Genetic evaluation of heat tolerance in Italian Holstein breed

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Abstract

Heat stress (HS) on dairy cows is triggered by a combination of high ambient temperature and high relative humidity: this phenomenon leads to physiological disorders that have a negative impact on the animal's wellbeing and productive and reproductive performances. The objective of this study was to identify the starting point of HS on milk production, measured on the temperature-humidity index (THI) scale, to define the heritability of the tolerance to HS based on milk production and to estimate breeding values for this trait in the Italian Holstein population. A single-trait repeatability linear animal model was used and the heritability was found to be 0.16. In conclusion, the possibility to select for heat tolerance (HT) based on milk production was confirmed. Further analyses will be performed to assess the possibility of selection for HT based on other productive and functional traits and to define its optimum weight in a selection index.

Introduction

High ambient temperature combined with high relative humidity negatively affects both productive (Bernabucci et al., 2014) and reproductive (Ravagnolo and Misztal, 2002) performance of dairy cows, resulting in a negative impact on herd profitability: this phenomenon is regarded as HS. Not all animals are affected the same way by HS. In Holstein cattle, tolerance to HS was found to be moderately heritable (Aguilar et al., 2009; Bernabucci et al., 2014), meaning that a selection for this trait is feasible. As the majority of the Italian Holstein population lives in areas characterized by hot and humid summer, a genetic evaluation for HT may be beneficial. The aim of our study was to investigate if heat stress results in different effects on Italian Holstein performance due to genetic differences in heat tolerance.

Materials & Methods

Data and data editing. Data came from the Italian National Breeders Association (AIA) and consisted, after editing, of 41,063,377 test-day milk production records of 2,591,002 Holstein cows. Heat tolerance was modelled by using data from weather stations. Daily maximum temperature and relative humidity were collected from 1994 till now. Weather measurements (777,980 daily records) were collected from 137 stations distributed across the national territory. Geographical coordinates and altitudes from all weather stations and from the communities of the farms were available. Distances between weather stations and farms were computed. Milk test day records were linked with the nearest weather stations within 80 km. Weather stations more than 500 m above or below the farm were omitted. Weather estimates for the farm were computed for the geometric center of the chosen weather stations as a weighted average accounting for the distance from the farm. The average distance between the geometric center of the chosen nearby weather stations and the farms was 13.5 km.

Holstein test-day records for milk production from the first three parities were included in this study. Records were from cows registered between 2004 and 2021. Cows were required to have, within parity, at least 3 test-days and the first one within 60 days from calving and test-days between 5 and 305 DIM. Cows were also required to have the first parity recorded. First parity cows were required to have an age at parity of minimum 22 months, second parities greater or equal than 34 months and later parity ones between 48 and 76 months. Moreover, in order to effectively compare the contemporaries for herd-year-season of recording (HYSR), groups with less than 30 observations were excluded from the analysis. The pedigree went back to four generations.

Because longer periods of heat stress might have a more severe effect than shorter periods, the average weather measurements of 2, 4, 5, 7, 10 and 14 days before test-day recording were considered.
The temperature-humidity index (THI) has been calculated as proposed by Kelly and Bond (1971) by combining maximum temperature, in degrees Celsius, and average relative humidity (as percentage) with the following expression:

$$THI = T_{max} - [0.55\, x\, (1 - RH)]\, x\, (T_{max} - 14.4) \quad (1)$$

where T_{max} is the maximum daily temperature in °C and RH is the average daily relative humidity.
The THI threshold value (THI_{thr}), above which milk yield declines, was identified visually after the computation of least square means of the fixed effect THI class. A function of THI, f(THI), was then created as in Equation 2:

$$f(THI) = \begin{cases} 0 & if\ THI \leq THI_{thr} \\ THI - THI_{thr} & if\ THI > THI_{thr} \end{cases} \quad (2)$$

The visual inspection showed that the threshold value of THI from which milk production starts to decline is ≥24 (Celsius like scale), and this value was defined as THI_{thr}. In addition, the average of 7 days before test-day recording has been found to be the most effective period for modelling the decline in milk production.

Statistical model. The selected model was a single trait repeatability linear animal model. Fixed effects were identified with SAS PROC GLM (SAS Institute Inc., Cary, NC, 2017): only the ones which resulted statistically significant (P<0.05) were retained. The effect of HS on production is modeled as a random regression.
The defined model is described in Equation 3:

$$Y_{ijklmno} = HYSR_i + YS_j + STPY_k + a_{general_l} + a_{heat_l}[f(THI_m)] + PE_{general_n} + PE_{heat_n}[f(THI_m)] + e_{ijklmno} \quad (3)$$

with Y_{ijklmn} is the measurement of daily milk production (kg/d), $HYSR_i$ is the fixed effect herd-year-season of recording i; YS_j is the fixed effect of year-season of calving j, $STPY_k$ is the fixed effect of stage of lactation-parity-year of calving class k. Regarding random effects, $a_{general_l}$ is the general additive genetic effect of cow l, a_{heat_l} is the additive genetic effect of HT for cow l, $PE_{general_n}$ as the general permanent environmental effect of cow l based on repeated measures both within and across lactations, PE_{heat_n} as the permanent environmental effect of HT for cow l and $e_{ijklmno}$ as the residuals. Parities were defined as first, second and later parities while seasons as December to February, March to May, June to August and September to November.

Estimation of genetic parameters. Variance components estimation was performed with the Gibbs sampler THRGIBBS1F90 (Misztal et al., 2002). Three analyses were performed on three samples of 200 herds each and a minimum of 30,000 cows each (average number of test-day records per sample: 817,481) randomly extracted from the full dataset, with 500,000 iterations, a burn-in of 50,000 and a thinning rate of 10. Post-Gibbs analysis was performed using the software POSTGIBBSF90 (Misztal et al., 2002) using the remaining 45,000 samples. Convergence was assessed by visual inspection. Heat tolerance heritability based on milk production was calculated as described in Equation 4:

$$h^2 = \frac{\sigma^2_{a_{general}} + \sigma^2_{a_{heat}} + 2\sigma_{a_{general}}\sigma_{a_{heat}}}{\sigma^2_{a_{general}} + \sigma^2_{a_{heat}} + 2\sigma_{a_{general}}\sigma_{a_{heat}} + \sigma^2_{pe_{general}} + \sigma^2_{pe_{heat}} + 2\sigma_{pe_{general}}\sigma_{pe_{heat}} + \sigma^2_e} \quad (4)$$

with $\sigma^2_{a_{general}}$ as the general additive genetic effect variance, $\sigma^2_{a_{heat}}$ as the additive genetic effect variance for HT, $\sigma_{a_{general}}\sigma_{a_{heat}}$ as the covariance between the two, $\sigma^2_{pe_{general}}$ as the general permanent environmental effect variance, $\sigma^2_{pe_{heat}}$ as the permanent environmental effect variance for HT, $\sigma_{pe_{general}}\sigma_{pe_{heat}}$ as the covariance between the two and σ^2_e as the residual variance.

Breeding value estimation. Heat Tolerance Breeding values (BVs) for daily milk production were estimated with MiX99 (Lidauer et al., 2019) and expressed on a scale with mean of 100 and standard deviation of 5: values higher than the mean refer to individuals that transmit a higher tolerance to HS.

Results

Estimation of genetic parameters. Posterior means and standard deviations for variance components and heritability were computed for the three samples. The mean heritability of the samples' posterior means was 0.16 (standard deviation = 0.006), confirming the feasibility of a selection for HT. As expected, the genetic correlation between the general additive genetic variance and the HT genetic variance was negative, -0.45 (0.048), meaning that high producing cows tend to be more susceptible to HS.

Genetic trend. The genetic trend for HT by year of birth of bulls is represented in Figure 1. The figure shows a strong decreasing trend in the early '90s, a plateau and finally an important increase in the last 20 years. This trend reflects the introduction of new breeding objectives in the Italian selection index, which progressively shifted some weight from production to functionality, therefore the positive trend can be explained by the negative genetic correlation found between milk production and HT.

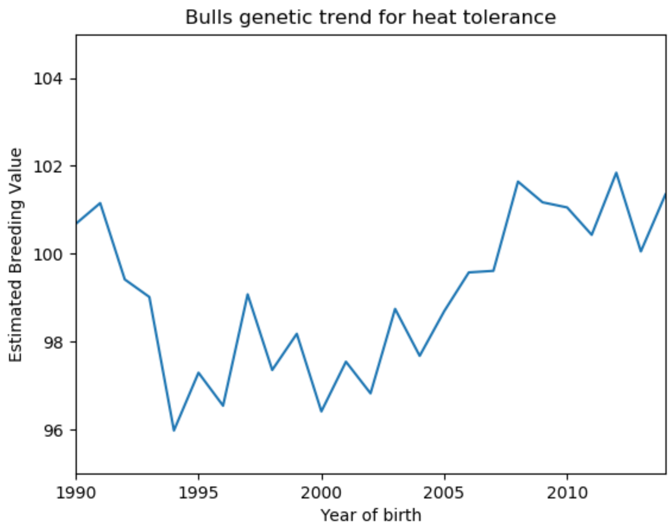

Figure 1. Genetic trend of heat tolerance by year of birth.

Conclusions

The feasibility of a selection for HT based on milk production was confirmed by the moderate heritability found for this trait, 0.16 (0.006). The negative genetic correlation between HT and milk production was also confirmed (-0.45), meaning that HT should not be used as a selection criterion by itself: economic analyses will be performed to define the optimum weight for this trait in a selection index. The use of the Italian selection index (PFT) has already selected, indirectly, for more heat tolerant bulls, it is clear that the availability of a direct index would allow a better selection for more heat tolerant individuals.

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