J. Dairy Sci. 99:2849–2862
http://dx.doi.org/10.3168/jds.2015-9685

Genomic selection for tolerance to heat stress in Australian dairy cattle

Thuy T. T. Nguyen,*[1] Phil J. Bowman,* Mekonnen Haile-Mariam,* Jennie E. Pryce,*† and Benjamin J. Hayes*†
*BioSciences Research Division, Department of Economic Developments, Jobs, Transport and Resources, and Dairy Futures Cooperative Research Centre, Agribio, 5 Ring Road, Bundoora, Victoria 3083, Australia
†La Trobe University, Bundoora, Victoria 3083, Australia

ABSTRACT

Temperature and humidity levels above a certain threshold decrease milk production in dairy cattle, and genetic variation is associated with the amount of lost production. To enable selection for improved heat tolerance, the aim of this study was to develop genomic estimated breeding values (GEBV) for heat tolerance in dairy cattle. Heat tolerance was defined as the rate of decline in production under heat stress. We combined herd test-day recording data from 366,835 Holstein and 76,852 Jersey cows with daily temperature and humidity measurements from weather stations closest to the tested herds for test days between 2003 and 2013. We used daily mean values of temperature-humidity index averaged for the day of test and the 4 previous days as the measure of heat stress. Tolerance to heat stress was estimated for each cow using a random regression model with a common threshold of temperature-humidity index = 60 for all cows. The slope solutions for cows from this model were used to define the daughter trait deviations of their sires. Genomic best linear unbiased prediction was used to calculate GEBV for heat tolerance for milk, fat, and protein yield. Two reference populations were used, the first consisted of genotyped sires only (2,300 Holstein and 575 Jersey sires), and the other included genotyped sires and cows (2,189 Holstein and 1,188 Jersey cows). The remainder of the genotyped sires were used as a validation set. All animals had genotypes for 632,003 single nucleotide polymorphisms. When using only genotyped sires in the reference set and only the first parity data, the accuracy of GEBV for heat tolerance in relation to changes in milk, fat, and protein yield were 0.48, 0.50, and 0.49 in the Holstein validation sires and 0.44, 0.61, and 0.53 in the Jersey validation sires, respectively. Some slight improvement in the accuracy of prediction was achieved when cows were included in the reference population for Holsteins. No clear improvements in the accuracy of genomic prediction were observed when data from the second and third parities were included. Correlations of GEBV for heat tolerance with Australian Breeding Values for other traits suggested heat tolerance had a favorable genetic correlation with fertility (0.29–0.39 in Holsteins and 0.15–0.27 in Jerseys), but unfavorable correlations for some production traits. Options to improve heat tolerance with genomic selection in Australian dairy cattle are discussed.

Key words: heat tolerance, milk production, temperature-humidity index, genomic selection

INTRODUCTION

Increases in ambient temperature, humidity, air flow, and radiation above a comfort threshold are known to lead to heat stress in dairy cattle (Armstrong, 1994). Dairy cows respond to heat stress in several ways, including reduced feed intake (Beede and Collier, 1986), lower milk yield and milk quality (Bohmanova et al., 2007; Hammami et al., 2013), and compromised fertility (Ravagnolo and Misztal, 2002; Haile-Mariam et al., 2008). Collectively, these responses increase management costs and result in loss of income (St-Pierre et al., 2003).

Heat stress in cows can be relieved by providing shades, fans, and sprinklers (Moran, 2005). However, this may not be practical, or particularly effective in pastoral systems common in Australia, New Zealand, and some other countries. A supplementary strategy would be selection for improved heat tolerance, which would have cumulative and permanent effects. Several authors have demonstrated that the extent of decline in milk production with increasing heat stress varies between animals and is a lowly to moderately heritable trait (Ravagnolo and Misztal, 2000; Bernabucci et al., 2014). This trait could be used as an indicator trait for heat tolerance. Whereas selection based on phenotype and pedigree could be applied for this trait, rates of genetic gain are likely to be slow given the heritability of the trait and long generation interval associated with

Received April 8, 2015.
Accepted December 21, 2015.
[1]Corresponding author: thuy.nguyen@ecodev.vic.gov.au

traditional selection in dairy cattle. Genomic selection is an attractive alternative, allowing young bulls (and heifers) to be selected on their heat tolerance genomic estimated breeding value (**GEBV**) as well as on other traits. In practice, as dairy bulls are increasingly selected for breeding based on GEBV (for a range of traits) rather than progeny testing, a GEBV for heat tolerance is necessary if this trait is to be considered in selection decisions. A further advantage of implementing a GEBV for heat tolerance is that because nearly all young dairy bulls are already genotyped, the marginal cost of the additional GEBV is very small. Accelerating the rate of genetic gain for heat tolerance in some dairy regions will become more and more important as the incidence of heatwave events rises to enable adaptation to these future climates (CSIRO and BoM, 2014).

The main challenges for developing a GEBV for heat tolerance are assembly of a reference population of genotyped animals with phenotypes for heat tolerance, choice of the phenotype itself, and the model used to incorporate genomic information. With regard to choice of phenotype, several studies have used temperature-humidity indices (**THI**) as an indicator of heat load and combined these data with test day records for milk yield traits to estimate genetic components of heat tolerance. Ravagnolo and Misztal (2000) reported an increase in additive genetic variance for heat tolerance as THI exceeded a thermoneutral threshold. Genetic variance for heat tolerance is also reported to increase with subsequent lactations (Aguilar et al., 2009; Bernabucci et al., 2014). In Australian dairy cattle, Hayes et al. (2003) demonstrated that protein production began to decline at THI of 60 (e.g., daily average temperature of 20°C and humidity of 45%). The advantage of using the decline in milk production as a phenotype for heat tolerance is that the phenotype can be collected on a very large scale by combining weather station data and herd recording data. This allows a large reference population to be assembled for estimating GEBV, as daughter trait deviations (**DTD**) can be calculated for this trait for nearly all genotyped sires.

To estimate variance components for heat tolerance in dairy cattle, many studies have assumed that all animals have a common comfort threshold and that production declines when the THI exceeds the threshold. A more realistic model was proposed by Sánchez et al. (2009), who estimated a threshold and slope for each animal. Those authors reported that the threshold and slope have large genetic components; however, the genetic correlation between them is 0.95 (Sánchez et al., 2009), indicating that an animal with a higher threshold of heat stress would also have a lower rate of decline and vice versa. Sánchez et al. (2009) suggested that selection on one component of heat tolerance would lead to favorable response for the other. In addition, as Sánchez et al. (2009) pointed out, the model that inferred both threshold and slope required fixing the mean threshold to a previously estimated value to obtain sensible estimates. Therefore, a simple model assuming a constant threshold at which THI affects milk production across animals, but different slopes, could result in reasonable estimates of breeding value that capture most of the genetic variation for heat tolerance. The reliabilities calculated from such a model may be biased, however, and this would have to be addressed in routine evaluations.

In dairy cattle breeding, many traits are selected simultaneously using selection index theory (Hazel, 1943), and most modern selection indices include a combination of production and health and fitness traits (Miglior et al., 2005). To include heat tolerance in a selection index, the accuracy of selection and correlations with other traits would be required in addition to the effect of the trait on net profitability of dairy farms (economic value).

Our aim was to assess the accuracy of GEBV that can be achieved for heat tolerance in Australian Holstein and Jersey cattle. To do this, we merged herd test-day records of production traits with weather data and derived the change in production for cows using a random regression model. The slope solution for cows from this model were used for DTD, which were used as the sire-pseudo phenotypes to be fitted in a genomic BLUP model. We also investigated the correlation of heat tolerance with other traits as the first step toward including this trait in selection indices for dairy cattle in regions where heat stress occurs.

MATERIALS AND METHODS

The Australian dairy industry is mainly pasture-based, and on most farms dairy cattle do not have access to barns during high-heat load periods. Therefore, it is reasonable to assume that the weather conditions for a herd location are likely to be similar to the nearest public weather station on the same day and time. Such an approach of combining field performance with public weather data has been extensively used in studies related to heat stress in many regions (Bohmanova et al., 2007; Aguilar et al., 2009), including Australia (Hayes et al., 2003; Haile-Mariam et al., 2008).

Climate Data

Climate data including hourly measures of dry bulb temperature and relative humidity were obtained from