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Genetic component of sensitivity to heat stress for nonreturn rate of Brazilian Holstein cattle

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A B S T R A C T

The objectives of the present study were: 1) to investigate variation in the genetic component of heat stress for nonreturn rate at 56 days after first artificial insemination (NR56); 2) to identify and characterize the genotype by environment interaction (G × E) due to heat stress for NR56 of Brazilian Holstein cattle. A linear random regression model (reaction norm model) was applied to 51,748 NR56 records of 28,595 heifers and multiparous cows. The decline in NR56 due to heat stress was more pronounced in milking cows compared to heifers. The age of females at first artificial insemination and temperature-humidity index (THI) exerted an important influence on the genetic parameters of NR56. Several evidence of G × E on NR56 were found as the high slope/intercept ratio and frequent intersection of reaction norms. Additionally, the genetic correlation between NR56 at opposite extremes of the THI scale reached estimates below zero, indicating that few of the same genes are responsible for NR56 under conditions of thermoneutrality and heat stress. The genetic evaluation and selection for NR56 in Holstein cattle reared under (sub)tropical conditions should therefore take into consideration the genetic variation on age at insemination and G × E due to heat stress.

1. Introduction

Heat stress is one of the factors responsible for decreased fertility in dairy cows. High temperatures and humidity lead to a reduction in overt estrus, appetite and dry matter intake, in addition to interfering with follicular development, plasma progesterone levels, uterine environment, and energy balance [1]. Thus, economic losses from heat stress by the dairy industry have been recognized to be very important [2]. The selection of animals that are genetically more tolerant to heat stress may be a suitable alternative to attenuate these problems.

The nonreturn rate after first artificial insemination (NR) is a trait commonly used to measure the capacity of the cow to conceive when inseminated [3,4]. Important harmful effects of heat stress on NR have been documented in the literature [5,6]. Ravagnolo and Misztal [7] adopted a random regression model using the temperature-humidity index (THI) as an environmental descriptor, and identified a substantial genetic component of heat stress for NR in Holstein cattle. The NR has been commonly analyzed as a distinct trait in virgin heifers and milking cows due to the physiological differences between these animals [3,4,8]. The flexibility of random regression models permits to simultaneously model the genetic component depending on both time and temperature and humidity [9]. In this respect, the objectives of the present study were: 1) to investigate variation in the genetic component of heat stress by simultaneously modeling the genetic variations in NR depending on age and THI values; 2) to identify and characterize the genotype by environment interaction (G × E) due to heat stress for NR of Brazilian Holstein cattle.

2. Materials and methods

2.1. Data

The database used in the present study belonged to the Dairy Cattle Genetic Breeding Program of CRV Lagoa (Gestor Leite). The data set comprised artificial insemination (AI) records performed on 28,595 Holstein heifers and cows between 1994 and 2015,

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daughters of 1420 sires and 18,802 dams, belonging to 89 herds located in 53 municipalities of 8 Brazilian states (Espírito Santo, 0.7% of AI records; Goiás, 2.7%; Minas Gerais, 16.9%, Mato Grosso do Sul, 0.2%; Paraná, 50.4%; Rio Grande do Sul, 6.7%; Santa Catarina, 0.1%; São Paulo, 22.3%). The southeast (Espírito Santo, Minas Gerais, and São Paulo) and midwest states (Goiás and Mato Grosso do Sul) of Brazil are characterized by highland tropical or humid tropical climate. The southern states (Paraná, Santa Catarina, and Rio Grande do Sul, 57.2% of the AI records) concentrate most of the herds in a predominantly subtropical climate. In general, the farms included in this study are technified and the seasonality of production is a matter of small importance. The management systems of the herds studied are mainly based on free-stall housing with use of concentrate, corn silage or sugarcane with urea. Depending on the region (e.g., Minas Gerais and São Paulo), rotational grazing systems in combination with concentrate feeding are also adopted. Most farms have at least fan systems for the animals and more technified farms also employ sprinklers. The parasite control is carried out systematically, especially in herds adopting rotational grazing systems. All these environmental modifications should ensure that most animals have the effect of potential tropical stressors at least alleviated.

The first recorded AI of each animal was assumed to be the first AI performed on virgin heifers (parity 0) and after each of the first three parities (1, 2, 3). Thus, the nonreturn rate at 56 days after first AI (NR56) was defined as 1 if there was no record of an AI before 56 days after first AI (i.e., assumed to be pregnant), and as 0 if there was a record of an AI before 56 days after first AI. In addition to the parity number information recorded in the reproductive file, an NR56 record was accepted if age at first AI was between 10 and 33 months for virgin heifers. For milking cows, an NR56 record was accepted if age at calving was between 19 and 42, 29 and 52, and 39 and 62 months for first, second and third calving, respectively. The accepted interval from calving to first AI was between 20 and 210 days. Thus, the age at each first insemination (AFI) for all females ranged from 311 to 2079 days. Classes of age at each first insemination were defined as one class for every 44 days (37 classes, the first class included data from 311 to 369 days and the last class included data from 1910 to 2079 days). If a female had recorded veterinary treatment of abortion, estrus synchronization and silent estrus or was culled before 56 days after first AI, the NR56record was discarded because these treatments affect the trait [4]. Data from herds with inaccurate reporting of breeding information (mean NR56 < 0.1 or > 0.9) were discarded according to the procedure adopted by Weigel and Rekaya [3].

The contemporary groups were defined as herd-year-season-parity number of AI, with the restriction that each group should contain at least five animals. Four seasons of AI were defined: December to February, March to May, June to August, and September to November. Three milk production classes were defined for milking cows based on average milk yield during the first 90 days of lactation: 1 = below −1 standard deviation, 2 = between −1 and +1 standard deviation, and 3 = above +1 standard deviation of the overall mean within parity.

The climate variables were daily dry bulb temperature (T in °C) and relative humidity (RH in %) recorded by the Instituto Nacional de Meteorologia (INMET, Brasília-DF, Brazil) at 29 weather stations located less than 50 km away from the farms (average distance = 40 km). T and RH were recorded at three standardized times every day (9:00, 15:00 and 21:00 h) in each weather station. The data recording procedure in the weather stations are standardized throughout the country according to the recommendation of the World Meteorological Organization. Temperature and humidity were combined in an index, THI, using the equation described by NRC [10]:

$$THI = [(1.8 \times T + 32) - (0.55 - (0.0055 \times RH) \times (1.8 \times T - 26))].$$

This formula was adopted because it is suited to the climatic variables available in Brazilian weather stations (T and RH). Moreover, other studies show the usefulness of this formula for this type of study [9]. The average THI obtained over the interval of 5 days before to 5 days after the AI date (interval of 11 days) was assigned to each AI record. The choice of 5 days before and after the AI date was based on the results of a separate study [11], which showed that this interval around the AI date explained most of the variability in NR56 and was associated with a decline in NR56. After all edits, 46.8, 31.9, 14.7 and 6.5% of the females had 1, 2, 3 and 4 NR56 records, respectively. Summary statistics of the weather and production data after editing is shown in Table 1.

2.2. Model and analysis

It was our intention in this study to model the effects of AFI and THI on NR56 with a random regression (two-dimensional). In the case of data including multiple parities, the most commonly used option would be to treat each parity as a different trait [12]. However, this option would make our model complex for a small amount of data, which could lead to erroneous estimates of the variance components. Thus, we chose to treat NR56 in parities 0, 1, 2, and 3 as repeated measures of the same trait. The following random regression repeatability model was applied to the data:

$$\begin{aligned} y_{ilmpr} &= CG_i + b_k DIM(PA_l) + MY_m(PA_l) + \sum_{n=1}^{q} \kappa_n \omega_n(d)(PA_l) \\ &+ \sum_{n=1}^{q} \psi_n \omega_n(t)(PA_l) + \sum_{n=1}^{q} \beta_{pn}\omega_n(d) + \sum_{n=1}^{q} \gamma_{pn}\omega_n(d) \\ &+ \sum_{n=1}^{q} \delta_{pn}\omega_n(t) + \sum_{n=1}^{q} \varepsilon_{pn}\omega_n(t) + e_{ilmpr} \end{aligned}$$

where y_{jlmpr} was the rth NR56 record of cow p; CG_i was the fixed effect of the ith contemporary group (defined as above); b_k was the fixed linear regression on days in milk (DIM) nested within the lth parity for milking cows; MY_m was the fixed effect of the mth milk yield class nested within the lth parity of milking cows; κ_n was the nth fixed regression coefficient by AFI class d nested within the lth parity; ψ_n was the nth fixed regression coefficient by THI t nested within the lth parity; β_{pn} was the nth random regression coefficient for the additive genetic effect of cow p by AFI class d; γ_{pn} was the nth random regression coefficient for the permanent environmental effect of cow p by AFI class d; δ_{pn} was the nth random regression coefficient for the additive genetic effect of cow p by THI t; ε_{pn} was the nth random regression coefficient for the permanent environmental effect of cow p by THI t; q was the number of regression coefficients; $\omega_n(d)$ was the nth orthogonal Legendre polynomial corresponding to AFI class d; $\omega_n(t)$ was the nth orthogonal Legendre polynomial corresponding to THI t, and e_{ijlmpr} was the random residual effect. For AFI class, fixed regression was modeled with Legendre polynomials of order 1 (intercept, linear) and the random regressions were modeled with Legendre polynomials of order 2 (intercept, linear, quadratic). For THI, fixed and random regressions were modeled with Legendre polynomials of order 1 (equivalent to a classical linear reaction norm model: intercept, linear). Residual variance was assumed to be homogeneous across AFI classes and THI values. The service sire was