Onset of heat stress and development of genomic predictions for heat tolerance in US Holsteins and Jerseys

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Abstract

The impact of heat stress on dairy production traits was investigated and genomic predictions for heat tolerance in US Holsteins and Jerseys were developed. Data included 12.8 and 2.1 million test-day records for milk, fat, and protein yield (kg) for the first five parities of 923,311 Holstein and 153,714 Jersey cows in 27 US states. Genotypes were available for 76,481 and 46,046 Holsteins and Jerseys, respectively. Production was affected by heat stress when the temperature-humidity index (THI) exceeded 69 for Holsteins and 72 for Jerseys. The additive genetic component of heat tolerance for production traits was estimated using a random regression repeatability model on a function of THI. Negative correlations between general and heat tolerance additive effects were observed for Holsteins (Jerseys): -0.38 (-0.37) milk, -0.51 (-0.49) fat, and -0.43 (-0.52) protein. Estimates for the heat tolerance additive genetic values were obtained with single-step GBLUP, potentially identifying heat-tolerant dairy cattle.

Introduction

High temperatures and relative humidity have negative impacts on production (Fuquay, 1981) and reproduction (Hansen and Aréchiga, 1999) of dairy cattle thus affecting overall economic return (Kadzere et al., 2002; St-Pierre et al., 2003). Cattle experience heat from both environmental factors including radiation, conduction, and convection as well as through metabolic processes such as exercise, growth, lactation, gestation, and feeding (Fuquay, 1981). Excess environmental heat unable to be managed through thermoregulation can result in heat stress. The stress can be mediated by provisions of cooling technologies such as sprinkler systems, fans, and shade. Additionally, developing a genetic evaluation for heat tolerance of dairy cattle will allow producers to select animals whose production is least affected by environmental heat stress. Different approaches have been previously explored with test-day yields in US Holsteins (Ravagnolo et al., 2000; Bohmanova et al., 2005, Aguilar et al., 2009), non-return rate in US Holsteins (Ravagnolo et al., 2002) and test-day yields in Australian Holsteins and Jerseys (Nguyen et al., 2016). The objectives of this study were to investigate the impact of heat stress on test-day yields and develop single-step genomic predictions to identify heat tolerant US Holsteins and Jerseys.

Materials & Methods

Test-day data. Select Sires, Inc. (SSI; Plain City, OH, USA) supplied 12.8 and 2.1 million test-day records from the first five parities containing milk, fat, and protein yield (kg) for 923,311 Holstein and 153,714 Jersey cows. Each cow was required to have at least 5 test-day records per lactation. Test-day records were obtained from 331 herds in 27 different US states from 2015 to 2021. Genotypes from different density arrays were available for 76,481 and 46,046 Holstein and Jersey animals, respectively. Genotypes were imputed to approximately 50k SNP density using FImpute3 software (Sargolzaei et al., 2014).

Weather data. Weather data was obtained from Automated Surface Observing System (ASOS) stations at airports closest to each herd. Iowa State University's Iowa Environmental Mesonet (IEM) provides this data and can be accessed using R package 'riem' (Salmon, 2016). Geographical coordinates for each herd were obtained using R package 'ggmap' (Kahle and Wickham, 2013) and the distances between each herd and each airport were calculated using the Haversine formula in R package 'geosphere' (Hijmans, 2019). The Haversine formula determines the distance between two geographical coordinates on Earth using an average radius of 6,371 km. This measure was used to determine the airport with the minimum distance to each herd. Daily mean temperature and daily mean relative humidity for the 4-days prior to and the day of test (Nguyen et al., 2016) were obtained for each airport and the daily temperature-humidity index (THI; NOAA, 1976) were calculated as proposed by Ravagnolo et al. (2000) as:

$$THI = (1.8 * t + 32) - (0.55 - 0.0055 * rh) * (1.8 * t - 26) \quad (1)$$

where t is the mean air temperature in degrees Celsius at approximately 2 meters, and rh is the mean relative humidity as a percentage. A final THI for each herd and test-day was calculated as the average THI over the 5 days.

Threshold. Statistical analyses were conducted separately based on the breed of the cow providing the test-day records. To determine the THI threshold where heat stress affects production traits, the least square estimates (LSE) of production were obtained from a repeatability multi-trait animal model as:

$$y_{hijklmno} = HTD_{ih} + (DIM * s)_{jh} + lact_{kh} + state_{lh} + THI_{mh} + age_{nh} + a_{oh} + pe_{oh} + e_{hijklmno} \quad (2)$$

where $y_{hijklmno}$ is the yield of milk, fat, and protein in kg for trait h, categorical fixed effects included herd test-day i (HTD_{ih}), days-in-milk class by calving season class j $(DIM*s)_{jh}$, lactation k ($lact_{kh}$), state l ($state_{lh}$), 5-day average THI of test-day m (THI_{mh}), and age of calving class n (age_{nh}). Random effects included general additive genetic effect for animal o (a_{oh}), general permanent environmental effect (pe_{oh}) for animal o, and residual ($e_{hijklmno}$). The LSE of production were regressed on THI. The discovered thresholds ($THI_{threshold}$) for each breed were used in a function, f(THI), and implemented in a random regression repeatability model to identify animals with superior genetic merit for heat tolerance:

$$f(THI) = \mathit{maximum}(0, THI_{TD} - THI_{threshold}) \quad (3)$$

where THI_{TD} is the calculated average THI of a given test-day.

Random regression. The multi-trait random regression repeatability model used for variance component estimation and genetic evaluation of test-day milk, fat, and protein yield (y) was:

$$y_{hijklno} = HTD_{ih} + (DIM * s)_{jh} + lact_{kh} + state_{lh} + age_{nh} + a_{oh} + \alpha_{oh}[f(THI)] + pe_{oh} + \pi_{oh}[f(THI)] + e_{hijklno} \quad (4)$$

that included the additive genetic random regression effect of heat tolerance for animal o (α_{oh}) and the permanent environmental random regression effect of heat tolerance for animal o (π_{oh}). Additive and permanent environmental variances were assumed only to change with heat stress. Variance components were calculated using GIBBS2F90 and estimates for heat tolerance additive genetic values were calculated using BLUP90IOD2OMP1 as implemented in the BLUPF90 family of programs (Misztal et al., 2014). The Algorithm for Proven and Young (APY; Misztal, 2016) was implemented with 11,000 Jersey and 15,000 Holstein core explaining >99% of variation.

Results

The average distance between herds and matched airports was 20 (12 SD) km with a minimum of 2 and maximum distance of 75 km. The 331 US herds averaged 44,913 (65,892 SD) test-day records but ranged from contributing 3 to 459,326 records. A substantial decrease in milk, fat, and protein yield for Holsteins occurred after a THI of 69, whereas for Jerseys this value was 72. Approximately 14.6% Holstein and 9.9% Jersey test-day records were recorded at THI above the respective thresholds and therefore under heat stress. The maximum THI observed was 82. Heritability for general genetic merit of Holsteins was 20.8% for milk, 15.7% for fat, and 17% for protein, whereas Jerseys was found to be 20.0%, 10.5%, and 13%, in the same order. The heritability for production at each heat stress level is presented in Figure 1. A negative correlation between general and heat tolerance additive effects was observed for Holsteins (Jerseys): -0.38 (-0.37) milk, -0.51 (-0.49) fat, and -0.43 (-0.52) protein for all THI. Statistics of heat tolerance additive genetic values for milk, fat, and protein yield are in Table 1; these are the random regression coefficients and represent the expected change in yield (kg) from average change for each unit above THI threshold.

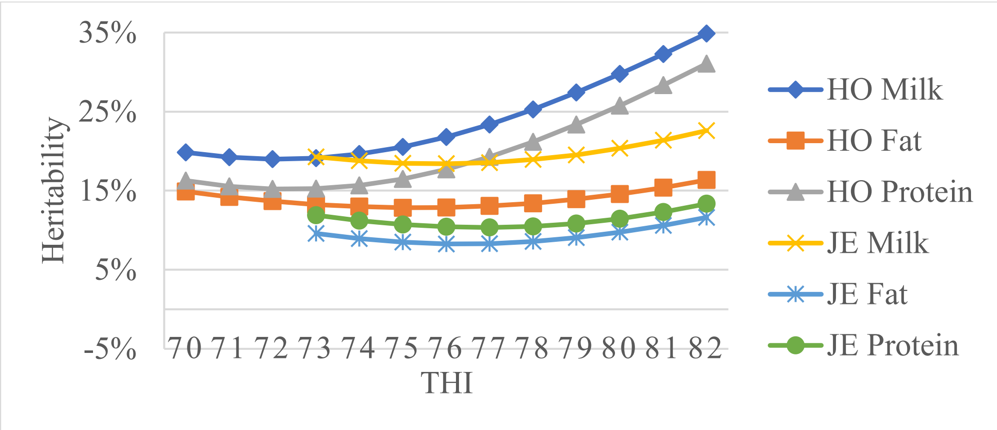

Figure 1. Heritability for production under heat stress for Holsteins (HO) and Jerseys (JE).

Table 1. Heat tolerance additive genetic values[1] for milk, fat, and protein yield for 1,189,386 Holstein and 240,813 Jersey animals.

Breed	Trait	Mean	Min	Max	SD
Holstein					
	Milk	0.033	-1.132	1.384	0.169
	Fat	0.001	-0.028	0.034	0.005
	Protein	0.001	-0.030	0.041	0.005
Jersey					
	Milk	-0.009	-0.516	0.475	0.086
	Fat	-0.001	-0.023	0.023	0.004
	Protein	0.000	-0.016	0.017	0.003

[1] Interpreted as the expected change in yield (kg) from average change for each unit above THI threshold

Discussion

Production yields decreased due to heat stress at different THI thresholds for each breed. It would be beneficial to have a greater number of test-days for cows experiencing heat stress. Heritability at each THI was greater than previously found in Ravagnolo et al. (2000) where first-parity Holstein milk yield was 16% at 72 THI and increased to 21% at 85 THI and little to no increase in fat and protein. In this study, a greater increase in heritability was observed from

20% at 70 THI to 35% at 82 THI when all five lactations were included. Heritability of protein increased from 16% to 31% from THI 70 to 82; thus, selection for heat tolerance for production traits is possible. Small increases in heritability at extreme THI could be due to artifacts of the random regression model and a need for more records under heat stress. The negative correlations between general and heat tolerance additive effects for production traits indicate an antagonistic relationship. High-producing cows are expected to have a lower heat tolerance. However, the low to moderate correlations and increasing heritability for heat tolerance over THI show potential to improve both production traits and heat tolerance simultaneously using a selection index. Estimates of heat tolerance additive genetic values for milk, fat, and protein yield were obtained with single-step GBLUP, potentially allowing the identification of heat-tolerant Holsteins and Jerseys. A validation on the genetic predictions will be explored. Production for first lactation cows has been observed to be least affected by heat stress. Further analysis of models containing first lactation only, and later lactations (lactations 2-5) will be explored.

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