The estimation of heritability and repeatability of first service conception and first cycle calving in Angus cattle

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INTRODUCTION

The economic viability of cow–calf operations is largely dependent on the reproductive success of individuals in the herd (Toghiani et al., 2017). Unable to conceive early or maintain a pregnancy, infertile females have a large impact on the profitability of an enterprise due to increased breeding expenses, excessive culling rates, smaller calf crops, and shortened reproductive life spans (Rahbar et al., 2016). As reported by Bellows et al. (2002), 4.5% of females on average are culled from the reproductive herd due to conception failure and/or loss of pregnancy. This inability of females to produce a calf leaves a need to improve the reproductive success in beef cattle production by further understanding the genetic and environmental influences on fertility and includes identification of infertile females.

Historically, fertility traits have not been widely evaluated due to limited data and the binary/threshold nature of many of the associated traits making them difficult to analyze (Bormann et al., 2010). Of these binary traits, first service conception (FSC) describes the outcome of the first service of artificial insemination (AI) during the breeding season. Furthermore, another binary trait (first cycle calving [FCC]) describes the success or failure of a female who can calve within the first 21 d of her AI due date where such success is preferential over females who calve late or fail to calve in the calving season, resulting in issues such as prolonged calving intervals and increased culling as described by Rahbar et al. (2016). Considered good predictors of a female's fertility and ability to conceive, further understanding influences on these traits could result in more efficient reproductive herds and maximized producer profit.

The objective of this study was to estimate the heritability and repeatability of FSC and FCC to further understand and partition the influence of genetics and the environment on a female's ability to conceive early and produce a calf.

MATERIALS AND METHODS

Due to the data being obtained from a historic dataset, the approval of an animal care and use committee was unnecessary.

Cattle Management

Data were sourced from the Colorado State University Beef Improvement Center in Saratoga, Wyoming, and included breeding and calving records from the years 1986 to 2018. The data include records of primarily Angus females but does include crossbred cattle in earlier years, which as described by Basarab et al. (2018) have been shown to be positively related to fertility and longevity, in terms of pregnancy rates and the ability to consistently produce a calf due to heterosis. The commercially managed herd undergoes estrus synchronization and one service of AI, and after a withholding period is introduced to a natural service (NS) bull for the remainder of the breeding season.

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Females are retained from the calf crop and developed to enter the cow herd as a bred heifer at 1 yr of age. Generally, heifers who undergo the breeding season and successfully conceive via AI are retained whereas those who fail to conceive to AI are culled. Older females in the cowherd are culled when determined nonpregnant using ultrasound/manual palpation at calf weaning approximately 55 d after AI and 120 d after the end of the breeding season. Females are also culled for poor structure or performance when culling rates for nonpregnancy are sufficiently low.

Determination of Calf Source and Phenotype Assignment

Although the parentage, and therefore the success or failure to conceive to AI and deliver that calf, was verified on calves from select years, in many years DNA was not available for that verification, and for those years calf sires (and therefore AI or NS conception) were determined using an algorithm that utilizes breeding and calving information to sort calves appropriately. In addition to the results of two ultrasound scans (~55 d and ~120 d postbreeding), to determine the likely source of the calf, industry values for gestation length and late gestation fetal growth rates were used to adjust calf birth weights to a 280-d gestation length. These adjusted weights were then compared to birth weight averages associated with calves born to that respective year, sex, and Beef Improvement Federation (BIF) age of dam to determine if their weight represented the gestation length according to an AI conception. Age of dam is categorized according to BIF recommendations, which consisted of 2, 3, 4, 5 to 10, and 11 yr of age or greater. Once the source was determined, the phenotype for FSC could be assigned describing the success or failure and production of a calf.

Phenotypes for FCC are assigned based on the difference between calving due date according to AI and the actual calving date. If the female calved within 21 d after her due date, she was assigned a success phenotype for FCC. If the difference in days was greater than 21, the phenotype was assigned as a failure for the trait.

Data Summary

The data spanned the years 1986 to 2018 and included 8,622 individual breeding records from a total of 1,970 females with birth years between 1975 and 2015. The pedigree consisted of 12,753 individuals with 853 unique sires and 3,352 dams. Mating types consisted of females bred 12 h after standing heat in the a.m., those bred 12 h after heat in the p.m., and females bred at mass mating. Protocol data included various management, synchronization products, and semen types including the use of 24-h calf removal prior to breeding, melengestrol acetate, one or two injections of gonadotropin-releasing hormone, Synchromate B implant, and the use of fresh, cooled, frozen, and/or sexed semen. These synchronization treatments varied across mating years. Previous calving ease for females was recorded on a scale from one to five for females greater than 1 yr of age at mating.

Statistical Analysis

Model selection was completed using stepwise regression and the associated Akaike's Information Criteria values to determine the most significant effects to be included in both the models for FSC and FCC. The model utilized is as follows:

$$\boldsymbol{y_i} = \boldsymbol{X_i b_i} + \boldsymbol{Z_i u_i} + \boldsymbol{e_i}$$

where the vector of observations ($\boldsymbol{y}_i$) refers to the trait *i*, $\boldsymbol{X}_i$ is an incidence matrix relating the fixed effects found in vector $\boldsymbol{b}_i$ to the observations in $\boldsymbol{y}_i$. In addition, random effects of animal and permanent environment were included as incidence matrices and denoted by $\boldsymbol{Z}_d$ and $\boldsymbol{Z}_{EP}$, respectively, relating the direct genetic effects and permanent environment effects to observations in $\boldsymbol{y}_i$, whereas *e* corresponded to the residual errors associated with the vector of observations.

The data were then analyzed using the statistical software package ASReml 3.0 (Gilmour et al., 2009) to partition phenotypic variance into its genetic, permanent environment, and residual variance components to estimate heritability and repeatability of the FSC and FCC traits.

RESULTS AND DISCUSSION

Heritability of beef cattle fertility traits is generally low. Of the heritability estimates for various fertility traits, Rahbar et al., (2016) found that they range from 0.015 to 0.123, suggesting little genetic influence. However, very little exists in the literature regarding the repeatability of the same reproductive traits. To obtain such estimates for both FSC and FCC, model selection was completed using stepwise regression. The resulting significant fixed effects for FSC were birth year ($P < 0.001$), mating year

($P < 0.001$), synchronization protocol ($P < 0.001$), mating type ($P < 0.001$), AI technician ($P < 0.001$), and previous calving ease ($P < 0.001$). An animal and permanent environmental effect were included as random effects in the model. Model selection completed for FCC resulted in the significant fixed effects of birth year ($P < 0.001$), mating year ($P < 0.001$), mating type ($P < 0.001$), synchronization protocol ($P < 0.001$), and previous calving ease ($P < 0.01$). Random effects for FCC included animal as well as the permanent environmental effect.

Heritability

The estimate of 0.06 ± 0.02 for heritability of FSC to AI fell within the range of estimates reported in literature (0.015 to 0.18; Bormann et al., 2006; Ghiasi et al., 2011; Peters et al., 2013; Rahbar et al., 2016). Estimates reported in other literature varied by breed, age, and sample size of the cattle evaluated. For example, Peters et al. (2013) estimated the heritability for FSC at 0.18 in Brangus heifers. Alternatively, Rahbar et al. (2016) calculated heritability for success of first service among other fertility traits in Holstein dairy cows.

Heritability of the novel trait FCC was estimated at 0.15 ± 0.03, and although it is still considered lowly heritable, the genetic influence on the trait is significantly higher than that of FSC. This may be explained by the efficiency of natural mating over AI and the reduction in risk for human error as described by Perry et al. (2011). Unmeasurable faults in synchronization, semen thawing, and insemination may result in failed conceptions in otherwise fertile females, who then conceive early in the breeding season by NS.

Repeatability

Repeatability estimates of FSC were calculated at 0.06 ± 0.02, the exact estimate for FSC heritability suggesting no permanent environmental effect on the trait. This value is larger than the repeatability estimated for success of first service in dairy cattle of 0.021 ± 0.008 reported by Rahbar et al. (2016). Furthermore, the heritability estimate of 0.015 calculated for first service success by Rahbar et al. (2016) shows a slight influence of permanent environment, something not corroborated in this study. Nonetheless, the trait would be considered lowly repeatable and therefore a single record of FSC should not be relied on to predict a female's ability to conceive at the first service of AI for future matings.

The repeatability estimated for FCC was found to be 0.15 ± 0.03, based on the heritability of 0.15 ± 0.03 of the trait, the permanent environment has no effect on FCC. Although no literature appears to have previously investigated the FCC trait, other reports include repeatability on similar traits such as days to calving (DC), or the difference in days between the introduction of bulls to the females and the birth of the resulting calf. Meyer et al. (1990) estimated the repeatability of DC for Hereford, Angus, and Zebu cross cattle at 0.216, 0.102, and 0.181 respectively. The repeatability estimated in this study for FCC in Angus cattle was elevated in comparison to what was found by Meyer et al. (1990), which may be explained by the slight difference in the trait definitions.

The resulting values for repeatability of both FSC and FCC of consecutive years suggest that the temporary environment is the most influential factor of AI first service success as well as a female's ability to conceive and calve early. As reported in literature, fertility can be influenced by a wide range of temporary environmental factors, including but not limited to nutrition, condition score, age, semen quality as well as AI technician (Perry et al., 2011; Shorten et al., 2015). Due to the many effects on a female's ability to conceive, the resulting low estimates for heritability and repeatability are in line with expectations.

IMPLICATIONS

The resulting estimates for heritability and repeatability were considered low, suggesting the majority of the influence on fertility for FSC and FCC is due to temporary environmental effects associated with each mating. Furthermore, the alike estimates for both heritability and repeatability suggest that the permanent environment effect that a female has experienced has no effect on her ability to conceive on the first insemination during the breeding season or her ability to conceive and calve early. Due to the minimal genetic or permanent environmental influence, it is suggested that cattle managers should continue to alter cattle environment through management practices to maximize reproductive success. However, there is more potential for making progress by selecting females who calve early in the calving season over females who conceive on their first service of AI. This is likely due to the addition of human management and risk for error when AI is employed. However if data were available, sufficient heritability exists in FCC to be usable in national cattle evaluation.

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Conflict of interest statement. None declared.

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