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Genetic analysis of heat tolerance regarding Holstein cows conception rate in Japan

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Summary

Fertility reduction in summer poses a considerable problem in dairy cattle. The present study performed a genetic analysis of heat tolerance regarding the conception rate (CR) during lactation, based on temperatures recorded at weather stations close to Holstein cow herds. The records of artificial insemination between 22 to 315 days in milk from 2012 to 2016 were obtained from the Livestock Improvement Association of Japan. Insemination data included 245,876 records (2,212 herds, 124,407 cows) for the first lactation, 206,875 records (2,222 herds, 100,922 cows) for the second lactation, and 140,474 records (2,194 herds, 69,000 cows) for the third lactation. The daily average dry-bulb temperature was recorded by the nearest weather station to cow herds (843 weather stations of Japan Meteorological Agency). Data were analyzed using the linear or the threshold random regression sire model based on temperature. The CR was 0.47 at 17 ºC, and decreased as the temperature at insemination increased from 20 ºC to 32 ºC. In the linear model, the heritability estimates of CR were 0.02–0.03 in the mid-temperature range (-10 ºC to 25 ºC). The heritability estimates of CR at -22 ºC were 0.03 in the first lactation and 0.08 in the second and third lactations; at 32 ºC the CR heritability estimates were 0.04 in the first and second lactations and 0.06 in the third lactation. The trend observed in heritability estimates with temperature changes was similar in both models, although the heritability estimates obtained by the threshold model were higher than those obtained by the linear model. Spearman's rank correlation coefficients between the transmitting ability of sires with 25 or more recorded daughters estimated by the linear and threshold models were high: 0.997, 0.995, and 0.988 in the first, second, and third lactation, respectively. These results indicated that the genetic estimates of CR did not differ between the models. Because the genetic correlation of CR between mid- and high-temperature conditions was low and that between low- and high-temperature conditions was high, the few genes controlling CR might be common under heat stress and low temperature, but might differ under moderate temperature.

Keywords: dairy cattle, heat stress, genetic analysis, reproduction

Introduction

Reduction in cattle fertility during summer is a major problem in the dairy industry. Conception rates at first service (CRF) in the first and second lactations are lower in summer than in the other seasons, and the magnitude of their reduction in moderate heat stress regions is particularly larger than that in no-heat stress regions (Hagiya *et al*., 2016). Hagiya *et al.*

(2016) also found a high genetic correlation for the CRF between the cows from regions with different heat stress levels (0.92–0.98). However, this genetic correlation did not show differences in genetic expression due to temperature, because the hot season (temperature-humidity index >72) lasts for only a few months even in moderate heat stress regions, and is similar across areas in the other months. The present study comprises the genetic analysis of heat tolerance in relation to the conception rate (CR) during lactation, based on the temperatures recorded at a weather station near the herds of Holstein cows.

Material and methods

Records of artificial insemination between 22 and 315 days in milk (DIM) from 2012 to 2016 of Holstein cows were obtained from the Livestock Improvement Association of Japan (http://liaj.lin.gr.jp/). Data on the relationship between the artificially inseminated cows were obtained from the National Livestock Breeding Center (http://www.nlbc.go.jp/index.asp). The maximum number of inseminations within a lactation period was 14. Insemination data included 245,876 records (2,212 herds, 124,407 cows) for the first lactation, 206,875 records (2,222 herds, 100,922 cows) for the second lactation, and 140,474 records (2,194 herds, 69,000 cows) for the third lactation. The average daily dry bulb temperature (ºC) recorded by the weather station nearest to each cow herd (843 weather stations, Japan Meteorological Agency) was used for the analysis. These weather data were obtained from the Agriculture, Forestry and Fisheries numeric database. The temperature-humidity index (THI)—a measure of humidity—at 156 weather stations was linearly correlated with temperature (R^2 = 0.994). Data were analyzed using the random regression sire model. The CR was analyzed by linear and threshold models, wherein CR was treated as a linear and threshold trait, respectively. Overall, 2,729 sires had daughters' records for CR, and 5,253 sires and maternal grandsires were used for pedigree data. The following model was used for analyzing CR in each lactation:

where $Y_{ijklmnop}$ is the insemination record p (conception = 1, non-conception = 0) of daughter n of sire o, HY_i is the fixed effect of herd-year at insemination class i, and RM_j is the fixed effect of region-month at insemination class j. The region was divided into four classes according to seasonal changes in milk yield (Sasaki *et al.*, 2013). AG_k is the fixed effect of age at calving class k and LP_l is the fixed effect of lactation period class l; the lactation period was divided into 14 classes each consisting of 21 days starting from 22 to 315 DIM. μ_q represents the q^{th} fixed regression coefficient, $\varphi_q(t)$ is the q^{th} Legendre polynomial at temperature t, ms_m is the random effect of insemination sire s, dau_n is the random effect of daughter n, $sire_{oq}$ represents the q^{th} additive genetic random regression coefficient of sire o, and $e_{ijklmnop}$ is the residual random effect. The (co)variances of the linear model were estimated using GIBBS2F90 (Misztal *et al.*, 2002), and those of the threshold model were estimated using THRGIBBS1F90 (Tsuruta & Misztal, 2006). The first 100,000 Gibbs samples were discarded as the burn-in. Convergence was checked for the next 100,000 samples by visual inspection of the graph and by the parameters of POSTGIBBSF90 (Tsuruta & Misztal, 2006) analyses. The latter samples were used to calculate the posterior means for the (co)variance components.
Considering **G** as the (co)variance matrix for sire regression coefficients, and , the matrix for sire (co)variance at temperature t () was defined as . The heritability at temperature t () was

then defined as:

where , , , and are the sire, insemination sire, daughter, and residual variances, respectively. The genetic correlation between temperatures *t1* and *t2* () was defined as:

where is the genetic covariance between temperatures *t1* and *t2*. Thus, the matrix for genetic covariance estimates between temperatures *t1* and *t2* was . The Spearman's rank correlation coefficient for all pairs of EBV was calculated using the CORR procedure of SAS software (SAS Institute Inc. 2006).

Results and Discussion

The CR was low in summer in the regions where a large decrease in milk yield was observed. The CR decreased with increasing age at insemination, and increased until 84 DIM in the first lactation or until 315 DIM in the second and third lactations. The CR remained around 0.47 under 17 ºC, and then decreased from 20 ºC to 32 ºC (Figure 1), reaching 0.34 at 30 ºC and above. Schüller *et al.* (2014) reported that the CR rapidly decreased when the THI exceeded 73, which corresponds to about 24 ºC in the present study. Thus, the results obtained here agree with those of Schüller *et al.* (2014).

In the linear model, the heritability estimates of CR were 0.02–0.03 in the mid-temperature range (-10 ºC to 25 ºC; Figure 2). The number of the CR records under -10 ºC at first, second, and third lactations were 8,894, 7,790, and 11,157, respectively. The number of the CR records over 25 ºC at first, second, and third lactations were 5,595, 4,130, and 4,328, respectively. Heritability estimates increased when the temperature rose or fell outside the mid-temperature range: at -22 ºC heritability estimate was 0.03 in the first lactation and 0.08 in the second and third lactations, whereas at 32 ºC heritability estimate was 0.04 in the first and second lactations and 0.06 in the third lactation. These estimates were slightly higher than that reported for CRF (0.01–0.03) (Hagiya *et al.*, 2016). Heritability estimates of the non-return rate at 56 days after artificial insemination (NR56) increased with increasing THI (Santana Jr. *et al.*, 2017). The trend observed in heritability according to temperature changes as estimated by the threshold model agreed with that estimated by the linear model. Based on the threshold model, in the mid-temperature range heritability was 0.02–0.05, which was slightly higher than that estimated by the linear model. The threshold model indicated that heritability estimates in the first, second, and third lactation were 0.06, 0.11, and 0.17, respectively, at -22 ºC and 0.10, 0.12, and 0.16, respectively, at 32 ºC. Carlén *et al.* (2006) indicated that the threshold model underlying the liability scale estimated higher heritability than the linear model underlying the observation scale. Therefore, the heritability estimate of the linear model transformed to the liability scale would be similar to the value estimated by the threshold model.

Positive genetic correlations among the CR of low-, mid-, and high-temperature ranges were detected (Figure 3). Genetically, the CR in the mid-temperature range was weakly correlated to that in low- and high-temperature ranges, however it was highly correlated between low- and high-temperature ranges. Santana Jr. *et al.* (2017) suggested that the same few genes would control CR under thermoneutrality or heat stress, because the genetic correlation of NR56 between moderate and high THI conditions was low. In the present study, the trend observed in the genetic correlation of CR among temperature ranges was similar between the linear and threshold models. However, genetic correlations between low-and high-temperature ranges were higher in the threshold than in the linear model in the first and second lactations. In the third lactation, the genetic correlation between low- and mid-temperature ranges was higher in the linear than in the threshold model. Carlén *et al*. (2006) reported that the correlation of breeding values estimated by the linear and threshold models was close to 1. Spearman's rank correlations of the transmitting ability of sires with 25 or more recorded daughters estimated by the linear and threshold models were also high (0.997, 0.995, and 0.988 in the first, second, and third lactation, respectively). These results indicated that the genetic estimates of CR did not differ between the models.

Conclusion

The genetic selection of heat tolerance for CR using genetic estimates under heat stress is effective, because the heritability under this condition was higher than that under mid-temperature ranges. Information on CR under mid-temperature ranges might not contribute to improve heat tolerance for CR, because the genetic correlation of CR between mid- and high-temperature ranges was low. The high genetic correlation of CR between low- and high-temperature ranges suggests that the same few genes might be responsible for CR under low- and high-temperature conditions.

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