National Genetic Evaluation of Milk Yield for Heat Tolerance of United States Holsteins

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Introduction

Heat stress is an important factor that has a substantial impact on production of dairy cattle in the United States. Estimated total annual economic losses to the dairy industry due to heat stress range from \$897 to \$1500 million (St-Pierre *et al.*, 2003). Therefore selection for heat tolerance could be cost effective. However, a major obstacle is the availability of data for such selection on a national basis. A temperature-humidity index (THI) is a widely used indicator of external heat load caused by a combination of temperature and relative humidity. Ravagnolo and Misztal (2000) presented a methodology for genetic evaluation for heat tolerance based on data from weather stations. When that method was applied for milk yield of Holsteins in Georgia, the genetic correlation between a traditionally predicted transmitting ability (PTA) and a PTA for heat tolerance was about –0.4, and the variance of heat-tolerance PTA was large at high THI. The objective of this study was to apply genetic evaluation methodology at the national level and to identify bulls with genetic extremes for tolerance to heat stress.

Materials and Methods

Data

The U.S. national data set consisted of 57,315,661 first-parity, test-day records of 6,906,815 Holsteins that calved from 1993 through 2004. Hourly temperature and relative humidity records were available from 202 public weather stations across the United States. Herds were assigned by distance to the nearest weather station.

Hourly THIs were computed from hourly temperature (temp) expressed in °C and relative humidity (rh) expressed as a percentage (NOAA, 1976):

$$\mathrm{THI} = [1.8(\mathrm{temp}) + 32] - [0.55 - 0.0055(\mathrm{rh})][1.8(\mathrm{temp}) - 26].$$

Hourly THIs then were used to calculate mean daily THI ($\overline{\mathrm{THI}}$). A dummy regression variable t was defined to estimate decline of milk yield due to heat stress. The threshold for heat stress was assumed to be $\overline{\mathrm{THI}} = 72$. Therefore, if $\overline{\mathrm{THI}} < 72$, then t = 0 (no heat stress), and if $\overline{\mathrm{THI}} \geq 72$, then $t = \overline{\mathrm{THI}} - 72$.

Model

The random regression repeatability model used for genetic evaluation of test-day milk yields (y) was

$$y_{ijk\ell m} = htd_i + dim_j + age_k + freq_\ell + a_m + p_m + \alpha_m t + \pi_m t + e_{ijk\ell lm},$$

where htd_i = fixed effect of herd-test date i (i = 1 to 2,658,042), dim_j = DIM class j (j = 1 to 37) with classes defined every 10 days, age_k = calving age class k (k = 1 to 8) , $freq_\ell$ = milking frequency ℓ (ℓ = 1 or 2), a_m = general additive genetic effect for animal m (m = 1 to 10,673,333), p_m = permanent environmental effect for animal m, α_m = additive genetic random regression effect of heat tolerance for animal m, π_m = permanent environmental random regression effect of heat tolerance for animal m, and $e_{ijk\ell mn}$ = residual effect. The variance-covariance structure was:

$$\mathrm{Var}\begin{bmatrix}\mathbf{a}\\ \boldsymbol{\alpha}\\ \mathbf{p}\\ \boldsymbol{\pi}\\ \mathbf{e}\end{bmatrix}=\begin{bmatrix}\mathbf{A}\sigma_{\mathrm{a}}^2 & \mathbf{A}\sigma_{\mathrm{a}\alpha} & \mathbf{0} & \mathbf{0} & \mathbf{0}\\ \mathbf{A}\sigma_{\mathrm{a}\alpha} & \mathbf{A}\sigma_{\alpha}^2 & \mathbf{0} & \mathbf{0} & \mathbf{0}\\ \mathbf{0} & \mathbf{0} & \mathbf{I}\sigma_{\mathrm{p}}^2 & \mathbf{I}\sigma_{\mathrm{p}\pi} & \mathbf{0}\\ \mathbf{0} & \mathbf{0} & \mathbf{I}\sigma_{\mathrm{p}\pi} & \mathbf{A}\sigma_{\pi}^2 & \mathbf{0}\\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{I}\sigma_{\mathrm{e}}^2\end{bmatrix},$$

where **A** = relationship matrix, **I** = identity matrix, σ^2 = variance, and σ = covariance. Genetic and environmental parameters were those estimated by Ravagnolo and Misztal (2000).

Results

The PTAs of 172,411 sires and 10.5 million cows were calculated by BLUP90IOD (Tsuruta, 2001) in 144 rounds and 8 hours. Heat-tolerance PTAs of sires ranged from –0.48 to 0.38 kg milk per THI unit above 72 per day; general milk-yield PTAs for sires were between –8.9 and 7.9 kg per day.

Based on estimated heat-tolerance PTAs, the 100 most and 100 least heat-tolerant sires were selected. For each of the 200 sires, official U.S. PTAs for February 2005 were compared with heat-tolerance PTAs (Table 1). Sires that were the most heat tolerant transmitted lower milk yields with higher fat and protein contents than did sires that were the least heat tolerant. Daughters of the most heat-tolerant sires had better type, worse dairy form, better udder and body composites, higher TPI, longer productive life, and higher daughter pregnancy rate than did daughters of the least heat-tolerant sires. Daughters of heat-tolerant bulls may have flatter lactation curves (B.J. Van Doormal, 2005, personal communication).

Many dairy producers in the southeastern United States are paid based on fluid milk. This pricing scheme provides incentives to select for cows with high milk yield without advantage for high fat and protein content. Based on results of this study, sires of such cows would be expected to transmit the least tolerance for heat stress. In a separate analysis, regional distribution of bulls was examined based on heat tolerance. Sires used in the southeastern United States had lower heat tolerance than the average U.S. bull. Problems of heat stress in hot climates may be compounded by selection of less heat-tolerant sires.

Table 1. Differences of heat-tolerance PTAs and TPIs from February 2005 U.S. official evaluations for the 100 most and 100 least heat-tolerant U.S. Holstein bulls.

Trait	Most heat tolerant	Least heat tolerant	Difference between most and least heat tolerant
Milk yield (kg)[1]	–751	373	–1124.00
Fat (%)[1]	0.08	–0.02	0.10
Protein (%)[1]	0.03	–0.03	0.06
Type[2]	0.11	–0.46	0.57
Dairy form[2]	–0.49	0.96	–1.44
Udder composite[2]	0.15	–0.58	0.73
Body composite[2]	0.07	–0.25	0.32
TPI[2]	984	948	35
Productive life (mo)[1]	–0.22	–1.12	0.90
Daughter pregnancy rate (%)[1]	0.14	–1.49	1.62

[1]Official evaluation source: Animal Improvement Programs Laboratory, USDA.

[2]Official evaluation source: Holstein Association USA, Inc.

Conclusions

Bulls that transmitted high tolerance to heat stress had daughters with lower milk yields, higher content of milk solids, more robust bodies, better udders, longer productive lives, and higher pregnancy rates. Continued selection for milk yield without consideration of heat tolerance may result in greater susceptibility to heat stress.

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