### Article Information

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<td>High temperature-humidity index is negatively associated with milk performance and quality in Korean dairy system: Big data analysis</td>
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<td><strong>Running Title (within 10 words)</strong></td>
<td>Heat stress, high THI is negatively associated with milk productivity</td>
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<td><strong>Author</strong></td>
<td>Dongseok Lee¹, Daekyum Yoo¹, Hyeran Kim², and Jakyeom Seo¹*</td>
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<tr>
<td><strong>Affiliation</strong></td>
<td>¹Department of Animal Science, Life and Industry Convergence Research Institute, Pusan National University, Miryang 50463, Korea ²Animal Nutrition and Physiology Team, National Institute of Animal Science, RDA, Wanju 55365, Korea</td>
</tr>
<tr>
<td><strong>ORCID (for more information, please visit <a href="https://orcid.org">https://orcid.org</a>)</strong></td>
<td>Dongseok Lee (<a href="https://orcid.org/0000-0002-4008-9164">https://orcid.org/0000-0002-4008-9164</a>) Daekyum Yoo (<a href="https://orcid.org/0000-0002-6430-9539">https://orcid.org/0000-0002-6430-9539</a>) Hyeran Kim (<a href="https://orcid.org/0000-0003-2207-3668">https://orcid.org/0000-0003-2207-3668</a>) Jakyeom Seo (<a href="https://orcid.org/0000-0002-9176-5206">https://orcid.org/0000-0002-9176-5206</a>)</td>
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<td>This work was carried out with the support of “Cooperative Research Program for Agriculture science and Technology Development (Project No. PJ01491606)” Rural Development Administration, Republic of Korea.</td>
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</table>
### Availability of data and material

Upon reasonable request, the datasets of this study can be available from the corresponding author.

### Authors' contributions

Please specify the authors’ role using this form.

- **Conceptualization:** Seo JK, Lee DS, Yoo DK
- **Data curation:** Seo JK, Lee DS, Kim HR
- **Formal analysis:** Seo JK, Lee DS
- **Methodology:** Seo JK, Lee DS
- **Software:** Lee DS
- **Validation:** Seo JK, Lee DS
- **Investigation:** Lee DS, Yoo DK
- **Writing - original draft:** Lee DS
- **Writing - review & editing:** Lee DS, Yoo DK, Kim HR, Seo JK

### Ethics approval and consent to participate

No animal experiments were performed.

### CORRESPONDING AUTHOR CONTACT INFORMATION

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<td>Jakyeom Seo</td>
</tr>
<tr>
<td><strong>Email address – this is where your proofs will be sent</strong></td>
<td><a href="mailto:jseo81@pusan.ac.kr">jseo81@pusan.ac.kr</a></td>
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<tr>
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</tr>
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</tr>
<tr>
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</tr>
<tr>
<td><strong>Office phone number</strong></td>
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High temperature-humidity index is negatively associated with milk performance and quality in Korean dairy system: big data analysis

Dongseok Lee¹, Daekyum Yoo¹, Hyeran Kim², and Jakyeom Seo¹∗

*Corresponding Author: Jakyeom Seo

Tel: +82-10-7202-3506, +82-55-350-5513, Fax: +82-55-350-5519, E-mail: jseo81@pusan.ac.kr

¹Department of Animal Science, Life and Industry Convergence Research Institute, Pusan National University, Miryang 50463, Korea

²Animal Nutrition and Physiology Team, National Institute of Animal Science, RDA, Wanju 55365, Korea

ORCID

Dongseok Lee: https://orcid.org/0000-0002-4008-9164
Daekyum Yoo: https://orcid.org/0000-0002-6430-9539
Hyeran Kim: https://orcid.org/0000-0003-2207-3668
Jakyeom Seo: https://orcid.org/0000-0002-9176-5206
High temperature-humidity index is negatively associated with milk performance and quality in Korean dairy system: big data analysis

ABSTRACT

Objective: The aim of this study was to investigate the effects of heat stress on milk traits in South Korea using comprehensive data (dairy production and climate).

Methods: The dataset for this study comprised 1,498,232 test-day records for milk yield, fat- and protein-corrected milk (FPCM), fat yield, protein yield, milk urea nitrogen (MUN), and somatic cell score (SCS) from 215,276 Holstein cows (primiparous: n=122,087; multiparous: n=93,189) in 2,419 South Korean dairy herds. Data were collected from July 2017 to April 2020 through the Dairy Cattle Improvement Program, and merged with meteorological data from 600 automatic weather stations through the Korea Meteorological Administration. The segmented regression model was used to estimate the effects of the temperature-humidity index (THI) on milk traits and elucidate the break point (BP) of the THI. To acquire the least-square mean of milk traits, the generalized linear model was applied using fixed effects (region, calving year, calving month, parity, days in milk, and THI).

Results: For all parameters, the BP of THI was observed; in particular, milk production parameters dramatically decreased after a specific BP of THI ($p < 0.05$). In contrast, MUN and SCS drastically increased when THI exceeded BP in all cows ($p < 0.05$) and primiparous cows ($p < 0.05$), respectively.

Conclusion: Dairy cows in South Korea exhibited negative effects on milk traits (decrease in milk performance, increase in MUN, and SCS) when the THI exceeded 70; therefore, detailed feeding management is required to prevent heat stress in dairy cows.

Keywords: Big data; Heat stress; Milk performance; Temperature-humidity index
INTRODUCTION

Heat stress (HS), caused by high temperature and humidity, is a harmful issue in dairy farms. Under HS conditions, cows show decreased feed intake and milk yield, but increased somatic cell counts (SCC) [1-3], thereby deteriorating milk quality. Hammami et al. [4] reported a reduction in milk composition (5.7 kg of milk fat/year, and 4.2 kg of protein/year) in a European dairy farm that had undergone severe HS. Similar to global climate change, an increase in air temperature has been observed in South Korea. It has been reported that the increase in annual average temperature has been 0.5 °C since decade (2010–2019) [5]; therefore, the decrease in dairy productivity is an emerging issue in South Korea. The temperature-humidity index (THI) is a value estimated using temperature (dry or wet) and humidity (direct or relative) to measure the degree of HS. It was first applied to monitor human health [6]; however, recently, livestock nutritionists have also been widely used THI to monitor the relationship between critical THI and the emergence of HS in animals. For example, in dairy cattle, a decrease in milk yield and feed intake [2, 7] was observed when the THI for dairy cattle was over 72. Recently, high-producing cows were found to be more sensitive to HS; therefore, a decrease in milk yield was observed at THI 68 in the US [8]. Bohmanova et al. [9] reported that the critical THI at which HS was observed in dairy cattle varied according to regional characteristics.

Recently, big data has been used to elucidate the association between HS and dairy production, along with technological advances in data accumulation, computer hardware, and sensors to monitor environmental parameters. For example, Hagiya et al. [10] developed 2-phase linear model using 17,245,709 test-day records from 2,018,406 cows and demonstrated that Japanese Holstein cows exhibited drastic milk depression at a THI of 70.4. Similar to a previous study [10], both dairy milking and climate data were provided from public data centers in South Korea; however, to the best of our knowledge, little research has been conducted to demonstrate the association between high THI and milk performance in Korean dairy cattle systems. Therefore, the aim of this study was to
investigate how heat stress adversely affects milk production and traits in South Korea using big data
daily milking, air temperature, humidity, and region of farms). The threshold values of THI for milk
performance were also estimated using segmented linear regression analysis.

MATERIALS AND METHODS

Data

Test-day records of milk yield, fat- and protein-corrected milk (FPCM), milk composition
(fat, protein, and urea nitrogen [MUN]), and SCC were collected from the Dairy Cattle Improvement
Center (NongHyup Agribusiness Group Inc., Korea) in Korea. Among the milk composition data,
SCC was log-transformed into somatic cell scores (SCS) using the following equation [11]:

SCS = log2(SCC/100000) + 3

and FPCM was estimated as suggested by [12]:

FPCM (kg/d) = (0.337 + 0.116 × fat (%) + 0.06 × protein (%)) × milk yield (kg/d)

Data were collected from 215,276 Holstein cows (122,087 primiparous cows and 93,189
multiparous [2-4 parities]) at 1–305 days in milk (DIM) for three years (2017–2020). The total
number of herds included in this study was 2,419. In total, 1,498,232 records were included in this
study. The descriptive statistics used in this study are presented in Table 1. Weather records (July
2017 to April 2020) from 600 weather stations near the respective herds were acquired from the Korea
Meteorological Administration (KMA) website. To collect weather records for each herd, the weather
records of the automatic weather checking station located closest to the respective herd were used,
and the daily THI was calculated using the following equation [13]:

THI = 1.8 × T +32(0.55-0.0055 × RH) × (1.8 × T - 26)
Where “T” is the daily average temperature (°C), and “RH” is the relative humidity (%).

Model

Test-day records for milk traits were linked to the daily average THI calculated from weather records. The effects of HS on milk traits were estimated using the following statistical model:

\[ Y_{ijklmn} = R_i + Y_j + M_k + P_l + DIM_m + THI_n + e_{ijklmn} \]  \hspace{1cm} (1)

where \( Y_{ijklmn} \) is an observation of test-day records for milk traits or SCS; \( R_i \) is the fixed effect of the region (five subclasses); \( Y_j \) is the fixed effect of year at calving (4 subclasses); \( M_k \) is the fixed effect of month (12 months); \( P_l \) is the fixed effect of parities (primiparous and multiparous); \( DIM_m \) denotes the days in milk \( m \) (305 subclasses); \( THI_n \) is the index heat stress as expressed by THI (40 subclasses); and \( e_{ijklmn} \) represents the vector of random residual effects. The distribution of data for the fixed effects used in the model is shown in Figure 1.

Considering that HS had significant results linearly, the break point (BP) of THI was evaluated using segmented regression analysis on R [14] Segmented package [15]. The least-square mean (LSM) of milk traits in different THI, which was calculated from Equation (1), was used as the dependent variable. The slope of the segmented linear regression was assumed as follows:

\[ y_i^* = a + b_1 * X_i + e_i; \text{ when } X_i \leq BP \]

\[ y_i^* = a + b_1 * X_i + b_2 * (X_i - BP) + e_i; \text{ when } X_i > BP \]

where \( y_i^* \) is the LSM of milk traits in different THI; \( a \) is an intercept; \( b_1 \) is a regression coefficient on THI \( X_i \) when \( THI X_i \) is lower than the BP; \( b_2 \) is a regression coefficient on THI \( X_i \) when \( THI X_i \) exceeds the BP; \( e_i \) is the random residual term; and BP is the break point, defined as the appropriate threshold value of THI. Linear regression was applied to the heat stress effect.
RESULTS AND DISCUSSION

The average milk yield and milk composition are presented in Table 1. The average daily milk yield, milk fat, and protein concentrations were 33.9 kg/d, 3.9%, and 3.2%, respectively. These results were in agreement with the annual domestic dairy production statistics for 2021 (milk yield, 34.1 kg/d; fat, 3.9%; and protein, 3.2%) [16]. Milk traits (milk yield, FPCM, composition, MUN, and SCC) were expressed as LSM values adjusted for region, age, month, parity, DIM, and THI (Figure 2). The BP of THI for milk yield was 71.9 and 70.6 for primiparous and multiparous cows, respectively (Figure 2 (a)). Similar to milk yield, FPCM, milk fat, and milk protein yields also had specific BP (Figure 2 (b), (c), and (d)). For all milk yield parameters, the BP in primiparous cows was higher than that in multiparous cows. After exceeding the BP, milk yield gradually decreased with increasing THI, regardless of parity. A decrease in each milk component was also observed when the THI exceeded the BP. The results of BP for milk and component yield suggested that dairy cows in South Korea started to exhibit thermal heat stress at around THI 70 (Figure 2 (a)–(d)). Different THI thresholds have been suggested in previous studies. Traditionally, it is believed that the threshold value between thermal comfort and mild HS is 72 [17], while Rensis et al. [18] reported that cows exhibited signs of mild HS when the experimental environment was designed to have a THI over 68. Hammami et al. [4] reported that a reduction in milk yield was observed after THI of 62. In Japan, the THI-BP for milk yield was 70.4 [10], similar to the results of this study. The difference in critical THI for dairy production might be explained by several environmental factors (cooling system, climatic region, and degree of genetic improvement) influencing the relationship between THI and production [19-21]. Higher THI thresholds for milk performance traits were found in primiparous cows than in multiparous cows (71.9 and 70.6 in milk yield; 71.2 and 70.5 in milk FPCM yield; 71.0 and 69.5 in milk fat yield; 71.5 and 69.9 in milk protein yield, respectively), indicating that multiparous cows were more susceptible to HS. This finding might be explained by the fact that
primiparous cows generate far less metabolic heat because they have a greater surface area compared with internal body mass and lower milk production. Because of metabolic heat production during milk synthesis, a severe response to HS is more easily observed in high-yielding cows than in normal cows [22].

The MUN concentration increased drastically after THI BP (74.6 in primiparas, and 74.3 in multiparous; Figure 2 (e)). Under HS, cows experience low ruminal pH and inefficient microbial crude protein production, thereby increasing ruminal ammonia concentrations [23]. Cowley et al. [24] suggested that the reduction in milk protein from heat-stressed cows is the result of downregulation of mammary protein synthetic activity, but also increased MUN due to catabolized muscle tissue, a process that is intensified under heat stress conditions. Similar to a previous study, a reduction in milk protein yield was observed at approximately 70 THI (Figure 2 (d)). In periods of heat stress, Koch et al. [25] observed stable transcription rates of enzymes influencing the urea cycle, and the group explained the increased MUN concentrations with lower kidney perfusion in periods of heat stress. Moreover, the observed high MUN levels indicated an energy deficiency due to reduced feed intake during heat stress.

The THI BP of SCS in primiparous cows was 66.7, and 53.6 in multiparous cows (Figure 2 (f)). When the threshold was exceeded, the SCS sharply increased in primiparous cows; however, a similar trend was not observed in multiparous cows. In Japan, a dramatic increase in SCS was also observed when the THI exceeded 68.5 [10], and the THI calculation method was the same as that used in this study [13]. Pragna et al. [22] explained that HS might impair the dairy immune system, which is eventually linked to udder infection. Based on the data obtained in this study, the increase in udder infection was not known; however, it is possible to speculate that HS over BP can influence udder health and increase SCS, especially in primiparous cows. In conclusion, this study represents the first comprehensive research on the effect of THI on Holstein cattle raised in South Korea. The negative effect of HS on dairy cattle performance, which has been reported in previous studies abroad,
was also confirmed in this study by analyzing big data on dairy performance and regional climates. Therefore, more detailed feeding management and construction of a farm cooling system are required to prevent HS from dairy cows when the THI is over the specific BP.
CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENTS

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REFERENCES


Table 1. General statistics for milk traits

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SD, Standard deviations.

†FPCM, fat-protein corrected milk yield; MUN, milk urea nitrogen; SCS, somatic cell scores.
Figure 1. The data distribution of fixed effects in the model
Figure 2. Least-square mean (LSM) and standard error (bars) for the relationship between heat stress (as indicated by temperature humidity index changes, [THI]) and milk traits in Korean Holstein cows (primiparous [▲] and multiparous [●]). Among milk traits, (a), milk yield; (b) fat and protein corrected milk yield; (c), milk fat yield; (d), milk protein yield; (e), milk urea nitrogen yield; (f), somatic cell score. BP, breaking points estimated by segmented regression analysis.