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Genetic components of heat stress for dairy cattle with multiple lactations

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ABSTRACT

Data included 585,119 test-day records for milk, fat, and protein yields from the first, second, and third parities of 38,608 Holsteins in Georgia. Daily temperature-humidity indexes (THI) were available from public weather stations. Models included a repeatability test-day model with a random regression on a function of THI and a test-day random regression model using linear splines with knots at 5, 50, 200, and 305 d in milk and a function of THI. Random effects were additive genetic and permanent environmental in the repeatability model and additive genetic, permanent environmental, and herd year in the random regression model. Additionally, models included fixed effects for herd test day, calving age, milking frequency, and lactation stage. Phenotypic variance increased by 50 to 60% from the first to second parity for all yield traits with the repeatability model and by 12 to 15% from the second to third parity. General additive genetic variance increased by 25 to 35% from the first to second parity for all yield traits but decreased slightly from the second to third parity for milk and protein yields. Genetic variance for heat tolerance doubled from the first to second parity and increased by 20 to 100% from the second to third parity. Genetic correlations among general additive effects were lowest between the first and second parities (0.84 to 0.88) and were highest between the second and third parities (0.96 to 0.98). Genetic correlations among parities for the effect of heat tolerance ranged from 0.56 to 0.79. Genetic correlations between general and heat-tolerance effects across parities and yield traits ranged from −0.30 to −0.50. With the random regression model, genetic variance for heat tolerance for milk yield was approximately one-half that of the repeatability model. For milk yield, the most negative genetic correlation (approximately −0.45) between general and heat-tolerance effects was between 50 and 200 d in milk for the first parity and between 200 and 305 d in milk for the second and third parities. The genetic variance of heat tolerance increased substantially from the first to third parity. Genetic estimates of heat tolerance may be inflated with the repeatability model because of timing of lactations to avoid peak yield during hot seasons.

Key words: heat stress, variance component, random regression model

INTRODUCTION

Heat stress in dairy cattle affects production (Maust et al., 1972; Fuquay, 1981; Bryant et al., 2007) and reproduction (Ravagnolo and Misztal, 2002; Jordan, 2003; Garcia-Ispierto et al., 2007). Economic losses attributable to heat stress are estimated to be between $897 million and $1,500 million per year for the US dairy industry (St-Pierre et al., 2003). Different approaches are used to manage heat stress in dairy cattle, including cooling, shading, and nutrition (West, 1999, 2003; Kadzere et al., 2002).

Misztal (1999) proposed a model to study the genetic component of heat stress in dairy cattle by using performance data and public weather information. Additive genetic variability for heat tolerance was shown to be important for milk, fat, and protein production of first-parity cows; additive genetic variance at a high temperature-humidity index (**THI**) was similar to additive variance under nonstress conditions (Ravagnolo and Misztal, 2000). Comparison of on-farm weather data with public information has shown that the latter are accurate sources of information (Freitas et al., 2006b). Bohmanova et al. (2005) developed a genetic evaluation for heat tolerance for first-parity US Holstein cows based on public weather data. Estimated breeding values were calculated for approximately 10 million animals by using a repeatability test-day model with a random regression on THI. Daughters of bulls with high genetic merit for heat tolerance had lower milk yields, higher contents of milk solids, more robust bodies, better udders, longer productive lives, and higher pregnancy rates than did daughters of bulls with low genetic merit for heat tolerance.

Longitudinal data are commonly analyzed with random regression models (Schaeffer, 2004). Different functions can be applied to model (co)variances across DIM. Splines have been used to model (co)variances

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Table 1. Numbers of Holstein cows and test-day records and lactation means and SD of milk, fat, and protein yields by parity

Parity	Cows, n	Test days, n	Milk, kg	Fat, kg × 100	Protein, kg × 100
1	38,608	350,623	27.5 ± 7.0	94.8 ± 27.7	85.7 ± 20.4
2	17,549	160,262	31.6 ± 9.4	109.3 ± 36.3	97.5 ± 26.3
3	8,210	74,834	33.0 ± 10.1	114.8 ± 39.5	100.7 ± 28.1

in test-day models (White et al., 1999; Torres, 2001; Druet et al., 2003; Silvestre et al., 2005; Bohmanova et al., 2007) or to model growth traits (Meyer, 2005; Robbins et al., 2005; Sanchez et al., 2008). Linear splines have good numerical properties and local effects and are easily interpretable (Misztal, 2006). The objective of this study was to estimate variance components for milk, fat, and protein yields from the first 3 parities by using test-day models that included a random regression on a function of THI.

MATERIALS AND METHODS

Data

Holstein test-day records for milk, fat, and protein yields from the first 3 parities were obtained from the Animal Improvement Programs Laboratory, ARS, USDA (Beltsville, MD). Records were from cows registered between 1993 and 2004 in Georgia. Lactation records were required to have only 2 or 3 milkings per day and at least 4 test days, with the first test day at <75 DIM and test days between 5 and 305 DIM. Calving ages were restricted to 18 to 35 mo for parity 1, from 28 to 49 mo for parity 2, and from 40 to 63 mo for parity 3. Cows also were required to have the first lactation recorded. A 3-generation pedigree file of 68,103 animals was extracted for 38,608 cows with 585,119 test-day records. The data are summarized in Table 1.

Hourly THI (National Oceanic and Atmospheric Administration, 1976) was calculated from data from public weather stations as proposed by Ravagnolo et al. (2000):

$$\mathrm{THI(t,rh)} = (1.8\mathrm{t} + 32) - (0.55 - 0.0055\mathrm{rh})(1.8\mathrm{t} - 26),$$

where t is temperature in degrees Celsius and rh is relative humidity, expressed as a percentage. Herds were matched with the closest weather station, based on minimum distances from latitude and longitude information obtained from the zip code. Mean herd distance from a weather station was 61 km, with a maximum of 137 km and a minimum of 3 km. Mean daily THI for the third day before each test day from the weather station closest to the farm was assigned as the THI for that test day, as suggested by Bohmanova et al. (2008). A function (f) of THI was created:

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

where $\mathrm{THI_{threshold}}$ was set to 72, as in Ravagnolo et al. (2000).

Model

Two models were used to estimate variance components for multiple lactations. The first model was a multiple-trait extension of the repeatability test-day model (**REP**) proposed by Ravagnolo and Misztal (2000) to estimate variance components for heat tolerance, considering multiple lactations as different traits:

$$y_{ijklmno} = \mathrm{HTD}_{ij} + \mathrm{DIM}_{kl} + \mathrm{age}_{jm} + \mathrm{freq}_{n} + a_{\mathrm{general}_{jo}} + a_{\mathrm{ht}_{jo}}[\mathrm{f(THI)}_i] + p_{\mathrm{general}_{jo}} + p_{\mathrm{ht}_{jo}}[\mathrm{f(THI)}_i] + e_{ijklmno},$$

where $y_{ijklmno}$ is test-day milk, fat, or protein yield for cow o in age class m within parity j (1, 2, or 3) and DIM class k within season l for herd test-day i within parity j and milking frequency n (2 or 3 daily milkings); HTD is a fixed effect of herd test day within parity; DIM is a fixed effect of DIM class within season; age is a fixed effect of calving age class within parity; freq is a fixed effect of milking frequency; a is a general random additive genetic effect for the cow within parity; a_{ht} is a random additive genetic effect of heat tolerance of the cow within parity; p is a general random permanent environmental effect for the cow within parity; p_{ht} is a random permanent environmental effect of heat tolerance of the cow within parity; and $e_{ijklmno}$ is the random residual effect. Classes of DIM were grouped by 10 d beginning at 5 DIM through 305 DIM (31 classes). Seasons were defined as December through February, March through May, June through August, and September through November. Calving ages were grouped into every 2 mo within parity (22 classes).

Let $\mathbf{a}' = \begin{bmatrix}\mathbf{a}'_{\mathrm{general}_j} & \mathbf{a}'_{\mathrm{ht}_j}\end{bmatrix}$ be the vector of random additive genetic effects and $\mathbf{p}' = \begin{bmatrix}\mathbf{p}'_{\mathrm{general}_j} & \mathbf{p}'_{\mathrm{ht}_j}\end{bmatrix}$ be the vector