms. They came to the conclusion that IRT is a remote, quick, and non-invasive method for screening FMD suspected animals during an outbreak after observing a notable increase in foot temperature two days after the first foot lesion appeared (Dunbar et al. 2009). Combination of telemetry and body temperature thermography gave very interesting information for explaining behavior in neonates of rabbits and rodents and the mechanism for prevention of hypothermia in the initial few days of birth (Gilbert et al., 2012). Even though thermography is applicable for disease diagnosis in wild as well as domestic animals (Dunbar et al. 2009) reported the study of the environment where reptiles inhabit in captivity, although still it is not consistently developed application. Analyzing thermal gradient in reptiles is beneficial as environmental thermal attributes are important in incubation, living and reproduction of any ectotherm. As per reports by, the examination of reptile enclosures will allow alteration of the “thermal” design which is suitable to individual species leading to optimum husbandry pratices and health.

Conclusion

In conclusion, IRT stands as a pivotal technology in animal sciences, offering non-invasive insights towards overall animal management. Its ability to detect subtle temperature variations aids in early diagnosis as well as continued monitoring across diverse field of animal sciences. By minimizing stress and providing rapid, contactless assessments, IRT enhances animal welfare and facilitates research in fields such as veterinary medicine and wildlife conservation. Continued advancements and standardization efforts further underscore its importance, ensuring its continued integration as a valuable tool for holistic animal care, disease management, and scientific understanding in the realm of animal sciences.

Authors contribution statement: AG and KJ: Conceptualization, methodology, and writing original draft; MS, DCY and AB: Literature review and editing of manuscript; SY and AKB: Critical revision of the manuscript for important intellectual content; DSB: Supervision and final approval of the version to be published.

Acknowledgement: The authors would like to express sincere gratitude to institutes viz. LUVAS and ICAR-CIRB for generously sharing extensive collection of research literature on the topic.

Declaration of interest statement: The authors declare no conflict of interest

References

1) Abdoun, K.A., Samara, E.M., Okab, A.B. and Al-Haidary, A.A. (2012). Regional and circadian variations of sweating and body surface temperature in camels (Camelus domedarius). Animal Science Journal, 83: 556-561.https://doi.org/10.1111/j.1740-0929.2011.00993.x

2) Abreu, M.M., Haddadin, S.S., Hott, M., Assis, A. and Silverman, D.G. (2010). Consistency of brain temperature tunnel measurements in different environmental temperature. From proceedings of the annual meeting of the American Society of Anesthesiologists, October 17th 2010 Anesthesiology, 113: a673.

3) Ahirwar, M.K., Kataktalware, M.A., Pushpadass, H.A., Jeyakumar, S., Jash, S., Nazar, S., Devi, L., Kastelic, J.P. and Ramesha, K.P. (2018). Scrotal infrared digital thermography predicts effects of thermal stress on buffalo (Bubalus bubalis) semen, Journal of Thermal Biology, 78: 51-57.https://doi.org/10.1016/j.jtherbio.2018.09.003

4) Alsaaod, M. and Buscher, W. (2012). Detection of hoof lesions using digital infrared thermography in dairy cows. Journal of Dairy Science, 95 (2): 735-742.https://doi.org/10.3168/jds.2011-4762

5) Alsaaod, M., Schaefer, A.L., Büscher, W. and Steiner A. (205). The Role of Infrared Thermography as a Non-Invasive Tool for the Detection of Lameness in Cattle. Sensors. 15(6):14513-14525. https://doi.org/10.3390/s150614513.

6) Alsaaod, M., Syring, C., Dietrich, J., Doherr, M.G., Gujan, T. and Steiner, A. (2014). A field trial of infrared thermography as a non-invasive diagnostic tool for early detection of digital dermatitis in dairy cows. The Veterinary Journal, 199: 281:285.https://doi.org/10.1016/j.tvjl.2013.11.028

7) Amezcua, R., Walsh, S., Luimes, P.H. and Friendship, R.M. (2014). Infrared thermography to evaluate lameness in pregnant sows. Canadian Veterinary Journal, 55: 268-272.

8) Balhara, A.K., Balhara, S., Kumar, K., Singh, K.P., Lailer, P.C., Makarabbi, G. and Singh, S. (2023): Banni buffalo production system for sustainable livelihoods in salty, tropical desert conditions, Agroecology and Sustainable Food Systems, 47(6): 777-790. https://doi.org/10.1080/21683565.2023.2196253

9) Balhara, A.K., Jan, M.H., Hooda, E., Kumar, K., Ghanghas, A., Sangwan, S., Balhara, S., Phulia, S.K., Yadav, S., Boora, A. and Kumar, S. (2024). Prediction of core body temperature using infra-red thermography in buffaloes. Italian Journal of Animal Science, 23(1), pp.834-841.https://doi.org/10.1080/1828051X.2024.2358872

10) Bobic, T., Mijic, P., Gantner, V., Glavas, H. and Gregic, M. (2018). The effects of parity and stage of lactation on hoof temperature of dairy cows using a thermovision camera. Journal of Central European Agriculture, 19 (4): 777-783. https://doi.org/10.5513/JCEA01/19.4.2354

11) Bortolami, A., Fiore, E., Gianesella. M,,Corro, M., Catania, S. and Morgante, M. (2015). Evaluation of the udder health status in subclinical mastitis affected dairy cows through bacteriological culture, somatic cell count and thermographic imaging. Polish Journal of Veterinary Science, 18(4): 799–805. http://dx.doi.org/10.1515/pjvs-2015-0104

12) Bowers, S., Gandy, S., Anderson, B., Ryan, P. and Willard, S. (2009). Assessment of pregnancy in the late-gestation mare using digital infrared thermography. Theriogenology, 72: 372-377.https://doi.org/10.1016/j.theriogenology.2009.03.005

13) Brito, L. F., Barth, A. D., Wilde, R. E. and Kastelic, J. P. (2012). Testicular vascular cone development and its association with scrotal temperature, semen quality, and sperm production in beef bulls. Animal Reproduction Science, 134(3-4): 135-140. https://doi.org/10.1016/j.anireprosci.2012.08.025
14) Byrne, D. T., Berry, D. P., Esmonde, H., McGovern, F., Creighton, P. and McHugh, N. (2019). Infrared thermography as a tool to detect hoof lesions in sheep. Translational Animal Science, 3(1), 577-588.https://doi.org/10.1093/tas/txy132
15) Cetinkya, M.A. and Demirutku, A. (2012). Thermography in the assessment of equine lameness. Turkish Journal of Veterinary and Animal Science. 36(1): 43-48. https://doi.org/10.3906/vet-1102-791
16) Cook, N.J., Chabot, B., Lui, T., Bench, C.J. and Schaefer, A.L. (2015). Infrared thermography detects febrile and behavioural responses to vaccination of weaned piglets. Animals, 9(2): 339-346.https://doi.org/10.1017/S1751731114002481
17) Dunbar, M.R., Johnson, S.R., Ryan, J.C. and McCollum, M. (2009). Use of infrared thermography to detect thermographic changes in mule deer (Odocoileushemionus) experimentally infected with foot-and-mouth disease. Journal of. Zoo and Wildlife Medicine, 40(2): 296-301.https://doi.org/10.1638/2008-0087.1
18) Gabbi, A.M., Kolling, G.J., Fischer, V., Pereira, L.G.R., Tomich, T.R., Machado, F.S., Campos, M.M., Silva, M.V.B.D., Cunha, C.S., Santos, M.K. and McManus Pimentel, C.M. (2022). Use of infrared thermography to estimate enteric methane production in dairy heifers. Quantitative InfraRed Thermography Journal, 19(3), pp.187-195.https://doi.org/10.1080/17686733.2021.1882075
19) Gayathri, S. L., Bhakat, M. and Mohanty, T. K. (2023). Short-milking-tube thermograms: An alternative to udder thermograms for mastitis detection in Sahiwal cows. Research in Veterinary Science, 165, 105056.https://doi.org/10.1016/j.rvsc.2023.105056
20) Gayathri, S. L., Bhakat, M. and Mohanty, T. K. (2024). Advancing mastitis assessment in dairy bovines via short milking tube thermography: A seasonal perspective. International Journal of Biometeorology, *68*(11), 2253-2265.https://doi.org/10.1007/s00484-024-02743-0
21) Gelasakis, A.I., Kalogianni, A.I., Moschovas, M., Tsimpouri, E., Pnevmatikos, T., Bossis, I., Arsenos, G. and Simitzis, P. (2021). Evaluation of infrared thermography for the detection of footrot and white line disease lesions in dairy sheep. Veterinary Sciences, *8*(10), p.219.https://doi.org/10.3390/vetsci8100219
22) Gerken, M. (2010). Relationships between integumental characteristics and thermoregulation in South American Camelids. Animals, 4(9): 1451-1459.https://doi.org/10.1017/S1751731109991443
23) Gilbert, C., McCafferty, D.J., Giroud, S., Ancel, A. and Blanc, S. (2012). Private heat for public warmth: how huddling shapes individual thermogenic responses of rabbit pups. Plos One, 7(3): e33553.https://doi.org/10.1371/journal.pone.0033553
24) Gloster, J., Ebert, K., Gubbins, S., Bashiruddin, J. and Paton, D.J. (2011). Normal variation in thermal radiated temperature in cattle: implications for foot-and-mouth disease detection. BMC Veterinary Research, 7: 73-82.https://doi.org/10.1186/1746-6148-7-73
25) Guadagnin, A.R., Matiello, J.P., Ribeiro, R.S., Pereira, L.G., Machado, F.S., Tomich, T.R., Campos, M.M., Heisler, G. and Fischer, V. (2023). Assessment of heat production and methane emission using infrared thermography in lactating Holstein and Gyrolando-F1 (½ Holstein ½ Gyr) crossbreed cows. Journal of Thermal Biology, *115*, p.103628.https://doi.org/10.1016/j.jtherbio.2023.103628
26) Infernuso, T., Loughin, C.A., Marino, D.J., Umbaugh, S.E. and Solt, P.S. (2010). Thermal imaging of normal and cranial cruciate ligament-deficient stifles in dogs. Veterinary Surgery, 39: 410-417.https://doi.org/10.1111/j.1532-950X.2010.00677.x
27) Islam, M.M., Ahmed, S.T., Hong-SeokMun, RubayetBostami, A.B.M., Yae-Jin Kim, and Chul-Ju Yang. (2015). Use of thermal imaging for the early xi Bibliography detection of signs of disease in pigs challenged orally with Salmonella typhimurium and Escherichia coli. Afr. Journal of Microbiological Research, 9(26): 1667-1674https://doi.org/10.5897/AJMR2015.7580
28) Janet L. L., Purohit, R.C., Boyle, M. and Shepherd, C. (2015). Use of Thermography for Functional Evaluation of Stallion Scrotum and Testes. Journal of Equine Veterinary Science, 35(6): 488-494. https://doi.org/10.1016/j.jevs.2015.01.008
29) Kammersgaard, T.S., Malmkvist, J. and Pedersen, L.J. (2013). Infrared thermography – a non-invasive tool to evaluate thermal status of neonatal pigs based on surface temperature. Animals, 7(12): 2026–2034.https://doi.org/10.1017/S1751731113001778
30) Kuhn, R.A. and Meyer, M. (2009). Infrared thermography of the body surface in the Eurasian otter Lutralutra and the giant otter Pteronurabrasiliensis. Aquatic Biology, 6: 143-152.https://doi.org/10.3354/ab00176

31) Leach, K.A., Tisdall, D.A., Bell, N.J., Main, D.C. and Green, L.E. (2012). The effects of early treatment for hindlimb lameness in dairy cows on four commercial uk farms. Veterinary Journal, 193, 626–632.https://doi.org/10.1016/j.tvjl.2012.06.043

32) Machado, N.A.F., Da Costa, L.B.S., Barbosa-Filho, J.A.D., De Oliveira, K.P.L., De Sampaio, L.C., Peixoto, M.S.M. and Damasceno, F.A. (2021). Using infrared thermography to detect subclinical mastitis in dairy cows in compost barn systems. Journal of Thermal Biology, 97:102881. https://doi.org/10.1016/j.jtherbio.2021.102881

33) Main, D.C., Stokes, J.E., Reader, J.D. and Whay, H.R. (2012). Detecting hoof lesions in dairy cattle using a hand-held thermometer. Veterinary Records, *171*, 504–506. https://doi.org/10.1136/vr.100533

34) Maloney, S.K., Fuller, A. and Mitchell, D. (2009). Climate change: is the dark Soay sheep endangered? Biology Letters, 5: 826-829. https://doi.org/10.1098/rsbl.2009.0424

35) Martins, R. F. S., Paim, T., Cardosa, C., Dallago, B. S. L., Melo, C. B., Louvandini, H. and McManus, C. (2012). Mastitis detection in sheep by infrared thermography. Research in. Veterinary Science, 94: 722-724.https://doi.org/10.1016/j.rvsc.2012.10.021

36) McManus, C., Tanure, C. B., Peripolli, V., Seixas, L., Fischer, V., Gabbi, A. M., and Costa, J. B. G. (2016). Infrared thermography in animal production: An overview. Computers and Electronics in Agriculture, 123: 10-16.https://doi.org/10.1016/j.compag.2016.01.027

37) McManus, C., Upcroft, B. and Newman, P. (2015). Learning place-dependant features for long-term vision-based localisation. Autonomous Robots, 39(3), pp.363-387.https://doi.org/10.1007/s10514-015-9463-y

38) Menegassi, S.R.O., Pereira, G.R., Bremm, C., Koetz-Jr, C., Lopes, F.G., Fiorentini, E.C., McManus, C., Dias, E.A., Rocha, M.K., Lopes, R.B. and Barcellos, J.O.J. (2016). Effects of ambient air temperature, humidity, and wind speed on seminal traits in Braford and Nellore bulls at the Brazilian Pantanal. International Journal of Biometeorology, https://doi.org/10.1007/s00484-016-1167-1672

39) Metzner, M., Sauter-Louis, C., Seemueller, P. W. and Klee, W. (2014). Infrared thermography of the udder surface of dairy cattle: Characteristics, methods, and correlation with rectal temperature. Veterinary Journal, 199: 57-62. https://doi.org/10.1016/j.tvjl.2013.10.030

40) Montanholi, Y.R., Lim, M., Macdonald, A., Smith, B.A., Goldhawk, C., Swartchkopf-Genswein, K. and Miller, S.P. (2015). Technological, environmental and biological factors: referent variance xvi Bibliography values for infrared imaging of the bovine. Journal of. Animal Science and Biotechnology, 6: 27.https://doi.org/10.1186/s40104-015-0027-y

41) Moura, D.J., Maia, A.P.D., Vercellino, R.D., Medeiros, B.B.I., Sarubbi, J. and Griska, P.R. (2011). Infrared thermography to evaluate the training horse thermoregulation. Engenharia Agricola, 31(1): 23-32.https://doi.org/10.1590/S0100-69162011000100003

42) Nienaber, J., Thonton, J., Horning, M., Polasek, l. and Mellish, J.A. (2010). Surface temperature patterns in seals and sea lions: a validation of temporal and spatial consistency. Journal of Thermal Biology, 35:435-440.https://doi.org/10.1016/j.jtherbio.2010.09.005

43) Oikonomou, G., Trojacanec, p., Ganda, E.K., Bichalo, M.L. and Bichalo, R.C. (2014). Association of digital cushion thickness with sole temperature measured with the use of infrared thermography. Journal of. Dairy Science, 97: 4208- 4215.https://doi.org/10.3168/jds.2013-7534

44) Olğaç, K.T., Akçay, E, Çil, B., Uçar, B.M. and Daşkın, A. (2017). The use of infrared thermography to detect the stages of estrus cycle and ovulation time in anatolian shepherd dogs. Journal of Animal Science Technology, (9):59-61.https://doi.org/10.1186/s40781-017-0146-4

45) Orman, A. and Endres, M.I. (2016). Use of thermal imaging for identification of foot lesions in dairy cattle, Acta Agriculture Scandinavica, Section Animal science, https://doi.org/10.1080/09064702.2016.1179785

46) Paim, T., Martins, R. F. S., Cardosa, C., Dallago, B. S. L., Melo, C. B., Louvandini, H. and McManus, C. (2013). Mastitis detection in sheep by infrared thermography. Research in. Veterinary Science, 94: 722-724.https://doi.org/10.1016/j.rvsc.2012.10.021

47) Poikalainen, V., Praks, J., Veermae, I. and Kokin, E. (2012). Infrared temperature patterns of cow's body as an indicator for health control at precision cattle farming. Agronomy Research, 1: 187-194. *Corpus ID: 17925859*

48) Polat, B., Colak, A., Cengiz, M., Yanmaz, L. E., Oral, H., Bastan, A., Kaya, S. and Hayirli, A. (2010). Sensitivity and specificity of infrared thermography in detection of subclinical mastitis in dairy cows. Journal of Dairy Science, 93: 3525-3532.https://doi.org/10.3168/jds.2009-2807

49) Rainwater-Lovett, K., Pacheco, J.M., Packer, C. and Rodriguez, L.L. (2009). Detection of foot- and-mouth disease virus infected cattle using infrared thermography. The Veterinary Journal, 180: 317-324.https://doi.org/10.1016/j.tvjl.2008.01.003

50) Ramires-Neto, C., Monteiro, G. A., Delfiol, D. J. Z., Fioratti, E. G., DellaquaJr, J. A., Papa, F. O. and Alvarenga, M. A. (2012). Study of testicular thermoregulation efficiency in stallion with different ages. Journal of Equine Veterinary Science, *32*(8), 510. http://dx.doi.org/10.1016/j.livsci.2013.06.026

51) Renn, N., Onyango, J. and McCormick, W. (2014). Digital infrared thermal imaging and manual lameness scoring as a means of lameness detection in cattle. Veterinary. Clinical Science, 2: 16-23.

52) Ruediger, F.R., Chacur, M.G.M., Chacur, F.C.P.E., Oba, E. and Ramos, A.A. 2016. Digital infrared thermography of the scrotum, semen quality, serum testosterone levels in Nellore bulls (Bos taurusindicus) and their correlation with climatic factors. Network of Scientific Journals from Latin America, 37(1): 221-232.https://doi.org/10.5433/1679-0359.2016v37n1p221

53) Sarubbi, F., Grazioli, G., Auriemma, G. and Palomba, R. (2020). A Potential Application of Infrared Thermography (IRT) in Mediterranean Lactating Buffalo. Asian Basic and Applied Research Journal, *2*(1), 50–55. https://jofresearch.com/index.php/ABAARJ/article/view/17

54) Sathiyabarathi, M., Jeyakumar, S., Manimaran, A., Pushpadass, H. A., Sivaram, M., Ramesha, K. P., Das, D. N., Kataktalware, M. A., Jayaprakash, G. and Patbandha, T. K. (2016). Investigation of body and udder skin surface temperature differentials as an early Bibliography XX indicator of mastitis in Holstein Friesian crossbred cows using digital infrared thermography technique. Veterinary World, 9(12): 1386-1391.https://doi.org/10.14202/vetworld.2016.1386-1391

55) Sathiyabarathi, M., Jeyakumar, S., Manimaran, A., Pushpadass, H.A., Sivaram, A., Ramesha, K.P., Das, D.N. and Kataktalware, M.A. (2017). Infrared thermal imaging of udder skin surface temperature variations to monitor udder health status in Bos indicus (Deoni) cows, Infrared Physics & Technology, 88: 239-244. doi: https://doi.org/10.1016/j.infrared.2017.11.028

56) Sathiyabarathi, M., S. Jeyakumar, A. Manimaran, Heartwin A. Pushpadass, A. Kumaresan, S. S. Lathwal, M. Sivaram, D. N. Das, K. P. Ramesha, and G. Jayaprakash. (2018). "Infrared thermography to monitor body and udder skin surface temperature differences in relation to subclinical and clinical mastitis condition in Karan Fries (Bos taurus× Bos indicus) crossbred cows." Indian Journal of Animal Sciences, 88(6): 694-699. https://doi.org/10.56093/ijans.v88i6.80887

57) Schutz, K.E., Rogers, A.R., Pulonin, Y.A., Cox, N.R. and Tucker, C.B. (2010). The amount of shade influences the behaviour and physiology of dairy cattle. Journal of Dairy Science, 93: 125-33.https://doi.org/10.3168/jds.2009-2416

58) Siddalingaiah, L.B.D., Jeyakumar, S., Manimaran, A., Pushpadass, H.A., Sivaram, M., Sathiyabarathi, M., Kumaresan, A., Kataktalware, M.A. and Ramesha, K.P., 2022. Digital infrared thermal imaging of body and hoof skin surface temperature profile in Murrah buffaloes (Bubalus bubalis): A preliminary report. Buffalo Bulletin, 41(4), pp.623-639.https://doi.org/10.56825/bufbu.2022.4143463

59) Silva, L.K.X., Sousa, J.S., Silva, A.O.A., Junior, J.B., Faturi, C., Martorano, L.G., Franco, I.M., Pantoja, M.H.A., Barros, D.V. and Garcia, A.R. 2017. Testicular thermoregulation, scrotal surface temperature patterns and semen quality of water Buffalo bulls reared in a tropical climate. Andorogia, https://doi.org/10.1111/and.12836

60) Stokes, J.E., Leach, K.A., Main, D.C. and Whay, H.R. (2012). An investigation into the use of infrared thermography (IRT) as a rapid diagnostic tool for foot lesions in dairy cattle. Veterinary Journal, 193, 674–678.https://doi.org/10.1016/j.tvjl.2012.06.052

61) Sykes, D.J., Couvillion, J.S., Cromiak, A., Bowers, S., Schenck, E. and Crenshaw, M. (2012). The use of digital infrared thermal imaging to detect estrus in gilts. Theriogenology, 78:147–52.https://doi.org/10.1016/j.theriogenology.2012.01.030

62) Talukder, S., Gabai, G. and Celi, P. (2015). The use of digital infrared thermography and measurement of oxidative stress biomarkers as tools to diagnose foot lesions in sheep. Small Ruminant Research, 127, 80-85.https://doi.org/10.1016/j.smallrumres.2015.04.006

63) Talukder, S., Kerrisk, K.L., Ingenhoff, L., Thomson, P.C. and Garcia, S.C. (2014). Infrared technology for estrus detection and as a predictor of time of ovulation in dairy cows in a pasture-based system, Journal of Theriogenology, 15: 81(7):925-35.https://doi.org/10.1016/j.theriogenology.2014.01.009

64) Tattersall, G., Andrade, D.V. and Abe, A.S. (2009). Heat exchange from the toucan bill reveals a controllable vascular thermal radiator. Science, 325: 468-470.https://doi.org/10.1126/science.1175553

65) Traulsen, I., Naunin, K., Muller, K. and Krieter, J. (2010). Application of infrared thermography to measure body temperature of sows. Zuchtungskunde, 82: 437-446.
66) Ugorets, V.I., Kozyrev, S.G., Soldatova, I.E., Khairbekov, S.W., Lagkueva, E.A., Gogaev, O.K. 2021.Effect of quality management of pasture lands in the mountain zone of Central Caucasus on dairy cow production. Journal of Livestock Science 12: 317-320 doi. 10.33259/JLivestSci.2021.317-320
67) Weissenbock, N.M., Weiss, C.M., Schwammer, H.M. and Kratochvil, H. (2010). Thermal windows on the body surface of African elephants (Loxodonta xxviii Bibliography africana) studied by infrared thermography. Journal of Thermal Biology, 35: 182- 188.https://doi.org/10.1016/j.jtherbio.2010.03.002
68) Wilhelm, K., Wilhelm, J. and Furll, M. (2014). Use of thermography to monitor sole haemorrhages and temperature distribution over claws of dairy cattle. Veterinary Records, 176: https://doi.org/10.1136/vr.101547
69) Wood, S., Lin, Y., Knowles, T.G. and Main, D.C. (2015). Infrared thermometry for lesion monitoring in cattle lameness. Veterinary Records, *176*, 308–311.https://doi.org/10.1136/vr.102571
70) Yadav, S.K., Singh, P., Kumar, P., Singh, S.V., Singh, A. and Kumar, S. 2019. Scrotal infrared thermography and testicular biometry: Indicator of semen quality in Murrah buffalo bulls. Animal Reproduction Science, https://doi.org/10.1016/j.anireprosci.2019.106145.
71) Zaninelli, M., Redaelli, V., Luzi, F., Bronzo, V., Mitchell, M., Dell'Orto, V., Bontempo, V., Cattaneo, D. and Savoini, G., 2018. First evaluation of infrared thermography as a tool for the monitoring of udder health status in farms of dairy cows. Sensors, 18(3), p.862.https://doi.org/10.3390/s18030862.