Research Article

Development of Regression Models for Temperature-Humidity Index (THI) and Their Impact on Milk Yield in Upland and Lowland Dairy Farms in West Sumatra

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Abstract | This study aims to develop regression models for the Temperature-Humidity Index (THI) and assess its impact on milk yield in Upland and Lowland dairy farms in West Sumatra, Indonesia. This research examines the relationship between THI and milk production, comparing dairy cattle productivity in regions with varying climatic conditions. THI data were collected from Upland and Lowland farms, and daily milk production records were analyzed. Linear regression models were developed to predict THI values, and correlation analysis was used to assess the strength of the relationship. In sequence, these were $y = 1.0153x + 3.8244$ and $y = 0.9694x – 2.5665$, with an r value close to 1. The results indicate that Upland farms, with lower THI, had higher milk yields (16.38 kg/cow/day), compared to Lowland farms, where THI was higher and milk production was lower (6.94 kg/cow/day). The regression models suggested a minimal effect of THI on milk production owing to other influencing factors. The study highlights the importance of environmental management to mitigate heat stress, especially in Lowland areas, and recommends strategies for improving dairy cattle productivity. These findings contribute to the understanding of climatic factors in dairy farming and provide insights for future research and policy-making in livestock management.

Keywords | Climate change, Dairy farm, Environment, Heat stress, Lowland, Milk yield

Received | December 15, 2025; **Accepted** | April 17, 2026; **Published** | July 23, 2026
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Citation | Ratni E, Arief, Roza E, Marlida Y (2026). Development of regression models for temperature-humidity index (THI) and their impact on milk yield in upland and lowland dairy farms in West Sumatra. J. Anim. Health Prod. 14(3): 1128-1133.
DOI | https://dx.doi.org/10.17582/journal.jahp/2026/14.3.1128.1133
ISSN (Online) | 2308-2801

INTRODUCTION

The dairy farming industry needs to be developed in Indonesia's livestock sector to make a significant contribution to the country's animal protein supply to its population. Milk, as a source of complete nutrition, is a leading commodity for supporting national food security. However, Indonesia's dairy cattle population remains low, with approximately 540,657 cows, and productivity is limited to 10–15 L per cow per day (BPS, 2023). Consequently, the national milk production only reaches 1 million metric tons annually (21% of the total need), while the national consumption is expected to rise to 4.7 million metric tons by 2024, creating a deficit of 3.7 million metric tons (79%). Despite a 6% annual increase in milk consumption, domestic production has grown by only 1% annually, reflecting the impact of the imbalance between supply and demand (BPS, 2023).

The Directorate General of Animal Husbandry and Animal Health (DG AHHA), Ministry of Agriculture, Indonesia, has implemented a 10-year acceleration program aimed at addressing these challenges by increasing milk production. The program focuses on expanding the dairy cattle population and improving farm quality, including outreach to lowland areas. Although dairy farming in Indonesia is primarily concentrated in highland areas with subtropical climates, lowland areas also present significant potential for dairy development. One major challenge in these areas is heating stress, resulting from high temperatures and humidity. Climate change exacerbates this issue, increasing the frequency and intensity of heatwaves, which reduce milk production, reproduction rates, and increase mortality rates in dairy cattle (Renaudeau *et al.*, 2012; Tariq *et al.*, 2024).

Dairy cattle are most comfortable within a temperature range of 16–25 °C, corresponding to a THI of less than 68 (Yousep, 1985; Avendaño-Reyes, 2012). Heat stress disrupts the physiological balance of dairy cattle, increasing their body temperature and metabolic stress, reducing feed intake, and causing declines in both milk yield and reproductive performance (Arief *et al.*, 2023; Asmarasari *et al.*, 2023). In addition, heat stress negatively impacts milk quality by increasing the somatic cell count (SCC) and decreasing fat and protein content (Dunshea *et al.*, 2018), thereby lowering the economic value of milk.

In West Sumatra, the dairy cattle population is smaller than that in other regions, such as Java, with an average milk production of 8 L per cow per day. The region has varied geographical conditions, ranging from lowland areas with high temperatures and humidity to highland areas with cooler conditions. Both areas face challenges related to heat stress, although its severity is influenced by seasonal and climatic conditions (Muhammad, 2023). Therefore, mitigation strategies are needed to reduce heat stress and enhance dairy cattle productivity in both upland and lowland regions, including physical cooling interventions and improved feed quality.

This study aimed to develop regression models to predict the THI and evaluate its impact on milk yield in dairy farms located in both the upland and lowland regions of West Sumatra. This study also aimed to recommend effective mitigation strategies for heat stress to improve dairy cattle productivity in these regions.

MATERIALS AND METHODS

Study area and dairy farms selection

This study was conducted in the Upland and Lowland regions of West Sumatra, Indonesia. Dairy farms in these regions were selected based on accessibility, smallholder farm size, and the availability of lactating cows in the barns. There were three smallholder dairy farms in the Upland regions, which are located at higher altitudes (above 700 m above sea level), in Padang Panjang city, and three identical farms in the Lowland regions, which are located at lower altitudes (below 300 m above sea level), in Padang city, as identified on Google Earth. Data collected on July – August 2025, as dry season in the research area.

Data collection and statistical analysis

The THI was measured on an hourly basis over a period in both Upland and Lowland dairy farms. Data were collected using digital thermometers and humidity sensors installed in dairy barns. The THI was calculated using the following formula:

$$THI= (1.8\times T+32) - [(0.55 - 0.0055 \times RH) \times (1.8\times T - 26)$$

Where T is the ambient temperature in °C and RH is the relative humidity in percentage. The average THI values for both Upland and Lowland were calculated based on categorized light stress. Dairy cows begin to show signs of heat stress at a THI of 68 or higher (NADIS, 2012).

Milk production data were collected from 15 lactating cows in both the Upland and Lowland regions. The daily milk yield per cow was recorded for morning and evening milking over one month. The cows are kept in intensive farming, without grazing on grassland, but the milking process is still done by hand-milking. Milk production was measured in liters per cow per day and then converted into a lactating period of 305 days in kilograms. Milk composition was measured using a Lactoscan analyzer in the Laboratory of Dairy Science, Universitas Andalas. The calculations involved were as follows: a) Milk production at 4% FCM = (0.4×milk yield [kg/day] + 15×fat yield), b) Milk yield [kg/day] = milk yield [L/day] ×density (kg/L), c) Fat yield = % fat × milk yield (kg), and d) 305-day standard milk production = 4% FCM milk production × 30 days/month of production (%).

All data were processed using Python and Excel. Statistical significance was determined at a 5% significance level ($p < 0.05$) using an independent two-sample t-test to compare data between the Upland and Lowland groups. Linear regression analysis was used to model the relationship between hourly THI values on Upland and Lowland dairy farms. A simple linear regression model was applied:

$$Y = mX + b$$

Where Y is the predicted THI Upland/Lowland, X is one of the THI values, m is the slope, and b is the intercept. After obtaining the regression coefficient (m) and intercept (b), the linear regression equation between THI Upland Mean and THI Lowland Mean can be written as, THI Lowland = $m \times$ (THI Upland) + b, and vice versa for THI Upland = (THI Lowland − b)/m. Pearson correlation analysis was performed to assess the relationship between

THI and milk production, separately for both Upland and Lowland regions. The correlation coefficient (r) indicates the strength and direction of the relationship: values approaching +1 or -1 indicate a very strong positive or negative correlation, respectively, while values near 0 suggest no linear correlation.

RESULTS AND DISCUSSION

Temperature-humidity index (THI) in upland and lowland dairy farms

The average THI show significant differences ($p < 0.05$) between the two regions (Table 1), for Upland was 72.3 and 77.2 for Lowland farms. The data show the hourly THI values for both upland and lowland dairy farms from 6:00 am to 8:00 pm. It is clear from the table that lowland dairy farms consistently experienced higher THI values than upland farms across all hours of the day. A THI above 72 °C indicates stressful conditions for dairy cattle, leading to lower milk yields, which supports the claim made in the study that THI directly impacts dairy production (Bohmanová *et al.*, 2007; Narmilan *et al.*, 2021).

As shown in Table 1, moderate heat stress begins at 10 a.m. in upland areas, but in lowland areas, it starts as early as 6 a.m. This indicates that lowland farms experience significant heat stress throughout the day, especially during peak hours, which could negatively impact milk production and cow health (Sukandi *et al.*, 2023). Even the highlands are not immune to heat; therefore, farmers must take immediate mitigation measures. Previous research by Ratni *et al.* (2025) also found that no free heat stress relief was available for farms in high-altitude areas, even for industrial-scale facilities with fans inside barns, and during the rainy season in the West Sumatra region.

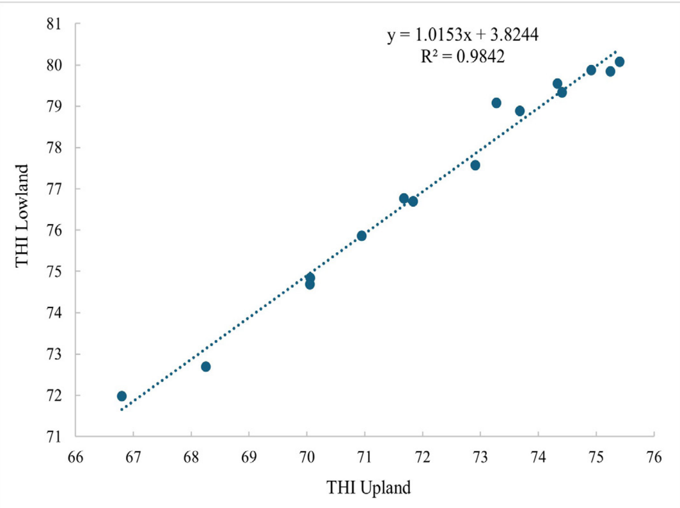

Figure 1: Linear regression relationship between THI in upland (independent variable) and lowland (dependent variable) dairy farms in West Sumatra

The data distribution in Figure 1 shows the linear regression model between THI values in upland and lowland areas, and vice versa, as shown in Figure 2. In sequence, these are y = 1.0153x + 3.8244 (r = 0.99) and y = 0.9694x – 2.5665 (r = 0.99), with an r value close to 1, indicating a high correlation. Using this equation, we can predict the THI Lowland Mean value based on the THI Upland Mean value at the same time; for example, for every 1 unit increase in THI Upland Mean, there will be an increase of 1.0153 units in THI Lowland Mean. Further, if THI Upland Mean is 0, the THI Lowland Mean is estimated to be approximately 3.8244, and the same applies for the equation in Figure 2.

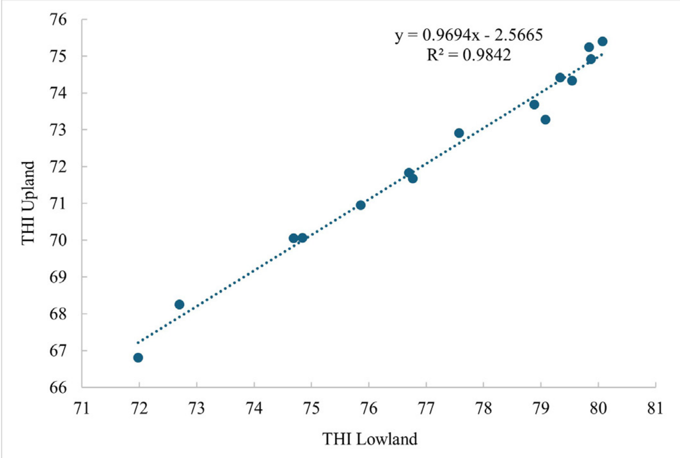

Figure 2: Linear regression relationship between THI in lowland (independent variable) and upland (dependent variable) dairy farms in West Sumatra.

Milk production in upland and lowland dairy farms

The average milk production in Upland was 16.38 kg per cow per day, whereas in Lowland, it was considerably lower at 6.94 kg per cow per day (Table 2). This stark contrast in milk yield is likely influenced by THI values, as Lowland areas with higher THI are known to cause heat stress, which can reduce both milk production and reproduction rates in dairy cattle. Some studies corroborate this observation, suggesting that increases in THI levels contribute to declines in milk production due to stress-induced dietary restrictions (Granzin, 2006; Brouček *et al.*, 2007).

Low milk production in lowland areas is likely attributed to high THI, which causes stress and reduces feed intake, thereby lowering milk yields. In contrast, Upland farms benefit from a more comfortable environment with lower THI, allowing dairy cattle to produce more milk. These findings align with previous research, which indicates that consistent exposure to elevated THI levels leads to significant stress in dairy cattle, adversely affecting their productivity and health (Bang *et al.*, 2021; Nam *et al.*, 2024).

Table 1: Overview of hourly temperature (T), relative humidity (RH), and temperature-humidity index (THI) of smallholder dairy farms in upland and lowland.

Time	Value of T in upland (°C), N=42					Value of T in lowland (°C), N=42				
	Mean	Median	Min	Max	SD	Mean	Median	Min	Max	SD
6:00	19.7	19.8	18.9	20.5	0.4	22.9	22.8	20.5	27.2	1.4
7:00	20.7	20.6	19.7	22.0	0.5	23.4	23.3	20.8	27.9	1.5
8:00	21.9	22.0	20.6	23.2	0.6	24.9	24.3	21.3	33.2	2.4
9:00	23.1	23.1	21.7	24.7	0.8	26.9	26.0	22.7	31.8	2.4
10:00	24.4	24.3	22.5	27.6	1.0	29.0	28.5	22.1	35.1	2.7
11:00	25.2	24.9	21.6	29.2	1.3	29.5	29.7	22.9	36.7	2.6
12:00	25.9	25.6	21.8	29.8	1.6	29.8	29.8	22.4	36.7	2.7
13:00	26.2	26.2	22.1	29.7	1.6	30.0	30.2	22.9	35.0	2.8
14:00	26.0	25.7	21.1	30.3	1.5	29.9	29.9	23.4	34.4	2.6
15:00	25.5	25.4	20.9	30.4	1.6	29.2	29.5	22.3	35.4	2.7
16:00	24.8	24.8	20.1	28.5	1.4	28.8	29.0	21.7	36.4	2.7
17:00	24.1	24.0	19.9	28.1	1.3	27.6	28.1	21.8	31.4	2.1
18:00	23.2	23.1	19.9	26.6	1.1	26.7	26.9	22.3	29.8	1.8
19:00	22.5	22.5	19.5	25.5	1.1	25.9	25.9	22.0	29.2	1.6
20:00	21.8	22.0	18.3	23.7	1.0	25.1	25.0	21.1	29.2	1.5
	Value of RH (%) in upland, N=42					Value of RH (%) in lowland, N=42				
6:00	86.6	87.0	80.0	91.0	2.4	84.7	84.0	69.0	97.0	5.4
7:00	84.1	85.0	74.0	91.0	3.2	83.3	84.0	67.0	93.0	5.8
8:00	80.8	82.0	72.0	86.0	3.9	79.8	80.0	56.0	88.0	5.9
9:00	77.5	78.0	69.0	84.0	3.1	71.9	71.5	51.0	90.0	7.8
10:00	74.3	75.0	63.0	83.0	4.2	65.5	64.5	49.0	90.0	8.3
11:00	72.3	72.5	59.0	84.0	4.8	63.6	63.0	45.0	89.0	9.1
12:00	70.5	70.0	56.0	85.0	6.3	62.9	61.0	45.0	86.0	8.7
13:00	68.1	69.0	52.0	87.0	7.2	63.2	59.0	46.0	87.0	10.7
14:00	67.3	67.5	54.0	85.0	7.1	62.3	58.5	48.0	87.0	9.9
15:00	68.5	69.0	54.0	84.0	7.5	66.0	62.0	44.0	89.0	12.0
16:00	72.2	72.5	61.0	85.0	5.9	66.5	64.0	46.0	87.0	10.3
17:00	75.3	76.5	60.0	86.0	6.4	70.2	67.5	55.0	89.0	10.4
18:00	78.1	79.5	66.0	87.0	5.7	73.5	72.0	58.0	89.0	9.0
19:00	80.2	80.5	69.0	88.0	5.4	76.3	75.0	62.0	89.0	8.1
20:00	82.8	82.5	75.0	89.0	4.1	79.0	79.0	65.0	89.0	7.6
	Value of THI in upland, N=42					Value of THI in lowland, N=42				
6:00	66.8	66.9	65.2	68.2	0.6	72.0	71.6	68.0	77.0	2.3
7:00	68.3	68.1	66.4	70.5	0.8	72.7	72.5	68.4	77.8	2.4
8:00	70.0	69.9	67.7	72.4	1.0	74.7	73.6	68.8	83.6	3.2
9:00	71.7	71.7	69.6	73.6	1.2	76.8	75.9	72.0	82.1	2.9
10:00	73.3	73.2	71.0	76.9	1.3	79.1	78.0	71.0	85.2	3.2
11:00	74.3	74.2	69.5	78.6	1.7	79.5	79.0	72.3	85.9	2.8
12:00	75.2	75.0	70.1	80.3	1.9	79.8	79.8	71.2	85.9	3.0
13:00	75.4	75.4	70.8	78.8	1.6	80.1	80.3	72.0	85.4	2.8
14:00	74.9	74.6	69.0	79.6	1.7	79.9	79.5	73.0	84.4	2.6
15:00	74.4	74.6	68.6	79.6	1.9	79.3	79.1	71.3	84.1	2.8
16:00	73.7	73.7	67.3	78.7	1.9	78.9	78.8	70.1	85.8	2.8
17:00	72.9	72.8	67.0	77.2	1.8	77.6	77.6	70.4	81.2	2.3
18:00	71.8	71.7	67.0	75.8	1.6	76.7	76.9	71.3	81.4	2.1
19:00	70.9	71.1	66.3	74.5	1.7	75.9	76.0	70.7	80.9	2.1
20:00	70.1	70.5	64.4	73.1	1.7	74.8	74.9	69.1	80.8	2.1

Table 2: Yield and components of milk from lactating cows in smallholder dairy farms in upland and lowland.

Parameters	Upland	Lowland
Milk yield (L)	15.93 ± 3.83	6.78 ± 2.75
Milk yield (kg)	16.38 ± 3.94	6.94 ± 2.82
Milk yield in 4% FCM (kg)	16.26 ± 3.91	6.47 ± 2.62
Milk yield in lactation period (305 days, kg)	4,063.82 ± 978.40	1,616.42 ± 655.9
Fat (%)	3.95 ± 1.45	3.54 ± 1.01
Protein (%)	3.08 ± 0.32	2.88 ± 0.81
Lactose (%)	4.61 ± 0.49	4.03 ± 1.22
Solid non-fat (%)	8.40 ± 0.89	7.84 ± 2.22
Density (kg/L)	1.0284±4.34	1.0247±1.03

Pearson scorrelation analysis was conducted to examine the relationship between THI and milk production in both regions. The results showed that the correlation between THI and milk production in both Upland and Lowland areas was extremely weak, with a correlation coefficient close to zero. This indicates that while THI affects milk production, other factors, such as nutrition, management, and breed, may have a more significant impact on determining milk yield (Ammer *et al*., 2017; Lee *et al*., 2024). The weak correlation suggests that THI alone cannot fully explain the variations in milk production. Other environmental and management factors (Gupta *et al*., 2022; Piscopo *et al*., 2024) should be considered for a more comprehensive understanding of milk yield on dairy farms.

Impact of THI on dairy cattle productivity

The results confirm that THI is a strong indicator of milk production, particularly in Lowland areas, where higher THI values can result in heat stress. THI values above 68 indicate discomfort for dairy cattle, and prolonged exposure to such conditions may reduce milk yield, affect feed intake, and increase stress levels. Upland farms, with lower THI, benefit from more favorable conditions, enabling higher milk production, although the highlands in West Sumatra still experience heating environments at certain times of the day in the barns.

This study shows that THI significantly influences milk production; however, other factors, such as nutrition and management, are also main factors. Despite the weak relationship between THI and milk production, the findings suggest that managing heat stress through environmental control (such as cooling systems) can improve milk yield, particularly on lowland farms. Further research should focus on incorporating additional factors, such as feeding strategies (Akbar *et al*., 2021) and genetics (Santana *et al*., 2015), into predictive models to better understand the full impact of environmental factors on dairy cattle productivity.

CONCLUSIONS

This study highlights the significant impact of the temperature–humidity index (THI) on milk production at Upland and Lowland dairy farms in West Sumatra. The findings indicate that lower THI values at Upland are associated with higher milk yields, whereas higher THI values at Lowland lead to reduced production, likely due to heat stress. The regression models developed in this study provide valuable insights for predicting THI and milk production, emphasizing the need for targeted heat stress mitigation strategies in Lowland areas. The results underscore the importance of environmental management in improving dairy cattle productivity, contributing to the long-term goal of enhancing milk production in Indonesia, particularly in West Sumatra. Effective adaptation to climate conditions can help address the challenges of increasing milk demand and support national food security.

ACKNOWLEDGMENTS

The authors express their gratitude to the Research and Community Engagement Institute, Universitas Andalas, Padang, West Sumatra, Indonesia. We gratefully acknowledge the assistance in funding this study through grant number 77/UN16.19/PT.01.03/PDD/2025. Additionally, we appreciate the contributions of farmers of smallholder dairy farms in the Upland and Lowland regions of West Sumatra for providing the data that made this study possible.

NOVELTY STATEMENT

This study introduces regression models to predict THI Lowland based on THI Upland data, offering a new approach for managing heat stress in dairy cattle. It provides novel insights into the impact of THI on milk production in both Upland and Lowland regions of West Sumatra, contributing to better dairy farm management and potential heat stress mitigation strategies.

AUTHOR'S CONTRIBUTION

All authors contributed to the conceptualization and design of the study, development of the methodology, data collection and analysis, and interpretation of the results. One author led the writing of the manuscript and provided critical revisions.

Ethical considerations

This study did not require any ethical guidelines from the Animal Welfare Department. Data on THI and milk production were obtained directly from daily farm records.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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