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Infrared thermographic and physiological responses of crossbred (Karan Fries) cows and Murrah buffaloes to heat stress in tropical climates

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Abstract

Heat stress limits dairy production across northern India, where cattle and buffaloes are managed together despite differing in skin morphology and evaporative capacity. Responses to a common summer heat load were compared by infrared thermography (IRT). Twenty Karan Fries crossbred cows and twenty Murrah buffaloes under common management at NDRI, Karnal, Haryana, India were studied weekly (April–July 2025). Thermograms of the udder, eye, muzzle, ear and forehead were acquired at 14:00 h (Fluke TiX580), no wallowing, showering or misting being permitted for 2 h beforehand; rectal temperature (RT), respiration rate (RR) and THI (McDowell, 1972) were recorded concurrently. Mean THI was 84.6 ± 0.45 , above heat-stress thresholds for both species. Despite this shared load, surface temperature was higher in buffaloes at every site: eye 38.9 ± 0.13 versus 38.2 ± 0.19 °C ($P = 0.005$), udder ($P = 0.021$), muzzle ($P = 0.015$) and ear ($P = 0.014$); the forehead was 0.6 °C higher but not significant ($P = 0.062$). Buffaloes nevertheless maintained lower RT (39.3 ± 0.10 versus 39.6 ± 0.09 °C; $P = 0.032$) and markedly lower RR (36.6 ± 0.67 versus 42.8 ± 0.74 breaths/min; $P < 0.001$; Cohen's $d = 1.96$). The core-to-shell gradient (RT minus surface) was 0.9 – 1.1 °C narrower in buffaloes throughout. This indicates greater reliance on sensible heat transfer across vasodilated skin in buffaloes, and on respiratory evaporative cooling in cattle. Site-specific IRT thus reveals a thermoregulatory strategy difference undetected by RT or THI alone; cattle-derived surface-temperature thresholds are inappropriate for buffaloes.

Keywords: Heat stress, Infrared thermography, Karan Fries, Murrah buffalo, Temperature–humidity index

1. Introduction

Heat stress is the main climatic constraint on dairy production in tropical India, and it is increasing. During summer, the temperature–humidity index (THI) in the northern plains rises well above the levels at which milk yield, fertility and welfare begin to fall. Cattle and buffaloes on these farms are usually kept together, in the same sheds, and are therefore exposed to the same heat load on the same days.

If the two species do not experience a given THI in the same way, the next question is whether they cope with it differently. Rectal temperature and respiration rate are the standard field measures, but they describe only the outcome of thermoregulation, and both require handling that can disturb the animal. Infrared thermography (IRT) offers a different view. It is non-contact, rapid and spatially resolved, so it reports the temperature of the skin at defined anatomical sites rather than a single value for the whole animal (Tattersall, 2016) ^[16]. Surface temperature is related to core temperature: Metzner *et al.* (2014) ^[8] derived a regression of rectal temperature on maximum udder surface temperature in dairy cattle, although the strength of that relationship depends on the site chosen and on how the region of interest is defined. The skin is where sensible heat is exchanged with the environment, which makes it the logical place to look for differences in how each species sheds heat.

IRT is well established in Indian dairy research, mainly in the context of udder health. It has been used to detect subclinical and clinical mastitis in Karan Fries (Sathiyabarathi *et al.*, 2016;

Sathiyabarathi *et al.*, 2018a; Sathiyabarathi *et al.*, 2018b)^[10, 11, 12] and in buffaloes (Kittur *et al.*, 2024; Gayathri *et al.*, 2024)^[6, 4]. Its use for comparing thermoregulation between species is more limited. Singaravadivelan *et al.* (2025)^[15] applied inner-canthus IRT to Murrah buffalo, crossbred and Vechur calves, and found crossbreds to have the highest eye temperature and the highest respiration rate. That study, however, used calves, was carried out in a humid tropical climate, and imaged a single anatomical site.

The present study therefore compared Karan Fries crossbred cattle and Murrah buffaloes under a common summer heat load in the semi-arid tropics of Haryana, using five IRT sites together with rectal temperature and respiration rate. The aim was to test whether, at the same THI, the two species distribute heat between the core and the skin in the same way.

2. Materials and Methods

2.1. Experimental site

The study was conducted from April to July 2025 at the Livestock Research Centre (LRC), ICAR–National Dairy Research Institute (NDRI), Karnal, Haryana, India. The site lies on the Indo-Gangetic alluvial plain at 250 m above mean sea level (29°43'14.4" N, 76°58'55.2" E). Weather data were obtained from the nearest meteorological station, at the Central Soil Salinity Research Institute (CSSRI), Karnal, 4.2 km from the LRC. Although separated by this distance, both locations lie within the same geographical and climatic region.

2.2. Animals and management

Twenty Karan Fries crossbred cows and twenty Murrah buffaloes were studied. All were in early lactation, of third to fifth parity, and clinically healthy throughout, as confirmed by routine veterinary examination. Both species were kept under uniform management in a loose housing system at the LRC. They were fed according to standard ICAR (2013)^[5] practices, on a balanced ration of green fodder and concentrate in a 60:40 roughage-to-concentrate ratio adjusted to production level. Drinking water was available ad libitum throughout the day.

2.3. Meteorological data and temperature–humidity index

Relative humidity (%) and dry- and wet-bulb temperature (°C) were recorded without interruption at the CSSRI station. THI was calculated according to McDowell (1972)^[7]:

$$\text{THI} = 0.72 (T_{\text{db}} + T_{\text{wb}}) + 40.6$$

where T_{db} is dry-bulb temperature (°C) and T_{wb} is wet-bulb temperature (°C). THI was classified after Armstrong (1994)^[1] for cattle and, for buffaloes, against the recalibrated scale of Umar *et al.* (2021)^[17].

2.4. Physiological measurements

Rectal temperature was recorded with a flexible-tip digital clinical thermometer (Model DMT-423, Hicks Thermometers India Ltd.), inserted into the rectum so that the probe tip remained in contact with the rectal mucosa, and held in position for 1 min before the reading was taken. Respiration rate was determined by counting flank movements over a timed interval. The count was made before the animal was restrained or otherwise handled, so that it was not inflated by handling. Both measurements were taken at 14:00 h, immediately alongside thermogram capture with the infrared camera, at weekly intervals.

2.5. Infrared thermographic acquisition

Thermograms were captured with a Fluke TiX580 infrared thermal camera (Fluke Corporation, Everett, WA, USA) producing 1280 × 960 quality images, with a calibration range of −25.0 to 105.0 °C. The camera features a 240° rotating screen with a 640 × 480 display, a thermal sensitivity of 0.1 °C, and an imaging range of approximately 1–20 m, and scans the image using an uncooled microbolometer with a 120 × 120 focal plane array. The camera was calibrated before the experiment and emissivity was set at 0.95.

Body surface temperature was captured with the above thermal camera at five anatomical windows — udder, eye, muzzle, ear and forehead — following the approach described by Sathiyabarathi *et al.* (2018b)^[12]. A fixed camera-to-animal distance of 1.0–1.5 m was maintained for every site, and all thermograms throughout the study were captured with the same camera by the same operator, minimising variability arising from handling and viewing geometry. Regions of interest were defined as follows: the eye, imaged in lateral view with the marker encompassing the orbital area including the inner canthus; the muzzle, imaged frontally with the marker placed over the hairless nasal planum; the forehead, imaged frontally with the marker placed over the frontal region between the orbits; the ear, imaged laterally with the marker placed over the outer surface of the pinna; and the udder, imaged in caudal view with the marker encompassing the rear quarters.

Thermograms were analysed using SmartView Classic 4.4 (Fluke Systems Inc.). A high-contrast colour palette was applied and the "elliptical marker" tool was positioned manually over each region of interest to determine mean temperature (°C). Thermographic image capture with the camera was carried out at weekly intervals, providing sufficient replicates for analysis.

2.6. Timing of imaging

Thermogram capture with the camera, and the concurrent rectal temperature and respiration rate measurements, were all made at a single daily time point, 14:00 h, corresponding to the period of peak diurnal heat load. To ensure that the surface temperatures captured by the camera reflected the animals' own thermoregulatory state rather than residual surface moisture, animals had no access to wallowing and received no showering or misting for at least 2 h before image capture.

2.7. Statistical analysis

Data were analysed using IBM SPSS Statistics Version 22.0 (SPSS Inc., Chicago, IL, USA). Between-species differences in each parameter were tested by Welch's two-sample t-test, which does not assume equal variances. Effect sizes are reported as Cohen's *d*. The core-to-shell gradient was computed for each site as rectal temperature minus the surface temperature at that site. Significance was assessed at $P < 0.05$, and results are presented as mean ± standard error (SE).

3. Results

3.1. Thermal environment

Mean THI over the study period was 84.6 ± 0.45 . Both species were kept in the same environment on the same days, so THI was identical for the two groups.

3.2. Rectal temperature and respiration rate

Rectal temperature was higher in Karan Fries cattle than in Murrah buffaloes (39.6 ± 0.09 versus 39.3 ± 0.10 °C; $P =$

0.032, $d = 0.71$). Respiration rate was also higher in cattle, at 42.8 ± 0.74 breaths/min against 36.6 ± 0.67 breaths/min in buffaloes, a difference of 6.2 breaths/min ($P < 0.001$, $d = 1.96$). Both parameters are shown in Fig. 1 and Table 1.

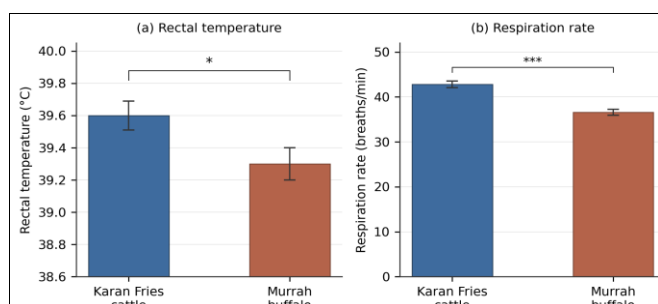


Fig 1: Rectal temperature (a) and respiration rate (b) in Karan Fries cattle and Murrah buffaloes under summer heat load (THI 84.6 ± 0.45). Bars show mean $\pm$ SE, $n = 20$ per species. * $p < 0.05$; *** $p < 0.001$ (Welch's t-test).

3.3. Infrared surface temperatures

Surface temperature was higher in buffaloes than in cattle at all five sites (Fig. 2 and Fig. 3; Tables 1 and 2). The difference was significant at the eye (38.9 ± 0.13 versus 38.2

± 0.19 °C; $P = 0.005$, $d = 0.96$), the udder (38.0 ± 0.23 versus 37.2 ± 0.24 °C; $P = 0.021$), the muzzle (37.2 ± 0.24 versus 36.4 ± 0.20 °C; $P = 0.015$) and the ear (38.4 ± 0.17 versus 37.8 ± 0.16 °C; $P = 0.014$). At the forehead the difference was 0.6 °C in the same direction but was not significant (37.4 ± 0.21 versus 36.8 ± 0.23 °C; $P = 0.062$). Averaged over the five sites, buffalo surface temperature was 0.7 °C higher.

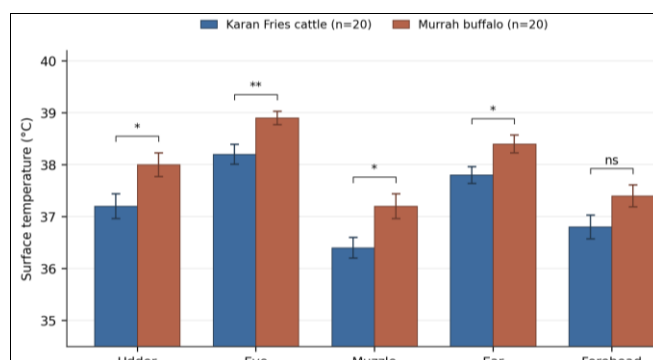


Fig 2: Infrared surface temperatures at five anatomical windows in Karan Fries cattle and Murrah buffaloes. Bars show mean $\pm$ SE, $n = 20$ per species. ** $P < 0.01$; * $P < 0.05$; ns, not significant (Welch's t-test).

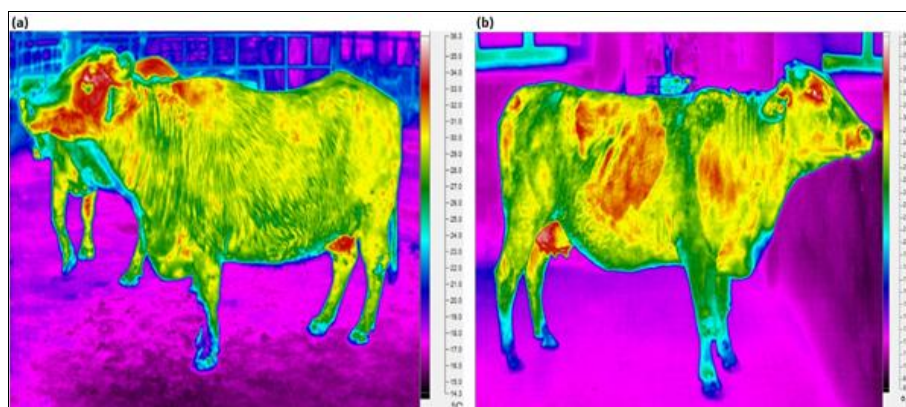


Fig 3: Infrared thermograms illustrating the eye, ear and udder as thermal windows in dairy animals: (a) Murrah Buffalo; (b) Karan Fries cattle

3.4. Core-to-shell gradient

The core-to-shell gradient, calculated as rectal temperature minus surface temperature, was narrower in buffaloes at all five sites (Fig. 4; Table 3). The difference between species

ranged from 0.9 to 1.1 °C. The narrowest gradient was recorded at the eye in buffaloes (0.4 °C, against 1.4 °C in cattle). The widest was recorded at the muzzle in both species (2.1 °C in buffaloes and 3.2 °C in cattle).

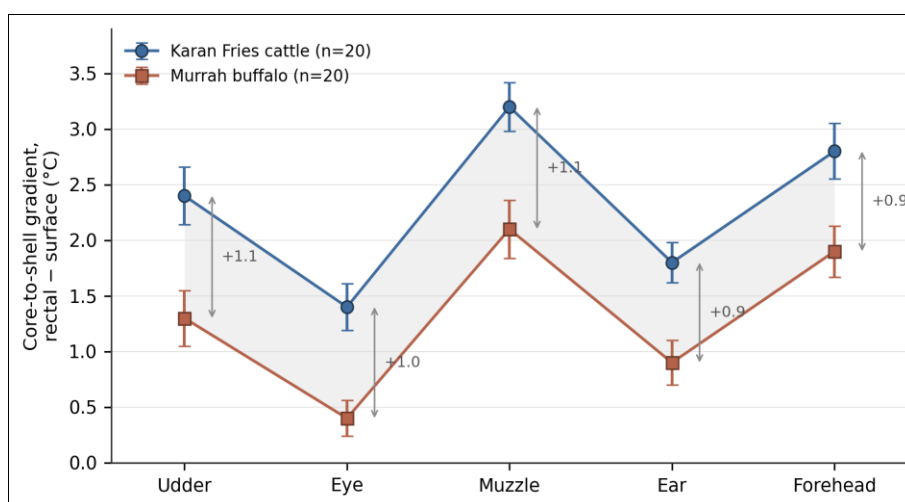


Fig 4: Core-to-shell thermal gradient (rectal temperature minus surface temperature) at five anatomical windows. Values are mean $\pm$ SE, $n = 20$ per species; arrows and labels give the cattle-minus-buffalo difference in gradient at each site. A narrower gradient indicates more heat reaching the skin surface.

Table 1: Mean ($\pm$ SE) THI, physiological responses and infrared surface temperatures of Karan Fries cattle and Murrah buffaloes during the summer season.

Parameter	Karan Fries cattle (n = 20)	Murrah buffalo (n = 20)
THI	84.6 $\pm$ 0.45	84.6 $\pm$ 0.45
Rectal temperature ($^{\circ}$ C)	39.6 $\pm$ 0.09	39.3 $\pm$ 0.10
Respiration rate (breaths/min)	42.8 $\pm$ 0.74	36.6 $\pm$ 0.67
Udder temperature ($^{\circ}$ C)	37.2 $\pm$ 0.24	38.0 $\pm$ 0.23
Eye temperature ($^{\circ}$ C)	38.2 $\pm$ 0.19	38.9 $\pm$ 0.13
Muzzle temperature ($^{\circ}$ C)	36.4 $\pm$ 0.20	37.2 $\pm$ 0.24
Ear temperature ($^{\circ}$ C)	37.8 $\pm$ 0.16	38.4 $\pm$ 0.17
Forehead temperature ($^{\circ}$ C)	36.8 $\pm$ 0.23	37.4 $\pm$ 0.21

THI = temperature–humidity index; SE = standard error of the mean. Both species were exposed to the same environment on the same days, hence identical THI.

Table 2: Between-species comparison of physiological and infrared thermographic parameters (Welch's two-sample t-test).

Parameter	Karan Fries	Murrah	Difference	t	df	P
Rectal temperature ($^{\circ}$ C)	39.6 $\pm$ 0.09	39.3 $\pm$ 0.10	+0.30	2.23	37.6	0.032*
Respiration rate (breaths/min)	42.8 $\pm$ 0.74	36.6 $\pm$ 0.67	+6.20	6.21	37.6	<0.001***
Udder temperature ($^{\circ}$ C)	37.2 $\pm$ 0.24	38.0 $\pm$ 0.23	-0.80	-2.41	37.9	0.021*
Eye temperature ($^{\circ}$ C)	38.2 $\pm$ 0.19	38.9 $\pm$ 0.13	-0.70	-3.04	33.6	0.005**
Muzzle temperature ($^{\circ}$ C)	36.4 $\pm$ 0.20	37.2 $\pm$ 0.24	-0.80	-2.56	36.8	0.015*
Ear temperature ($^{\circ}$ C)	37.8 $\pm$ 0.16	38.4 $\pm$ 0.17	-0.60	-2.57	37.9	0.014*
Forehead temperature ($^{\circ}$ C)	36.8 $\pm$ 0.23	37.4 $\pm$ 0.21	-0.60	-1.93	37.7	0.062

Difference = Karan Fries minus Murrah. * P < 0.05; ** P < 0.01; *** P < 0.001. Values are mean $\pm$ SE, n = 20 per species.

Table 3: Core-to-shell thermal gradient (rectal temperature minus surface temperature, $^{\circ}$ C) at five anatomical windows.

Site	Karan Fries cattle	Murrah buffalo	Difference
Udder	2.40 $\pm$ 0.26	1.30 $\pm$ 0.25	+1.10
Eye	1.40 $\pm$ 0.21	0.40 $\pm$ 0.16	+1.00
Muzzle	3.20 $\pm$ 0.22	2.10 $\pm$ 0.26	+1.10
Ear	1.80 $\pm$ 0.18	0.90 $\pm$ 0.20	+0.90
Forehead	2.80 $\pm$ 0.25	1.90 $\pm$ 0.23	+0.90

Difference = Karan Fries gradient minus Murrah gradient. A narrower gradient indicates more heat reaching the skin. SEs are propagated from the component means.

4. Discussion

The heat load during the study was severe. A THI of 84.6 falls in the moderate band (80–89) on the cattle scale of Armstrong (1994) [1]. On the buffalo scale of Umar *et al.* (2021) [17], where severe stress starts at THI 77, the same value is severe. Thresholds worked out locally are lower still, which makes the load more severe again. Dash *et al.* (2015) [3] studied the Murrah herd, using weather records from the same CSSRI station. They reported a THI threshold of 75 for fertility traits and placed the critical heat-stress zone at THI 80.3 to 81.6. Choudhary and Sirohi (2019) [2] looked at ten years of milk yield from a buffalo herd. They found that yield drops by more than 1% for every unit of THI above 82. The load in the present study was therefore above every published threshold for both species. Since THI was the same for both groups, it cannot explain the differences between them.

Rectal temperature was 0.3 $^{\circ}$ C higher in Karan Fries cattle than in Murrah buffaloes. Karan Fries is a Holstein-Friesian crossbred, and Holstein-Friesian is a *Bos taurus* breed. *Bos taurus* cattle do not tolerate heat well. At a THI of 84.6 they are far outside their comfort zone, and milk yield, fertility and welfare all fall (Armstrong, 1994; Polsky and von Keyserlingk, 2017) [1, 9]. A higher rectal temperature in the cattle means they were less able to keep their core temperature steady under this load.

Sharma *et al.* (2023) [13] compared crossbred cattle and riverine buffalo for 14 months. They found significant differences in rectal temperature between the two species at THI 71, 72 and 73. The present study extends that comparison to a much higher load. The direction of the difference, however, needs explaining. Both Sharma *et al.* (2023) [13] and

Umar *et al.* (2021) [17] report that heat stress starts earlier in buffaloes than in cattle. That would suggest buffaloes should have the higher rectal temperature. The opposite was found here. One likely reason is that the studies looked at different levels of heat load. The THI at which stress begins is not the same as the ability to cope once the load is already severe. A species can start to feel the heat sooner and still hold its core temperature steadier when the heat is extreme.

Respiration rate was 6.2 breaths/min higher in cattle than in buffaloes. This was the largest difference in the study (d = 1.96). Animals breathe faster when they are hot, because panting carries heat away from the body through the lungs and airways. A higher rate in the cattle therefore means they used this route more.

This applies with earlier work. Singaravadelan *et al.* (2025) [15] compared Murrah buffalo, crossbred and Vechur, and found respiration rate highest in the crossbreds. Sharma *et al.* (2023) [13] also found significant differences in respiration rate between crossbred cattle and buffalo at several THI levels. The same pattern appears in different breeds, at different ages and in different climates. This suggests it is a feature of the species, and not something specific to one farm.

Surface temperature was higher in buffaloes at all five sites, by 0.6 to 0.8 $^{\circ}$ C. The reason most likely lies in skin. Buffaloes have only about one-eighth as many sweat glands as cattle. Their skin is also thicker, their hair is sparse, and their skin is dark (Umar *et al.*, 2021; Sharma *et al.*, 2023) [17, 13]. Sweating is therefore not a useful way for a buffalo to lose heat. Instead, a buffalo must move heat out to the skin and let it escape as radiation and convection. To do this, the blood vessels near the skin widen and carry warm blood to the

surface. This makes the skin hotter. A warm skin in a buffalo is therefore a sign that heat is leaving the body, not a sign that heat is trapped inside.

Cattle can sweat, and in this study, they also breathed 17% faster. Both cool the skin by evaporation. This explains why their skin was cooler.

Two parts of the study design support this explanation. First, the animals had no wallowing, showering or misting for at least 2 h before imaging. The skin was therefore dry, so water on the skin cannot explain why the buffaloes were warmer. Second, the same result appeared at all five sites, on the head, the ear and the udder. An error at one site could not produce this pattern.

The present result differs from Singaravadelan *et al.* (2025) [15], who imaged the inner canthus of 6–12-month calves in humid tropical and ranked crossbreds hottest, Murrah buffaloes intermediate and Vechur cattle coolest. Two differences matter. Their calves were growing; the animals here were early-lactation adults shedding the heat of peak milk production. More importantly, evaporation weakens as humidity rises, and cattle then fall back on moving blood to the skin, which raises its temperature (Shephard and Maloney, 2023) [14]. In humid air a crossbred cow cannot sweat effectively and its skin runs hot.

The core-to-shell gradient was narrower in buffaloes at all five sites, by 0.9 to 1.1 °C. This gradient shows how much of the body's heat has reached the skin. A narrow gradient means heat is moving out easily. A wide gradient means heat is being held inside.

At the eye, the gradient in buffaloes was only 0.4 °C, against 1.4 °C in cattle. The buffalo skin was therefore almost as warm as the body core, which means heat was reaching the surface easily. The difference between the species was similar at every site, between 0.9 and 1.1 °C. Because it was the same everywhere, it points to a whole-body difference in blood flow to the skin, and not to something happening at one site only.

Taken together, the three measurements describe two different ways of losing heat. Buffaloes moved more heat out through their skin. Cattle relied more on panting and still ended up hotter inside.

Surface temperature and core temperature placed the two species in opposite order at the same THI. A thermal image judged by cattle standards will therefore give the wrong answer for a buffalo. A buffalo with an eye temperature of 38.9 °C is not under more heat stress than a cow at 38.2 °C. In the present study the buffalo was the animal with the cooler core and easier breathing.

Choudhary and Sirohi (2019) [2] studied buffalo herd and found a critical THI threshold of 74 for buffaloes. This is higher than the threshold for crossbred cows at the same site. Buffaloes here can therefore take more heat before milk yield starts to fall. The present study suggests why. At the same THI, the buffalo skin was warmer, the core was cooler, and the breathing was easier.

For farms that keep both cattle and buffaloes, thermal images should therefore be judged separately for each species. Umar *et al.* (2021) [17] made the same argument for THI. The present results extend it to infrared thermography.

5. Conclusion

Under a common summer heat load of THI 84.6, Karan Fries cattle and Murrah buffaloes did not respond in the same way. Murrah Buffaloes maintained a lower rectal temperature and a substantially lower respiration rate while running a warmer

skin at all five thermographic windows, producing a core-to-shell gradient roughly 1 °C narrower than that of Karan Fries cattle at every site. The two species appear to be routing heat differently — Murrah buffaloes more through sensible transfer across a vasodilated skin, Karan Fries cattle more through respiratory evaporative effort, and with less success at defending core temperature. Because surface and core measures rank the two species in opposite directions, infrared thermographic reference values derived from cattle cannot be applied to buffaloes, and thermal screening on mixed farms should be interpreted against species-specific expectations.

Declarations

Ethical approval

The approval of all the experiments carried out in this research work was obtained from the Animal Ethics Committee of the National Dairy Research Institute, Karnal, according to the Committee for Control and Supervision of Experiments on Animals rules laid down by the Government of India (No. 1705/GO/Re/L/13/CPCSEA, dated 23/07/2021).

Conflict of Interest

The authors declare no conflict of interest.

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Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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