Genetic parameters for dystocia, milk yield and age at first calving in Brazilian Holstein cows

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ABSTRACT
The present study aims to estimate genetic parameters for dystocia, milk yield and age at first calving of Holstein cows reared in intensive production systems located in the southeastern region of Brazil. A total of 26,987 first-lactation records of Holstein cows were used. The following traits were analysed: 305-day cumulative first lactation milk yield (MY305), age at first calving (AFC) and dystocia. Dystocia was defined as a binary trait, with 0 indicating failure and 1 indicating success. Success was attributed to cows that had a normal calving, and failure was attributed to cows that had a difficult or human-assisted parturition. The (co)variance components were estimated using a Bayesian approach. The heritability estimates were 0.15 (0.01), 0.27 (0.02), and 0.17 (0.03) for MY305, AFC and dystocia, respectively. Dystocia showed genetic correlations of 0.30 (0.09) with AFC and −0.17 (0.11) with MY305. Early maturing heifers may be genetically prone to a more difficult first calving.

Introduction
Difficult parturition (dystocia) has severe consequences for dam and calf welfare, including pain, high surgery risk, mortality, and culling (Mee 2008a), and causes significant economic consequences (Fenlon et al. 2017), especially for first-calf heifers. Dystocia is defined as a calving requiring assistance, and can be caused by environmental factors, but also by factors intrinsic to cow and/or foetus. Risk factors for dystocia associated with the dam have been identified: parity, with first parity animals having higher incidence of calving difficulty (Mee et al. 2011); nutritional status, and its interaction with age at first calving (AFC), particularly with the cow under or over condition at calving (Drew 1986); previous history of dystocia (Mee et al. 2011). Similarly, risk factors associated with the calf have been identified: higher birth weight and consequently calf/dam weight ratio (Mee 2008b), gestation length, twinning, and sex (Ettema and Santos 2004). The phenotype of calf is determined both by the cow calving and the sire of the calf (Price and Wiltbank 1978; Weller and Ezra 2016).

The Holstein breed is recognised for its high profitability due to its superiority in milk yield and, under Brazilian tropical conditions, is reared predominantly in intensive systems, due largely to the temperature/humidity and related nutritional factors. The selection for milk yield over the years by choosing animals with greater capacity for feed intake, have caused dam body size and calf birth weight increase. This increases the risk of dystocia (Mee 2008b). Moderate and positive genetic correlations between calving ease (where higher value indicates more difficult calving) and milk yield in first lactation have been reported in the literature, with estimates ranging from 0.23 to 0.34 (Lee et al. 2003; Muir et al. 2004; Eaglen et al. 2013), and suggesting that individuals with high genetic merit for milk yield are genetically prone to a more difficult first calving.

In addition, selection for higher milk yield may reduce AFC, which represents an important factor in reducing cost of rearing replacements in dairy herds (Ettema and Santos 2004). According to Muir et al. (2004), AFC is the most heritable (0.19) of reproductive traits, and its genetic correlation with milk yield was negative (−0.37), in addition to unfavourable genetic correlation with calving difficulty (−0.35). The authors concluded that heifers that were younger when first inseminated tended to have greater milk yield in first lactation and tended to have greater calving difficulty at first calving. The heritability estimates for dystocia traits reported in the literature are low, ranging from 0.01 to 0.09 (Cole et al. 2016; Hossein Salimi et al. 2017; Vanderick et al. 2017). Furthermore, the analysis should yield a significant gain in accuracy when it includes the sire of calf effects (Weller and Ezra 2016). Thus, this trait is mainly affected by environmental and non-additive effects. This demonstrates the importance to study correlated traits that can have higher heritability estimates.
There are no studies for Brazilian dairy cows about genetic parameters and genetic relationships for dystocia. Therefore, the objective of the present study was to estimate genetic parameters for dystocia, 305-day cumulative first lactation milk yield (MY305) and age at first calving (AFC) of Holstein cows reared in intensive production systems in Brazil.

**Material and methods**

The database used in the present study belonged to the Dairy Cattle Genetic Breeding Program of CRV Lagoa (Gestor Leite). The data set comprised of 26,987 first-lactation records of Brazilian Holstein cows that calved between 1993 and 2018 and from 19 herds located in the southeastern region of Brazil. In this region, temperature conditions and rainfall are considered moderate compared to other parts of the country. The herd management systems are mostly freestall housing by using some source of concentrate, corn silage and sugarcane with urea. The farms have fan or employ sprinklers systems depending upon available technology. The parasite control is carried out systematically, especially for herds in rotational grazing systems. The farms had veterinary and nutrition counsel.

Only cows with at least dam or sire known were kept in database. Records from primiparous cows with calving age between 19 and 36 months, and from 1500 to 16,000 kg of 305-day cumulative milk yield were used. The following traits were analysed: 305-day cumulative milk yield in the first lactation (MY305), age at first calving (AFC) and dystocia. Dystocia was defined as a binary trait, with 0 indicating failure and 1 indicating success. Success was attributed to cows that had a normal calving, and failure was attributed to cows that had a difficult or human-assisted parturition. A total of 19,910 observations of service sire (sire of calf born) were included, with 905 different bulls represented in the data. The pedigree file included a total of 39,839 animals, 26,987 animals with records and 12,852 parents without records. Table 1 summarises the structure of the dataset used in this study after quality control and restrictions.

The contemporary groups (CG) were composed by animals in the same herd, year and calving season. Two calving seasons were considered: wet season (October to March) and dry season (April to September). CG with less than four seasons were considered: wet season (October to March) and dry season (April to September). CG with less than four animals were removed. For MY305 and AFC, animals with records outside three standard deviations from the mean of CG were removed. For dystocia, CG without variability were eliminated (Harville and Mee 1984).

The analysis was performed by using a multi-trait animal model to estimate the variance components and genetic parameters for the traits. The choice of the effects included in the model was based on a preliminary analysis. The model included CG as fixed effect for all traits, and age of cow at calving as covariate (linear effect) for MY305 and dystocia. The additive genetic, service sire (for dystocia) and residual effects were included as random effects.

A Bayesian approach was applied to estimate the (co)variance components by using the THRGIBBS1F90 program (Miszta et al. 2002). This program generates Markov chains for model parameters by Gibbs sampling. A uniform a priori distribution was adopted for fixed effects and an inverse Wishart distribution with a minimum degree of confidence for random effects.

The analysis consisted of a single chain of 800,000 cycles, with a conservative burn-in of 300,000 and a thinning interval of 100. Thus, 5000 samples were effectively used to estimate the parameters and high-density intervals. Convergence was verified by using the criterion proposed by Geweke (1991). The posterior estimates were obtained via POSTGIBBSF90 program (Miszta et al. 2002).

The complete model can be written in matrix notation as follows:

\[
y = Xb + Z_1a + Z_2s + e
\]

where \( y \) was a vector that represented the unobserved liabilities for dystocia and the actual observed phenotypic values for MY305 and AFC. The vector \( b \) included the fixed effects (CG and age of cow at calving). The vector \( a \) included the random direct additive effects, \( s \) was a vector of random service sire effect, and \( e \) was the vector of residual effects. Incidence matrices \( X, Z_1 \), and \( Z_2 \) were known with the appropriate dimensions relating the vector \( y \) to \( b, a, \) and \( s \), respectively.

The assumptions here were:

\[
\begin{align*}
b & \sim \text{constant} \\
|G| & \sim \text{NMV}[0, (G \otimes A)] \\
|P| & \sim \text{NMV}[0, (I \otimes P)] \\
G|S_{rr}, & v_r \sim IW|S_{rr}, v_r | \\
P|S_p, & v_p \sim IW|S_p, v_p | \\
R|S_r, v_r & \sim IW|S_r, v_r |
\end{align*}
\]

where \( A \) is an additive genetic relationship matrix, \( G \) is a genetic (co)variance matrix for additive direct effect, \( P \) is a (co)variance matrix for service sire, \( R \) is the residual (co)variance matrix and \( I_n \) is an identity matrix (of order \( n \)); \( \otimes \) is the Kronecker product; \( S_g \) and \( S_p \) are \( v_g \) and \( v_p \); \( S_r \) and \( v_r \) are a priori values and degrees of freedom for the direct additive, service sire and residual (co)variances, respectively.

The threshold model used links the response observed on a categorical scale to a continuous underlying normal scale. It is assumed that the underlying scale has a normal distribution:

\[
U|\theta \sim N(W\theta, \sigma^2_U)
\]

where \( U \) is the vector of the base scale of order \( r; \theta' = (b', a', s') \) is the vector of location parameters of order \( s \) with \( b \) (defined from a frequentist point of view as fixed effects), \( a \) (as random additive effect) and \( s \) (as random service sire effect); \( W \) is a known incidence matrix of order \( r \) by \( s \); \( I \) is an identity matrix of order \( r \) by \( r \), and \( \sigma^2_U \) is the residual variance. Since

| Table 1. Structure of the dataset for 305-day milk yield in the first lactation (MY305), age at first calving (AFC) and dystocia. |
|----------------|---------|---------|---------|
| Information    | MY305 (kg) | AFC (day) | Dystocia |
| Number of females with observations | 23,929 | 26,782 | 17,904 |
| Number of contemporary groups | 359 | 425 | 259 |
| Number of females with known sire | 18,990 | 21,002 | 14,731 |
| Number of females with known dam | 17,885 | 19,585 | 13,308 |
found in the literature for Holstein cows, ranging from 0.19 to 0.27 (Paula et al. 2008; Irano et al. 2014; Stefani et al. 2018). The heritability for AFC was slightly higher to those found in the literature, ranging from 0.19 to 0.20 (Muir et al. 2004; Canaza-Cayo et al. 2018). The heritability estimate for dystocia was of moderate magnitude, indicating that the incidence of dystocia could be reduced through selection. This estimate was higher to values described in literature for primiparous Holstein cows, whose estimates ranged from 0.01 to 0.16 (Cole et al. 2016; Hossein Salimi et al. 2017; Vanderick et al. 2017). The heritability estimates for dystocia seemed relatively high, given the known effects of non-genetic factors for this disorder. However, the recording of dystocia appears to be very complete in the studied herds, which probably contributed to this high estimate. Furthermore, dystocia, unlike calving ease, is a binary trait, as there is no ambiguity or subjectivity regarding the severity of the disorder.

Service sire variance components (Table 3) explained 11% of the phenotypic variance for dystocia, very similar to results reported by Weller and Ezra (2016) and Price and Wittbank (1978), demonstrating the sire, through his genetic contribution, plays an important role in calf size.

The genetic correlation between MY305 and AFC was nearly zero in this study, −0.04 (0.06) (Table 4). Phenotypic and residual correlations were also of small magnitude. The values reported in the literature were of greater magnitude, ranging from −0.49 to −0.37 (Muir et al. 2004; Canaza-Cayo et al. 2018). A possible cause of this low estimate of genetic

### Table 3.

| Trait        | Parameter | Mean (SD) | 95% HPD            |
|--------------|-----------|-----------|--------------------|
| MY305 (kg)   | σ²a       | 0.15 (0.03) | 0.09 – 0.12        |
|              | σ²e       | 0.46 (0.05) | 0.38 – 0.54        |
|              | σ²p       | 0.24 (0.05) | 0.17 – 0.30        |
|              | h²        | 0.15 (0.01) | 0.12 – 0.18        |
| AFC (day²)   | σ²a       | 0.17 (0.11) | 0.13 – 0.20        |
|              | σ²e       | 0.03 (0.06) | 0.01 – 0.06        |
|              | σ²p       | 0.08 (0.01) | 0.05 – 0.11        |
| Dystocia     | h²        | 0.17 (0.03) | 0.12 – 0.23        |

### Table 4.

| Parameter | Mean (SD) | 95% HPD            |
|-----------|-----------|--------------------|
| MY305 – AFC | rₐ       | −0.04 (0.06) | −0.17 – 0.08        |
|            | rₑ       | 0.11 (0.02)  | 0.08 – 0.14        |
|            | rₚ       | 0.08 (0.01)  | 0.06 – 0.10        |
| MY305 – Dystocia | rₐ | −0.17 (0.11) | −0.38 – 0.04        |
|            | rₑ       | 0.08 (0.02)  | 0.04 – 0.13        |
|            | rₚ       | 0.04 (0.01)  | 0.01 – 0.06        |
| AFC – Dystocia | rₐ | 0.30 (0.09)  | 0.10 – 0.46        |
|            | rₑ       | −0.03 (0.03) | −0.08 – 0.00        |
|            | rₚ       | 0.04 (0.02)  | 0.01 – 0.08        |

### Results and discussion

Descriptive statistics of MY305, AFC and dystocia are given in Table 2. The mean first-lactation MY305 was 7899 (2427) kg (Table 2), reflecting the high genetic pattern of cows in the Holstein herds studied. Some authors reported mean yields ranging from 5217 to 11,000 kg (Irano et al. 2014; Chester-Jones et al. 2017; Stefani et al. 2018). The overall mean of AFC was 806 days, similar to those found in the literature for Holstein cows (Hutchison et al. 2017; Heise et al. 2018). The average incidence of dystocia observed in the present study was 18%, and is comparable to other international estimates to primiparous cows (Hiew et al. 2016; Vieira-Neto et al. 2017; De Amicis et al. 2018).

The heritability estimates were 0.15 (0.01), 0.27 (0.02), and 0.17 (0.03) for MY305, AFC and dystocia, respectively (Table 3). The heritability of MY305 was slightly lower to those found in the literature for Holstein cows, ranging from 0.19 to 0.27 (Paula et al. 2008; Irano et al. 2014; Stefani et al. 2018). The heritability for AFC was slightly higher to those found in the literature, ranging from 0.19 to 0.20 (Muir et al. 2004; Canaza-Cayo et al. 2018). The heritability estimate for dystocia was of moderate magnitude, indicating that the incidence of dystocia could be reduced through selection. This estimate was higher to values described in literature for primiparous Holstein cows, whose estimates ranged from 0.01 to 0.16 (Cole et al. 2016; Hossein Salimi et al. 2017; Vanderick et al. 2017). The heritability estimates for dystocia seemed relatively high, given the known effects of non-genetic factors for this disorder. However, the recording of dystocia appears to be very complete in the studied herds, which probably contributed to this high estimate. Furthermore, dystocia, unlike calving ease, is a binary trait, as there is no ambiguity or subjectivity regarding the severity of the disorder.

Service sire variance components (Table 3) explained 11% of the phenotypic variance for dystocia, very similar to results reported by Weller and Ezra (2016) and Price and Wittbank (1978), demonstrating the sire, through his genetic contribution, plays an important role in calf size.

The genetic correlation between MY305 and AFC was near to zero in this study, −0.04 (0.06) (Table 4). Phenotypic and residual correlations were also of small magnitude. The values reported in the literature were of greater magnitude, ranging from −0.49 to −0.37 (Muir et al. 2004; Canaza-Cayo et al. 2018). A possible cause of this low estimate of genetic

### Table 2.

| Trait | n | Mean | SD   | Min. | Max. | CV |
|-------|---|------|------|------|------|----|
| MY305 (kg) | 23,929 | 7899 | 2427 | 1500 | 15,766 | 31% |
| AFC (day²) | 26,782 | 806 | 98 | 580 | 1098 | 12% |
| Dystocia | 17,904 | 82% | 18% |
correlation in the studied herds would be a non-linear relationship between these traits, with a desirable optimum at intermediate performances for MY305 and AFC. Future research should explore this possibility in more details.

Genetic correlation between dystocia and MY305 was negative and of low magnitude, \(-0.17\) (0.11) (Table 4). This estimate could indicate that individuals with high genetic merit for milk yield are slightly associated to a more difficult first calving. However, the genetic correlation was estimated with high standard deviation and large highest posterior density interval, which indicate uncertainty surrounding this result. Thus, it is not reasonable to use MY305 as a selection criterion for improving dystocia. Eaglen et al. (2013), Lee et al. (2003) and Muir et al. (2004) found estimates ranging from 0.23 to 0.34 between calving ease and MY305. Eaglen et al. (2013) related that difficult calving primiparous cows were likely associated with being high-producing, wide and deep animals, with a reduced ability to subsequently conceive.

The estimate of genetic correlation between dystocia and AFC was moderate and positive, 0.30 (0.09), indicating that increased AFC is related to a higher probability of success for dystocia, i.e. cows that calve with later age may have a lower risk of dystocia. Muir et al. (2004) found a genetic correlation of 0.35 between age at first service and calving ease, and stated that early maturing heifers may need to be mated to calving ease sires to decrease dystocia at first calving. The major cause of dystocia is disproportion between the size of calf and the size of birth canal (Pond 2004). Careful sire selection can control birth weight, but the dam’s relative maturity and pelvic width are also critical. Inadequate skeletal maturity can be a problem if the AFC is too low. Hence, AFC is a benchmark that should be properly managed in order to achieve the highest economic return and longer productive life.

The direct genetic gain to dystocia was 0.17 indicating the response to the probability of success per generation by selecting dystocia. The correlated response for dystocia would be \(-0.03\) and 0.07 if selection would be based on AFC and MY305, equivalent to a relative selection efficiency of \(-16\)% and 38%, respectively. Thus, the indirect selection for dystocia based on these traits would be less efficient than the direct selection for dystocia. Further studies are needed to develop a selection index that would incorporate the studied traits.

Conclusions

For high-producing Holstein cows reared in intensive production systems, early maturing heifers are likely associated to a more difficult first calving. It is possible to promote genetic gains in dystocia by selecting for the moderately correlated traits, but the maximum selection efficiency will be achieved by selecting directly by dystocia. The heritability estimate suggests that incidence of dystocia could be reduced through selection. The endpoint is to aim for an animal that calves successfully at an appropriate age. This study allowed to demonstrate the importance of the inclusion of dystocia in national breeding goals, but is also essential to understand how calving performance will be affected by future selection.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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