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A Systematic Review of Reproductive Adaptation and Management Strategies of Tropical Cattle under Heat Stress in Kalimantan

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Abstract. *Unpredictable climate fluctuations are now a challenge to the survival of livestock, one of the largest food commodities in Kalimantan. As one of Indonesia's largest island, straddled by the equator, has a tropical climate that frequently experiences culmination phenomena due to year-round sunlight. This study aims to analyze livestock suitable for breeding in Kalimantan, considering various criteria from a reproductive perspective. This review integrates recent empirical studies and regional data to evaluate reproductive responses, adaptive physiology, and management strategies of tropical cattle under the environmental stressors typical of Kalimantan. Data collection will present various data on livestock in extreme hot environments from various parts of the world, which can reproduce well as a reference for adoption in Kalimantan. The novelty of this study lies in its synthesis of tropical reproductive physiology with practical interventions specific to Kalimantan's humid equatorial environment. Recommended adaptive strategies include selective breeding for heat-tolerant genotypes, nutritional fulfillment, water supply, and thermal housing management. Collectively, these measures strengthen the resilience of tropical cattle production systems, improving food security and sustainability under climate variability.*

Keywords: *Climate change, Heat stress, Reproductive adaptation, Thermal stress, Tropical livestock*

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INTRODUCTION

Climate change fluctuations are now a major challenge for the survival of livestock as one of the largest food supporting commodities in Kalimantan. Kalimantan, as one of the largest island in Indonesia, which is crossed by the equator, has a tropical climate which is characterized by the culmination phenomenon due to sunlight throughout the year. These conditions often cause extreme variations in temperature and rainfall, which have a negative impact on livestock productivity, including reproductive aspects such as fertility rates, birth intervals, and survival of livestock calves (Cooke et al., 2020; Janssens et al., 2012; Sejian et al., 2018). East Kalimantan Province's 2021 livestock data records a variety of large livestock such as beef cattle, dairy cattle, buffalo, and horses, with a focus on meat and milk production. Small livestock include goats, sheep, pigs, and rabbits, with data on meat production and ownership per household. The poultry sector includes native chickens, layers, broilers, ducks, Manila ducks, quail, and pigeons, with egg and meat production metrics.

The livestock industry is supported by chicken breeding and cattle fattening, as well as the trade of commodities such as meat, eggs, milk, offal, and hides. This livestock diversity demonstrates the potential for food security in Kalimantan, although tropical climate challenges continue to impact livestock management (data.kaltimprov.go.id). The discussion will focus on ruminant commodities, particularly cattle, which are the second-largest production commodity after poultry in Kalimantan, due to their significant contribution to meat and milk supply. Furthermore, there is a need for studies on cattle farmers' efforts to implement the Minister of Agriculture's regulations, which encourage fattening companies to also engage in breeding activities to enhance reproductive sustainability and address climate-related challenges.

Breeding practices in Kalimantan are still relatively low compared to cattle fattening farms due to limited knowledge, resources, and infrastructure. This makes it difficult to optimize livestock reproduction potential amid current climate challenges. Globally, climate change, caused by global warming, has an impact on the food supply chain and food security in tropical regions such as Kalimantan, where the livestock sector contributes significantly to the local and national economy (Tawaf, 2018). This study aims to analyze the types of livestock that are suitable for development in

Kalimantan by considering various criteria from a reproductive perspective, such as tolerance to heat, reproductive efficiency, and adaptation to extreme environments. This approach is important to identify livestock species or breeds that can adapt well under tropical climate stress, thereby supporting the development of sustainable livestock farming.

Through this analysis, it is hoped that it can provide practical recommendations for breeders and policy makers in Kalimantan, including strategies for selecting livestock breeds that are resistant to climate fluctuations, thereby increasing productivity and regional food security. This research also contributes to the scientific literature on tropical livestock adaptation, by integrating empirical data from global studies to the local Indonesian context.

LITERATURE REVIEW

Livestock in tropical regions face unique environmental challenges due to high temperatures, humidity, variable rainfall, and limited forage quality. These factors significantly impact reproductive traits, often leading to reduced fertility, delayed puberty, and lower conception rates compared to temperate climates. Key species include cattle, goats, sheep, pigs, and poultry, with adaptations varying by breed. Understanding these traits is crucial for sustainable farming in areas with tropical climate.

Tropical environments influence several reproductive parameters through heat stress, nutritional deficiencies, and disease prevalence (Adjassin et al., 2022; Sae-tiao et al., 2019). High temperatures and humidity in tropical regions can induce heat stress, which may disrupt hormonal balance and reduce fertility rates in livestock (Wankhade et al., 2017). Nutritional deficiencies, often caused by seasonal variations in forage availability, can limit the energy and nutrients needed for optimal reproductive performance. Additionally, the prevalence of diseases, exacerbated by warm and humid conditions, can negatively affect reproductive health and offspring viability (Somé et al., 2024). These combined factors create challenging conditions for maintaining consistent reproductive outcomes in tropical livestock systems.

Heat stress (temperatures above 25–30°C) disrupts hormonal balance, reducing sperm quality in males and ovulation in females. In cattle, conception rates can drop by 20–50% during hot seasons. Spermatogenesis is highly sensitive to temperature;

increased scrotal temperature triggers oxidative stress, damages sperm DNA, and decreases sperm motility and concentration, thus decreasing fertilization capacity (Khan et al., 2023). Goats and sheep show similar declines, with bucks producing fewer viable sperm (van Wettere et al., 2021).

Tropical cattle often experience delayed puberty and a delayed first reproductive age due to a combination of environmental stress (including high temperatures) and suboptimal nutritional conditions. Native breeds such as Zebu cattle (*Bos indicus*) mature at 18–24 months, compared to 12–18 months for temperate breeds (Samadi et al., 2014). This delays breeding cycles and reduces lifetime productivity. Studies also note that management conditions such as weaning weight, prepubertal weight gain, and body condition significantly influence when tropical heifers enter puberty (Day & Nogueira, 2013)

Heat stress significantly shortens the duration and intensity of estrus in cows, negatively impacting mating detection and insemination success. For example, studies have shown that in dairy cows exposed to high temperature-humidity (HH) conditions, estrus duration is reduced from an average of 18 hours to approximately 12 hours, and the proportion of estrus marked by standing behavior for mating is drastically reduced (Zhang et al., 2025). The mechanism involves disruption of the hypothalamic pituitary gonadal axis high heat inhibits normal LH and FSH secretion and reduces estradiol production by granulosa cells, ultimately reducing ovulation and causing "silent estrus" (Arifin et al., 2019; Takahashi, 2012).

Prolonged heat exposure in female cattle including high temperatures combined with high humidity causes significant physiological and hormonal instability, thereby increasing the risk of abortion (loss of pregnancy) and stillbirth. In dairy cattle, it is believed that high temperatures can cause early embryonic death or implantation failure due to oocyte damage and a suboptimal uterine environment (Miętkiewska et al., 2022). Other studies have shown that the risk of abortion and stillbirth increases in areas with a high temperature-humidity index (THI) because elevated body temperature impairs placental blood flow, reduces progesterone levels, and accelerates the breakdown of the corpus luteum tissue that supports pregnancy (Mee, 2023). Therefore, poor thermal management during gestation should be considered a major risk factor for reduced livestock productivity through increased pregnancy loss and stillbirth.

RESEARCH METHODS

This narrative review employed a systematic literature search to synthesize evidence on the reproductive adaptations and management strategies of tropical cattle under heat stress in Kalimantan, drawing primarily from peer-reviewed sources published between 2010 – 2025. The search was conducted using two major academic databases Scopus and Google Scholar as the primary platforms for identifying relevant studies, supplemented by targeted exploration of regional Indonesian repositories to ensure contextual applicability. Specific search queries combined key terms such as "impact of tropical environments on livestock reproduction," "heat stress in livestock," and "nutritional deficiencies in tropical livestock" alongside variants focused on cattle, reproduction, and Kalimantan specific conditions. This approach aimed to capture a broad yet focused spectrum of empirical data, review articles, and case studies that addressed reproductive outcomes in tropical or subtropical settings, with priority given to works reporting quantifiable effects on fertility, hormonal balance, gamete quality, or embryonic viability under elevated temperature humidity indices.

This review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, recognized globally as the benchmark for conducting and presenting rigorous systematic reviews. By implementing the PRISMA framework, the entire research process from formulating the literature search strategy and selecting relevant studies to extracting data, performing analysis, and synthesizing findings was executed in a structured, systematic, and fully traceable manner. This methodology not only enhances the transparency and methodological integrity of the study but also facilitates its replication by future researchers.

Search Strategy

Article selection followed a structured yet pragmatic inclusion framework to balance comprehensiveness with relevance. Studies were retained if they presented original empirical observations, experimental results, or robust observational data centered on livestock particularly ruminants in tropical environments, with a clear linkage to reproductive performance metrics such as conception rates, estrus expression, puberty onset, or pregnancy maintenance. Preference was accorded to research involving indigenous or adapted breeds prevalent in Indonesia, including Bali cattle, Peranakan Ongole, or swamp buffalo, while excluding investigations limited to

temperate breeds without crossbreeding context or those lacking any reproductive focus. No formal quality appraisal tools were applied, as the narrative synthesis prioritized thematic coherence over meta-analytic rigor; however, sources were manually screened for methodological soundness, regional transferability, and recency, resulting in the inclusion of approximately 25 core references that spanned global tropical insights and localized Kalimantan findings.

Selection and Synthesis

Data synthesis was performed through iterative thematic grouping and narrative integration rather than statistical aggregation. Key reproductive parameters such as conception rate declines under THI >72, shortened estrus duration due to suppressed LH and estradiol, delayed puberty in Bos indicus heifers, and elevated embryonic mortality from oxidative uterine stress were extracted and cross referenced across studies to construct cohesive explanatory threads. Management interventions, including environmental cooling, adaptive nutrition, timed artificial insemination, and genetic selection for thermotolerance, were similarly consolidated into practical, Kalimantan applicable recommendations. This interpretive process highlighted convergent evidence on native breed resilience while underscoring the amplifying role of Kalimantan's equatorial humidity, ultimately framing a holistic narrative that bridges physiological mechanisms with field level strategies to enhance reproductive sustainability amid ongoing climate variability.

RESULTS AND DISCUSSION

The PRISMA guidelines were followed to systematically identify, select, and screen studies, ensuring transparent and reproducible tracking of all articles identified, filtered, and ultimately included in the analysis (Haddaway et al., 2022).

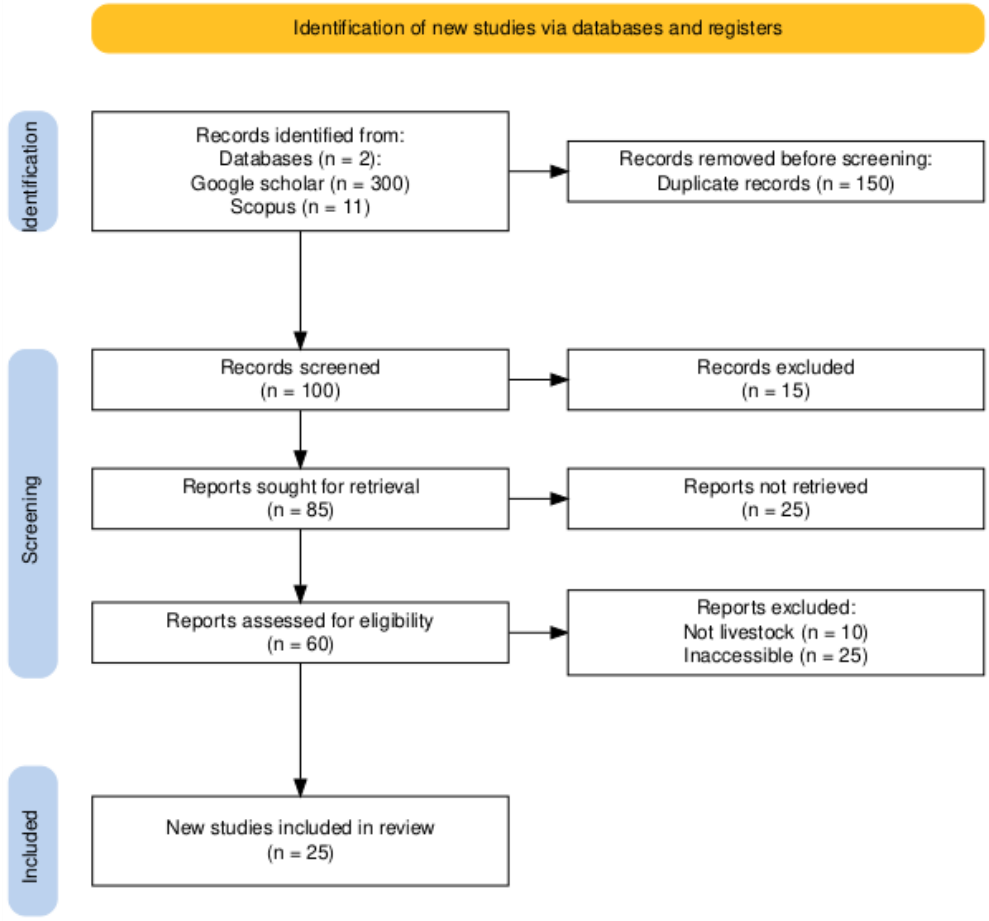

Figure 1. PRISMA Flow Diagram

Literature analysis shows that tropical environments such as those in Kalimantan face high temperatures and humidity, which consistently place ruminants under heat stress. Environmental temperatures exceeding the comfort range that is, above approximately 25 °C with a high temperature humidity index (THI) significantly reduce physiological and reproductive efficiency in ruminants (Habeeb et al., 2023). Considering that Kalimantan straddles the equator and experiences year-round sunshine and extreme variations in rainfall, heat stress experienced by poorly managed livestock is likely greater than in temperate climates. This suggests that environmental factors are a major competitor in ruminant livestock development efforts in this region.

Table 1. The Effects of Tropical Climate on Livestock Reproduction.

No.	Reproductive Parameter	Livestock Species	Environmental Factor	Key Findings	Reference (Year)
1	Conception rate	Dairy cattle	Heat stress (THI > 72)	Conception rate decreased by 20–30% during heat stress periods due to reduced oocyte quality and embryo mortality.	Khan et al., 2023
2	Estrus duration	Cattle	High temperature-humidity (THI > 75)	Estrus duration shortened from ~18 h to 12 h; silent estrus increased due to suppressed LH and estradiol.	Zhang et al., 2025
3	Puberty age	Zebu (*Bos indicus*) vs. *Bos taurus*	Nutritional and thermal stress	*Bos indicus* heifers reached puberty at 18–24 months, while *Bos taurus* at 12–18 months under optimal nutrition.	Samadi et al., 2014; Day & Nogueira, 2013
4	Sperm quality	Cattle, goats	Elevated scrotal temperature	Heat stress increased oxidative stress and DNA damage in sperm; motility and concentration significantly declined.	Khan et al., 2023
5	Embryonic mortality	Dairy cattle	Prolonged heat exposure	High THI caused early embryonic death and implantation failure due to uterine oxidative imbalance.	Miętkiewska et al., 2022
6	Abortion / Stillbirth	Cattle	Chronic heat stress during gestation	Increased abortion and stillbirth rates linked to placental blood flow reduction and low progesterone levels.	Mee, 2023
7	Reproductive hormone balance	Cattle, buffalo	Heat and nutritional stress	Disruption of hypothalamic–pituitary–gonadal axis decreases LH, FSH, and progesterone, reducing fertility.	Sejian et al., 2024
8	Reproductive efficiency index	Mixed ruminants	Combined heat and nutritional stress	Heat and feed limitation together reduce lifetime productivity by ~25–35% in tropical herds.	Adjassin et al., 2022
9	Adaptation traits	Zebu, Sahiwal, Kacang goats	Tropical climate adaptation	Native breeds show better thermotolerance, reproductive recovery, and oocyte viability under heat stress.	van Wettere et al., 2021
10	Management intervention	Dairy cattle	Cooling & nutritional adjustment	Providing shade and high-energy diets improved conception rate by ~15–20% under hot climate.	Sae-tiao et al., 2019

Table 1 shows that tropical livestock reproduction parameters are greatly influenced by environmental temperature and humidity, which reduce reproductive efficiency through physiological (hormonal disruption and gametogenesis) and managerial (feed and estrus detection) pathways. Native species such as *Bos indicus* and local goats show better adaptation to heat stress than introduced breeds (*Bos taurus*), but

still require good nutritional and environmental management support to achieve optimal productivity. The implementation of adaptation strategies such as providing shade, high-energy feed, heat-tolerant genetic selection, and planned reproductive management are key to the sustainability of tropical livestock farming in Kalimantan.

Potential Livestock Types in Kalimantan

In tropical environments with challenging climatic and nutritional pressures, a combination of age management, body condition, and adaptive genetics is essential to achieve optimal productivity. Below are some livestock breeds that are adaptable to the tropical climate in Kalimantan. Bali cattle demonstrated the best adaptation to heat stress in Central Kalimantan's peatlands compared to crossbred cattle. Measurements of physiological parameters such as rectal temperature, heart rate, respiratory rate, and heat tolerance coefficient showed lower values in Balinese cattle, indicating a lower level of heat stress. This reflects Balinese cattle's ability to maintain body heat balance in an environment with high temperature and humidity (Adrial et al., 2023).

Swamp buffalo, *Bubalus bubalis carabanensis*, are native to Kalimantan, where they are extensively raised in swampy areas ("kalang"). These buffaloes have an average live weight of 380 kg for males and 312 kg for females, with a carcass percentage of 46% for males and 44% for females (Sumantri et al., 2022). Swamp buffaloes have the potential to be an adaptive livestock species in Kalimantan, but they also face specific production challenges. Based on population and production data, goat farming has good potential in Indonesia. Goats are adaptable to Indonesia's tropical environment, making them a viable alternative for development in Kalimantan (Baharuddin et al., 2023).

Table 2. Comparative Data for Tropical Cattle Adaptation.

Adaptation Trait	Bali Cattle (Kalimantan)	Zebu (Nellore/Gir, Brazil/India)	FH Crosses (Kalimantan)	Impact on Reproduction
Coat Color/Length	Light, short	Light, very short, glossy	Dark, long	↑ Heat dissipation; ↓ Follicular atresia
RT under THI 80–85	38.5–39.0°C	38.6–39.1°C	40.0–40.5°C	↓ Embryonic loss
RR under HS	<70/min	55–65/min	>90/min	↑ Estrus expression
DMI Reduction (HS)	10–15%	8–12%	20–30%	↑ Energy for ovulation
Sweating Rate	1.5–2 L/h	1.8–2.5 L/h	0.8–1 L/h	↓ Core temperature rise

*RT: Rectal Temperature; HS; Heat Stress; RR: Respiratory Rate; DMI: Dry Matter Intake (Adrial et al., 2023; Asmarasari et al., 2023; Martello et al., 2016)

Tropical cattle in Kalimantan, such as Bali breeds, demonstrate superior thermotolerance compared to temperate *Bos taurus* breeds, as shown in Table 2. Zebu cattle (e.g., Nellore, Gir, Guzerat) from Brazil, India, and Africa provide a valuable global benchmark due to their widespread adaptation to hot-humid and hot-dry climates. Bali cattle exhibit lower Rectal Temperature (RT) (38.5–39°C vs. 40°C in FH) and Respiratory Rate (RR) (<70/min) due to efficient panting and sweating, adapted to humid tropics. In comparison, Zebu cattle (Nellore) in Brazil under THI 82–88 maintain RT at 38.6–39.1°C and RR at 55–65 breaths/min significantly lower than European breeds (RT >40.5°C, RR >90) under similar conditions. Coat characteristics short, shiny, and light colored reflect 70–90% of solar radiation, minimizing absorbed heat in both Bali and Zebu.

Reduced dry matter intake (DMI) diverts energy to cooling, but adapted breeds maintain rumen pH stability, supporting follicular development. Zebu cattle show only 8–12% DMI reduction under chronic HS (vs. 20–30% in Holstein), preserving energy for reproduction and growth (Martello et al., 2016).

Strategies for Improving Reproductive Health

The review integrates physiological insights with practical interventions, avoiding redundancy by categorizing solutions into environmental, nutritional, and genetic domains. Environmental modifications, such as providing shade and evaporative cooling, have been shown to reduce rectal temperature and respiration rates significantly, improving estrus detection in heat-stressed herds.

Selecting and breeding cattle with inherent thermotolerance is becoming an indispensable strategy for maintaining reproductive performance in hot tropical climates. Genetic traits such as lower basal rectal temperature, efficient sweating, short glossy coat, and robust immune response have been linked to superior heat resilience and better fertility under heat stress (Osei-Amponsah et al., 2019). Cows selected for high immune-responder phenotypes showed less increase in rectal temperature and higher expression of Heat-Shock-Protein70 (HSP70) under heat challenge, indicating greater tolerance to thermal stress (Abera, 2025; Țogoe & Mincă, 2024). Genetic selection for heat-tolerant genotypes, such as incorporating slick hair traits from Senepol into Bali cattle crosses, offers long-term resilience, potentially boosting conception rates by 15-25% (Michael et al., 2022). By prioritizing these traits in

breeding programs, production systems in tropics such as in Kalimantan can gradually build herds that sustain fertility despite elevated ambient temperatures.

Livestock need to be prepared to store feed during periods of shortage to maintain effective reproductive function. In tropical regions, rising temperatures and decreased rainfall reduce pasture productivity and accelerate pasture decline, while higher heat levels reduce feed intake and impair energy conversion in animals (Hiemstra & Tvedt, 2008). Climatic factors, including temperature and rainfall patterns, influence the availability of pasture and forage annually, as well as the prevalence of diseases and parasites that compromise reproductive health (Lamy et al., 2012). Consequently, livestock expend extra energy to regulate body temperature, resulting in inefficient feed utilization, delayed estrus cycles, extended mating periods, and extended calving intervals. To address these challenges, strategic breeding planning is crucial to optimize reproductive outcomes, supported by advanced reproductive technologies. Furthermore, nutritional adaptations, such as antioxidant supplementation like vitamin E, help reduce oxidative damage to gametes, with a recent 2024 study showing improved progesterone stability and lower embryonic mortality in supplemented herds (Kotsampasi et al., 2024; Negrón-Pérez et al., 2019).

Adequate water provision and optimal housing to manage heat loads are crucial factors in the management of tropical cattle farming systems. Ensuring unimpeded access to clean, cool water allows for increased peripheral blood flow and evaporative cooling, which are particularly important when ambient temperatures exceed the cow's thermoneutral zone (Habimana et al., 2023). Concurrently, housing improvements by providing shade, cross-ventilation, and in some cases, sprinkler systems or fogging can reduce the temperature-humidity index (THI) surrounding the animal, shorten the respiratory rate, and mitigate reproductive decline (e.g., reduced estrus duration, embryonic mortality) that occurs under heat stress (Oliveira et al., 2025). Therefore, effective thermal housing complements genetic and nutritional strategies to protect fertility in hot climates. Adequate water supply and optimized housing to manage heat load are essential management levers in tropical cattle systems. Ensuring unrestricted access to clean, cool water allows for increased peripheral blood flow and evaporative cooling, which is critical when ambient temperatures exceed cows’ thermoneutral zone.

Concurrently, improving housing by providing shade, cross-ventilation, and in some cases sprinklers or fogging systems can reduce the temperature humidity index (THI) around animals, shorten respiratory rates, and mitigate reproductive declines (e.g., reduced estrus length, embryo mortality) observed under heat stress (Hufana-Duran & Duran, 2020). Effective thermal housing therefore complements genetic and nutritional strategies to protect fertility in hot climates.

Considering the socioeconomic dimensions of local farms, smallholder farms in Kalimantan face resource constraints that limit the adoption of advanced technologies, such as scheduled Artificial Insemination (AI), which can actually shorten calving intervals (Hambisa, 2025). This economic disparity exacerbates the vulnerability of HS, as low-income farmers rely on extensive grazing systems that are vulnerable to forage shortages during the dry season, which can delay puberty in heifers.

CONCLUSION

In conclusion, although heat stress is the most critical reproductive constraint, an integrated management framework combining genetic, environmental, and nutritional strategies supported by supportive policies can restore fertility and secure livestock-based food systems in Kalimantan. Improving reproduction under these conditions requires selecting heat-tolerant cattle breeds, providing balanced nutrition and water, and improving housing to reduce heat load. Tropical cattle such as Bali and Zebu cattle demonstrate strong adaptation to heat stress through efficient body temperature control, improved feed intake, and higher fertility at high temperatures and humidity. Support from governments and research institutions is needed to help farmers implement these strategies and develop integrated reproductive management systems appropriate for tropical climates.

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