Renewed Genetic Evaluation of Heat Tolerance in Italian Holsteins

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Abstract

Heat stress is a significant and growing challenge for the Italian dairy industry, adversely affecting milk production, fertility, and animal welfare. This study presents a renewed genetic evaluation for heat tolerance in Italian Holstein cattle, expanding upon a previous 2021 index that focused solely on milk yield. The primary objective was to develop a more comprehensive selection tool by incorporating five production traits: milk yield (kg), fat yield (kg), protein yield (kg), fat percentage, and protein percentage. Test-day production records were augmented with meteorological data from 137 weather stations across Italy to calculate a 7-day average Temperature-Humidity Index (THI) for each record. A repeatability mixed model was first employed to identify the specific THI thresholds at which each of the five traits begins to decline. Subsequently, a random regression mixed model was implemented to estimate genetic parameters and calculate Estimated Breeding Values (EBVs) for both general production merit and specific heat tolerance. THI thresholds were identified for all traits, with milk yield declining above a THI of 70. Heritabilities for heat tolerance traits were found to be low to moderate, ranging from 0.12 for fat yield to 0.37 for protein percentage, indicating sufficient genetic variation for selection. An aggregate index, the Heat Tolerance Index (IHT), was developed by assigning economic weights to each trait Heat Tolerance EBV. Validation results demonstrated the index's efficacy: daughters of high-IHT bulls (+1 SD) lost 0.91 kg/d less milk during summer compared to daughters of low-IHT bulls (-1 SD). This renewed evaluation provides a robust tool to select for more resilient animals, offering a tangible strategy to mitigate economic losses and improve animal welfare in a warming climate.

Key words: heat tolerance, genetic evaluation, Holstein, THI, milk production, regression

Introduction

Heat stress poses a substantial threat to the dairy industry worldwide, leading to significant reductions in milk yield, impaired reproductive performance, and compromised animal welfare. As global temperatures continue to rise, these challenges are becoming increasingly prevalent, particularly in Mediterranean climates like in Italy. The economic consequences of heat stress are severe. In Italy, with a population of approximately one million Holstein cows, summer-related production losses are estimated to be around 1.5 kg of milk per cow per day over a 180-day period, culminating in an annual loss of approximately 270,000 tons of milk.

While management strategies such as cooling systems can alleviate some effects, they represent a recurring cost. Genetic selection offers a cumulative and permanent solution by breeding cows that are naturally more resilient to heat stress. In 2021, a heat tolerance index based solely on milk yield was introduced for Italian Holsteins (Finocchiaro et al., 2022). To enhance the selection process, a more robust and comprehensive evaluation was desired.

The objectives of this study were therefore to: 1) expand the genetic evaluation for heat tolerance to include five key production traits: milk (kg/d), fat (kg/d and %), and protein (kg/d and %); 2) determine the specific Temperature-Humidity Index (THI) thresholds at which these traits begin to decline; 3) estimate the heritability of heat tolerance for each trait; and 4) develop and validate a new aggregate selection index (IHT) to improve heat resilience in Italian Holstein cattle.

Materials and Methods

Data Source and Preparation

Test-day production records for milk, fat, and protein yields from first, second, and third lactation Italian Holstein cows were obtained from the national database of the Italian Holstein Friesian and Jersey Breeders Association (ANAFIBJ).

Meteorological data, including daily maximum temperature and relative humidity, were collected from 137 weather stations across Italy for the period starting in 1994. Herds were assigned geographic coordinates based on their municipality, and each herd was linked to an average of 2.3 nearby weather stations, with an average distance of 13.5 km. For each test-day record, a corresponding Temperature-Humidity Index (THI) was calculated using the formula from Kelly and Bond (1971). To account for the cumulative effects of heat, a 7-day average THI preceding the test day was used for all analyses.

Statistical Analyses

THI Threshold Identification

To identify the critical THI value above which production traits decline, a repeatability model was fitted using ASReml software. The model was:

$$\boldsymbol{Y = HYS + YC + DIM * age * parity + THI + a + pe + e}$$

where **Y** is the phenotype for a given trait; **HYS** is the fixed effect of herd-year-season of test day; **YC** is the fixed effect of year of calving; **DIM*age*parity** is the fixed effect for the interaction of days in milk, age at calving, and parity (1, 2, 3); **THI** is the linear regression on the THI value; **a** is the random additive genetic animal effect; **pe** is the random permanent environmental effect; and **e** is the random residual.

Genetic Parameter Estimation

A random regression model was used to estimate genetic parameters and breeding values for heat tolerance using MiX99 software. The model equation was:

$$\boldsymbol{Y = HYS + YC + DIM * age * parity + a + \alpha\big(f(THI)\big) + pe + \beta(f(THI)) + e}$$

The fixed effects are as described above. The function **f(THI)** models the heat stress effect as a linear slope only when the THI exceeds the predetermined threshold for that trait:

$$f(THI) = \begin{cases} 0, \mathrm{THI} \leq \mathrm{THI_{threshold}} \\ \mathrm{THI} - \mathrm{THI_{threshold}}, \mathrm{THI} > \mathrm{THI_{threshold}} \end{cases}$$

The random effects include the general additive genetic merit **a**, the specific genetic effect for heat tolerance **α(f(THI))**, the permanent environmental effect **pe**, and the permanent environmental effect related to heat tolerance **β(f(THI))**.

Heat Tolerance Index (IHT)

Estimated Breeding Values (EBVs) for heat tolerance (**α**) were calculated for all five production traits. These individual EBVs were then combined into an aggregate Heat

Tolerance Index (IHT). The weights assigned to each trait were: 45% for protein kg, 25% for milk kg, 15% for fat kg, 10% for protein %, and 5% for fat %. The final IHT EBVs were standardized to a mean of 100 and a standard deviation of 5.

Results & Discussion

THI Thresholds and Genetic Parameters

The analysis identified distinct THI thresholds at which different production traits begin to decline (Table 1). Milk yield was the most resilient, with a decline observed only when the THI exceeded 70. Protein and fat components, both in kilograms and percentage, were affected at lower THI values, with thresholds ranging from 52 to 59. This suggests that metabolic changes affecting milk composition occur before a substantial drop in milk volume.

Table 1: THI thresholds for decline in milk production traits.

Milk production trait	Threshold level
Milk (kg/d)	70
Protein (kg/d)	59
Fat (kg/d)	52
Protein %	55
Fat %	52

The estimated heritabilities (h^2) for heat tolerance and genetic correlations are presented in Table 2. Heritabilities ranged from 0.12 for fat kg to 0.37 for protein %, indicating that there is sufficient genetic variation to achieve progress through selection. The genetic correlations between general production merit and heat tolerance were consistently moderate and negative (from -0.42 to -0.51). This antagonism implies that selection solely for high production may lead to a slight decline in heat tolerance, reinforcing the need for a balanced, multi-trait breeding goal.

Table 2: Heritabilities (h^2) for heat tolerance and genetic correlations (r_g) with general production merit.

Milk production trait	Genetic Correlation (r_g)	Heritability (h^2)
Milk (kg/d)	-0.51	0.16
Protein (kg/d)	-0.48	0.13
Fat (kg/d)	-0.42	0.12
Protein %	-0.43	0.37
Fat %	-0.50	0.26

Validation of the Heat Tolerance Index (IHT)

To validate the IHT, the performance of daughters from bulls with high heat tolerance (IHT ≥ +1 SD) was compared to that of daughters from bulls with low heat tolerance (IHT ≤ -1 SD). The comparison focused on the difference in milk yield between summer and winter test days (Table 3) (Flamenbaum, 2016).

Daughters of low-tolerance bulls experienced a substantial drop in production of -1.24 kg/d during the summer. In contrast, daughters of high-tolerance bulls showed a much smaller decline of only -0.33 kg/d. This resulted in a net difference of +0.91 kg/d in favor of the high-IHT group, providing strong evidence that the IHT effectively identifies sires whose progeny are more resilient to heat stress. This difference represents a significant economic advantage and a notable improvement in animal welfare.

Table 3: Comparison of summer vs. winter milk yield loss in daughters of high and low IHT bulls.

Group	Winter milk (kg/d)	Summer milk (kg/d)	Difference (kg/d)
High HT (≥ +1 SD)	30.38	30.05	-0.33
Low HT (≤ -1 SD)	31.14	29.90	-1.24

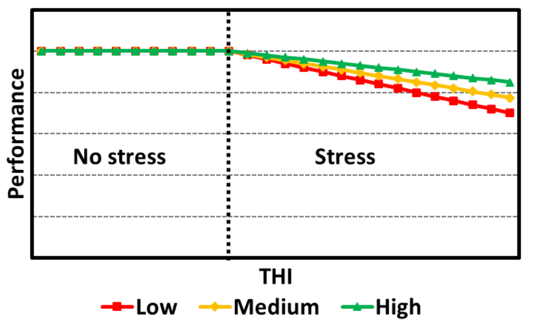

Figure 1. Example of heat stress for low, medium, high tolerance cows

Conclusions

This study successfully developed and implemented a renewed, multi-trait genomic evaluation for heat tolerance in Italian Holstein cattle. By analyzing milk, fat, and protein traits, the evaluation provides a comprehensive assessment of an animal's ability to maintain productivity under heat stress conditions. The resulting Heat Tolerance Index (IHT) has been validated as an effective tool for identifying genetically superior animals. The daughters of high-IHT bulls demonstrate significantly lower milk production losses during hot summer months. The adoption of the IHT in the national breeding program offers a powerful, sustainable, and cumulative strategy to enhance the resilience of the Italian Holstein population, thereby reducing economic losses and improving animal welfare in the face of ongoing climate change.

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