J. Dairy Sci. 100:1–9
https://doi.org/10.3168/jds.2016-12060

Genomic evaluation of age at first calving

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ABSTRACT

From their time of birth until their first lactation, dairy heifers incur management, health, and feed expenses while not producing milk. Much effort has been made to estimate optimal ages of first calving (AFC) for cows to reduce these costs, which can be as high as $2.50 per day, and ensure that animals are productive earlier in life. To identify AFC for 3 dairy cattle breeds (Holstein, Jersey, and Brown Swiss) that maximizes production, we retrieved phenotypic records for more than 14 million cows calving between 1997 and 2015 from the US national dairy database. The mean AFC for Holstein and Jersey has decreased by 2.4 and 2.7 mo, respectively, since 2006. When comparing the association of AFC with production and fertility traits, we found that decreased AFC was correlated with greater fertility and higher milk yield for all but the earliest group (18 to 20 mo). We also identified an unfavorable correlation of lower AFC with increasing stillbirth rates in Holstein (0.047 least squares means compared with a baseline of 24 mo) and Brown Swiss (0.062 least squares means). Finally, we identified favorable genetic correlations of lower AFC with lifetime net merit, heifer conception rate, cow conception rate, and daughter pregnancy rate in Holstein and Jersey cattle, and favorable correlations for net merit and heifer conception rate in Brown Swiss. To maximize lifetime production and reduce the effects of AFC on stillbirth, the AFC that maximizes production for Holstein and Brown Swiss is 21 to 22 mo, and for Jersey it is 20 to 21 mo. However, the effect of AFC on stillbirth reduces the benefits of calving at very young ages. Calculated genomic predicted transmitting ability for AFC showed an improvement in reliability of 20 percentage points in genomic young bulls compared with parent averages in Holstein, suggesting that genomic testing can improve selection for this trait.

Received September 27, 2016.
Accepted May 3, 2017.
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Key words: genomic selection, age at first calving, trait

INTRODUCTION

Heifer rearing is a major expense for the US dairy industry, accounting for 15 to 20% of the total cost of producing milk. Total rearing costs are difficult to predict, as they appear to be influenced heavily by growth (Bach and Ahedo, 2008), estrus (Gabler et al., 2000), and mortality (Tozer and Heinrichs, 2001) in heifers. Of these, growth is perhaps the most important trait as it is frequently shown to be correlated with both BW and age at first calving (**AFC**; Le Cozler et al., 2008). Assuming a cost of $2.50 per day for raising heifers (http://www.dairyherd.com/dairy-resources/calf-heifer/manager-to-manager/Whats-it-cost-to-raise-a-dairy-heifer-239463381.html; https://fyi.uwex.edu/heifermgmt/files/2015/02/Putting-a-price-tag.pdf), direct benefits for reducing AFC could be as high as $75 per animal per month. Given that an earlier AFC allows an animal to generate income earlier, much work has been done to calculate the effects of AFC on production traits in dairy cattle (Do et al., 2013; Mohd Nor et al., 2013).

A prior study showed an estimated decrease in rearing costs of 18% when calving age was reduced from 25 to 21 mo (Tozer and Heinrichs, 2001). Ettema and Santos (2004) found that a reduction in AFC in first-parity Holsteins was correlated with increases in stillbirth and a lower first-lactation milk production (**FLP**), which needs to be factored into overall profitability estimates. Curran et al. (2013) found that cows calving before 24 mo have lower FLP, and reported that optimal AFC in terms of FLP and lifetime production vary with herd management characteristics, suggesting that optimal AFC may vary from herd to herd. It appears that selecting for AFC must be balanced against the reduction in FLP (Mohd Nor et al., 2013) and increased stillbirth rate to maximize the return on individual dairy cattle of any breed. Polish Holsteins calving before 23 mo of age had better fertility and lower culling risk than cows calving later (Zavadilová and Štípková, 2013). To identify an AFC that reduces stillbirth risk and maximizes milk production in 3 major US dairy breeds [Holstein (**HO**), Jersey (**JE**), and Brown Swiss (**BS**)], we estimated the effect of AFC on 14 traits using data derived from the Council on Dairy Cattle Breeding's (Bowie, MD) national dairy database (https://www.uscdcb.com/cgi-bin/general/Qpublic/query-selection.cgi).

MATERIALS AND METHODS

Data consisted of records stored in the national dairy database at the Council on Dairy Cattle Breeding and included 13,947,041 Holstein, 1,205,096 Jersey, and 90,465 Brown Swiss cows with first calvings from January 1, 1997, to December 31, 2015. Sires were required to be 2 to 20 yr old and AFC was limited to 18 to 35 mo. These filters removed less than 1% of the total records for Holstein and Jersey calvings, and approximately 1.4% of the records of Brown Swiss calvings for the studied years. Statistical analyses of all traits considered in this study were performed using the general linear models procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC). Traits were analyzed using the linear model

$$y = HY + YSM + AFC_i$$

where y was the trait being analyzed, HY was the herd-year of calving, YSM was the year-state-month of calving, and AFC_i was the age at first calving category (i = 18 to 20, 21, 22, . . ., 31, and 32 to 35 mo). Use of state-month instead of year-state-month (YSM) to eliminate the double-counting for years in the model did not significantly change the estimates of the model (Pearson correlation of the estimates from the 2 models = 1). Age at first calving was fit as a categorical variable because previous work by our group found that fitting some quantitative trait data as covariates resulted in slightly lower correlation with actual phenotypes (Kuhn and Hutchison, 2008). Additionally, quite large differences in AFC estimates were found among our classified AFC groups, suggesting that a polynomial curve would not fit the data well.

The phenotypes analyzed included actual milk, fat, and protein yield, milk persistency, cow and heifer conception rate, daughter pregnancy rate, calving ease, and stillbirth. Lifetime traits including lifetime milk, fat, and protein yield, DIM, and days open were also examined. To calculate average milk yield per day of life, we had to estimate the days of life for each cow in the data set. Days of life were calculated by subtracting the birth date of the animal from the left-the-herd date. In cases where the animal did not have a left-the-herd date, the last calving date plus DIM for the last lactation was used as an approximation. Least squares means (SAS Institute Inc.) and significance levels were computed for each AFC group. P-values were computed with a 2-tailed t-test for the null hypothesis that performance in other groups differed from the mean for 24 mo. The best AFC age groups for Holstein and Jersey were determined by identifying the AFC age group that maximized lifetime milk, fat, and protein production. Due to the variance caused by lower sample counts for Brown Swiss AFC groups, we were unable to determine an AFC that maximizes lifetime production and instead identified the AFC group that maximized heifer conception rate (**HCR**) and minimized stillbirth.

We also compared the use of our linear model against an animal model that used pedigree kinship to estimate AFC effects on actual milk production. The model we used for comparison was

$$y = HY + YSM + AFC_i + a_i,$$

where the terms HY, YSM, and AFC_i are the same for the equation above, y is the trait (in this case, actual milk yield), and a_i is the breeding value for the ith animal. Values were estimated using multitrait animal model software (VanRaden et al., 2014). We found that, for actual milk yield in Holsteins (Supplemental Table S1; https://doi.org/10.3168/jds.2016-12060), the predicted values were nearly identical (Pearson's r = 0.9997; $P < 0.001$) to the values generated by our linear model. Therefore, we chose to use the linear model for the remainder of our analysis of the effects of AFC on other production traits.

Traditional PTA

Predicted transmitting abilities for AFC were calculated using the following within-breed animal model:

$$AFC = HYS + A + e,$$

where AFC is age at first calving, HYS is the fixed effect of herd-year-season of birth, A is the random additive genetic effect, and e is the random residual error. Animal and residual error effects were distributed as $N\left(0, \mathbf{A}\sigma_a^2\right)$ and $N\left(0, \mathbf{I}\sigma_e^2\right)$, respectively, where $\mathbf{A}$ is the numerator relationship matrix, $\mathbf{I}$ is an identity matrix, σ_a^2 is the additive genetic variance, and σ_e^2 is the error variance. The (co)variance components were estimated using AIREMLF90 ver. 1.45 (Misztal, 1999), and multistep genomic PTA were computed using software of VanRaden et al. (2014) for the traditional evaluation and VanRaden (2008) to include genomic information.