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Shikha Pareek

M.V.Sc. Scholar, Department of
Veterinary Physiology,
DUVASU, Mathura, Uttar
Pradesh, India

Mukul Anand

Associate Professor, Department
of Veterinary Physiology,
DUVASU, Mathura, Uttar
Pradesh, India

Sarvajeet Yadav

Professor, Department of
Veterinary Physiology,
DUVASU, Mathura, Uttar
Pradesh, India

Anchal Sharma

M.V.Sc. Scholar, Department of
Veterinary Physiology,
DUVASU, Mathura, Uttar
Pradesh, India

Rahul Dhariya

Department of Veterinary
Physiology, DUVASU, Mathura,
Uttar Pradesh, India

Corresponding Author:

Shikha Pareek

M.V.Sc. Scholar, Department of
Veterinary Physiology,
DUVASU, Mathura, Uttar
Pradesh, India

Effect of seasonal climatic variation on ejaculate characteristics and sperm structural integrity in Sirohi breeding bucks

**Shikha Pareek, Mukul Anand, Sarvajeet Yadav, Anchal Sharma and
Rahul Dhariya**

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Abstract

The present study evaluated the influence of seasonal variations in temperature and humidity on semen characteristics of Sirohi breeding bucks. Ten clinically healthy bucks were assessed across three seasons: hot-dry (May-June), hot-humid (July-August), and warm-humid (September-October) with semen; collected biweekly and analysed using standard laboratory procedures. Mean ambient temperature and relative humidity varied markedly across seasons. Ejaculate volume was significantly higher ($p \leq 0.01$) during the hot-dry season compared to the hot-humid season, whereas mass motility, sperm concentration, and pH remained statistically comparable. Sperm morphological abnormalities, particularly bent and coiled tail defects, were significantly elevated during humid seasons ($p \leq 0.05$). The findings indicate that combined thermal and humidity stress adversely affects certain seminal traits, emphasizing the importance of climatic considerations in reproductive management and breeding strategies for Sirohi goats under changing environmental conditions.

Keywords: Sirohi bucks, seasonal variation, heat stress, semen quality, sperm morphology, relative humidity

1. Introduction

Goat production systems play a vital role in sustaining rural livelihoods, particularly in arid and semi-arid regions, due to the species' inherent adaptability to harsh climatic conditions and limited feed resources (Moula *et al.*, 2024) ^[2]. Nevertheless, reproductive efficiency, one of the most critical determinants of productivity and genetic improvement in goats, is highly sensitive to environmental stressors, especially climatic variability (Silanikove, 2000) ^[16]. In the context of global climate change and the increasing practice of translocating livestock across agro-climatic zones, understanding the influence of climate on reproductive performance has gained considerable scientific importance (Rojas-Downing *et al.*, 2017) ^[13]. Climatic stress, particularly elevated ambient temperature and humidity, profoundly affects reproductive physiology by disrupting thermoregulation, endocrine balance, metabolic homeostasis, and oxidative status (Danso *et al.*, 2024) ^[14]. Heat stress has been shown to impair the hypothalamic-pituitary-gonadal axis, alter estrous behaviour, reduce gamete quality, and ultimately compromise conception and kidding rates (Marai *et al.*, 2007; Sejian *et al.*, 2018) ^[10, 14]. Although indigenous goat breeds exhibit superior adaptive traits within their native environments, their reproductive responses to unfamiliar climatic conditions may vary depending on breed resilience, duration of exposure, and intensity of stress (Silanikove, 2000) ^[16].

The Sirohi goat is a well-recognized indigenous breed originating from the hot and dry regions of Rajasthan and is valued for its adaptability, moderate productivity, and comparatively stable reproductive performance under arid climatic conditions. Owing to these attributes, Sirohi goats are increasingly being introduced into regions with contrasting climatic profiles, including hot and humid and moderately hot and humid environments. However, exposure to

elevated temperature-humidity index levels beyond the breed's native comfort zone may impose thermal stress, thereby adversely affecting reproductive efficiency (Dash *et al.*, 2016; Sejian *et al.*, 2018) [4, 14]. Despite its growing geographic spread, systematic information on the reproductive adaptability of Sirohi goats under diverse climatic conditions remains limited. Understanding how variations in climatic conditions modulate breed-specific reproductive responses is crucial for formulating climate-resilient breeding and management strategies to sustain goat production under evolving environmental scenarios. Therefore, the present research programme was designed to elucidate the influence of changes in key climatic variables namely temperature and humidity on the semen quality of Sirohi goats.

Materials and Methods

The study was conducted on ten clinically healthy Sirohi breeding bucks of comparable age (3-4 years) and body weight (50-60 kg). All animals were maintained under an intensive management system throughout the experimental period. The bucks were housed in well-ventilated pens with adequate space, proper hygiene, and routine health care facilities. Feeding was standardized for all animals, and the ration was formulated to meet the nutrient requirements of breeding bucks as recommended by the National Research Council (NRC, 2013). Clean drinking water was provided *ad libitum* to ensure proper hydration and physiological stability. The research programme was carried out under three distinct seasonal conditions characterized by variations in climatic variables, namely summer (hot and dry), rainy season (hot and humid), and autumn (moderately hot and moderately humid). Each season was considered an independent experimental phase. The same group of bucks was evaluated across all three seasons to assess the influence of changing climatic conditions on reproductive efficiency. Animals were studied for a period of two months during each season to ensure adequate data collection and reliable assessment.

Semen collection was carried out on a biweekly schedule, resulting in a total of seven ejaculates per buck per season. Collections were performed using a standard artificial vagina under controlled and hygienic conditions to minimize handling stress and maintain uniformity across seasons. This standardized procedure ensured consistency in semen quality assessment and reduced experimental variability.

Fresh semen samples were evaluated immediately after collection to determine ejaculate characteristics and sperm structural integrity in relation to seasonal climatic variation. Ejaculate volume was measured directly in millilitres using a graduated collection cup with an accuracy of 0.1 mL, and colour and consistency were assessed by visual examination. Semen pH was recorded using a calibrated digital bench-top pH meter immediately after collection to avoid alteration due to environmental exposure. Mass motility was assessed by placing a small drop of fresh semen on a clean, grease-free slide maintained at 37 °C and examining it under a phase-contrast microscope (10× objective). Wave motion and overall sperm activity were graded on a 0-5 scale based on the intensity and pattern of movement.

Sperm concentration was determined using an AccuRead™ photometer (IMV Technologies, France) calibrated with normal saline solution as per the manufacturer's instructions. For each reading, semen was appropriately diluted in saline and analysed using the photometric system operating at 595

nm, and the value displayed was recorded as sperm concentration ($\times 10^6/\text{mL}$).

Sperm morphological abnormalities in fresh semen were evaluated using a computer-assisted semen analysis system (IVOS II, Hamilton Thorne, USA) under negative phase-contrast microscopy with a stage maintained at 37 °C. Samples were diluted to an optimal concentration to permit accurate detection, and approximately 700-1000 spermatozoa were analysed per ejaculate using standardized settings that remained constant throughout the study. Structural defects were classified as bent tail, coiled tail, detached mid-piece remnants, proximal cytoplasmic droplets, and distal cytoplasmic droplets, and each abnormality was expressed as a percentage of the total sperm examined. All evaluations were conducted under uniform laboratory conditions to ensure that differences observed reflected seasonal climatic influences rather than procedural variation.

Statistical analysis

Data obtained from behavioral, seminal, and antioxidative assessments were compiled systematically and subjected to statistical analysis. The effect of seasonal variation on reproductive parameters was analyzed using one-way analysis of variance (ANOVA). Differences among seasonal means were considered statistically significant at the prescribed probability level. All statistical analyses were performed using standard statistical software.

Results

The climatic variables recorded during the study period demonstrated marked seasonal variation and are presented in Table 1. During Season 1 (May-June; hot-dry), the mean ambient temperature was highest at 37.3 °C (range: 31.7- 42.9 °C), while relative humidity was lowest at 22.5% (18.0-27.0%). In Season 2 (July-August; hot-humid), the mean temperature declined to 32.5 °C (28.8-36.1 °C), accompanied by a sharp rise in relative humidity to 60.0% (52.0-68.0%). Season 3 (September-October; warm-humid) recorded the lowest mean temperature of 29.4 °C (24.6-34.2 °C) with moderate humidity levels of 49.0% (42.0-56.0%). These findings indicate that bucks were exposed to distinct thermal and humidity stress conditions across seasons, providing a suitable framework to assess seasonal influences on semen quality.

The effect of seasonal variation on freshly ejaculated semen parameters of Sirohi bucks revealed significant differences in ejaculate volume (Table 2). Semen volume was significantly higher ($p \leq 0.01$) during the hot-dry season (1.03 ± 0.07 ml) compared to the hot-humid season (0.64 ± 0.06 ml), while the warm-humid season (0.85 ± 0.08 ml) showed intermediate values. Mass motility, sperm concentration, and pH did not differ significantly among seasons ($p > 0.05$), although comparatively lower mass motility (3.97 ± 0.26) and concentration ($7.46 \pm 0.38 \times 10^6/\text{ml}$) were observed during the hot-humid season.

Seasonal influence on sperm morphological abnormalities assessed through CASA also showed significant variations (Table 3). The percentage of bent tail spermatozoa was significantly higher ($p \leq 0.01$) in the hot-humid ($3.00 \pm 0.33\%$) and warm-humid ($2.47 \pm 0.29\%$) seasons compared to the hot-dry season ($1.05 \pm 0.12\%$). Similarly, coiled tail abnormalities were significantly elevated ($p \leq 0.05$) during the hot-humid season ($0.93 \pm 0.15\%$) compared to the hot-dry season ($0.41 \pm 0.10\%$), with intermediate values in the warm-

humid season. However, detached mid-piece remnants (DMR), proximal droplets, and distal droplets did not differ significantly across seasons ($p > 0.05$), although numerically higher values were observed during humid conditions.

Overall, the results indicate that elevated humidity combined with thermal stress adversely affected certain semen quality parameters, particularly ejaculate volume and specific morphological defects in Sirohi bucks.

Table 1: Seasonal variation in ambient temperature and relative humidity during the study period

Season	Mean ambient temperature during the study period (°C)	Mean relative humidity during the study period (%)
Season 1 (May-June)	37.3 (31.7-42.9)	22.5 (18.0-27.0)
Season 2 (July-August)	32.5 (28.8-36.1)	60.0 (52.0-68.0)
Season 3 (September-October)	29.4 (24.6-34.2)	49.0 (42.0-56.0)

Table 2: Effect of seasons on Freshly Ejaculated Semen Parameters in Sirohi Bucks

Parameters Season	Volume (ml)	Mass Motility	Concentration ($\times 10^6/\text{ml}$)	pH
Season 1 (May-June); Hot-dry	1.03 ± 0.07^B	4.23 ± 0.10	8.29 ± 0.21	6.78 ± 0.03
Season 2 (July-August); Hot-humid	0.64 ± 0.06^A	3.97 ± 0.26	7.46 ± 0.38	6.81 ± 0.04
Season3 (Sept-Oct); Warm-humid	0.85 ± 0.08^{AB}	4.06 ± 0.13	8.08 ± 0.32	6.75 ± 0.03
p-value	0.001**	0.076 (NS)	0.140 (NS)	0.214 (NS)

Table 3: Effect of Seasons on Sperm Morphological Abnormalities as observed through CASA in ejaculate of Sirohi Bucks

Parameter Season	Bent tail (%)	Coiled tail (%)	DMR (%)	Proximal droplet (%)	Distal droplet (%)
Season 1 (May-June); Hot-dry	1.05 ± 0.12^A	0.41 ± 0.10^A	4.12 ± 0.35	0.08 ± 0.02	0.39 ± 0.08
Season 2 (July-August); Hot-humid	3.00 ± 0.33^B	0.93 ± 0.15^B	5.95 ± 1.66	0.10 ± 0.04	0.66 ± 0.11
Season 3 (Sept-Oct); Warm-humid	2.47 ± 0.29^B	0.72 ± 0.11^{AB}	5.20 ± 0.23	0.08 ± 0.02	0.65 ± 0.09
p-value	0.001**	0.015*	0.420(NS)	0.819(NS)	0.059(NS)

Discussion

The present investigation demonstrated clear seasonal modulation of semen quality in Sirohi breeding bucks, particularly under hot-humid climatic conditions. The marked elevation in ambient temperature during the hot-dry season and the combined heat-humidity load during the hot-humid season created distinct thermal environments capable of influencing testicular thermoregulation and spermatogenesis (Pascal *et al.*, 2024) [11]. Among the seminal attributes evaluated, ejaculate volume and specific sperm morphological abnormalities (Bent tail and coiled tail) were significantly affected by season, highlighting the sensitivity of accessory sex gland function and sperm structural integrity to climatic stress.

The significantly higher ejaculate volume observed during the hot-dry season compared to the hot-humid season suggests that humidity plays a critical role in modulating secretory activity of accessory sex glands. Elevated humidity impairs evaporative heat loss, thereby increasing the effective thermal load despite comparatively lower ambient temperatures. Prolonged exposure to such conditions may compromise scrotal thermoregulation and reduce androgen-dependent secretory function of seminal vesicles and prostate glands (Gonçalves *et al.*, 2021) [6]. Previous studies in small ruminants have indicated that heat stress reduces semen volume by altering endocrine balance, particularly testosterone secretion and luteinizing hormone pulsatility (Marai *et al.*, 2008; Sejian *et al.*, 2012) [10, 14]. In bucks, spermatogenic efficiency and accessory gland function are highly dependent on optimal scrotal temperature, typically maintained 2-6 °C below core body temperature (Setchell, 2018) [15]. Disruption of this gradient under humid heat stress may explain the reduced semen volume recorded during the hot-humid season in the present study.

Interestingly, sperm concentration and mass motility were not significantly altered across seasons, although numerically lower values were recorded during the hot-humid period. This indicates that while spermatogenic output remained relatively stable, subtle functional impairments may occur prior to overt

quantitative decline. Similar findings have been reported in tropical goat breeds, where adaptation mechanisms maintain sperm production within physiological limits despite environmental stress (Dias *et al.*, 2017) [5]. The resilience observed in Sirohi bucks may reflect breed-specific adaptation to semi-arid climates, underscoring the importance of evaluating indigenous germplasm under region-specific environmental stressors.

The most pronounced seasonal effects were observed in sperm morphological abnormalities, particularly bent tail and coiled tail defects, which were significantly elevated during humid seasons. Structural tail abnormalities are often linked to disturbances during epididymal maturation or osmotic imbalance in seminal plasma. Heat stress increases reactive oxygen species (ROS) production in testicular and epididymal tissues, leading to lipid peroxidation of sperm membranes rich in polyunsaturated fatty acids (Aitken and Baker, 2006) [1]. The axonemal structure of the sperm tail is particularly vulnerable to oxidative damage, which may result in bending or coiling defects. Increased humidity further exacerbates oxidative stress by limiting heat dissipation and elevating scrotal temperature for prolonged durations. Studies in bucks and rams have shown that thermal stress elevates abnormal sperm percentages, particularly tail defects, due to impaired microtubular assembly during spermiogenesis (Kadirve *et al.*, 2014; Rahman *et al.*, 2018) [8, 12].

The non-significant variation in detached mid-piece remnants and cytoplasmic droplets suggests that primary spermatogenic disruption was minimal; rather, the observed defects appear predominantly secondary and stress-induced. This pattern supports the hypothesis that humid heat stress affects sperm maturation and membrane integrity more than the early stages of spermatogenesis (Kujoana *et al.*, 2024) [9]. The findings therefore highlight the combined temperature-humidity effect, rather than temperature alone, as a critical determinant of sperm structural quality.

From a physiological standpoint, increased thermal load activates the hypothalamic-pituitary-adrenal (HPA) axis, elevating cortisol levels, which can negatively influence

gonadotropin secretion and testicular steroidogenesis. Chronic activation of stress pathways has been associated with compromised sperm membrane integrity and altered seminal plasma antioxidant capacity (Hansen, 2009) [7]. The significant rise in tail abnormalities during humid seasons in the present study may therefore reflect cumulative oxidative and endocrine perturbations induced by environmental stress. The novelty of the present research lies in its focused evaluation of seasonal climatic variables in Sirohi bucks, a breed adapted to semi-arid regions but increasingly exposed to erratic climatic fluctuations due to global climate change. While several studies have documented seasonal effects in sheep and cattle, limited data exist regarding indigenous Indian goat breeds under distinct hot-dry versus hot-humid conditions. By differentiating between dry heat and humid heat stress, the present study provides a more nuanced understanding of environmental impacts on male fertility. This distinction is particularly relevant under tropical and subtropical production systems, where humidity-driven heat stress is becoming more frequent and intense.

The findings have practical implications for breeding management in tropical goat production systems. The elevated incidence of morphological defects during humid seasons suggests that semen collection for artificial insemination or cryopreservation programmes may yield superior quality ejaculates during relatively dry periods. Additionally, implementation of heat mitigation strategies such as improved ventilation, shading, evaporative cooling, and antioxidant supplementation may help counteract the detrimental effects observed during humid seasons.

In conclusion, the study demonstrates that seasonal climatic variation, particularly the synergistic effect of elevated temperature and humidity, significantly influences ejaculate volume and specific sperm morphological traits in Sirohi bucks. These results emphasize the importance of integrating climatic indices into reproductive management strategies and contribute valuable breed-specific data to the growing body of literature addressing climate resilience in small ruminant reproduction.

Conflict of interest

Not available.

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Not available.

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