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Brown Swiss Cows Exhibit Higher Temperature-Humidity Index Thresholds and Greater Thermotolerance than Holsteins under Temperate Continental Climate Conditions

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Abstract | Heat stress significantly affects dairy cow productivity, where temperature-humidity index (THI) is considered a key metric for assessing its impact. This study aimed to determine breed-specific THI thresholds for milk yield and composition decline in Holstein and Brown Swiss cows, considering their differing thermotolerance. The study was conducted on two commercial dairy farms in Ukraine, involving 736 Holstein and 1285 Brown Swiss cows. Data on milk yield, fat, and protein content were collected from May to September and analyzed using receiver operating characteristic (ROC) analysis to establish critical THI thresholds. The results reveal that Holstein cows exhibited lower THI thresholds across all parameters, with milk yield declined at THI ≤70.0, compared to ≤70.7 in Brown Swiss cows. Similarly, Holstein cows showed greater sensitivity in milk composition, with fat and protein reductions at THI ≤58.9 and ≤63.9, while Brown Swiss cows maintained higher thresholds of ≤66.1 and ≤69.1, respectively. The higher specificity and AUC values in Holsteins suggest a sharper but more predictable response, whereas Brown Swiss cows demonstrated a highly adaptable reaction to thermal stress. These findings highlight the necessity of breed-specific management strategies to optimize dairy production under heat stress. Holstein herds require earlier and more intensive interventions, such as shading, ventilation, and dietary adjustments, whereas Brown Swiss cows are better suited for warm climates with limited cooling infrastructure. Further research should focus on genetic selection for heat tolerance and integrated THI-based monitoring systems to enhance climate resilience in dairy farming.

Keywords | Dairy cows, Heat stress, Temperature-humidity index (THI), Milk yield, Milk composition, Holstein, Brown swiss, Breed-specific thresholds, ROC analysis, Climate resilience

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INTRODUCTION

Heat stress is a significant environmental factor affecting dairy cow productivity, particularly in high-producing breeds such as Holstein and Brown Swiss. The temperature-humidity index (THI) is widely used to assess the impact of heat stress on milk yield and composition, with threshold values often varying depending on breed, region, and production system (Hoffmann *et al.*, 2021; Li *et al.*, 2023). Elevated temperatures combined with high

humidity levels induce physiological and metabolic changes that can adversely affect milk production, composition, and overall animal health (Habimana *et al.*, 2023; Moore *et al.*, 2024).

Holstein cows, known for their exceptional milk yield, exhibit greater sensitivity to heat stress due to their higher metabolic heat production and reduced thermotolerance (Mylostyvyi *et al.*, 2021; Rockett *et al.*, 2023). In contrast, Brown Swiss cows demonstrate superior heat resilience, which is attributed to breed-specific physiological adaptations and more efficient thermoregulatory mechanisms (Cuellar *et al.*, 2023). The physiological and metabolic adaptations to heat stress, including changes in feed intake, water balance, and immune response, contribute to breed-related variations in milk composition and quality (Stefanska *et al.*, 2024). Notably, recent studies suggest that the decline in milk yield often precedes changes in milk fat and protein content, with THI thresholds for these parameters being breed-specific (Vroege *et al.*, 2023; Chen *et al.*, 2024).

Although THI ≥ 72 has traditionally been regarded as the threshold for heat stress-induced production losses (Bohmanova *et al.*, 2007), recent research suggests that high-producing cows may experience performance declines at lower THI levels (Moore *et al.*, 2023). Furthermore, Brown Swiss cows appear to tolerate higher THI levels before experiencing significant productivity losses, reinforcing the necessity for a breed-specific approach to heat stress management (Maggiolino *et al.*, 2020). Despite extensive research on heat stress in dairy cows, limited data exist on THI thresholds specifically for Brown Swiss cows compared to Holsteins under similar management conditions.

This study aims to determine the critical THI thresholds for milk yield, fat, and protein reduction in Holstein and Brown Swiss cows using receiver operating characteristic (ROC) analysis. By identifying breed-specific THI thresholds, this research will help refine targeted management strategies to mitigate the adverse effects of heat stress on dairy production and improve efficiency in herd management.

MATERIALS AND METHODS

The study was conducted on two commercial dairy farms in Ukraine, where Holstein (n = 736) and Brown Swiss (n = 1285) cows were bred. The Holstein farm was located at 48°28′44″ N, 35°36′46″ E, while the Brown Swiss farm was situated at 48°34′03.1″ N, 34°54′47.0″ E, with a geographical distance of approximately 52.6 km between them. The study was conducted during the warm period of the year, from May to September, to capture seasonal variations in milk productivity under potential heat stress conditions.

Housing Conditions

Both farms applied similar management practices, with lactating cows housed in naturally ventilated barns (NVBs) under free-stall conditions. Sand bedding was used in the stalls to improve hygiene and animal comfort. Cows were provided a total mixed ration (TMR) year-round, balanced for essential nutrients according to NRC (2001) recommendations. The diet consisted of maize silage, barley, oats, maize grain, lucerne silage, grass hay, wheat straw, rapeseed, sunflower, and soybean meals, as well as dried beet pulp and mineral-vitamin supplements. Feed ingredients were thoroughly mixed using specialised mixers equipped with electronic scales, and both feeding frequency and ration size were managed by computer software. The cows had free access to feeders and water troughs.

Climatic Conditions

The study region falls under a humid continental climate with hot summers (Dfa) according to the Köppen climate classification. Meteorological data were obtained from the nearest weather stations via the Ukrainian Hydrometeorological Centre, as previously described (Mylostyvyi *et al.*, 2023a). Weather conditions were monitored throughout the study period (May–September), with particular attention to temperature and humidity fluctuations affecting dairy productivity. Temperature-humidity index (THI) values were calculated to assess heat stress levels in cows.

Milk Productivity

Daily milk yield (kg), fat (%), and protein (%) content for Holstein and Brown Swiss cows were recorded from May to September using the Dairy Comp 305 herd management system on each farm. This period was chosen to assess the impact of seasonal temperature variations on milk production and composition.

Statistical Analysis

Data processing was performed using STATISTICA 10 (StatSoft, Inc., Tulsa, OK, USA). Since most data distributions did not meet normality assumptions, nonparametric statistical methods were applied. Results were expressed as mean ± standard error (SE), and the Mann-Whitney test was used to compare groups, with significance set at $P < 0.05$.

Determination of THI Threshold Values

Threshold values of THI for milk yield, fat, and protein reduction were determined using receiver operating characteristic (ROC) analysis in MedCalc® Statistical Software v20.106 (MedCalc Software Ltd, Ostend, Belgium). THI

values were calculated based on daily mean values recorded throughout the study period. Classification followed the assumption that Brown Swiss cows respond similarly to Holsteins, with a reference threshold of THI = 72 for milk yield reduction. ROC analysis was based on binary classification, assessing the trade-off between true positive rate (Sensitivity) and false positive rate (100-Specificity). Separate ROC analyses were performed for milk yield, fat content, and protein content, considering daily mean THI values. Model performance was evaluated using the area under the ROC curve (AUC), classified as follows: 0.9–1.0 (excellent), 0.8–0.9 (good), 0.7–0.8 (fair), 0.6–0.7 (poor), and 0.5–0.6 (fail), with values near 0.5 indicating random classification (Mylostyvyi *et al*., 2023b).

RESULT AND DISCUSSION

The analysis of monthly variations in milk yield and composition between Holstein and Brown Swiss cows revealed significant differences in their productive responses under heat stress conditions. Brown Swiss cows consistently exhibited higher milk yield than Holsteins throughout the study period. The mean milk yield in Brown Swiss cows ranged from 28.1 kg to 28.2 kg in May and June, with a slight decline to 27.7 kg in July and August, before recovering to 28.0 kg in September. In contrast, Holstein cows produced lower milk yields, fluctuating between 24.2 kg and 25.2 kg during the same period (Figure 1). These findings indicate that Brown Swiss cows maintained superior milk production stability under heat stress conditions, while Holsteins experienced a more pronounced seasonal decline, particularly in mid-summer.

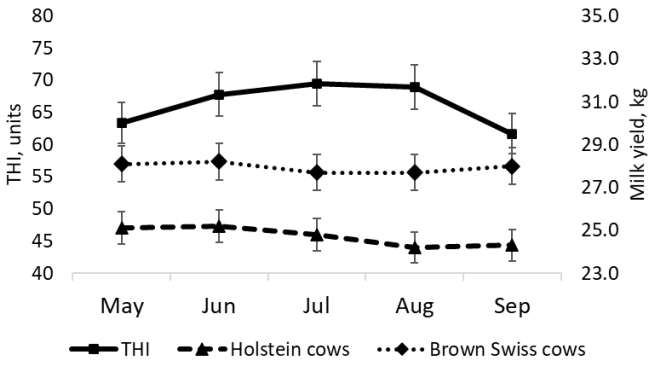

Figure 1: Monthly variations in milk yield (kg) in Holstein and Brown Swiss cows during the warm period.

Milk fat content followed a different pattern, with Holstein cows consistently exhibiting higher values compared to Brown Swiss cows. The fat percentage in Holsteins ranged from 3.53% to 3.74%, showing a gradual increase from May to September. In Brown Swiss cows, the fat content remained lower in early summer (3.47% in May) but increased toward the end of the study period, reaching 3.84% in September. This suggests that Holstein cows maintained a more stable fat percentage, while Brown Swiss cows demonstrated a delayed but stronger adaptive response, likely compensating for metabolic shifts due to heat stress (Figure 2).

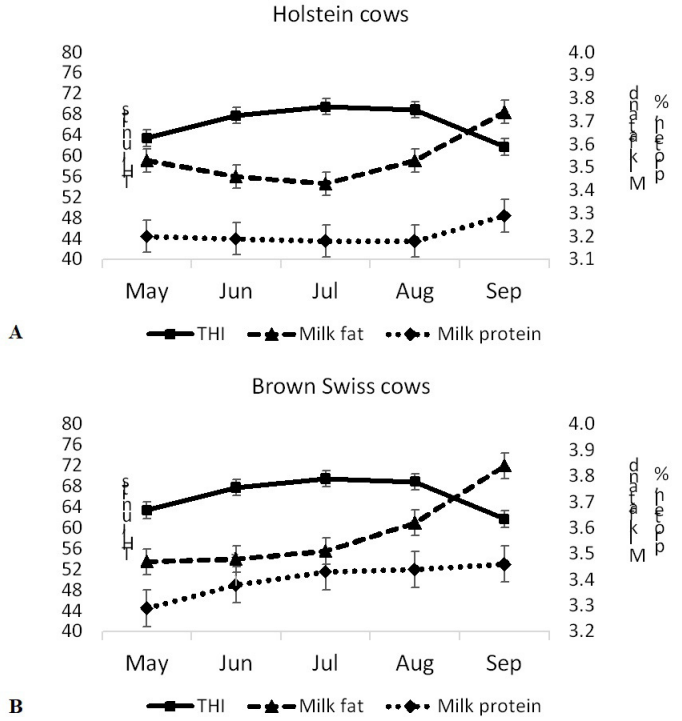

Figure 2: Monthly variations in milk fat (%) and milk protein (%) content in Holstein and Brown Swiss cows during the warm period.

Milk protein content exhibited similar breed-specific differences. Holstein cows showed lower protein values throughout the study, with a range from 3.18% to 3.29%. The lowest protein content was recorded in June and July, followed by a gradual increase toward September. Brown Swiss cows, in contrast, had higher and more stable protein values, ranging from 3.29% to 3.46%. The observed differences suggest that Holstein cows are more susceptible to seasonal variations in protein composition, whereas Brown Swiss cows maintain a more stable milk protein profile, indicating their superior adaptation to changing environmental conditions.

Overall, Brown Swiss cows demonstrated superior milk yield and greater production stability across the warm months, reinforcing their resilience to heat stress. Holsteins, while exhibiting lower milk production, maintained higher milk fat and protein content, albeit with greater seasonal fluctuations. These findings highlight the importance of breed-specific management strategies to optimise production efficiency under heat stress conditions, considering the differing responses of Holstein and Brown Swiss cows to environmental challenges.

The analysis of threshold values of the temperature-humidity index (THI) for milk yield and composition decline revealed notable differences between Holstein and Brown Swiss cows in their response to heat stress. The THI threshold for milk yield reduction was slightly lower in Holstein cows (≤70.0) compared to Brown Swiss cows (≤70.7). However, the predictive accuracy of this threshold was higher in Brown Swiss cows, as reflected in the greater area under the curve (AUC = 0.917) and higher specificity (87.9%) compared to Holstein cows (AUC = 0.704, specificity = 67.7%). This suggests that while Holstein cows can maintain milk yield at slightly higher THI levels, their response to heat stress is more variable, whereas Brown Swiss cows exhibit a more clearly defined threshold beyond which milk yield declines significantly (Figure 3).

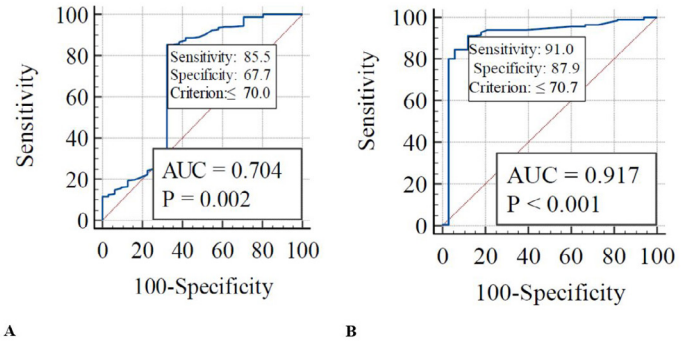

Figure 3: Threshold values of temperature-humidity index (THI) for milk yield reduction in Holstein (A) and Brown Swiss (B) cows.

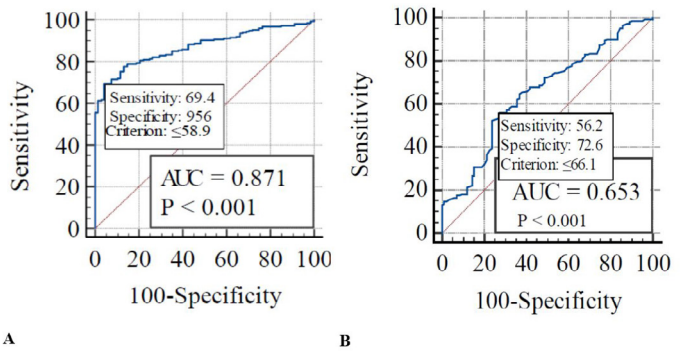

Figure 4: Threshold values of temperature-humidity index (THI) for milk fat content reduction in Holstein (A) and Brown Swiss (B) cows.

Milk fat content demonstrated a more pronounced difference between breeds in response to heat stress (Figure 4). The THI threshold for fat reduction was substantially lower in Holstein cows (≤58.9) compared to Brown Swiss cows (≤66.1), indicating that Holsteins experience a decline in milk fat content at lower levels of heat stress. The predictive accuracy of this threshold was also significantly higher in Holstein cows (AUC = 0.871), with specificity reaching 95.6%, while in Brown Swiss cows, the AUC was lower (0.653), and specificity was only 72.6%. This suggests that milk fat content in Brown Swiss cows is more stable under heat stress, whereas in Holsteins, it is a more sensitive indicator of thermal load.

Milk protein content exhibited a similar trend (Figure 5), with Holstein cows showing a lower THI threshold for decline (≤63.9) compared to Brown Swiss cows (≤69.1). The sensitivity and specificity of this threshold were higher in Holsteins (77.8% and 89.8%, respectively), whereas in Brown Swiss cows, specificity was notably lower (56.1%), and the predictive accuracy (AUC = 0.638) was weaker than that of Holsteins (AUC = 0.889). This suggests that Holstein cows are more susceptible to heat stress-induced reductions in milk protein content, whereas Brown Swiss cows display greater resilience, though with more variability in their response.

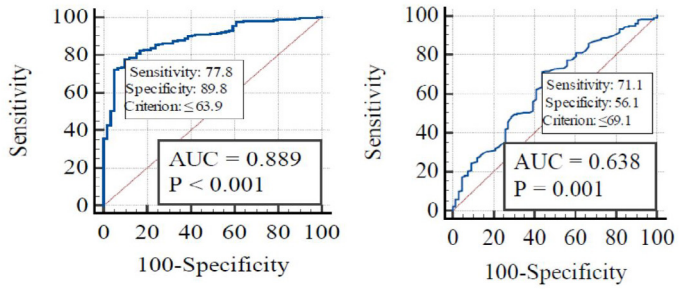

Figure 5: Threshold values of temperature-humidity index (THI) for milk protein content reduction in Holstein (A) and Brown Swiss (B) cows.

Overall, Holstein cows demonstrated lower THI thresholds across all evaluated milk production parameters, confirming their higher susceptibility to heat stress. The greater AUC values observed in Holsteins indicate a more precise definition of threshold values for this breed, whereas Brown Swiss cows exhibited higher thresholds for milk fat and protein, suggesting their greater resilience to thermal conditions. However, the lower specificity in Brown Swiss cows suggests more variability in their response to heat stress, making it harder to establish a clear threshold. The results confirm that Holstein cows experience a sharper decline in milk yield and composition when exposed to heat stress, while Brown Swiss cows maintain more stable production parameters under similar conditions. These findings highlight the necessity of breed-specific management strategies to mitigate the effects of heat stress on milk production efficiency.

These results confirm that Holstein cows exhibit lower THI thresholds across all evaluated milk production parameters, reinforcing their higher susceptibility to heat stress. The observed AUC values suggest that the THI threshold for Brown Swiss cows was more clearly defined,

indicating greater predictability and resilience in their response to thermal stress. These findings align with previous studies showing that Brown Swiss cows are better adapted to heat stress due to more efficient evaporative cooling, lower core body temperature fluctuations, and improved water retention mechanisms (Brown-Brandl, 2018; Mylostyvyi *et al*., 2023b; Ceciliani *et al*., 2024).

In contrast, Holstein cows demonstrated a sharper and more predictable decline in milk yield and composition, suggesting that management interventions such as enhanced shading, forced ventilation, and dietary modifications should be implemented at lower THI levels compared to Brown Swiss cows (Chapman *et al*., 2023; Moore *et al*., 2023; Mejia Turcios *et al*., 2024). Furthermore, ongoing efforts in genetic selection for heat tolerance in Holstein populations could serve as a long-term strategy to enhance resilience and maintain productivity under warming climatic conditions (Gujar *et al*., 2023; Lemal *et al*., 2023).

Understanding breed-specific THI thresholds provides a valuable tool for optimising dairy herd management in heat-stressed environments. Given their higher THI thresholds, Brown Swiss cows require less intensive cooling interventions, making them more suitable for regions with limited access to advanced cooling technologies. Future research should explore integrated THI-based monitoring systems that incorporate physiological, metabolic, and genomic markers to improve early detection and prevention of heat-induced production losses in dairy cattle (Marquez-Acevedo *et al*., 2023; Arias *et al*., 2024; Chen *et al*., 2024).

CONCLUSIONS AND RECOMMENDATIONS

This study determined breed-specific THI thresholds for milk yield and composition decline in Holstein and Brown Swiss cows, highlighting significant differences in their responses to heat stress. Holstein cows exhibited lower THI thresholds, indicating higher susceptibility to heat stress-induced production losses, whereas Brown Swiss cows demonstrated greater resilience, maintaining more stable milk yield, fat, and protein content under elevated temperatures.

The results underscore the importance of breed-specific management strategies in heat-stressed dairy operations. Holstein herds require earlier and more intensive interventions, such as shading, forced ventilation, and dietary adjustments, to mitigate productivity losses. Conversely, Brown Swiss cows are better suited for regions with limited cooling infrastructure, as they can maintain productivity under higher THI conditions.

Future research should explore integrating THI-based monitoring systems with physiological and genetic markers to enhance early detection and mitigation of heat stress effects. Additionally, genetic selection for heat tolerance in Holstein cows could serve as a long-term strategy for improving dairy production sustainability under climate change.

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NOVELTY STATEMENT

This study is the first to establish breed-specific temperature-humidity index (THI) thresholds for milk yield and composition decline in Holstein and Brown Swiss cows under temperate continental climate conditions. By applying ROC analysis to field data from two commercial herds, the research highlights significant differences in thermotolerance between breeds. The findings offer a novel basis for precision heat stress management, enabling tailored intervention strategies to enhance resilience and productivity in dairy farming.

AUTHOR'S CONTRIBUTIONS

Roman Mylostyvyi: Conceptualization, data collection, statistical analysis, interpretation, writing – original draft, visualization.
Bohdan Gutyj, Vadym Lykhach: Support in discussion of results, review and editing of the final version.
Tetiana Taran, Oksana Orishchuk, Oksana Yanovska, Vita Logvinova: Final review and approval of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest related to the published article.

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