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# Seasonal Thermal Stress and Its Impact on Dairy Productivity in Kerala: A Temperature–Humidity Index (THI) Based Analysis

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## ABSTRACT

*Seasonal thermal stress is emerging as a major constraint to dairy productivity in Kerala's humid tropical climate. High ambient temperature combined with elevated relative humidity results in a higher Temperature-Humidity Index (THI), often exceeding the thermoneutral zone for dairy cattle. This paper synthesises empirical evidence from studies conducted in Kerala, particularly those published in the Journal of Tropical Agriculture, the International Journal of Livestock Research, and the Indian Journal of Animal Reproduction. The findings indicate that seasonal heat stress significantly affects physiological responses, milk composition, feed intake, and reproductive efficiency of crossbred dairy cows. The study highlights the urgent need for climate-adaptive management strategies in Kerala's dairy sector.*

**Keywords:** Thermal stress, Temperature Humidity Index, dairy cattle, Kerala, milk production, reproductive health

## 1.1 Introduction

Agriculture in Kerala is uniquely characterised by its humid tropical climate, diverse cropping systems, and strong integration with livestock, particularly dairy farming. However, in recent decades, rising temperatures and increased Humidity have intensified heat stress across the agricultural sector. One of the most widely used indicators to assess this phenomenon is the Temperature–Humidity Index, which combines ambient temperature and relative Humidity to evaluate the degree of thermal stress experienced by animals and, indirectly, crops.

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In Kerala's climatic conditions, high relative Humidity significantly reduces the efficiency of natural cooling mechanisms such as evaporation, making both crops and livestock more vulnerable to thermal stress even at moderate temperatures. Heat stress adversely affects physiological functions, productivity, and overall farm efficiency—particularly in dairy cattle, where it reduces feed intake, lowers milk yield, and impairs reproductive performance. Beyond livestock, elevated thermal conditions also influence crop growth, soil moisture dynamics, and pest incidence, thereby posing a broader challenge to agricultural sustainability.

With increasing climate variability and the projected impacts of global warming, understanding and managing heat stress through tools like THI has become essential for developing adaptive strategies in Kerala's agriculture. This highlights the need for climate-resilient farming practices, improved livestock management, and policy interventions to mitigate the adverse effects of thermal stress.

### 1.2 Heat stress and the Kerala Dairy sector

Kerala's dairy sector plays a vital role in rural livelihoods, nutritional security, and women-centred household income systems. However, the state's humid tropical climate exposes dairy cattle to significant seasonal thermal stress. Unlike dry regions, Kerala experiences high relative Humidity throughout the year, which reduces the efficiency of evaporative cooling in cattle. Thermal stress is commonly measured using the Temperature-Humidity Index (THI). When THI exceeds 72, dairy cows begin experiencing heat stress. In Kerala, summer THI values frequently exceed 80, placing animals under moderate to severe stress.

Research conducted at Kerala Veterinary and Animal Sciences University and published in the Journal of Tropical Agriculture and International Journal of Livestock Research confirms strong seasonal variations in physiological stress and productivity parameters among crossbred dairy cows.

### 1.3 Importance of the study

The analysis of heat stress using the Temperature–Humidity Index is critically important for agriculture in Kerala, where the humid tropical climate creates persistent thermal stress year-round. Unlike arid and semi-arid regions, Kerala experiences high relative Humidity even at moderate temperatures, which reduces the efficiency of evaporative cooling mechanisms in both crops and livestock. Studies conducted in Kerala have shown that **THI values often remain above the comfort threshold across seasons,** indicating continuous exposure of animals to thermal stress. This makes the study of THI particularly relevant for understanding region-specific agricultural vulnerability.


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From a productivity perspective, heat stress significantly affects livestock performance, particularly in the dairy sector, a key component of Kerala's agrarian economy. Research indicates that increasing THI levels leads to **elevated respiration rate and body temperature, and to a decline in milk yield, particularly when THI exceeds critical thresholds (around 72–80)**. Furthermore, global and tropical studies confirm that even a unit increase in THI can reduce milk production and feed intake, leading to substantial economic losses for farmers. In Kerala's smallholder dairy systems, where farmers depend heavily on daily milk income, such productivity losses directly threaten livelihood security. The importance of this study also lies in its implications for animal health and reproduction. Heat stress has been found to impair reproductive efficiency by reducing conception rates and affecting embryo development, particularly when THI exceeds critical thresholds. Additionally, prolonged exposure to high THI increases disease susceptibility and physiological stress, as evidenced by changes in metabolic and hormonal responses in dairy animals. In humid regions like Kerala, where disease prevalence is already high due to climatic conditions, the interaction between THI and animal health becomes a crucial area of investigation.

Beyond livestock, the study contributes to a broader understanding of the impacts of climate change on agriculture. Rising temperatures and erratic seasonal patterns are intensifying thermal stress conditions, making traditional farming practices less efficient. THI serves as a **comprehensive, integrative indicator that links environmental variables to** biological and economic outcomes, thereby enabling better climate risk assessment and adaptation planning. It helps identify seasonal stress patterns, optimise resource allocation, and design location-specific interventions, such as improved housing, ventilation, and feeding strategies.

Finally, this study holds significant policy relevance. Quantifying the impact of heat stress using THI provides a scientific basis for developing **early warning systems, climate-resilient livestock management practices, and targeted government support programs**. In the context of increasing climate variability, such research is essential to ensure sustainable agricultural development, enhance farmers' resilience, and secure long-term food and nutritional security in Kerala.

### 1.4 Objectives of the Study

The main objectives of the study are:

1. To analyse the seasonal variation of the Temperature–Humidity Index across different regions of Kerala.
2. To assess the level of heat stress experienced by livestock under varying climatic conditions.

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3. To examine the relationship between THI and dairy productivity, particularly milk yield.
4. To suggest suitable adaptation and mitigation strategies for managing heat stress in agriculture.

## 1.5 Methodology and Data Sources

### 1.5.1 Study Area

The study is conducted in Kerala, a humid tropical region in southwestern India. The state is characterised by high rainfall, high Humidity, and moderate to high temperatures year-round. These climatic features make Kerala highly suitable for analysing heat stress conditions in agriculture, particularly in the dairy sector. The study may cover selected districts or the entire state, depending on data availability.

### 1.5.2 Data Sources

The study primarily relies on secondary data from reliable, authentic institutional sources to examine the impact of climatic variations, particularly heat stress, on the dairy sector in Kerala. Meteorological data, including temperature and relative humidity, were obtained from the India Meteorological Department and weather stations maintained by Kerala Agricultural University. These data were used to compute the Temperature Humidity Index (THI) and to analyse seasonal and district-wise climatic variations across the state. The meteorological information was collected on a monthly and seasonal basis to identify long-term climate trends and the occurrence of heat stress conditions affecting dairy animals.

Data related to dairy production, milk yield, cattle population, and livestock statistics were collected from the Department of Animal Husbandry, the Dairy Development Department, and the National Dairy Development Board. These sources provided district-wise and state-level statistics on milk production, productivity of milch animals, breed composition, and livestock population trends. Additional supporting information was also gathered from government reports, annual publications, livestock census reports, research journals, and policy documents related to climate change and dairy development. The data were collected for a specified period of approximately 10–20 years in order to facilitate a comprehensive temporal and seasonal analysis. The long-term nature of the data enabled the study to identify trends, fluctuations, and possible associations between climatic factors and dairy productivity. The collected data were systematically classified, tabulated, and analysed to assess the extent of heat stress and its implications for dairy farming in Kerala.

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### 1.5.3 Measurement of Heat Stress (THI Calculation)

Heat stress is measured using the Temperature–Humidity Index, which integrates ambient temperature and relative Humidity. The Temperature–Humidity Index is the most widely used measure for quantifying heat stress in livestock under tropical conditions, such as those in Kerala. It combines air temperature and relative Humidity into a single value that reflects the thermal comfort level of animals.

**THI Formula**

$$\mathbf{THI=(1.8T+32) - (0.55-0.0055RH)\,(1.8T-26)}$$

Where:

**T** = Temperature (°C)

**RH** = Relative Humidity (%)

Heat stress assessment in Kerala was conducted using the Temperature–Humidity Index via a systematic procedure. Initially, daily data on ambient temperature and relative Humidity were collected from reliable meteorological sources such as IMD and agricultural weather stations. Based on these observations, THI values were computed for each day using the standard formula, allowing heat stress levels to be measured.

Subsequently, the computed daily THI values were aggregated to obtain monthly and seasonal averages, which helped in identifying temporal patterns and variations in thermal stress across different periods. Finally, the calculated THI values were classified into predefined stress categories—no stress, mild, moderate, and severe—to assess the intensity of heat stress and its potential impact on livestock productivity.

### 1.5.4 Classification of Heat Stress

The classification of heat stress is essential for understanding the impact of climatic conditions on livestock productivity and agricultural performance. In humid tropical regions like Kerala, animals are frequently exposed to varying degrees of thermal stress due to temperature fluctuations and high relative Humidity. To effectively assess and manage these conditions, it is necessary to categorise heat stress intensity into distinct levels.

The Temperature–Humidity Index is widely used for this purpose because it combines temperature and humidity into a single, measurable value. However, the interpretation of THI becomes meaningful only when it is classified into stress categories such as no stress, mild,

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moderate, and severe stress. This classification helps in identifying critical thresholds beyond which animal performance begins to decline.

By grouping THI values into specific stress levels, researchers and farmers can better understand the degree of risk livestock face under different climatic conditions. It also enables timely decision-making regarding management practices such as cooling systems, feeding adjustments, and shelter modifications. Therefore, the classification of heat stress serves as a practical and scientific tool to improve productivity, ensure animal welfare, and enhance climate resilience in agricultural systems.

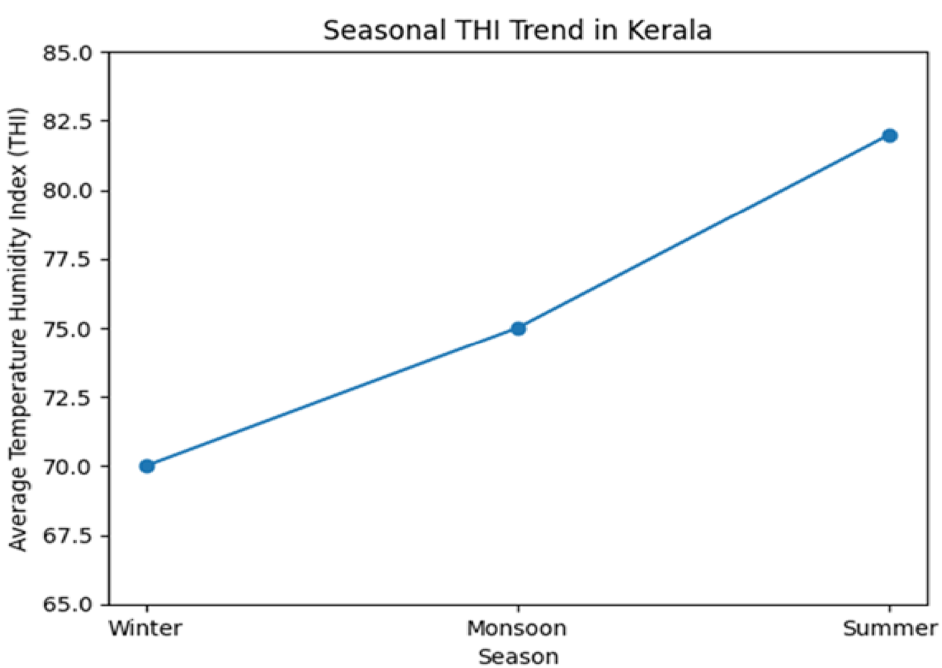
**Table 1.1 Heat Stress Category**

| THI Range | Stress Category |
|---|---|
| < 72 | No stress |
| 72–78 | Mild stress |
| 79–88 | Moderate stress |
| > 88 | Severe stress |

This classification helps identify the degree of thermal stress experienced by livestock.

### 1.6 Kerala's Seasonal Climate Pattern and THI

**Figure 1.1 THI Trend in Kerala**





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Kerala has a humid tropical climate with three main seasons—winter, monsoon, and summer—each showing distinct temperature and humidity patterns. The Temperature–Humidity Index varies across these seasons, remaining in the comfort zone during winter, rising to mild stress in the monsoon due to high Humidity, and reaching moderate to severe stress in summer with higher temperatures. This seasonal variation highlights the increasing thermal stress on livestock from winter to summer, affecting productivity and farm management practices.

**Table 1.2 Climatic Seasons**

Kerala experiences three major seasons, as divided by the Animal Husbandry Department of Kerala

| Season | Temperature (°C) | Relative Humidity (%) | Estimated THI | Stress Category |
|---|---|---|---|---|
| Winter | 22–28 | 60–75 | ~70 | Comfort Zone |
| Monsoon | 24–30 | 75–90 | ~75 | Mild Stress |
| Summer | 30–36 | 70–85 | ~82 | Moderate–Severe Stress |

The seasonal THI chart (above) clearly shows a rising trend from winter to summer.

The seasonal pattern of the Temperature–Humidity Index in Kerala clearly reflects the combined influence of temperature and Humidity on heat stress levels across different seasons. During the **winter season**, relatively lower temperatures (22–28°C) and moderate Humidity (60–75%) keep THI values around 70, which falls within the comfort zone for livestock. Under these conditions, animals can maintain normal physiological functions, resulting in optimal feed intake, improved milk production, and better reproductive performance. Heat stress is minimal, and productivity remains stable.

In the **monsoon season**, although temperatures remain moderate (24–30°C), the sharp increase in relative Humidity (75–90%) elevates THI values to around 75, indicating mild stress. High Humidity reduces the efficiency of evaporative cooling mechanisms such as sweating and panting in animals. As a result, even without extreme temperatures, livestock begin to experience discomfort, leading to slight reductions in feed intake and productivity.

The **summer season** shows the most critical conditions, with temperatures rising to 30–36°C and humidity levels remaining relatively high (70–85%). This combination pushes THI values to


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around 82, falling under moderate to severe stress. At this stage, animals experience significant physiological strain, including increased respiration rate, elevated body temperature, and reduced feed consumption. Consequently, milk yield declines, reproductive efficiency is impaired, and the risk of diseases increases.

Overall, the rising trend in THI from winter to summer indicates that heat stress in Kerala is not solely driven by temperature but is significantly intensified by high humidity. This seasonal variation underscores the need for targeted management strategies, particularly during the summer and monsoon seasons, to mitigate the adverse effects of thermal stress on agricultural productivity.

### 1.7 Economic and Physiological Implications of Seasonal Thermal Stress on Dairy Cattle

#### 1.7.1 Farm-Level Income Loss

Heat stress has serious economic implications for dairy farmers, particularly during the summer season when milk productivity declines considerably. Reduction in milk yield directly affects the daily income of dairy households, especially small and marginal farmers who depend primarily on dairy farming for livelihood security. Studies conducted in Kerala indicate that an average reduction of about 2.6 litres of milk per cow per day is commonly observed during periods of high Temperature Humidity Index (THI).

The economic loss can be estimated as follows:

- Average reduction in milk yield = 2.6 litres/day
- Average milk price = ₹40 per litre
- Daily income loss per cow = 2.6 × 40 = ₹104

Assuming that severe summer conditions persist for nearly 90 days:

- Seasonal income loss per cow = ₹104 × 90 = ₹9,360

For small-scale dairy farmers maintaining two or three milch animals, the cumulative loss becomes substantial and may severely affect household income, savings, and repayment capacity. In addition to direct milk loss, farmers also incur extra expenditures on cooling measures, veterinary care, nutritional supplements, and water management during the summer months. Thus, heat stress not only reduces productivity but also increases the overall cost of dairy production, thereby lowering farm profitability.


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## 1.8 Physiological Responses to Seasonal Thermal Stress

### 1.8.1 Body Temperature Variation

Thermal stress significantly alters the physiological functioning of dairy animals. One of the most important indicators of heat stress is the increase in rectal temperature, which reflects the animal's inability to effectively dissipate excess body heat. A study conducted in Palakkad reported significantly higher rectal temperatures during periods of elevated THI values ($p < 0.05$), confirming the adverse impact of summer heat on dairy cattle.

**Table 1.3 Statistical Findings**

| **Season** | **Mean Rectal Temperature** |
|---|---|
| Winter | 38.4°C |
| Summer | 39.5°C |

The observed increase of more than 1°C during summer indicates that animals are pushed beyond their thermoneutral zone. Under such conditions, cattle experience physiological strain, increased respiration rate, excessive sweating, and elevated heart rate in an attempt to maintain thermal balance. Prolonged exposure to these stressful conditions weakens immunity, reduces productivity, and increases susceptibility to diseases.

The statistically significant difference between summer and winter temperatures confirms that seasonal thermal load has a measurable physiological impact on dairy cattle. High rectal temperature is therefore considered a reliable indicator of heat stress severity in tropical dairy systems.

### 1.8.2 Feed Intake and Body Condition Score

Heat stress also influences the feeding behaviour and metabolic status of dairy animals. Research published in the *Journal of Veterinary and Animal Sciences* reported a substantial decline in feed intake during periods of high THI. Dairy cattle generally reduce feed consumption as a natural adaptive mechanism to minimise metabolic heat production.

Major findings include:

- 8–12% reduction in feed intake during summer
- Decline in body condition score during early lactation


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- Development of negative energy balance in high-producing animals

Reduced feed intake directly affects nutrient availability for milk synthesis and body maintenance. Consequently, animals mobilise body reserves to meet energy requirements, leading to weight loss and deterioration in body condition. Negative energy balance during summer also affects hormonal regulation, reproductive efficiency, and immune function.

The reduction in dry matter intake is particularly severe in high-yielding crossbred cattle because of their greater metabolic heat production. Nutritional stress combined with environmental heat load creates metabolic instability and reduces overall animal performance.

### 1.8.3 Impact on Milk Production and Composition

Seasonal thermal stress has a pronounced effect on both milk quantity and milk quality. Elevated ambient temperature adversely affects mammary gland activity, feed utilisation efficiency, and metabolic processes associated with milk synthesis.

A 2024 study published in the *International Journal of Livestock Research* identified significant seasonal variations in milk yield among dairy cattle.

**Table 1.4 Seasonal Milk Yield Variation**

| **Season** | **Average Milk Yield (Litres/day)** |
|---|---|
| Winter | 11.5 |
| Monsoon | 10.2 |
| Summer | 8.9 |

The findings reveal that milk production during summer declines by nearly 22 percent compared to winter. This reduction is mainly attributed to heat-induced decline in feed intake, hormonal imbalance, dehydration, and physiological stress.

Winter conditions provide a relatively comfortable thermal environment for dairy animals, resulting in higher feed consumption, better metabolic efficiency, and increased milk production. In contrast, summer conditions impose severe thermal stress, reducing the productive capacity of dairy cattle.

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### 1.8.4 Changes in Milk Composition

Apart from quantity, heat stress also affects milk composition and processing quality. Several studies have reported notable seasonal variations in milk constituents during periods of elevated THI.

Major changes observed during summer include:

a. Reduction in milk fat percentage

b. Alteration in fatty acid profile

c. Decrease in protein concentration

d. Lower total solids content

These compositional changes negatively influence the nutritional value, processing efficiency, and shelf life of dairy products. Reduced milk fat and protein content can adversely affect the manufacture of value-added dairy products such as butter, cheese, curd, and milk powder. Changes in fatty acid composition may also alter the sensory characteristics and consumer acceptability of milk products. Thus, heat stress has implications not only for primary milk production but also for the dairy processing industry and market value of milk.

### 1.8.5 Reproductive Impacts of Heat Stress

Heat stress significantly impairs the reproductive performance of dairy cattle. Studies published in the *Indian Journal of Animal Reproduction* reported several adverse reproductive outcomes associated with elevated summer temperatures.

Major reproductive impacts include:

a. Reduced progesterone secretion

b. Lower conception rates

c. Increased service period

d. Delayed onset of estrus

e. Higher incidence of repeat breeding

Elevated body temperature disrupts endocrine function and affects ovarian activity, leading to poor reproductive efficiency. Heat stress also reduces oocyte quality and embryo survival,


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thereby lowering the likelihood of conception. Extended service periods and repeat breeding increase the economic burden on dairy farmers through higher insemination costs, reduced calving intervals, and lower animal lifetime productivity. Consequently, reproductive inefficiency caused by thermal stress becomes a major constraint to sustainable dairy development in tropical regions.

### 1.9 Adaptation Strategies for Mitigating Heat Stress

Effective adaptation strategies are essential to minimise the adverse effects of thermal stress on dairy cattle and to sustain milk production under changing climatic conditions.

#### 1.9.1 Important Farm-Level Strategies for Mitigating Heat Stress in Dairy Cattle

**a) Construction of Well-Ventilated Sheds**

Proper housing design plays a crucial role in reducing heat stress among dairy animals. Well-ventilated sheds promote continuous airflow, which helps remove excess heat and moisture from the animal environment. Sheds constructed with adequate roof height, open sidewalls, ridge ventilation, and east–west orientation minimise direct solar radiation and improve thermal comfort. Good ventilation reduces internal shed temperature, lowers humidity accumulation, and improves the overall health and productivity of dairy cattle during hot summer conditions.

**b) Installation of Sprinkler and Misting Systems**

Sprinkler and misting systems are effective cooling mechanisms widely used in dairy farms during periods of high temperature. These systems reduce body heat by promoting evaporative cooling on the skin surface of animals. Sprinklers release larger droplets of water that wet the animal's body, while misting systems produce fine droplets that cool the surrounding air. When combined with fans or natural ventilation, these systems significantly reduce body temperature, respiration rate, and physiological stress. Regular cooling improves feed intake, milk production, and reproductive performance during summer months.

**c) Use of Shade Nets and Tree-Based Shelter Systems**

Providing shade is one of the simplest and most economical ways to reduce thermal stress on dairy farms. Shade nets help block direct solar radiation and reduce the temperature around animal resting and feeding areas. Similarly, tree-based shelter systems create a cooler microclimate by providing natural shade and lowering environmental temperature through evapotranspiration. Agroforestry-based shelter systems not only improve animal comfort but also contribute to environmental sustainability. Animals protected from direct sunlight experience lower heat load, reduced stress, and improved productivity.

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**d) Provision of Adequate Clean Drinking Water**

Water is essential for maintaining body temperature and metabolic functions in dairy cattle. During summer, water requirements increase substantially because animals lose large quantities of water through sweating and respiration. Continuous access to clean, cool, and fresh drinking water helps animals regulate body temperature and prevents dehydration. Adequate water intake also supports digestion, nutrient absorption, milk synthesis, and electrolyte balance. Insufficient water availability during hot weather can intensify heat stress, reduce feed intake, and lead to severe productivity losses.

**e) Nutritional Supplementation with Minerals and Antioxidants**

Heat stress often leads to mineral imbalance, oxidative stress, and reduced nutrient utilisation in dairy cattle. Nutritional supplementation with minerals, vitamins, electrolytes, and antioxidants improves the animal's physiological resilience under stressful environmental conditions. Supplements such as sodium, potassium, magnesium, vitamin E, selenium, and zinc support metabolic stability, immune response, and cellular protection against oxidative damage. Feeding bypass fat and high-energy diets can also compensate for reduced feed intake during summer. Proper nutritional management, therefore, plays an important role in sustaining milk production and animal health under heat stress conditions.

**f) Feeding During Cooler Hours of the Day**

Dairy cattle tend to consume less feed during periods of extreme heat because digestion generates additional metabolic heat. Feeding animals during cooler hours, such as early morning and late evening, encourages better feed intake and improves nutrient utilisation. Providing fresh and highly digestible feed during these periods reduces heat load associated with digestion and enhances feeding efficiency. This practice helps maintain energy balance, milk yield, and body condition during summer. Splitting feed into multiple smaller meals may also improve consumption and reduce thermal discomfort.

**g) Adoption of Heat-Tolerant and Indigenous Breeds**

Breed selection is an important long-term adaptation strategy for climate-resilient dairy farming. Indigenous cattle breeds are well adapted to tropical climates, with superior heat tolerance, disease resistance, and lower maintenance requirements. These breeds have physiological and genetic traits that enable them to withstand high temperature and humidity more effectively than exotic or high-yielding crossbred cattle. Promoting heat-tolerant breeds can help reduce production losses during summer and improve the sustainability of dairy farming under changing

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climatic conditions. Selective breeding programmes that combine productivity with thermal tolerance are also important for future dairy development.

Proper housing and cooling systems help reduce heat accumulation within animal shelters and improve thermal comfort. Nutritional interventions such as electrolyte balance, bypass fat supplementation, and antioxidant feeding can enhance metabolic stability during periods of thermal stress. The promotion of indigenous breeds is particularly important because native cattle possess greater heat tolerance, disease resistance, and adaptability to tropical climates than exotic breeds.

**h) Policy-Level Adaptation Measures**

Climate-induced stress in the dairy sector requires coordinated policy support and institutional interventions. Long-term climate resilience in dairy farming can be strengthened through appropriate government initiatives and technological support systems.

## 1.10 Major Policy Recommendations

### 1.10.1 Development of Climate-Resilient Dairy Infrastructure

The development of climate-resilient dairy infrastructure is essential to protect dairy animals from extreme weather conditions and rising temperatures. Climate-resilient infrastructure includes scientifically designed cattle sheds, efficient ventilation systems, heat-resistant roofing materials, rainwater harvesting structures, and proper drainage facilities. Such infrastructure helps maintain a favourable microclimate within dairy farms and reduces the adverse effects of heat stress on animal health and productivity. Investment in resilient infrastructure also improves long-term sustainability and reduces economic losses caused by climate variability.

### 1.10.2 Introduction of Seasonal Livestock Insurance Schemes

Seasonal livestock insurance schemes can provide financial protection to dairy farmers against productivity losses caused by heat stress, disease outbreaks, and climate-related disasters. During extreme summer conditions, farmers often experience reduced milk yield, reproductive failure, and increased veterinary expenses. Insurance support helps compensate farmers for these losses and improves their economic stability during adverse climatic periods. Special climate-linked insurance policies designed for seasonal risks can encourage farmers to continue dairy farming while reducing financial vulnerability.

### 1.10.3 Establishment of THI-Based Early Warning Systems

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Temperature Humidity Index (THI)-based early warning systems are important tools for predicting heat stress conditions in advance. These systems use meteorological data such as temperature and relative humidity to forecast periods of severe thermal stress. Early warning alerts help farmers take timely preventive measures, including increasing water availability, activating cooling systems, modifying feeding schedules, and reducing animal exposure to direct sunlight. Such forecasting systems can significantly reduce productivity losses, disease incidence, and mortality during heat waves. Integration of THI advisories through mobile applications and extension services can improve farmer preparedness and climate resilience.

### 1.10.4 Promotion and Conservation of Indigenous Cattle Breeds

Indigenous cattle breeds possess superior adaptability to tropical climatic conditions and are naturally more tolerant to heat stress compared to exotic breeds. Promoting and conserving native breeds can therefore improve the resilience of the dairy sector under changing climate conditions. Indigenous breeds generally have better disease resistance, lower maintenance requirements, and higher survival capacity during periods of environmental stress. Government-supported breeding programmes, conservation initiatives, and awareness campaigns can help preserve valuable native genetic resources while promoting sustainable dairy farming systems.

### 1.10.5 Expansion of Climate-Smart Dairy Extension Services

Climate-smart dairy extension services play a crucial role in educating farmers about heat stress management and sustainable dairy practices. Extension programmes can provide training on improved housing systems, nutritional management, water conservation, breed selection, and the use of cooling technologies. Farmers can also receive guidance on climate adaptation strategies, weather forecasting, and disease prevention measures. Strengthening extension networks ensures effective dissemination of scientific knowledge and encourages the adoption of modern climate-resilient dairy practices at the grassroots level.

### 1.10.6 Financial Support for Cooling Technologies and Water Management

Many small and marginal dairy farmers are unable to afford advanced cooling technologies and efficient water management systems due to financial constraints. Government subsidies, low-interest loans, and financial assistance programmes can help farmers adopt technologies such as sprinklers, misting systems, fans, shade structures, and water storage facilities. Financial support for water conservation measures, including rainwater harvesting and efficient irrigation systems for fodder cultivation, can also improve farm resilience during periods of water scarcity. Such investments help reduce thermal stress, improve milk productivity, and enhance the overall sustainability of dairy farming under climate change conditions.


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THI-based forecasting and advisory systems can help farmers take preventive measures during extreme heat events. Seasonal insurance mechanisms can protect farmers from economic losses associated with reduced productivity and animal mortality. Government support for climate-smart dairy technologies and breed improvement programmes will play a vital role in enhancing the sustainability and resilience of the dairy sector under future climate change scenarios.

### 1.11 Conclusion

Seasonal thermal stress has emerged as a major challenge to the sustainability and productivity of the dairy sector, particularly in tropical regions such as Kerala. Rising temperature and humidity levels adversely affect the physiological health, feed intake, reproductive efficiency, milk yield, and milk composition of dairy cattle. The resulting decline in productivity causes significant economic losses for dairy farmers, especially small and marginal households that depend heavily on dairy farming for their livelihood. The study clearly indicates that prolonged exposure to high Temperature Humidity Index (THI) conditions pushes animals beyond their thermoneutral zone and reduces their overall productive performance.

The findings also highlight the importance of adopting effective adaptation and mitigation measures at both farm and policy levels. Farm-level interventions such as improved housing, cooling systems, proper nutrition, adequate water supply, and the use of heat-tolerant breeds can substantially reduce the adverse impacts of heat stress. At the same time, policy support through climate-resilient infrastructure, livestock insurance, THI-based early warning systems, financial assistance, and climate-smart extension services is essential for strengthening the resilience of the dairy sector. In the context of climate change and the increasing frequency of extreme weather events, sustainable dairy development requires an integrated approach that combines scientific management, institutional support, and climate-resilient technologies. Promoting adaptive strategies and improving farmer awareness will be crucial for protecting animal welfare, maintaining milk productivity, and ensuring the long-term stability of the dairy economy.

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