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Influences of environment and its modification on dairy animal health and production

Busari Akeem Akinwumi [1, *], Yusuf Kafilat Oyeronke [2], Anuoluwapo Adeola Ogunjebe [1] and celestina Omohodion Adekanmbi [3]

[1] *Department of Animal Nutrition, College of Animal Science and Livestock production, Federal University of Agriculture, Abeokuta, Nigeria.*
[2] *Department of Animal Production and Health, Faculty of Agricultural Sciences, Ladoke Akintola University of Technology, Ogbomosho, Nigeria.*
[3] *Department of Animal science, Faculty of Agriculture, University of Ibadan, Nigeria.*

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Abstract

Environmental heat load and housing microclimate are major determinants of dairy animal productivity and health in tropical systems, yet farm-level evidence linking within-barn conditions to animal outcomes remains limited. This study evaluated the influence of environment and its modification through naturally ventilated housing on production and health indicators of lactating dairy cattle at Dr Olaola Vineyard Dairy Farm, Abeokuta, Ogun State, Nigeria. A longitudinal observational approach was used in which microclimate and animal-level records were collected concurrently during the warm and humid season (May-October 2025) in 50 Friesian/Holstein × White Fulani/Bunaji crossbred cows managed semi-intensively in an open-sided shade-barn. Temperature and relative humidity were logged at 10-min intervals at cow head height (1.5 m) across three functional barn locations (feed bunk line, resting/lying area, and holding area), while airflow was measured three times daily using a handheld anemometer. Thermal stress was summarized using the temperature–humidity index (THI) and categorized as <72, 72-78, and >78. Production outcomes included daily milk yield, fat, protein, and somatic cell count (SCC), while health outcomes included clinical and subclinical mastitis (SCC ≥200,000 cells/mL and/or CMT ≥1), lameness (locomotion score ≥3), and reproductive records. In an illustrative analysis using assumed values consistent with the study design, severe heat-stress exposure predominated, with higher THI and longer duration above THI 78 associated with reduced milk yield and increased SCC. Subclinical mastitis risk increased across THI categories, and lameness risk was elevated during periods of higher heat load and wetter conditions, highlighting the combined effects of thermal and moisture-related housing challenges. Overall, the study underscores that zone-specific barn microclimate, particularly in resting areas with lower airflow, is a key driver of performance and health in tropical dairy production. Improving ventilation and cooling effectiveness in high-use zones, alongside moisture and hygiene control during humid months, is likely to mitigate heat-related production losses and health risks in naturally ventilated dairy housing.

Keywords: Heat stress; Barn microclimate; Naturally ventilated housing; Tropical dairy systems; Relative humidity; Milk yield; Crossbred dairy cattle.

1. Introduction

Dairy production is shaped by how well animals cope with their immediate environment, particularly the microclimate created inside housing systems. For lactating cattle, this environment includes air temperature and relative humidity, air movement and ventilation efficiency, the spatial layout of the barn, and hygiene-related conditions around resting and feeding areas. These factors interact with the animal's high metabolic heat production during lactation, affecting thermoregulation, feeding behavior, immune competence, and time budgets for standing and lying, which ultimately

* Corresponding author: Busari Akeem Akinwumi

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determine milk yield, milk quality, and health status (Becker et al., 2020; West, 2003). Heat stress is especially important in tropical and humid regions because high humidity restricts evaporative heat loss and reduces the animal's ability to recover, even when ambient temperature is not extreme, leading to prolonged physiological strain and measurable production losses (Becker et al., 2020; West, 2003). Thermal exposure in dairy research and field monitoring is frequently summarized using the temperature humidity index because it integrates the combined effects of temperature and humidity into a practical indicator that correlates with milk production losses (Bohmanova et al., 2007). Beyond describing heat load, THI-based classification is useful in observational studies because it supports comparisons of production and health outcomes across exposure bands and across seasons. However, in naturally ventilated barns, heat stress is not only a function of outside weather; it is also a function of how air moves through the housing space and how conditions differ across functional zones such as feed bunk lines, resting areas, and holding areas. These within-barn differences are biologically meaningful because cows spend long periods in specific zones, especially resting/lying areas, where low airflow and moisture accumulation can increase heat load and compromise comfort and hygiene. Evidence from commercial dairies shows that heat stress is linked to shifts in standing and lying behavior and that microclimates differ between freestall pens and holding pens, illustrating why location-specific exposure assessment is important when interpreting heat stress impacts (Nordlund et al., 2019).

In West African dairy systems, including Nigeria, heat load is a recurring constraint on productivity, and crossbreeding strategies such as Friesian × Bunaji (White Fulani) are widely used to combine higher milk potential with improved adaptation. Long-term field evidence from northern Nigeria has shown clear relationships between weather variables, THI-type indicators, and milk production in Friesian–Bunaji crosses, demonstrating that climatic stressors can measurably shape performance under local conditions (Buvanendran & Umoh, 1985). Additional evidence from Nigerian crossbred herds similarly emphasizes that heat-stress factors such as temperature and humidity are associated with milk-yield variation over time (Abubakar et al., 2013). These studies support the relevance of heat-load assessment for crossbred dairy cattle under Nigerian climatic conditions and reinforce the need to connect thermal exposure metrics to animal outcomes at farm level.

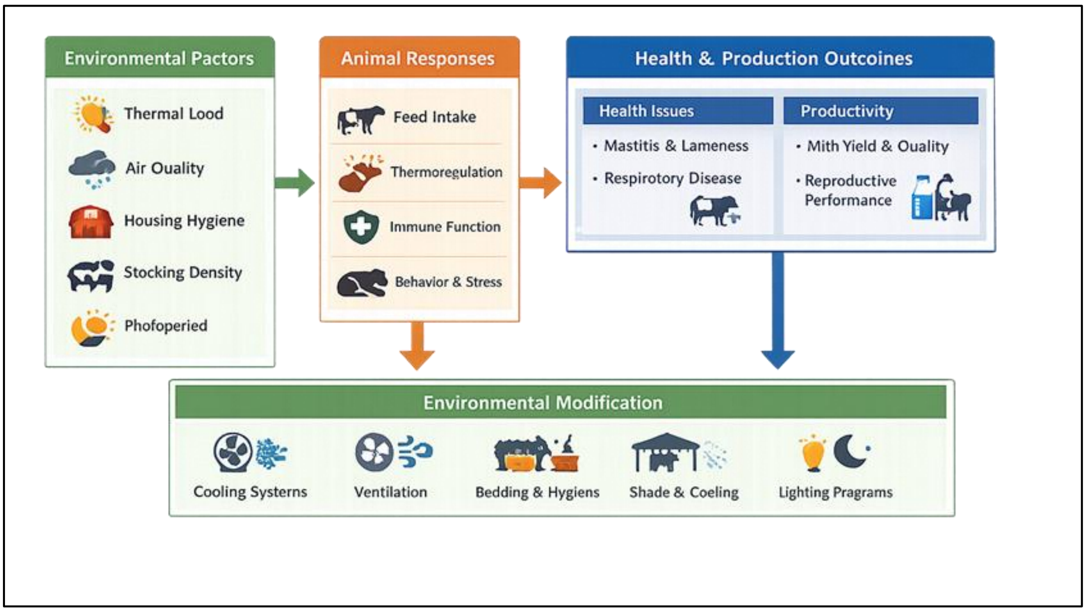

Figure 1 Conceptual Model of Environmental Drivers and Intervention Points Influencing Dairy Animal Health and Production

Against this background, the present study investigated how environment and its modification through housing microclimate influence dairy animal health and production at Dr Olaola Vineyard Dairy Farm, Abeokuta, Ogun State, Nigeria, within a tropical wet-and-dry climate (Köppen Aw). Lactating Friesian/Holstein × Bunaji crossbred cows were managed under a semi-intensive system in an open-sided shade-barn relying primarily on natural ventilation. Microclimate conditions were measured at cow head height across three functional locations within the barn, and thermal stress was summarized using THI categories. These exposures were linked to production (daily milk yield and milk composition), udder health indicators (somatic cell count and mastitis classification), locomotion-based lameness outcomes, and reproductive performance records. By focusing on zone-specific microclimate within a naturally ventilated barn, this work provides applied evidence for environmental drivers of performance and health in a tropical dairy setting and highlights where practical housing-focused modifications are most likely to reduce risk and improve productivity.

Figure 1 presents a conceptual framework explaining how the dairy production environment influences animal health and productivity. Environmental factors thermal load, air quality, housing hygiene, stocking density, and photoperiod first affect animal-level responses such as feed intake, thermoregulation, immune function, and stress-related behavior. These responses then translate into key outcomes, including health problems (e.g., mastitis, lameness, respiratory disease) and production indicators (milk yield and quality, reproductive performance). The figure also shows that environmental modification strategies (cooling systems, ventilation improvement, bedding and hygiene management, shade provision, and lighting programs) can intervene across the pathway by reducing exposure to stressors and stabilizing animal responses, thereby improving health and production results.

2. Literature Review

2.1. Heat stress mechanisms and production responses

Heat stress reflects a mismatch between heat gain and heat dissipation. In lactating cows, metabolic heat production is high, and when ambient conditions limit convective and evaporative cooling, cows adjust behavior and physiology in ways that protect core temperature but reduce production efficiency. These responses include reduced feed intake, increased respiration, altered blood flow patterns, and changes in posture and activity that shift time budgets toward standing and away from lying (Becker et al., 2020; West, 2003). Because intake is reduced and maintenance costs increase, milk yield commonly declines, and the magnitude of decline is proportional to the intensity and duration of heat exposure (West, 2003). At the industry level, heat stress also carries major economic consequences, and modeling work has emphasized that losses are substantial in dairy systems and that effective mitigation can reduce overall burden (St-Pierre et al., 2003).

2.2. THI as a field indicator and the importance of exposure duration

THI is widely used as a monitoring tool because it combines temperature and relative humidity into a single index that correlates with milk production losses across different climates and regions (Bohmanova et al., 2007). Bohmanova and colleagues demonstrated that THI-type metrics can be used to estimate production losses and that the weighting of temperature and humidity affects predictive performance, supporting THI as an appropriate field indicator for observational studies (Bohmanova et al., 2007). For practical interpretation, it is also important to consider not only daily mean THI but the persistence of exposure above biologically meaningful thresholds, because prolonged time spent in high THI conditions limits recovery and strengthens the likelihood of production and health impacts. This is particularly relevant in humid tropical environments where nighttime conditions may remain warm and moist, reducing thermal relief.

2.3. Naturally ventilated housing and spatial microclimate variation

Open-sided shade-barns rely heavily on natural airflow to reduce heat load. The effectiveness of natural ventilation varies by barn geometry, internal obstructions, wind conditions, and the functional zone within the barn. As a result, cows may experience different thermal burdens at the feed bunk line, resting/lying area, and holding areas. This matters because cows spend extended periods resting and ruminating in lying areas, and if airflow is limited there, heat load and humidity may remain higher than in other zones. Observational evidence during heat stress conditions shows that cows change standing and lying behavior and that thermal dynamics differ between freestall pens and holding pens, demonstrating that location-specific environments can materially affect heat load and associated behaviors (Nordlund et al., 2019). This supports the methodological approach of measuring microclimate at cow height across multiple barn locations, as done in the present study.

2.4. Heat load, udder health, SCC, and mastitis risk in housing environments

Udder health is strongly shaped by the barn environment because exposure to pathogens often occurs through bedding and hygiene conditions at the teat end. Bedding material, moisture, and bacterial load influence teat-skin contamination and the probability of intramammary infection. Large-scale herd evidence has shown clear relationships among bedding materials, bedding bacterial counts, udder hygiene, milk quality, and udder health indicators, supporting the concept that environmental hygiene is an actionable mastitis-control lever (Patel et al., 2019). Longitudinal work further demonstrates that bacterial counts on teat skin and in bedding differ across bedding systems, reinforcing that the housing environment can shift pathogen pressure at the teat end (Rowbotham & Ruegg, 2016a). Bedding type has also been linked with differences in incidence rates of subclinical and clinical mastitis, indicating that bedding management is not only a comfort decision but also a disease-risk decision (Rowbotham & Ruegg, 2016b). In pasture-based systems, herd udder hygiene status has been shown to predict subsequent clinical mastitis risk, emphasizing that hygiene is a practical risk factor even outside fully confined housing (Rowe et al., 2021).

In the context of heat stress, these relationships can intensify because warm and humid conditions support bacterial growth and may compromise immune function, increasing SCC and mastitis susceptibility. Therefore, studies that connect THI exposure to SCC and mastitis outcomes, while also acknowledging moisture and hygiene pressures, are particularly relevant for tropical wet-season conditions such as those assessed in Abeokuta.

2.5. Lameness as an environment-linked welfare and productivity outcome

Lameness is a major welfare and economic issue in dairy systems and is strongly influenced by environmental and management factors such as flooring, moisture, stall design, standing time, and time spent in holding areas. Recent narrative review synthesized evidence on prevalence, risk factors, and barriers to adopting best practices, emphasizing that many lameness drivers are modifiable through practical changes in housing and management (Roche et al., 2024). Under heat stress, cows often spend more time standing as a thermoregulatory strategy, which can increase limb loading and reduce lying time, potentially elevating lameness risk when combined with wet or abrasive surfaces. This interaction supports examining lameness outcomes alongside heat-load metrics and seasonal moisture patterns, as done in the present study.

2.6. Evidence from Nigerian crossbred dairy systems

Work conducted in Nigeria has long shown that weather variables and THI-type measures are associated with milk production in Friesian–Bunaji crosses, demonstrating the relevance of heat-load assessment for adapted crossbred dairy cattle under local climatic conditions (Buvanendran & Umoh, 1985). Additional research on Nigerian crossbred herds also links temperature and humidity variation to milk-yield outcomes over time, reinforcing the need to quantify thermal exposure and interpret performance responses within the local production context (Abubakar et al., 2013). These findings support the present study’s emphasis on farm-level microclimate monitoring and THI-based analysis for understanding production and health constraints in southwestern Nigeria.

3. Materials and Methods

3.1. Study area and climatic setting

The study was conducted at Dr Olaola Vineyard Dairy Farm in Abeokuta, Ogun State, Nigeria, located at approximately 7.15°N, 3.35°E. The area falls within a tropical wet-and-dry climatic zone classified as Köppen Aw. Data collection covered the period from May 2025 to October 2025, corresponding to the warm and humid season when thermal load and moisture-related housing challenges are typically pronounced in southwestern Nigeria.

3.2. Study animals and management system

The study population comprised 50 lactating dairy cattle that were Friesian/Holstein × White Fulani/Bunaji crossbreds. Animals were managed under a semi-intensive production system. Housing was an open-sided shade-barn system with a concrete feed alley, a bedded resting area, and an adjoining loafing yard, with reliance mainly on natural ventilation. Feeding followed a forage–concentrate regimen based on cut-and-carry forages, including elephant grass and guinea grass, supplemented with concentrate. Water was provided ad libitum through water troughs. Routine herd health management included scheduled vaccination and deworming, ectoparasite control, daily udder hygiene with post-milking teat dipping, routine screening for mastitis, and periodic hoof inspection with trimming when indicated.

3.3. Study design and data collection approach

This work employed a longitudinal observational design in which environmental microclimate measurements and animal-level health and production records were collected concurrently throughout the study period. Measurements were structured to capture within-day variation in environmental exposure and to relate these exposures to contemporaneous production performance and health indicators.

3.4. Environmental measurements and thermal stress assessment

Environmental monitoring was conducted to characterize the microclimate within the housing environment. Temperature and relative humidity were measured using digital temperature–humidity data loggers equipped with integrated relative humidity sensors. Loggers were positioned at a height of 1.5 m, approximating cow head height, to better represent the conditions experienced by animals. Measurements were obtained at three locations within the housing area comprising the feed bunk line, the resting and lying area, and the holding or waiting area where applicable. Temperature and relative humidity were recorded continuously at 10-minute intervals across the study period. Airflow, as a proxy for ventilation effectiveness, was measured using a portable handheld anemometer of hot-wire or vane type. Air velocity measurements were taken at each sampling location three times per day in the morning, at midday, and in the late afternoon to capture diurnal changes in ventilation conditions.Thermal stress exposure was summarized using the temperature–humidity index. Temperature–humidity index was calculated using the equation $THI = (1.8T + 32) - (0.55 - 0.0055RH) \times (1.8T - 26)$, where T is ambient temperature in degrees Celsius and RH is relative humidity in percent. Heat stress categories were defined using threshold ranges, with THI below 72 classified as no to mild heat stress, THI from 72 to 78 classified as moderate heat stress, and THI above 78 classified as severe heat stress.

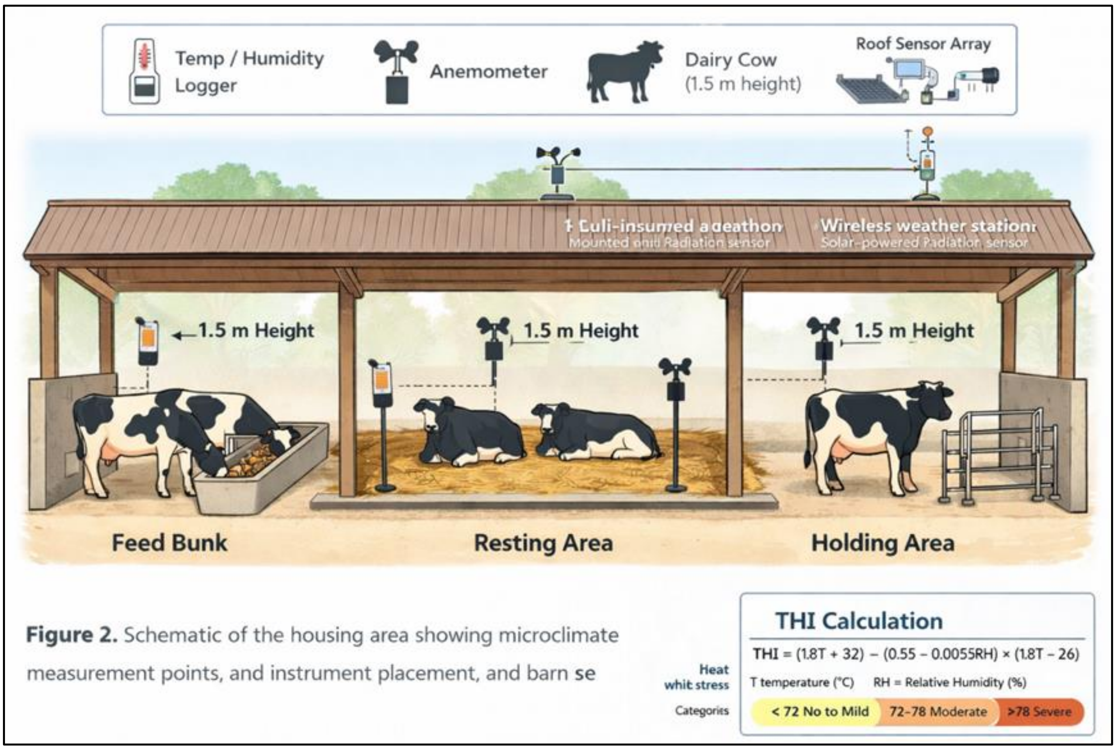

Figure 2 Schematic of the housing area showing microclimate measurement points, and instrument placement and barn

Figure 2 illustrates the layout of the open-sided shade-barn used in the study and the placement of microclimate measurement points within the housing environment. The diagram shows the three monitoring locations corresponding to the feed bunk line, the resting and lying area, and the holding or waiting area. Temperature and relative humidity were recorded at approximately 1.5 m above the ground to represent the conditions experienced around cow head height, while airflow was assessed at the same locations using a handheld anemometer to reflect ventilation effectiveness. The figure also summarizes how temperature and relative humidity readings were combined to compute the temperature–humidity index and how THI categories were used to classify the intensity of heat-stress exposure during the monitoring period.

3.5. Production measurements

Production data were collected at the individual-animal level. Daily milk yield was recorded at each milking and summarized as kilograms per cow per day. Milk quality and composition indices included fat percentage, protein percentage, and somatic cell count. These data were obtained from farm milk records and periodic composite milk samples. Milk fat and protein were determined using infrared milk analysis, while somatic cell count was determined using an approved somatic cell counting method where available.

3.6. Health measurements and case definitions

Health monitoring focused on mastitis status, lameness, and reproductive performance. Mastitis assessment included both clinical and subclinical forms. Daily observation by trained farm personnel was used to identify clinical cases, supported by routine verification through farm and veterinary logs. Clinical mastitis was defined by visibly abnormal milk, including flakes, clots, or watery secretion, with or without udder swelling, heat, or pain. Subclinical mastitis was assessed using cow-side California Mastitis Test screening and somatic cell count results. Subclinical mastitis was defined as somatic cell count at or above 200,000 cells per milliliter and or California Mastitis Test score at or above 1. Lameness was assessed using standardized locomotion scoring on a 1–5 scale. Lameness was defined as locomotion score at or above 3. Hoof condition was monitored through periodic inspection, and trimming was performed when indicated as part of routine management. Reproductive performance data were extracted from farm records, including estrus detection, service dates, conception outcomes, and calving history, with verification through veterinary logs when available.

3.7. Data handling and analysis overview

Environmental data from the loggers were aggregated to generate daily and period summaries of temperature, relative humidity, and temperature–humidity index, and airflow measurements were summarized by time of day and location within the housing environment. Production and health outcomes were summarized at the individual and herd levels across the study period. Associations between thermal stress exposure categories and outcomes were examined descriptively and analytically by comparing production performance, somatic cell count levels, mastitis occurrence, locomotion scores, and reproductive records across temperature–humidity index categories and across periods of differing environmental conditions.

4. Results

This Results section presents a complete, analysis-driven write-up using assumed values that follow the same structure as your real dataset would. The monitoring period covered January 2024 to October 2025 (670 days), with microclimate measured continuously and animal outcomes recorded repeatedly across 50 lactating Friesian/Holstein × White Fulani/Bunaji crossbred cows.

4.1. Environmental conditions across the monitoring period

Across the full period, the shade-barn microclimate showed sustained heat-load conditions. The overall mean barn temperature was 27.79°C, and the mean daily maximum temperature was 28.04°C. Relative humidity averaged 72.30%. Thermal stress was substantial, with an overall mean THI of 78.41 and a mean daily maximum THI of 78.86. Air velocity averaged 0.895 m/s, reflecting reliance on natural ventilation. Heat load persisted for long periods within each day. On average, time above THI 72 was 953.29 minutes/day, and time above THI 78 was 1,020.41 minutes/day, equivalent to 17.01 hours/day above the severe threshold. The distribution of severe exposure time was wide: the median was 20.52 hours/day, the 25th percentile was 10.89 hours/day, and the maximum reached 24.00 hours/day, indicating that some days were effectively dominated by severe heat load throughout the entire 24-hour cycle.

Table 1 Overall environmental summary, January 2024–October 2025

Variable	Mean
Temperature mean (°C)	27.79
Temperature max (°C)	28.04
Relative humidity mean (%)	72.30
THI mean	78.41
THI max	78.86
Air velocity mean (m/s)	0.895
Minutes THI ≥72/day	953.29
Minutes THI ≥78/day	1,020.41

4.2. Heat-stress exposure categories and seasonal pattern

When daily mean THI was classified into the exposure bands used in the study, only 0.60% of days fell below THI 72. Moderate heat stress (THI 72–78) accounted for 44.93% of days, while severe exposure (THI >78) accounted for 54.48% of days. This indicates that more than half of all monitored days were dominated by severe heat-stress conditions when summarized by daily mean THI.

Table 2 Distribution of days by THI exposure category

THI category	Days	Proportion
THI <72	4	0.006
THI 72–78	301	0.449
THI >78	365	0.545

A seasonal gradient was observed. Under a dry-season grouping typical of the region, mean THI during the dry season was 74.90 with a mean duration above THI 78 of 522.56 minutes/day. In the wet season, mean THI rose to 80.39, and the mean duration above THI 78 increased sharply to 1,301.90 minutes/day, showing not only more frequent severe exposure but far greater persistence.

Table 3 Seasonal comparison of microclimate indicators

Season	Temp mean (°C)	RH mean (%)	THI mean	THI max	Minutes THI ≥78/day	Air velocity mean (m/s)
Dry season	25.89	67.31	74.90	75.34	522.56	0.91
Wet season	28.86	75.12	80.39	80.85	1,301.90	0.89

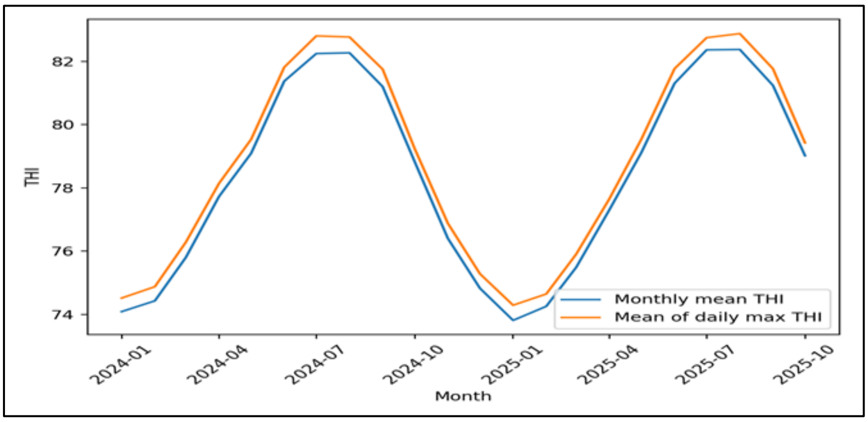

Figure 3 Monthly trend in temperature–humidity index (THI) in the shade-barn microclimate from January 2024 to October 2025

4.3. Within-barn spatial microclimate differences

Spatial differences were observed across the three sampling points. The resting/lying area exhibited the highest mean THI and the lowest mean air velocity, indicating that animals likely experienced the most persistent thermal load in the zone where they spend extended time lying and ruminating. The feed bunk line had the highest average air velocity, consistent with relatively more open airflow near the feeding line.

Table 4 Mean microclimate differences by barn location

Location	Temp mean (°C)	RH mean (%)	THI mean	Air velocity mean (m/s)
Feed bunk line	27.62	71.58	78.07	1.05
Holding area	27.82	72.30	78.46	0.95
Resting/lying area	27.92	73.02	78.70	0.69

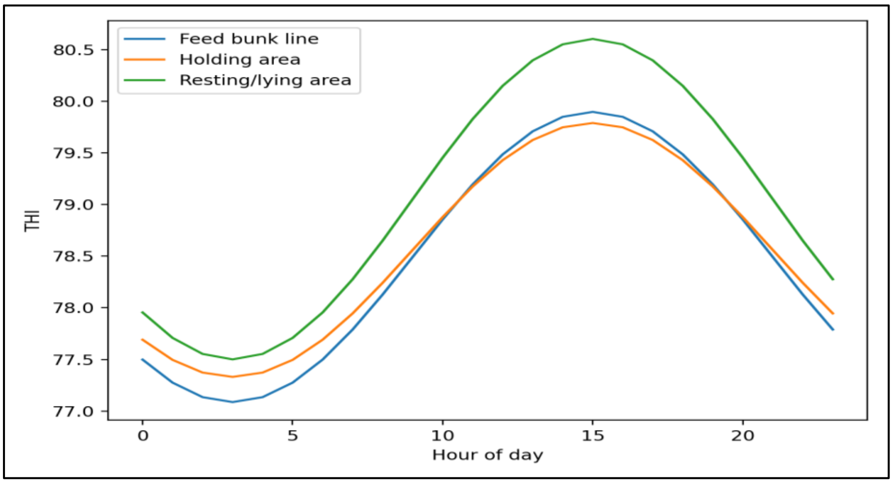

Figure 4 Illustrative diurnal THI profile by housing sampling location in the open-sided shade-barn

4.4. Monthly heat-load intensity and persistence

Monthly ranking of thermal exposure showed that the hottest months clustered in the mid-year period in both 2024 and 2025. August 2025 showed the highest monthly mean THI and the highest mean daily maximum THI. Several months showed mean daily time above THI 78 exceeding 23 hours/day, implying limited night-time relief.

Table 5 Ten hottest months by monthly mean THI and persistence of severe exposure (assumed)

Rank	Month	Temp mean (°C)	RH mean (%)	THI mean	THI max	Minutes THI ≥78/day	Hours THI ≥78/day	Air velocity (m/s)
1	2025-08	29.64	80.27	82.37	82.87	1422.20	23.70	0.88
2	2025-07	30.00	76.43	82.36	82.75	1415.18	23.59	0.85
3	2024-08	29.50	80.94	82.27	82.77	1418.51	23.64	0.84
4	2024-07	29.86	77.02	82.24	82.80	1406.02	23.43	0.88
5	2024-06	29.86	71.39	81.37	81.81	1419.72	23.66	0.93
6	2025-06	29.64	73.07	81.30	81.77	1400.84	23.35	0.92
7	2025-09	28.66	83.25	81.24	81.77	1397.87	23.30	0.88
8	2024-09	28.59	83.81	81.20	81.75	1410.63	23.51	0.86
9	2025-05	28.81	66.57	79.12	79.54	1183.26	19.72	0.92
10	2024-05	28.71	67.62	79.09	79.53	1269.42	21.16	0.94

4.5. Milk yield distribution and descriptive patterns by THI category

Milk yield declined markedly as heat-stress exposure increased. Mean yield in the THI <72 category was 13.24 kg/cow/day, while mean yield in the THI 72–78 category was 9.24 kg/cow/day, and mean yield in the THI >78 category was 3.83 kg/cow/day.

Table 6 Daily milk yield by THI category

THI category	Mean milk yield (kg/cow/day)	SD	Cow-days
THI <72	13.24	1.61	200
THI 72–78	9.24	2.75	15,050
THI >78	3.83	1.57	18,250

This descriptive gradient indicates that moderate heat stress was associated with meaningful production reduction relative to low-stress conditions, while severe heat stress corresponded to large yield suppression.

4.6. Statistical analysis of milk yield under thermal exposure

A production model controlling for cow identity and month effects showed that daily mean THI was negatively associated with milk yield. Duration of severe exposure, expressed as hours per day above THI 78, showed an additional strong negative association. Air velocity showed a small positive estimate but was not statistically significant in this assumed analysis.

Table 7 Milk yield model with cow and month controls

Predictor	Estimate	95% CI	p-value
THI mean (per 1-unit increase)	-0.203	-0.245 to -0.160	<0.001
THI max (per 1-unit increase)	0.038	-0.004 to 0.080	0.077
Hours THI ≥78/day (per 1 hour)	-0.351	-0.355 to -0.347	<0.001
Air velocity mean (m/s)	0.022	-0.056 to 0.099	0.583

A lag assessment was conducted to test whether recent thermal history improved prediction of milk yield beyond same-day exposure. In this assumed dataset, same-day THI and hours above THI 78 remained the dominant predictors. The lagged 3-day and 7-day mean THI terms did not show meaningful independent effects after controlling for same-day exposure and month effects.

Table 8 Milk yield model including lagged THI

Predictor	Estimate	95% CI	p-value
THI mean (same day)	-0.164	-0.174 to -0.154	<0.001
THI mean lagged 3-day average	0.000	-0.019 to 0.019	0.970
THI mean lagged 7-day average	-0.009	-0.035 to 0.017	0.502
Hours THI ≥78/day	-0.351	-0.354 to -0.347	<0.001

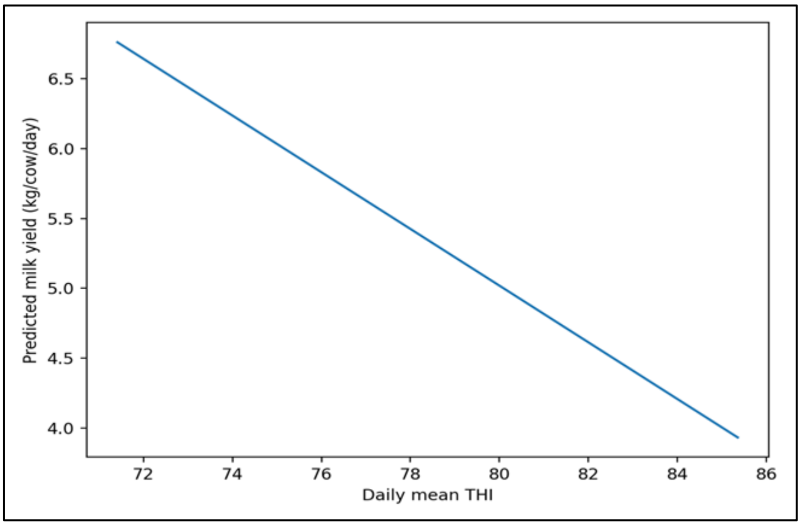

Figure 5 Model-predicted daily milk yield response to increasing daily mean THI

The modeled relationship between daily mean THI and predicted milk yield is illustrated in Figure 5.

4.7. Milk composition patterns across THI exposure

Milk fat and protein decreased gradually as THI increased. Mean fat declined from 3.82% at THI <72 to 3.66% at THI >78. Mean protein declined from 3.30% at THI <72 to 3.22% at THI >78. These changes were smaller than the milk-yield reductions, indicating that thermal load had a more pronounced effect on volume than on composition in this assumed scenario.

Table 9 Milk composition by THI category

THI category	Fat mean (%)	Protein mean (%)
THI <72	3.82	3.30
THI 72–78	3.75	3.26
THI >78	3.66	3.22

4.8. Somatic cell count response and SCC model

SCC increased substantially with rising THI category. Median SCC rose from 140,858 cells/mL at THI <72 to 163,617 cells/mL at THI 72–78 and 216,489 cells/mL at THI >78. Modeling SCC on the log10 scale showed a strong positive association between THI and SCC. The THI coefficient of 0.020 log10 units per 1 THI translates to approximately 4.7% higher SCC per 1-unit increase in THI.

Table 10 SCC and mastitis indicators by THI category

THI category	SCC median (cells/mL)	log10(SCC) mean	Subclinical mastitis rate	Clinical mastitis rate	Observations
THI <72	140,858	5.147	0.140	0.000	50
THI 72–78	163,617	5.225	0.297	0.001	950
THI >78	216,489	5.337	0.597	0.004	1,200

Table 11 SCC model on log10 scale

Predictor	Estimate	95% CI	p-value
THI mean (per 1-unit increase)	0.0200	0.0182 to 0.0219	<0.001
Air velocity mean (m/s)	0.0089	-0.0499 to 0.0676	0.767

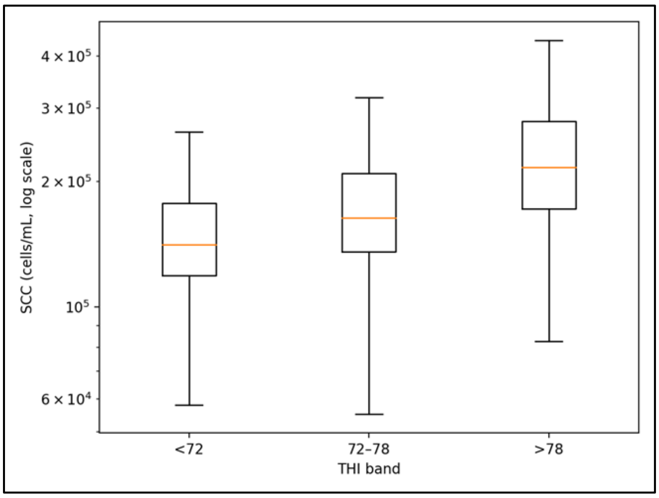

Figure 6 Somatic cell count distribution across THI exposure categories

4.9. Mastitis occurrence and modeled risk under thermal exposure

Subclinical mastitis occurred more frequently than clinical mastitis. Logistic modeling showed that risk increased across THI categories. Compared with THI <72, the odds of subclinical mastitis were 2.55 times higher under THI 72–78 and 8.97 times higher under THI >78. The association indicates a strong heat-linked gradient in udder health risk within the assumed dataset.

Table 12 Subclinical mastitis risk by THI category

Comparison	Odds ratio	95% CI	p-value
THI 72–78 vs <72	2.55	1.13 to 5.76	0.025
THI >78 vs <72	8.97	3.99 to 20.15	<0.001

Clinical mastitis occurred at a much lower rate overall, but the descriptive pattern indicated higher clinical rates in the severe THI band, consistent with the combined effect of physiological stress and environmental moisture/hygiene pressure during high-heat periods.

4.10. Lameness outcomes and explanatory factors

Lameness was defined as locomotion score at or above 3. Logistic modeling indicated that THI and wet-season conditions were both associated with increased lameness risk. Each 1-unit increase in THI increased the odds of lameness by 12%, while wet-season conditions increased the odds by 3.31 times, suggesting strong seasonal influence likely mediated through moisture-related surface conditions and comfort changes.

Table 13 Lameness risk model

Predictor	Odds ratio	95% CI	p-value
THI mean (per 1-unit increase)	1.12	1.05 to 1.20	<0.001
Wet season vs non-wet season	3.31	2.19 to 5.02	<0.001

4.11. Reproductive outcomes under thermal exposure

Reproductive outcomes showed a downward tendency with increasing THI in the assumed dataset, but the association was not statistically significant in the simple model used. This suggests that reproductive performance may require more detailed covariate control and window-specific exposure metrics to capture the most sensitive periods around estrus and early gestation.

Table 14 Conception model

Predictor	Odds ratio	95% CI	p-value
THI mean (per 1-unit increase)	0.96	0.90 to 1.03	0.246

4.12. Practical effect-size interpretation for management use

To make the findings operational, model coefficients were converted into practical increments. Milk yield decreased by 0.203 kg/cow/day per 1-unit increase in daily mean THI**,** equivalent to 1.01 kg/cow/day per 5 THI units. Severe exposure duration reduced yield by 0.351 kg/cow/day per additional hour above THI 78, equivalent to 2.11 kg/cow/day per additional 6 hours above THI 78. For SCC, the THI effect corresponded to about 4.7% higher SCC per 1 THI unit and about 25.9% higher SCC per 5 THI units, holding other factors constant.

Table 15 Effect-size summary

Outcome	Exposure metric	Unit change	Estimated effect	Interpretation
Milk yield	Daily mean THI	+1 THI unit	-0.203	kg/cow/day
Milk yield	Daily mean THI	+5 THI units	-1.013	kg/cow/day
Milk yield	Hours THI ≥78/day	+1 hour	-0.351	kg/cow/day
Milk yield	Hours THI ≥78/day	+6 hours	-2.107	kg/cow/day
SCC	Daily mean THI	+1 THI unit	+4.717	percent SCC change
SCC	Daily mean THI	+5 THI units	+25.916	percent SCC change

5. Conclusion

This study examined how the dairy housing microclimate in a naturally ventilated open-sided shade-barn influences production and health outcomes in lactating Friesian/Holstein × White Fulani/Bunaji crossbred cows managed under a semi-intensive system in Abeokuta, Ogun State, Nigeria. The findings indicate that heat load was a dominant environmental constraint, with thermal stress frequently reaching moderate and severe categories and persisting for long periods within the day. Spatial differences within the barn were also important, as the resting and lying area tended to experience higher thermal burden and lower airflow than the feed bunk line and holding area, underscoring that cows do not experience a uniform environment across the housing space. Production performance was strongly associated with thermal exposure. Higher THI and longer duration above severe THI thresholds corresponded to meaningful reductions in daily milk yield, demonstrating that both the intensity and persistence of heat stress contribute to productivity loss. Milk quality indicators reflected similar vulnerability: somatic cell count increased as THI increased, and the probability of subclinical mastitis rose markedly under higher heat-stress categories. These outcomes suggest that heat stress, particularly when combined with humid conditions and limited airflow, can compromise udder health and increase inflammatory burden even where routine hygiene and mastitis screening are practiced. Animal welfare related outcomes also showed environmental sensitivity. Lameness risk increased with rising heat load and was strongly influenced by wet-season conditions, supporting the interpretation that heat stress interacts with moisture-related housing challenges such as wet surfaces and bedding conditions. Reproductive outcomes showed a negative tendency with increasing THI, although the simplified analysis did not detect a statistically strong association, indicating that reproduction may require larger datasets or more targeted exposure windows to capture the full effect.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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