

Thermal Thresholds and Body Surface Temperature Dynamics in Sub-Tropical Jamunapari and Barbari Goats

Srashti Dixit

srashtidixit5@gmail.com

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan <https://orcid.org/0009-0005-1615-9731>

Rajneesh Sirohi

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Brijesh Yadav

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Mamta .

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Ajay Kumar

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Yajuvendra Singh

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Chandan Kumar

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Vishakha Singh Gaur

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Charu Singh

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Akanksha Detha

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Laxmikant Shukla

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Aakansha Mathur

DUVASU: Uttar Pradesh Pandit Deen Dayal Upadhyaya Pashu Chikitsa Vigyan Vishwavidyalaya Evam Go Anusandhan Sansthan

Research Article

Keywords: Eyeball, Ear, Lower critical temperature, Muzzle, Perineum, Upper critical temperature

Posted Date: August 25th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10191537/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Thermal Thresholds and Body Surface Temperature Dynamics in Sub-Tropical Jamunapari and Barbari Goats

¹Srashti Dixit, ¹Rajneesh Sirohi, ²Brijesh Yadav, ¹Mamta, ¹Ajay Kumar, ¹Yajuvendra Singh, ¹Chandan Kumar,

¹Vishakha Singh, ¹Charu Singh, ¹Akanksha Detha, ¹Laxmikant Shukla, ¹Aakansha Mathur

¹Department of Livestock Production Management, ²Department of Veterinary Physiology

College of Veterinary Science and A.H., DUVASU, Mathura (U.P.), India -281001

Corresponding author: Srashti Dixit

Email: srashtidixit5@gmail.com

Abstract

This study evaluated the body surface temperatures (BSTs), temperature-humidity index (THI) thresholds and lower/upper critical temperatures (LCT/UCT) of goats under thermal stress. Conducted in a Psychrometric chamber, the trial utilized 12 goats (six Jamunapari, six Barbari; aged 4.5–5 years, 20–30 kg). During the cold stress phase, goats were exposed to decreasing ambient temperatures from 24°C to 9°C for six hours daily over 10 consecutive days per temperature level. In the heat stress phase, temperatures were progressively increased (24°C to 42°C; THI 67–93). On the tenth day of each exposure, BSTs at the eyeball, muzzle, ear and perineum were measured using infrared thermography. Segmented regression analysis was applied to identify precise LCT and UCT breakpoints. Results demonstrated that thermal stress significantly altered BSTs, with Jamunapari goats exhibiting greater magnitude changes than Barbari goats in both extreme conditions. Under heat stress, the UCT breakpoints (THI/°C) for the eyeball, ear, muzzle and perineum in Jamunapari goats were 78.45/31.02, 78.45/31.38, 78.93/31.56 and 89.62/28.14, respectively. For Barbari goats, these UCT thresholds were 76.79/28.86, 85.58/34.80, 76.07/28.50 and 89.62/28.86. During cold stress, Jamunapari exhibited LCT breakpoints (THI/ °C) for the same anatomical sites at 62.19/13.65, 68.17/20.10, 67.53/19.65 and 62.83/16.05. Therefore, these findings establish precise regional thermal limits, highlighting breed-specific thermoregulatory adaptations and providing reference thresholds for surface temperatures in goats for improving their management and welfare in sub-tropical climates.

Keywords: Eyeball, Ear, Lower critical temperature, Muzzle, Perineum, Upper critical temperature

Abbreviations: BST: Body surface temperature; LCT: Lower critical temperature; UCT: Upper critical temperature; THI: Temperature Humidity Index; Tdb: Dry bulb temperature; Twb: Wet bulb temperature; RH: Relative humidity; T_{Max}: Maximum temperature; T_{Min}: Minimum temperature; AvgRH: Average Relative humidity; Infrared thermography: IRT

Introduction

Small ruminant production and welfare are continuously threatened by environmental stressors like extreme ambient temperatures, solar radiation and humidity (Berihulay et al., 2019; Joy et al., 2020), particularly in tropical, subtropical, and arid regions (Sejian et al., 2022). Climate variability driven by Super El Niño and La Niña increases a dual thermal challenge in the Indian subcontinent (IMD, 2025; NOAA, 2025). As goat farming gains economic significance, understanding these environmental interactions is critical (Banerjee et al., 2015). Although goats exhibit remarkable resilience due to strong thermotolerance and disease resistance (Ortiz et al., 2019; Reshma Nair et al., 2021), they still suffer significant production and welfare declines under severe stress. While heat stress is extensively studied, cold stress also forces compensatory mechanisms to prevent core heat loss, resulting in slow growth, increased mortality and substantial global economic losses (Hu et al., 2021). Determining the critical THI and temperature breakpoints is essential for identifying climate-resilient breeds (Ferreira et al., 2023) and their climate smart management. Exposing goats to ambient temperature above UCT and below LCT results in heat stress and cold stress, respectively (Yousef, 1985). Thus, defining the LCT and UCT for thermal stress is crucial for implementing timely management interventions.

While evaluating body temperature is vital for monitoring physiological status (Nikkhah 2015), standard rectal measurements require physical restraint that induces stress, masks true physiological responses (Hoffmann et al. 2013) and risks injury to both animals and handlers (Nääs et al. 2014). Consequently, IRT provides a non-invasive alternative for assessing thermal adaptation (Silva et al. 2014; Giannetto et al. 2020; Costa et al. 2023) by capturing emitted infrared radiation as thermograms (Church et al. 2014; McManus et al. 2016). These thermograms detect rapid body surface temperature (BST) fluctuations triggered by skin thermoreceptors (Lezama-García et al. 2022) and driven by radiative heat exchange and vasomotor blood redistribution (da Silva and Maia 2012; McCafferty et al. 2018). This heat exchange occurs primarily at highly vascularized, hairless 'thermal windows' (Andrade 2015; Lowe et al. 2019; Napolitano et al. 2020; Mota-Rojas et al. 2021a). Understanding the distinct responses of these sites is crucial for comprehending whole-body thermoregulation. Targeting these sensitive windows enables stress-free physiological evaluations (Nääs et al. 2014; Flores-Peinado et al. 2020; Mota-Rojas et al. 2021a) and positions IRT-derived BSTs as reliable indicators of thermal tolerance in goats (Čukić et al. 2023; Samara et al. 2024).

To accurately map these thresholds, comparing breeds with distinct phenotypic traits is essential. The Jamunapari is a large-framed breed with notably long, pendulous ears that potentially facilitate heat dissipation (Singh

et al. 2010), whereas the Barbari is smaller, compact and highly prolific (Singh et al. 2020). Despite their adaptability, comprehensive data regarding the dynamic variations of surface temperatures in these sub-tropical Indian goats remains absent and exact breakpoints for BSTs are undefined. Therefore, this study aimed to continuously monitor BSTs at the eyeball, ear, muzzle and perineum in Jamunapari and Barbari goats. Using segmented regression analysis, this research seeks to precisely identify LCT and UCT breakpoints, establishing critical reference thresholds for these breeds under thermal stress.

Material and Methods

Location of experiment

The study was conducted in the Psychrometric chamber of Professor M.D. Pandey Bio-Climatology Laboratory within the Department of Veterinary Physiology, DUVASU, Mathura (U.P) from November, 2024 to June, 2025. This semi-arid region experiences extreme climate fluctuations, with summer temperatures peaking at 48°C and winter lows of 2°C. Annual rainfall averages 793 mm, while RH ranges from 20% to 80%.

Psychrometric/ Climatic chamber

This airtight, puff-insulated steel chamber (9.0m × 4.0m × 3.0m) is equipped with individual tie-stalls, feeders and diagonally placed inlet and outlet exhaust fans to ensure optimal air circulation. It provides precise environmental control, regulating temperatures from 5–55°C ($\pm 1^\circ\text{C}$ accuracy) and RH between 15–75%. An external automation panel programs the specific microclimate, which is monitored continuously by internal sensors. The system requires a 10 to 30-minute stabilization phase to achieve the programmed conditions prior to animal introduction. Throughout the exposure period, a data logger systematically records environmental variables at regular intervals.

Experimental Animals

Twelve clinically healthy adult female goats (six Jamunapari and six Barbari) were transported from the university farm complex to the chamber (Fig.1). Prior to the experiment, all goats were dewormed, vaccinated as per standard health schedules and acclimatized to the chamber for 10 days to minimize confinement and handling stress.

Experimental design

The study employed a repeated-measures design where goats served as their own controls across cold (Nov–Jan; 24°C to 9°C, 6 levels) and heat stress phases (Apr–Jun; 24°C to 42°C, THI 67–93, 7 levels), separated by a two-month rest.

Goats were exposed for 6 hours daily for 10 consecutive days per level, with BSTs recorded on day 10. Between exposures, animals rested in a controlled antechamber. Transition temperatures were maintained within $\pm 4-5^{\circ}\text{C}$ to prevent thermal shock. Chamber conditions were continuously monitored via dry and wet-bulb thermometers, with THI calculated according to NRC (1971):

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

Meteorological parameters: The schedule of meteorological variables of chambers is presented in Table 1 and 2

Table 1 Schedule of Temperature, Relative Humidity & THI of the Chamber during winter phase

Psychrometric Chamber					Antechamber		
T _{db} (°C)	T _{wb} (°C)	RH (%)	THI	CO ₂ (PPM)	T _{Max} (°C)	T _{Min} (°C)	AvgRH (%)
24	23.50	95.90	74.80	800±50	26.42	21.20	54.20
21	20.50	95.60	70.48	800±50	25.21	20.80	58.12
18	17.50	95.20	66.16	800±50	21.43	16.51	64.00
15	14.60	95.90	61.91	800±50	19.81	12.23	70.21
12	11.76	97.30	57.71	800±50	15.54	8.80	76.11
9	8.80	97.50	53.42	800±50	12.24	6.41	74.23

Table 2 Schedule of Temperature, Relative Humidity & THI of the Chamber during summer phase

Psychrometric Chamber					Antechamber		
T _{db} (°C)	T _{wb} (°C)	RH (%)	THI	CO ₂ (PPM)	T _{Max} (°C)	T _{Min} (°C)	AvgRH (%)
24	23.5	95.90	74.80	800±50	30.50	22.32	76.34
27	24	77.90	77.32	800±50	33.12	23.50	64.40
30	25	66.50	80.20	800±50	33.41	25.40	68.60
33	27	62.60	83.80	800±50	36.40	26.80	65.23
36	30	64.40	88.12	800±50	38.22	27.50	62.90
39	32	61.00	91.72	800±50	41.10	28.60	59.36
42	34	58.00	95.32	800±50	44.50	29.80	55.21

Infrared Thermography

BSTs (°C) of goats were recorded using an Infrared thermography camera (FLIR Series A320; FLIR Systems, USA) from four anatomical regions: Eyeball, Ear, Muzzle and Perineum (Fig. 2 and Fig. 3) by restraining goats inside the chamber to minimize movement and to avoid direct solar radiation and air currents. The camera was positioned at a

fixed distance of approximately 1 meter perpendicular to the site, with preset emissivity. The recorded thermographic images were stored digitally and analyzed using FLIR Tools software (version 6.4) to obtain mean BST values.

Statistical analysis

Statistical analyses, comprising repeated-measures one-way ANOVA and Tukey's post-hoc test, were performed in SPSS v26.0 (IBM Corp., USA) following Snedecor and Cochran (1994). Segmented regression was conducted using SegReg (Oosterbaan 2017) to identify breakpoints and establish the lower and upper critical temperature/THI thresholds for BSTs. Visualizations, including heat maps and graphs, were created using Graph Pad Prism v8.0.2.

Results

Effect of cold stress on Body surface temperatures of Jamunapari goats

In Jamunapari goats, muzzle temperature decreased significantly at 21°C, while other regions remained stable ($p > 0.05$). By 18°C, ear temperature also dropped (Table 5, Fig. 4). Further cooling to 9°C caused progressive, highly significant declines in both the muzzle and ear, with the muzzle showing the maximum overall reduction, whereas eyeball and perineum temperatures exhibited only modest decreases ($p < 0.05$) throughout the cold phase.

Table 5 Body surface temperature (Mean±SEM) of Jamunapari goats in cold stress

Temperature (°C)/ THI	Eyeball	Muzzle	Ear	Perineum
24 (THI=74.80)	35.05 ^a ±0.29	32.20 ^a ±0.28	33.76 ^a ±0.29	35.25 ^a ±0.24
21 (THI=70.48)	35.01 ^a ±0.27	32.08 ^b ±0.29	33.71 ^a ±0.39	35.23 ^a ±0.21
18 (THI=66.16)	34.81 ^a ±0.29	30.00 ^c ±0.33	30.91 ^b ±0.19	35.13 ^a ±0.21
15 (THI=61.91)	34.55 ^b ±0.35	24.48 ^d ±0.19	25.53 ^c ±0.18	34.95 ^a ±0.17
12 (THI=57.71)	33.96 ^c ±0.36	16.66 ^e ±0.19	17.03 ^d ±0.16	34.38 ^b ±0.19
9 (THI=53.42)	32.36 ^d ±0.44	15.21 ^f ±0.33	16.65 ^d ±0.31	33.66 ^c ±0.34

Means bearing different superscripts^(abcdef) within the columns vary significantly ($p < 0.05$)

Lower Critical Temperatures and THIs for BSTs in Jamunapari goats

In Jamunapari goats, eyeball, ear, muzzle and perineum exhibited lower critical thresholds at THI 62.19, 68.17, 67.53 and 62.83, with corresponding temperature exposures of 13.65, 20.10, 19.65 and 16.05, respectively (Fig. 10 and 11).

Effect of cold stress on Body surface temperatures of Barbari goats

In Barbari goats, BSTs across all sites remained stable between 24°C and 21°C ($p > 0.05$) (Table 6, Fig. 5). At 18°C, significant temperature reductions occurred in the ear and muzzle, while the eyeball and perineum remained

unchanged. Subsequent cooling to 9°C induced marked, progressive declines in both ear and muzzle temperatures. By 9°C, the eyeball and perineum had exhibited only gradual, modest decreases ($p < 0.05$), whereas the muzzle recorded the maximum overall temperature reduction among all measured anatomical sites.

Table 6 Body surface temperature (Mean±SEM) of Barbari goats in cold stress

Temperature(°C)/ THI	Eyeball	Muzzle	Ear	Perineum
24 (THI=74.80)	35.05 ^a ±0.30	32.28 ^a ±0.26	33.76 ^a ±0.23	35.25 ^a ±0.30
21 (THI=70.48)	34.95 ^a ±0.30	32.18 ^a ±0.28	33.75 ^a ±0.26	35.20 ^a ±0.25
18 (THI=66.16)	35.00 ^a ±0.27	30.53 ^b ±0.35	31.65 ^b ±0.30	35.16 ^a ±0.31
15 (THI=61.91)	34.83 ^a ±0.21	24.60 ^c ±0.23	26.45 ^c ±0.36	35.11 ^a ±0.24
12 (THI=57.71)	34.78 ^a ±0.24	17.23 ^d ±0.15	17.71 ^d ±0.28	34.71 ^a ±0.22
9 (THI=53.42)	33.83 ^b ±0.20	16.56 ^c ±0.15	17.76 ^d ±0.32	34.18 ^b ±0.18

Means bearing different superscripts (abcdef) within the columns vary significantly ($p < 0.05$)

Lower Critical Temperatures and THIs for BSTs in Barbari goats

In Barbari goats, eyeball, ear, muzzle and perineum exhibited lower critical thresholds at THI 58.55, 67.74, 67.53 and 61.97, with corresponding temperature exposures of 12.60, 19.65, 19.65 and 15.45, respectively (Fig. 10 and 11)..

Effect of heat stress on Body surface temperatures of Jamunapari goats

In Jamunapari goats (Table 3, Fig. 6), BSTs remained stable across all sites through 27°C ($p > 0.05$). At 30°C, significant elevations occurred in the eyeball, ear and perineum, whereas the muzzle only exhibited a significant increase at 33°C. Progressive heating to 42°C induced continuous elevations across all sites; however, at this peak thermal load, the muzzle displayed the most pronounced overall temperature increase.

Table 3 Body surface temperature (Mean±SEM) of Jamunapari goats during heat stress

Temperature (°C)/THI	Eye ball	Muzzle	Ear	Perineum
24 (THI=74.80)	35.05±0.29	32.21±0.29	33.76±0.29	35.33±0.25
27 (THI=77.32)	35.08±0.28	32.36±0.24	33.80±0.33	35.51±0.24
30 (THI=80.20)	35.31 ^b ±0.29	32.56±0.26	34.10 ^b ±0.31	35.88 ^b ±0.21
33 (THI=83.80)	35.73 ^c ±0.26	33.33 ^b ±0.32	34.75 ^c ±0.30	36.85 ^c ±0.18
36 (THI=88.12)	37.70 ^d ±0.27	35.10 ^c ±0.30	36.21 ^d ±0.48	37.66 ^d ±0.18
39 (THI=91.72)	38.73 ^e ±0.23	37.15 ^d ±0.38	37.70 ^e ±0.26	38.21 ^e ±0.14
42 (THI=95.32)	39.85 ^f ±0.25	39.10 ^e ±0.05	39.38 ^f ±0.20	39.26 ^f ±0.20

Means bearing different superscripts (abcdef) within the columns vary significantly ($p < 0.05$)

Upper Critical Temperatures and THI for BSTs in Jamunapari goats

The segmented linear regression analysis revealed breakpoints at THI 78.45 and temperature exposure 31.02 for eyeball, THI 78.45 and temperature exposure 31.38 for ear, THI 78.93 and temperature exposure 31.56 for muzzle and THI 89.62 and temperature exposure 28.14 for perineum (Fig. 8 and 9).

Effect of heat stress on Body surface temperatures of Barbari goats

In Barbari goats, thermal stability was sustained across ambient temperatures of 24°C to 30°C ($p > 0.05$), with only the eyeball displaying a modest, significant increase at 30°C (Table 4, Fig. 7). However, at 33°C there was a significant temperature elevations across all assessed anatomical sites. These surface temperatures continued to elevate significantly and consistently through the 36°C and 39°C exposures, culminating at the 42°C threshold. During this peak heat stress, the muzzle recorded the highest temperature surge relative to the other monitored sites.

Table 4 Body surface temperature (Mean±SEM) of Barbari goats during heat stress

Temperature (°C)/ THI	Eye ball	Muzzle	Ear	Perineum
24 (THI=74.80)	35.05 ^a ±0.30	32.28 ^{ab} ±0.26	33.76 ^a ±0.23	35.21 ^{ab} ±0.28
27 (THI=77.32)	35.18 ^a ±0.25	32.23 ^b ±0.33	33.88 ^a ±0.21	35.25 ^a ±0.25
30 (THI=80.20)	35.41 ^b ±0.25	32.83 ^a ±0.25	33.91 ^{ab} ±0.20	35.65 ^b ±0.20
33 (THI=83.80)	36.38 ^e ±0.32	34.48 ^e ±0.41	34.55 ^b ±0.37	36.36 ^c ±0.17
36 (THI=88.12)	37.51 ^d ±0.06	36.05 ^d ±0.29	35.03 ^c ±0.39	37.01 ^d ±0.09
39 (THI=91.72)	38.26 ^e ±0.10	37.66 ^e ±0.30	36.36 ^d ±0.37	37.86 ^e ±0.11
42 (THI=95.32)	39.25 ^f ±0.20	38.63 ^f ±0.15	38.83 ^e ±0.17	38.91 ^f ±0.16

Means bearing different superscripts (^{abcdef}) within the columns vary significantly ($p < 0.05$)

Upper Critical Temperatures and THI for BSTs in Barbari goats

The segmented linear regression analysis revealed breakpoints at THI 76.79 and temperature exposure 28.86 for eyeball, THI 85.58 and temperature exposure 34.80 for ear, THI 76.07 and temperature exposure 28.50 for muzzle and THI 89.62 and temperature exposure 28.86 for perineum (Fig. 8 and 9).

Discussion

Effect of Cold stress on Body Surface Temperatures of Goats

Under cold exposure, marked drop in BST is driven by compensatory peripheral vasoconstriction, which redirects blood volume away from skin surface toward the visceral core (Al-Tamimi 2007). By peripheral

vasoconstriction, the animals minimize heat loss, effectively turning the skin tissue into an insulating barrier against hypothermia (Mota-Rojas et al. 2021b). The two breeds exhibited distinctly different thresholds for these vascular responses. Jamunapari goats initiated peripheral cooling earlier, with muzzle and eyeball temperatures dropping significantly at 21°C and 15°C, respectively. In contrast, Barbari goats maintained thermal stability in these regions much longer, demonstrating significant declines only at 18°C (muzzle) and 9°C (eyeball). Similarly, perineum temperature decreased earlier in Jamunapari goats, whereas Barbari goats preserved perineum warmth down to 9°C. Both breeds experienced initial ear temperature reductions at 18°C, followed by a sharp decline between 12°C and 9°C. This localized aural cooling is facilitated by the highly reactive network of the auricular arteries and veins (Violin et al. 2025). Overall, the magnitude of BST reduction across all anatomical sites was more pronounced in Jamunapari goats indicating their lower cold thermotolerance compared to the resilient Barbari breed.

Lower critical temperatures (LCT) and THIs for Body surface temperatures

Across both breeds, the cold threshold hierarchy remained consistent: ear, muzzle, perineum and lastly, the eyeball. The ear responded earliest to cold via rapid peripheral vasoconstriction to prevent core heat loss. This autonomic response occurred earlier in Jamunapari goats, attributed to their long, highly vascularized ears and large surface-area-to-mass ratio facilitating major heat loss (Romanovsky 2014). The earlier Jamunapari perineum response is similarly driven by larger hindquarter mass and sparsely haired structures accelerating local heat exchange. Conversely, the eyeball exhibited the lowest breakpoints, proving the most cold-tolerant. Supplied heavily by the internal carotid artery, ocular temperature remains tightly coupled to core thermal status (Mota-Rojas et al. 2021b). This prolonged stability demonstrates that cranial blood flow is prioritized to protect the brain, even as the extremities undergo severe cooling (Leon-Medina et al. 2026). Overall, consistently delayed breakpoints in Barbari goats confirm their superior cold tolerance.

Effect of heat stress on Body surface temperatures (BSTs) of Goats

Skin temperature serves as a highly sensitive, rapid indicator of microclimatic adaptation, rising with environmental heat as dermal vasodilation redirects core body heat to the skin surface for rapid dissipation (Maria et al. 2018; Yamani & Koluman 2020; Mota-Rojas et al. 2021b). Consistent with observations across numerous goat breeds globally, the present study recorded significant elevations in BSTs across all measured sites during heat stress,

reinforcing BST as a reliable metric for physiological monitoring (Marques et al. 2021; Francis et al. 2024; Gopikrishnan et al. 2025).

Eyeball temperatures in both breeds raised significantly from 30°C onward. This response is driven by rapid changes in local blood flow to the eye, making ocular temperature a strong, non-invasive indicator of physiological stress (Idris et al. 2021; Ghezzi et al. 2024). Muzzle temperature remained stable until rising at 33°C, eventually reaching the maximum thermal peak at 42°C due to increased respiration which is a primary mechanism dissipating up to 30% of metabolic heat causing shifts in local blood flow and heart rate variability (Nienaber and Hahn 2007; Stewart et al. 2017). Breed specific differences were clearly evident as ear and perineum temperatures in Jamunapari goats escalated at 30°C, Barbari goats displayed delayed elevations, maintaining stability up to 33°C. Overall, Jamunapari goats experienced higher BSTs than Barbari goats indicating superior heat tolerance of the Barbari breed, likely attributed to a smaller structural profile which provides a higher surface-area-to-mass ratio to optimize heat dissipation, aligning recent comparative thermoregulatory studies (Yamin et al. 2022; Syafiq et al. 2023; Francis et al. 2024).

Upper critical temperatures (UCT) and THIs for Body surface temperatures

BSTs serve as predictive diagnostic benchmarks for characterizing breed specific thermal tolerance (Jereme and Romero 2026). Study revealed distinctly divergent patterns of thermoregulatory responses between Jamunapari and Barbari goats. In Barbari goats, upper critical thresholds for the eyeball and muzzle occurred earlier than in Jamunapari goats indicating that Barbari goats deploy rapid, highly sensitive cephalic circulatory adjustments to defend core homeothermy early in a thermal challenge (Idris et al. 2021; Leon-Medina et al. 2026). This superior resilience is strongly linked to their smaller structural profile, providing a higher surface-area-to-mass ratio that promotes heat tolerance (Seixas et al. 2017; Mitchell et al. 2018). Conversely, the ear, acts as a critical thermal window for sensible heat loss (Zhou et al. 2026), exhibited a highly sensitive and contrasting thermal response. Delayed UCT of ear in Barbari goats compared to Jamunapari demonstrated their ability to withstand higher heat loads before relying on their ears for maximum heat dissipation. However, both breeds shared an identical THI breakpoint for perineum, despite slightly different temperature thresholds. This reveals a shared physiological threshold under severe heat stress (THI > 89). At this extreme, both breeds display a uniform thermoregulatory adjustment, maximizing peripheral blood flow as a final adaptive strategy to dissipate excess heat.

Therefore, the study establishes precise body surface temperature breakpoints, revealing a distinct anatomical hierarchy in the thermoregulatory responses of Indian sub-tropical goats. Specifically, the muzzle emerged as the most responsive site, exhibiting the maximum temperature elevation and decrease during thermal extremes. While the eyeball maintained the greatest thermal stability. Barbari goats demonstrated superior thermotolerance and delayed thermal thresholds compared to the Jamunapari breed under both heat and cold extremes. Amid climate change, integrating these baseline thermal thresholds into precision livestock farming and breeding programs can significantly enhance climate-smart management, welfare and productivity in goats

Acknowledgements: The authors sincerely thank Dr. Rajneesh Sirohi, Guide and Head of LPM at DUVASU, for his continuous guidance. Special thanks to Dr. Brijesh Yadav for his supervision and providing the Bioclimatology Lab facilities. The support and infrastructure provided by all LPM faculty members and the DUVASU administration are also gratefully acknowledged.

References

- Al-Tamimi HJ (2007) Thermoregulatory response of goat kids subjected to heat stress. *Small Rumin Res* 71:280-285
- Andrade DV (2015) Thermal Windows and Heat Exchange. *Temperature* 2:451.
- Banerjee D, Upadhyay RC, Chaudhary UB, Kumar R, Singh S, Ashutosh, De S (2015) Seasonal variations in physio-biochemical profiles of Indian goats in the paradigm of hot and cold climate. *Biol Rhythm Res* 46:221-236.
- Berihulay H, Abied A, He X, Jiang L, Ma Y (2019) Adaptation mechanisms of small ruminants to environmental heat stress. *Animals* 9:75.
- Church JS, Hegadoren PR, Paetkau MJ, Miller CC, Regev-Shoshani G, Schaefer AL, Schwartzkopf-Genswein KS (2014) Influence of environmental factors on infrared eye temperature measurements in cattle. *Res Vet Sci* 96:220-226.
- Costa EDO, Gordiano LA, Ferreira FG, Santos SA, de Carvalho GGP, de Araújo MLG, Tosto MS (2023) Thermography as an indicator of goat welfare in an intensive production system. *Trop Anim Health Prod* 55:373.

230 Čukić A, Rakonjac S, Djoković R, Cincović M, Bogosavljević-Bošković S, Petrović M, Savić Ž, Andjušić L, Andjelić
 231 B (2023) Influence of Heat Stress on Body Temperatures Measured by Infrared Thermography, Blood
 232 Metabolic Parameters and Its Correlation in Sheep. *Metabolites* 13:957.

233 da Silva RG, Maia ASC (2012) *Principles of Animal Biometeorology*. Springer, New York

234 Francis FLA, Parkunan T, De S (2024) Effect of season on hematological, physio-biochemical and electrolyte profiles
 235 of indigenous goat breeds. *Biol Rhythm Res* 55:520-534.

236 Ferreira J, Silveira R, Façanha D, McManus C (2023) Understanding the environmental stress on thermoregulation
 237 actions of native goats using broken-line regression. *Int J Biometeorol* 67:1031-1037.

238 Flores-Peinado S, Mota-Rojas D, Guerrero-Legarreta I, Mora-Medina P, Cruz-Monterrosa R, Gómez-Prado J,
 239 Guadalupe Hernández M, Cruz-Playas J, Martínez-Burnes J (2020) Physiological Responses of Pigs to
 240 Preslaughter Handling: Infrared and Thermal Imaging Applications. *Int J Vet Sci Med* 8:71-84.

241 Ghezzi MD, Napolitano F, Casas-Alvarado A, Hernández-Ávalos I, Domínguez-Oliva A, Olmos-Hernández A,
 242 Pereira AMF (2024) Utilization of Infrared Thermography in Assessing Thermal Responses of Farm
 243 Animals under Heat Stress. *Animals* 14:616

244 Giannetto C, Arfuso F, Giudice E, Giancesella M, Fazio F, Panzera M, Piccione G (2020) Infrared methodologies for
 245 the assessment of skin temperature daily rhythm in two domestic mammalian species. *J Therm Biol*
 246 92:102677.

247 Gopikrishnan P, Jose RA, Abraham J, Mathew DKD, Raji K, Ibrahim NPS, Vijayan V (2025) The effect of heat stress
 248 on the physiological parameters and blood biomarkers in Malabari goats. *Cell Stress Chaperones*.
 249 30:100082.

250 Hoffmann G, Schmidt M, Ammon C, Rose-Meierhöfer S, Burfeind O, Heuwieser W, Berg W (2013) Monitoring the
 251 body temperature of cows and calves using video recordings from an infrared thermography camera. *Vet*
 252 *Res Commun* 37:91-99.

253 Hu L, Brito LF, Abbas Z, Sammad A, Kang L, Wang D, Wu H, Liu A, Qi G, Zhao M, et al (2021) Investigating the
 254 short-term effects of cold stress on metabolite responses and metabolic pathways in inner-mongolia sanhe
 255 cattle. *Animals* 11:2493

256 Idris M, Uddin J, Sullivan M, McNeill DM, Phillips CJC (2021) Non-Invasive Physiological Indicators of Heat Stress
257 in Cattle. *Animals* 11:71.

258 India Meteorological Department (IMD) (2025) Seasonal Outlook for Temperatures over India. Ministry of Earth
259 Sciences. <http://imd.gov.in>. Accessed 28 April 2026.

260 Jerem P, Romero LM (2026) Body surface temperatures as biomarkers of physiological environmental adaptation in
261 wild birds and mammals. *Biol Rev Camb Philos Soc* 101:336-363.

262 Joy A, Dunshea FR, Leury BJ, Clarke IJ, DiGiacomo K, Chauhan SS (2020) Resilience of small ruminants to climate
263 change and increased environmental temperature: A review. *Animals* 10:867.

264 Leon-Medina L, Jackson C, Dillahunty M, Mills M, Lemley CO, Rios L (2026) 148. Non-Invasive Thermal Imaging
265 of Unrestrained Goats in Paddocks: Identifying Optimal Regions for Accurate Body Temperature
266 Measurement. *J Anim Sci* 104(Supplement_2):skag057-102.

267 Lezama-García K, Mota-Rojas D, Pereira AMF, Martínez-Burnes J, Ghezzi M, Domínguez A, Gómez J, de Mira
268 Geraldo A, Lendez P, Hernández-Ávalos I, et al (2022) Transient Receptor Potential (TRP) and
269 Thermoregulation in Animals: Structural Biology and Neurophysiological Aspects. *Animals* 12:106.

270 Lowe G, Sutherland M, Waas J, Schaefer A, Cox N, Stewart M (2019) Infrared Thermography—A Non-Invasive
271 Method of Measuring Respiration Rate in Calves. *Animals* 9:535.

272 Maria NR, Neila LR, Riccardo B, Roberto GC (2018) Physiological and biochemical blood variables of goats
273 subjected to heat stress - a review. *J Appl Anim Res* 46:1036-1041.

274 Marques JI, Leite PG, Lopes Neto JP, Furtado DA, de M Lopes FF (2021) Estimation of rectal temperature of goats
275 based on surface temperature. *Eng Agríc* 41:591-598.

276 McCafferty DJ, Pandraud G, Gilles J, Fabra-Puchol M, Henry PY (2018) Animal thermoregulation: a review of
277 insulation, physiology and behaviour relevant to temperature control in buildings. *Bioinspir Biomim*
278 13:011001

279 McManus C, Tanure CB, Peripolli V, Seixas L, Fischer V, Gabbi AM, Costa JBG Jr (2016) Infrared thermography in
280 animal production: An overview. *Comput Electron Agric* 123:10-16.

281 Mitchell D, Snelling EP, Hetem RS, Maloney SK, Strauss WM, Fuller A (2018) Revisiting concepts of thermal
 282 physiology: predicting responses of mammals to climate change. *J Anim Ecol* 87:956-973.

283 Mota-Rojas D, Pereira AMF, Wang D, Martínez-Burnes J, Ghezzi M, Hernández-Avalos I, Lendez P, Mora-Medina
 284 P, Casas A, Olmos-Hernández A, et al (2021a) Clinical Applications and Factors Involved in Validating
 285 Thermal Windows Used in Infrared Thermography in Cattle and River Buffalo to Assess Health and
 286 Productivity. *Animals* 11:2247.

287 Mota-Rojas D, Titto CG, de Mira Geraldo A, Martínez-Burnes J, Gómez J, Hernández-Ávalos I, Casas A, Domínguez
 288 A, José N, Bertoni A, Reyes B, Pereira AMF (2021b) Efficacy and Function of Feathers, Hair, and Glabrous
 289 Skin in the Thermoregulation Strategies of Domestic Animals. *Animals (Basel)* 6;11(12):3472

290 Nääs IA, Garcia RG, Caldara FR (2014) Infrared Thermal Image for Assessing Animal Health and Welfare. *J Anim*
 291 *Behav Biometeorol* 2:66-72.

292 Napolitano F, Mota-Rojas D, Guerrero-Legarreta I, Orihuela A (2020) The Latin American River Buffalo, Recent
 293 Findings, 3rd edn. BM Editores, Mexico City

294 National Oceanic and Atmospheric Administration (NOAA) (2026) El Niño/Southern Oscillation (ENSO) Diagnostic
 295 Discussion. Climate Prediction Center. www.noaa.gov. Accessed 28 April 2026.

296 National Research Council (1971) A guide to environmental research on animals. National Academy of Sciences,
 297 Washington, DC

298 Nienaber JA, Hahn GL (2007) Livestock Production System Management Responses to Thermal Challenges. *Int J*
 299 *Biometeorol* 52:149-157.

300 Nikkhah A (2015) Infrared Thermography as a Prognostic Live stock. *Agrotechnology: A Critique. Agrotech* 4:e112.

301 Oosterbaan RJ (2017) SegReg 1.7.0.0. Segmented linear regression with breakpoint and confidence intervals.
 302 <https://www.waterlog.info/segreg.htm>. Accessed 10 Jan 2026

303 Ortiz AM, Solaiman SG, Maloney MA, Reddy G (2019) Effects of heat stress on feed intake, water intake, and thermo-
 304 regulation in goats. *Small Rumin Res* 176:41-47.

305 Reshma Nair MR, Sejian V, Silpa MV, Fonsêca VFC, de Melo Costa CC, Devaraj C, Krishnan G, Bagath M, Nameer
306 PO, Bhatta R (2021) Goat as the ideal climate-resilient animal model in a tropical environment: revisiting
307 advantages over other livestock species. *Int J Biometeorol* 65:2229-2240.

308 Romanovsky, A. A. (2014). Skin temperature: its role in thermoregulation. *Acta physiologica*, 210(3), 498-507.

309 Samara EM, Al-Badwi MA, Abdoun KA, Al-Haidary AA (2024) Applicability of thermography as a potential non-
310 invasive technique to assess the body-thermal status of heat-stressed and water-deprived goats (*Capra*
311 *hircus*). *J Therm Biol* 119:103790.

312 Seixas L, de Melo CB, Tanure CB, Peripolli V, McManus C (2017) Heat tolerance in Brazilian hair sheep. *Asian-*
313 *Australas J Anim Sci* 30:593.

314 Sejian V, Shashank CG, Silpa MV, Madhusoodan AP, Devaraj C, Koenig S (2022) Non-invasive methods of
315 quantifying heat stress response in farm animals with special reference to dairy cattle. *Atmosphere* 13:1642.

316 Silva EMN, de Souza BB, de Assis Silva G, de Alcântara MDB, Cunha MDGG, Marques BAA (2014) Avaluation of
317 the adaptability of dairy goats with help of thermographic precision in the semiarid brazilian. *Braz J Vet*
318 *Med* 36:231-237.

319 Singh MK, Dutta TK, Sharma RB, Dos AK, Singh AP (2010) Evaluation of growth, feed conversion efficiency and
320 carcass traits of Jamunapari goats under intensive feeding system. *Indian J Anim Sci* 80:382-384.

321 Singh MK, Kumar R, Singh SP (2020) Comparative Performance of Barbari goats under different rearing system in
322 semi-arid regions. *Indian J Anim Sci* 90:483-486.

323 Snedecor GW, Cochran WG (1994) *Statistical Methods*, 8th edn. Iowa State University Press, Ames

324 Stewart M, Wilson MT, Schaefer AL, Huddart F, Sutherland MA (2017) The Use of Infrared Thermography and
325 Accelerometers for Remote Monitoring of Dairy Cow Health and Welfare. *J Dairy Sci* 100:3893-3901.

326 Syafiq NN, Zulkifli I, Zuki ABM, Meng Goh Y, Kaka U (2023) Physiological, haematological and
327 electroencephalographic responses to heat stress in Katjang and Boer goats. *Saudi J Biol Sci* 30:103836.

328 Violin G, Mochizuki N, Warju SSA, Itoh M, Aoki T (2025) Evaluation of Ear Thermographic Imaging as a Potential
329 Variable for Detecting Hypocalcemia in Postpartum Holstein Dairy Cows. *Animals* 15:2055.

330 Yamani H, Koluman N (2020) Impact various seasons on expression patterns HSP60 and physiological parameters. J
331 Dairy Vet Anim Res 9:10-13.

332 Yamin D, Beena V, Ramnath V, Zarina A, Harikumar S, Venkatachalapathy RT, Gleeja VL (2022) Impact of thermal
333 stress on physiological, behavioural and biochemical parameters in native and crossbred goats. Small
334 Ruminant Research, 216:106794.

335 Yousef MK (1985) Stress physiology in livestock. CRC Press, Boca Raton

336 Zhou J, Jiang R, Xie D, Shimamura T (2026) Research on Seasonal Disease Warning Methods for Northern Winter
337 Sheep Based on Ear-Base Temperature. Animals 16:344.

338 **Declarations**

339 **Conflict of Interest Statement:** The authors declare no conflicts of interest.

340 **Funding:** This research did not receive any specific funding. The necessary institutional infrastructure and animal
341 facilities were provided by DUVASU, Mathura.

342 **Ethical approval:** The study protocol complied with the guidelines of the Committee for Control and Supervision of
343 Experiments on Animals (CCSEA), Government of India, and was approved by the Institutional Animal Ethics
344 Committee of the Veterinary University, Mathura (Approval no. IAEC/24/1/47 dated 05.03.2024).

345 **Competing interest:** The authors declare no competing interest

346 **Author Contributions:** Srashti Dixit: Methodology, Formal analysis, Investigation, Data Curation, Writing-Original
347 draft and Visualization. Rajneesh Sirohi and Brijesh Yadav: Conceptualization, Writing-Review and Editing,
348 Supervision, Resources. Mamta, Ajay Kumar, Yajuvendra Singh and Chandan Kumar: Supervision, Resources,
349 Writing-Review and Editing. Vishakha Singh, Charu Singh, Akanksha Detha, Laxmikant Shukla, Aakansha Mathur:
350 Writing-Review and Editing.

351 **Data availability:** Data will be made available on request.



Fig. 1 Goats in Psychrometric chamber



Fig. 2 Infrared thermography of goats inside Psychrometric chamber

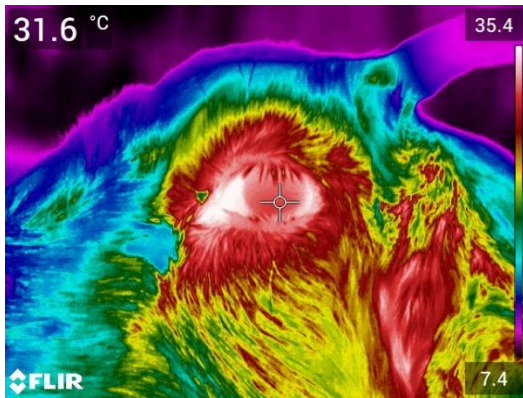


Fig. 3a Eyeball

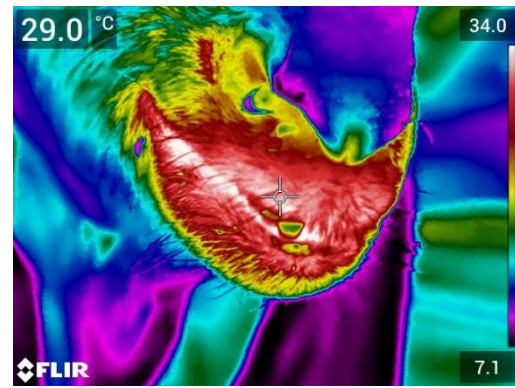


Fig. 3b Muzzle

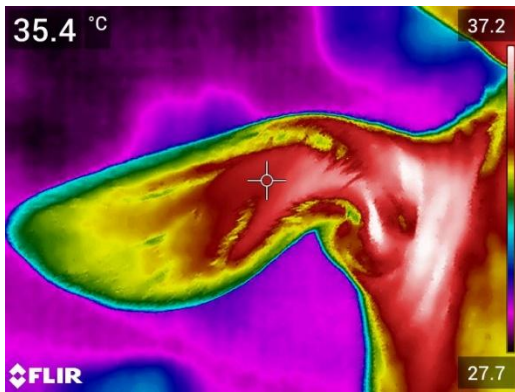


Fig. 3c Ear

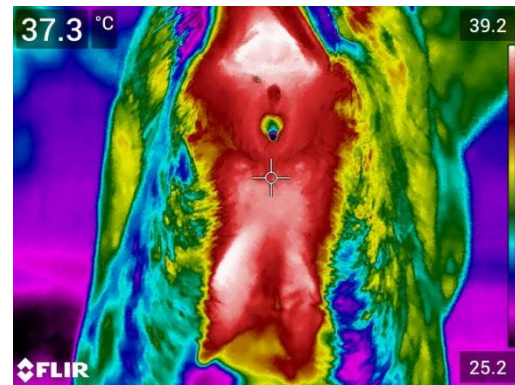


Fig. 3d Perineum

Fig. 3 Thermographs for different anatomical sites of goats

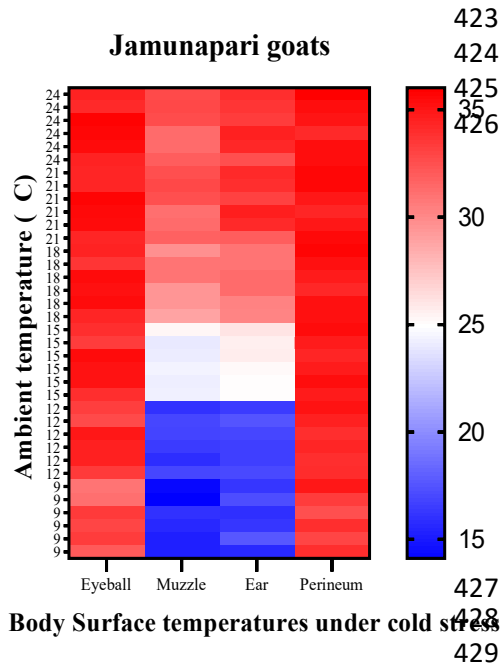


Fig. 4a

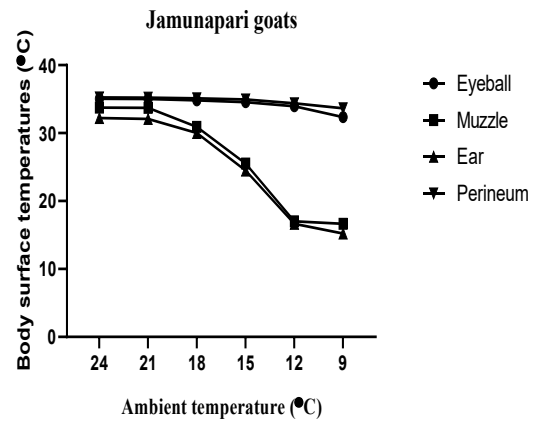


Fig. 4b

Fig 4 Variation in BSTs of Jamunapari goats under cold stress

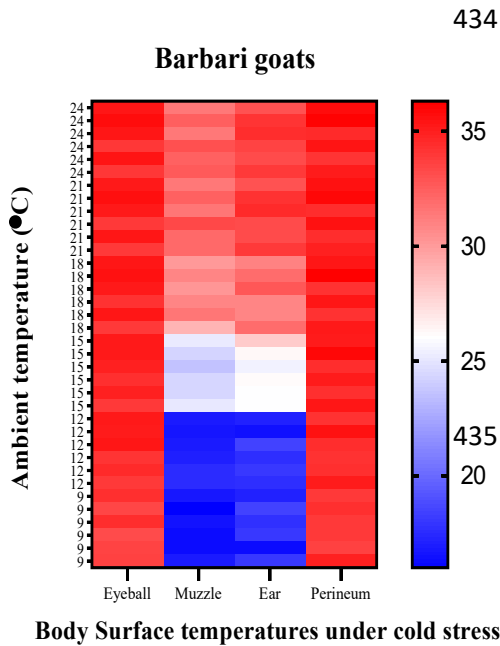


Fig. 5a

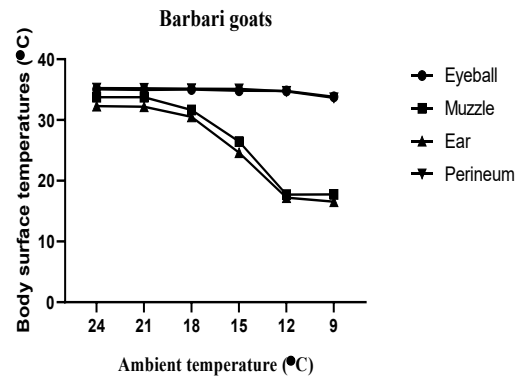


Fig. 5b

Fig. 5 Variation in BSTs of Barbari goats under cold stress

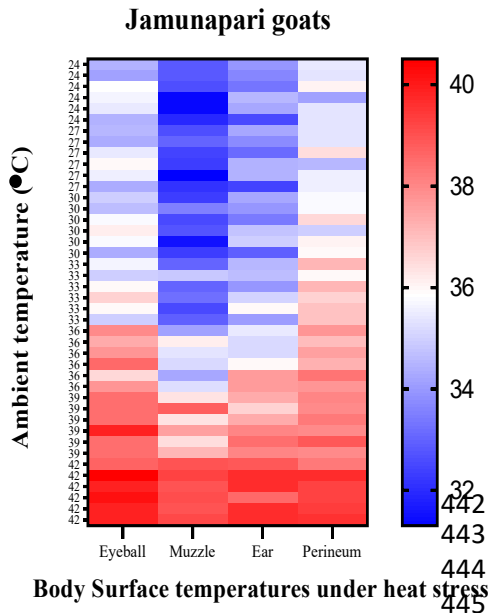


Fig. 6a

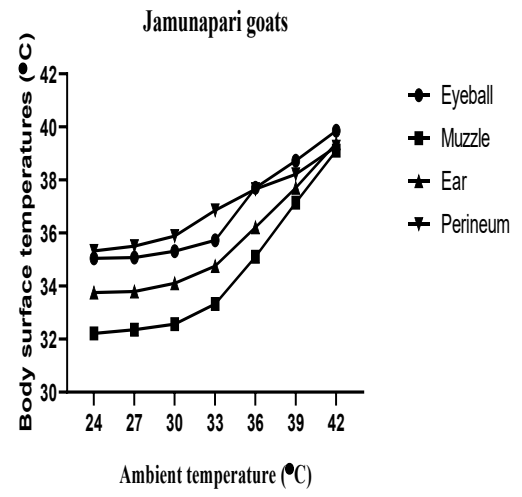


Fig. 6b

Fig. 6 Variation in BSTs of Jamunapari goats under heat stress

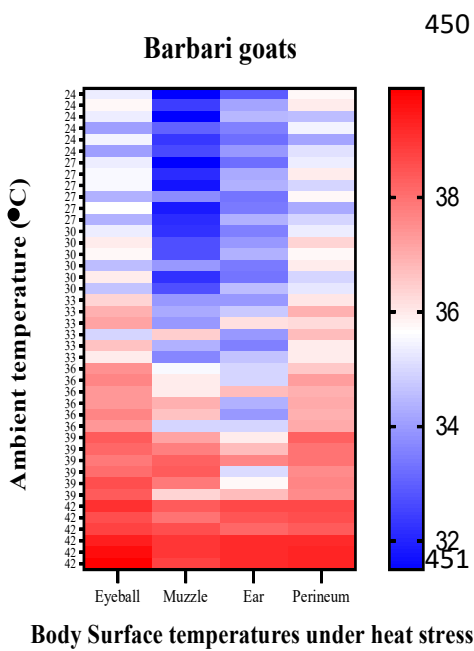


Fig. 7a

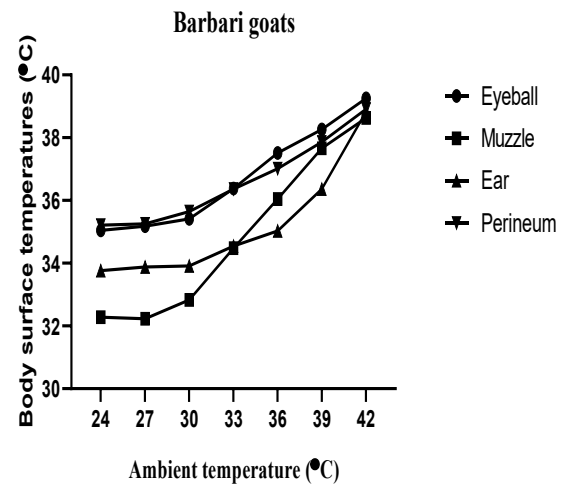


Fig. 7b

Fig. 7 Variation in BSTs of Barbari goats under heat stress

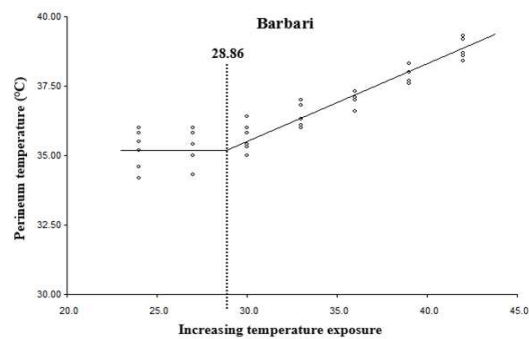
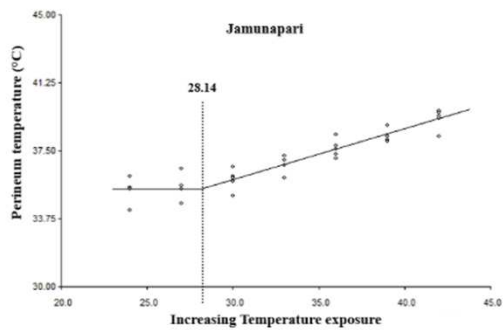
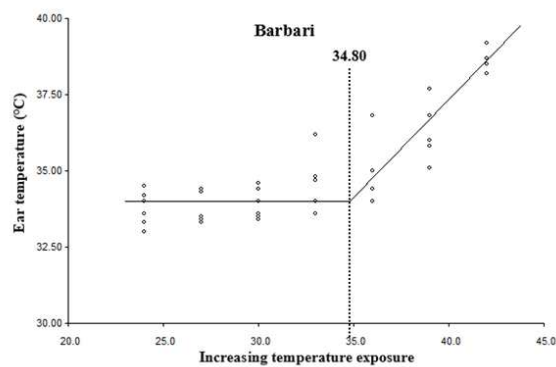
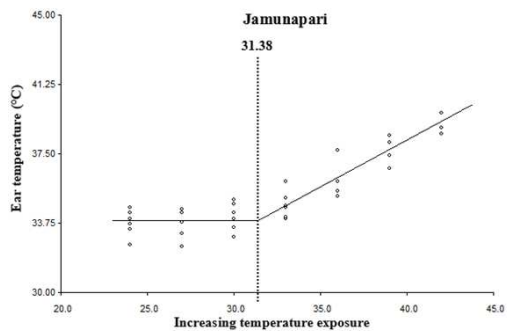
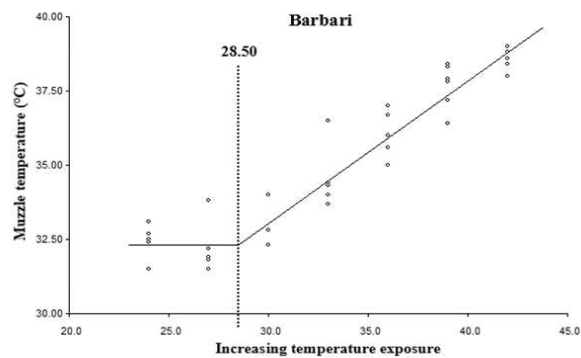
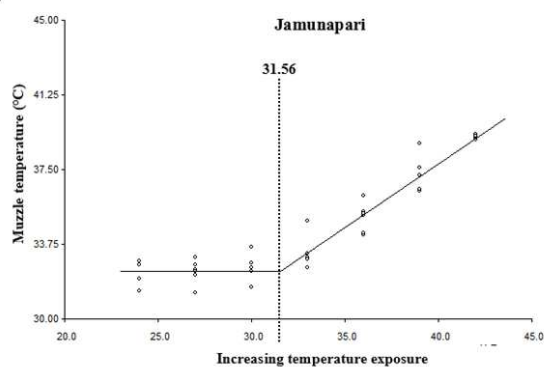
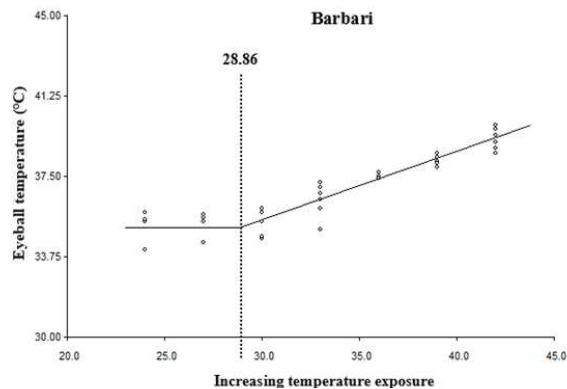
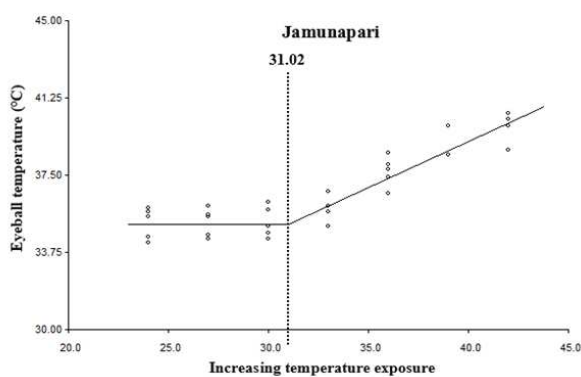


Fig. 8 Segmented regression showing breakpoints for UCT for Body surface temperatures

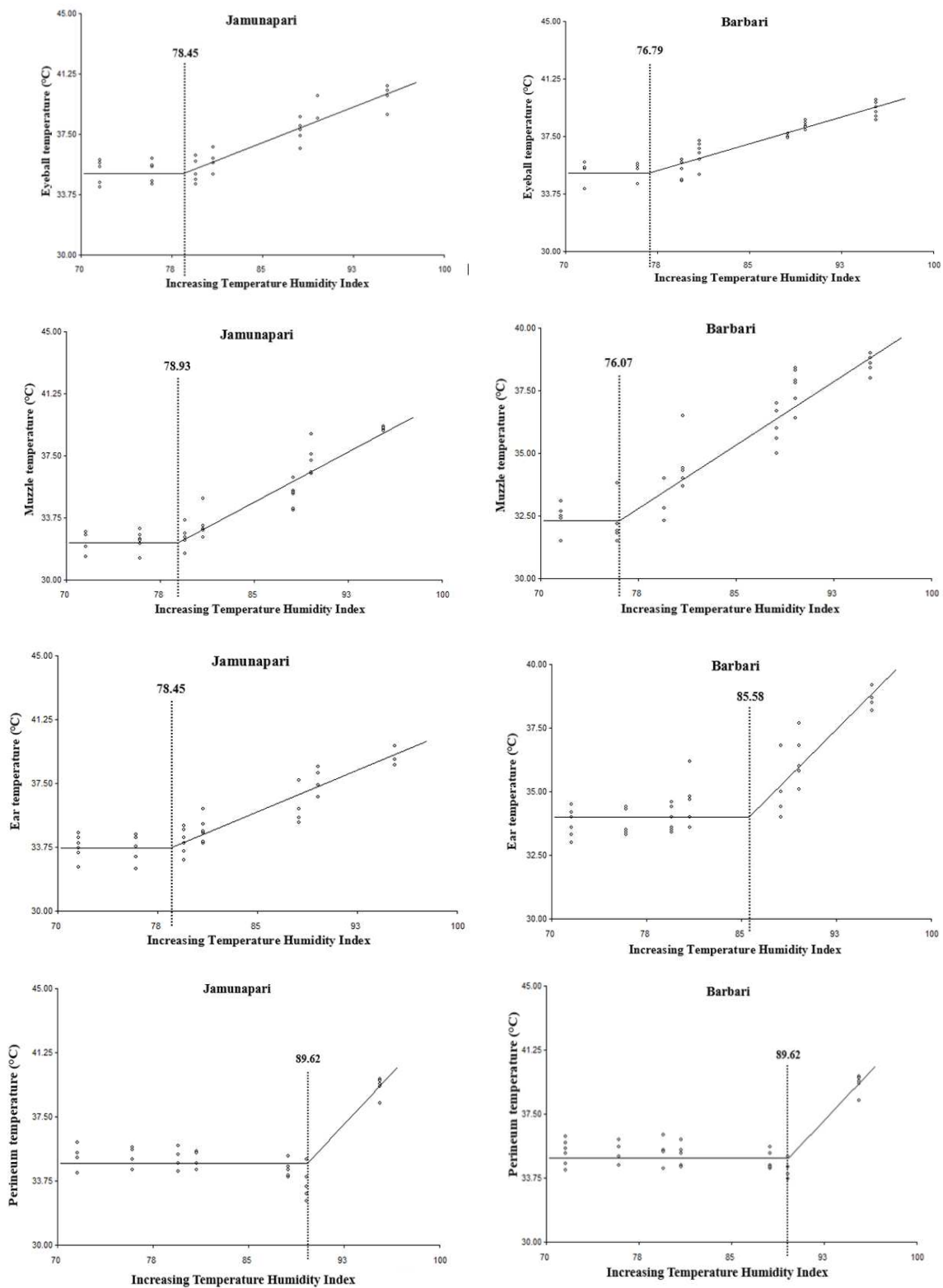


Fig. 9 Segmented regression showing breakpoints for Upper critical THI for Body surface temperatures

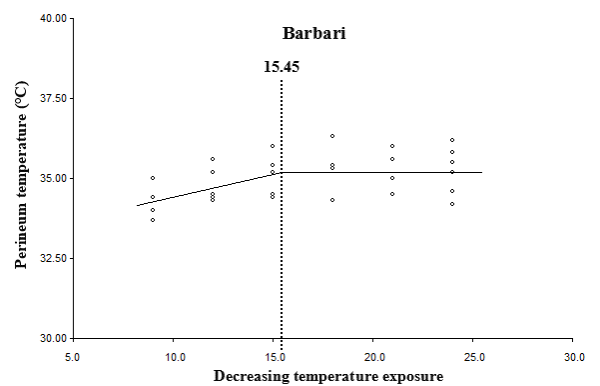
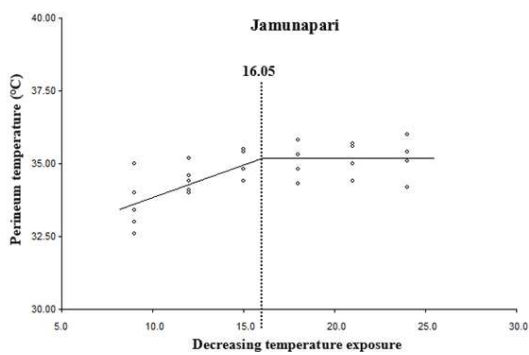
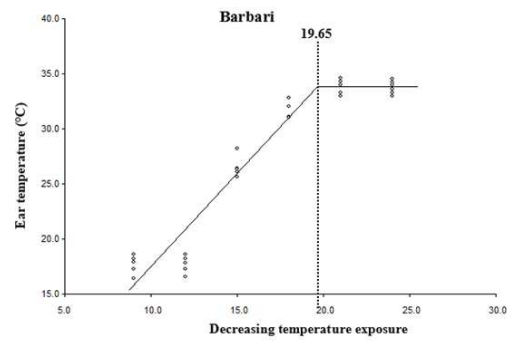
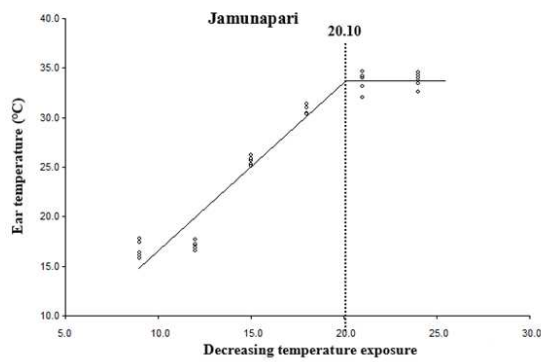
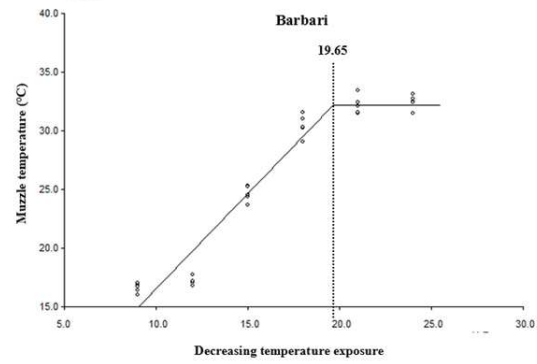
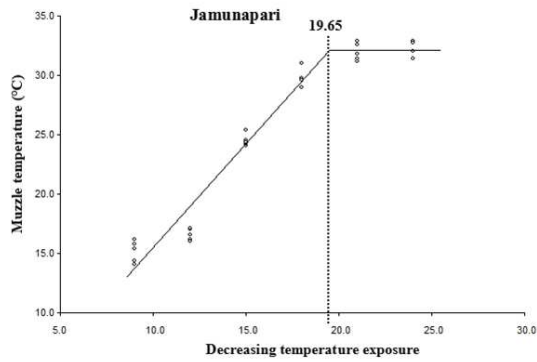
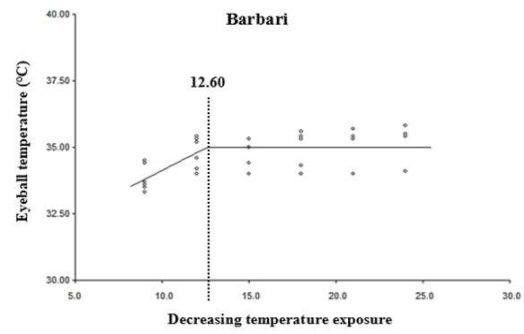
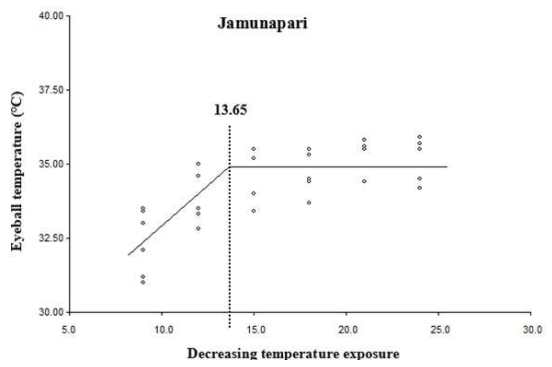


Fig. 10 Segmented regression showing breakpoints for LCT for Body surface temperatures

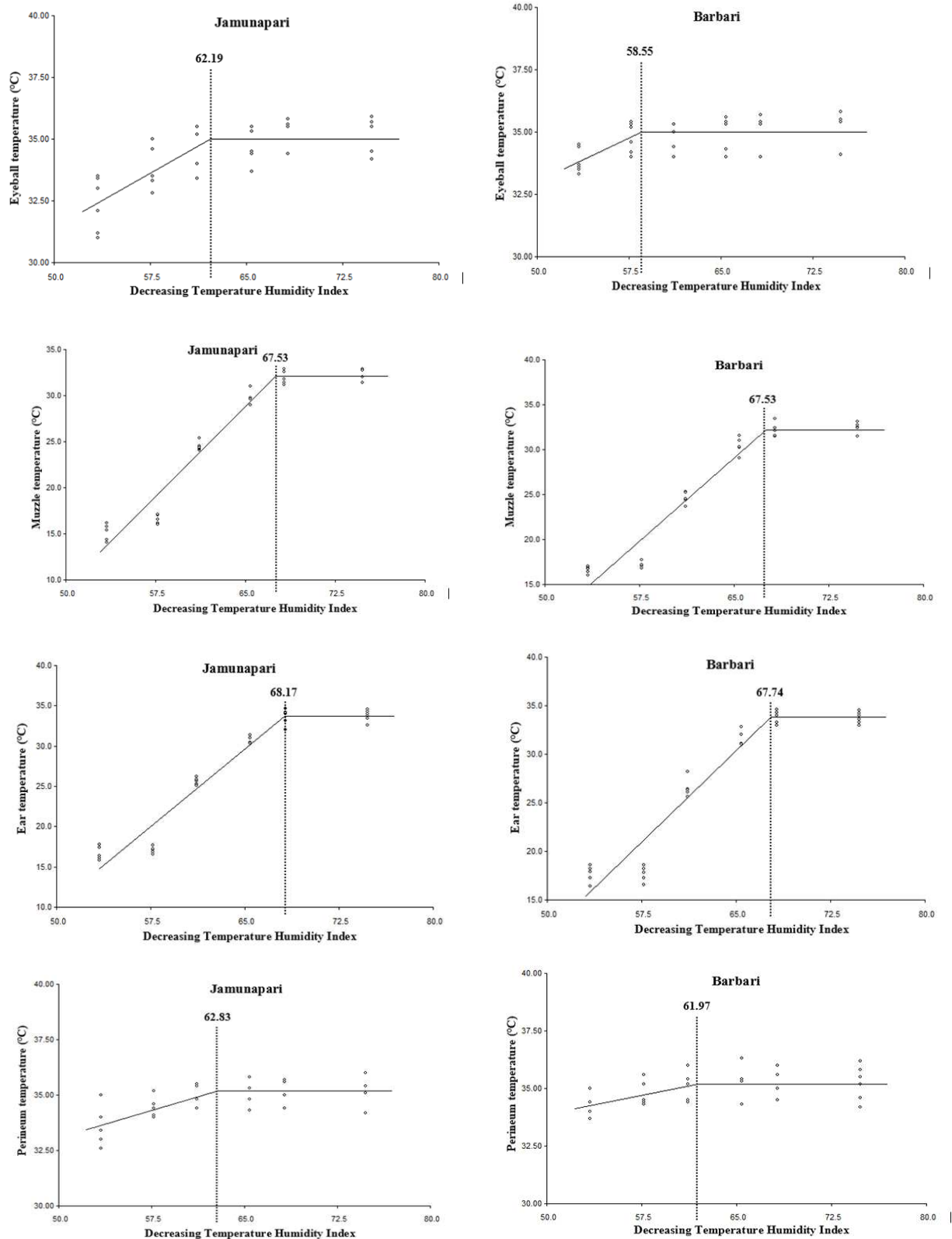


Fig. 11 Segmented regression showing breakpoints for lower critical THI for Body surface temperatures