Heterosis effects on age at first calving in a multibreed beef cattle herd in Panama

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INTRODUCTION
Livestock in Panama occupy more than 37% of the agricultural landscape and employ more than 20% of the labor force in the rural sector. However, measures of cattle performance suggest low production efficiency, which is reflected mainly in their reproductive ability, where an average annual birth rate of 54% is reported, with a range from 35% to 60% (INEC, 2017). Improvement in reproductive performance has been suggested to be up to four times more economically important than the final product (Melton, 1995). However, beef cattle breeding programs in Panama have focused mainly on improving carcass and growth traits and not reproductive rates.

Given the tropical climate conditions, Zebu cattle are the most predominant breeds in cow–calf systems; however, crossbreeding systems have been widely used in order to obtain the benefits of heterosis in growth and reproductive traits. Heterosis was defined by Dickerson (1973) as the difference in phenotype between the mean of the F1 crossbred offspring and their purebred parents. In animal breeding, this is usually expressed as mid-parent heterosis or the superiority of the F1 cross over the mean performance of the two parents. Also, the greater the differences between the parent breeds, the greater the heterosis effect, especially in traits of low heritability (Schiermiester et al., 2015). Reproductive traits are typically lowly heritable ($h^2 < 0.20$), and given the high economic impact in cattle production system, it becomes an attractive target in the breeding improvement programs (Formigoni et al., 2005).

Collection, measurement, and evaluation of fertility traits in tropical conditions are difficult as beef cattle production is conducted in extensively managed pastures (Cavani et al., 2015). One reproductive trait indicating a herd’s fertility is the age at first calving (AFC), a continuous trait. This trait is related to puberty and is easy to measure (Boligon and Albuquerque, 2011; Berry and Evans, 2014; Costa et al., 2019). A genetic improvement program focused on reducing the AFC would benefit the cost of raising replacement heifers and, therefore, the overall cost of beef production (Cavani et al., 2015). Therefore, the objectives of this study were to determine heterosis and breed percentage effects on AFC in a multibreed beef cattle herd in Panama.

MATERIALS AND METHODS
The data used in this study were obtained from an existing database; therefore, the study was not subject to animal care and use committee approval.

Data Collection and Editing
The data were provided by the Livestock Experimental Station of Panama Agricultural Innovation Institute (IDIAP) in Gualaca, province.
of Chiriquí Republic of Panama, and were generated between the years 2000 and 2019. This experimental station is located in the Tropical Premontane wet forest life zone (Holdridge and Grenke, 1971), with an average elevation of 100 m above sea level, 4,200 mm of annual rainfall, and an average daily temperature of 26 °C and 80% relative humidity.

Data included 580 heifers with records for AFC and 1,140 individuals including three generations in the pedigree. Heifers were bred via artificial insemination, and (or) natural service after 18 mo of age, or when they were over 317.5 kg (700 lb). Calving seasons were concentrated between April to June and October to December. Animals with varying percentages of Brahman (BR), Nellore (Ne), undefined Bos indicus (BI), Simmental (SM), Angus (A), Romosinuan (RS), Red Angus (AR), Limousin (LM), Charolais (CH), Beefmaster (BF), Wagyu (Wa), Guaymi Creole (CR), Senepol (SP), Others (Oth) and Others (Oth) were grouped according to their breed composition based on the following criteria. Breed groups were defined as Zebu (BR, Ne, BI), F1 (Zebu × Bos taurus [BT]), Three cross (Three cx) (F1 × different BT), R1 (Backcross BR), R2 (Backcross BT), Composite (combination of at least four different breeds with less than 25% of Zebu), Upgrade (87.5% BR + 12.5% BT), B1 (62.5% Zebu + 37.5% BT), Japanese (Wagyu), Creole (Guaymi Panamanian Creole), and B2 (62.5% BT + 37.5% Zebu). Calving year, calving season, calving age, and sex of calf were recorded for all animals. Individual outcross was calculated using the breed percentages of the individual’s parents and the formula presented by Bourdon (2000), as shown below:

\[ \text{Degree of outcross} = \left[ 1 - \sum_{i=1}^{n} P_{si} P_{di} \right] \times 100 \]

Where: \( P_{si} \) is the proportion of the \( i \)th breed in the sire, and \( P_{di} \) is the proportion of the \( i \)th breed in the dam of the individual.

**Statistical Analysis**

AFC was evaluated using a single-trait animal model to estimate the effect of heterosis and breed on AFC. This model is presented below, in matrix form:

\[ y = Xb + Zu + e \]

In the above equation, \( y \) is a vector of AFC observations; \( b \) is a vector of unknown fixed effects (consisting of year, breed group, and breed percentage or degree of outcross as covariate); \( u \) is a vector of unknown direct additive genetic effects; \( X \) and \( Z \) are known incidence matrices relating observations in \( y \) to both fixed and random effects in \( b \) and \( u \), respectively, and \( e \) is a vector of unknown residual errors. The observations in \( y \) were assumed to have an average of \( \mathbf{X} b \) and variances were assumed to be:

\[ \text{Var} \left[ \begin{bmatrix} u \\ e \end{bmatrix} \right] = \begin{bmatrix} \sigma^2_a \\ 0 \\ 0 \\ \sigma^2_e \end{bmatrix} \]

Above, \( A \) represents Wright’s numerator relationship matrix, \( I \) is an identity matrix whose order is equal to \( n \times 1 \), and \( \sigma^2_a \) and \( \sigma^2_e \) are the additive genetic and residual variances, respectively. All analyses were performed using the statistical software package ASREML 3.0 (Gilmour et al., 2009).

**RESULTS AND DISCUSSION**

The average AFC measurements in these data were 44.13 ± 11.05 mo, with a range of 18 to 91 mo. Summary statistics for AFC according to breed group are presented in Table 1. Considerable differences in the number of records per breed group were observed as Zebu was the largest group representing approximately 39.1% of the data, the next largest group was the F1 with 19.1%, and the Three cx with 16.9%. The B. taurus-influenced groups such as Composite, R1, R2, Upgrade, B1, Japanese, Creole, and B2 groups comprised less than 10.0%, 8.27%, 2.24%, 1.55%, 1.55%, 0.6%, 0.5%, and 0.3%, respectively.

| Breed group | N  | Average | SD  | Min  | Max  | BLUE Diff. |
|-------------|----|---------|-----|------|------|------------|
| Zebu        | 227| 47.1    | 10.7| 27.0 | 90.0 | 0.00       |
| F1          | 111| 40.6    | 11.0| 24.0 | 88.0 | -5.36      |
| Three cx    | 98 | 41.1    | 9.6 | 18.0 | 81.0 | -7.15      |
| Composite   | 56 | 44.7    | 13.9| 21.0 | 91.0 | -4.47      |
| R1          | 48 | 44.4    | 7.5 | 24.0 | 58.0 | -4.05      |
| R2          | 13 | 40.5    | 11.2| 26.0 | 70.0 | -8.86      |
| Up grade    | 9  | 46.0    | 12.6| 34.0 | 74.0 | -2.60      |
| B1          | 9  | 43.7    | 8.1 | 29.0 | 55.0 | -6.26      |
| Japanese    | 4  | 43.0    | 19.4| 26.0 | 64.0 | -2.94      |
| Creole      | 3  | 44.0    | 5.2 | 38.0 | 47.0 | -3.08      |
| B2          | 2  | 39.5    | 14.8| 29.0 | 55.0 | -10.5      |
| Total       | 580| 44.13   | 11.05|18.00|91.00|——          |

Zebu (BR, Ne, BI), F1 (Zebu × BT), Three cx (F1 × different BT), R1 (Backcross BR), R2 (Backcross BT), Composite (combination of at least four different breeds with less than 25% of Zebu), Upgrade (87.5% BR + 12.5% BT), B1 (62.5% Zebu + 37.5% BT), Japanese (Wagyu), Creole (Guaymi Panamanian Creole), and B2 (62.5% BT + 37.5% Zebu).

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This data structure was a reflection of the commercial beef herds of Panama, and it represents one of the challenges associated with the use of field data for multibreed analyses as acknowledged in previous reports (Golden et al., 2009). The average degree of outcross observed in this study was 52.8 (ranging from 0 to 100) and its effects, as well as those relative to breed differences on AFC measurements, are presented in Table 2. The estimated regression coefficient for AFC on heterosis was \(-0.051 \pm 0.02\) mo/percent of outcross \((P = 0.001)\). This heterosis effect was similar to the report of Vergara et al. (2009), which reported a negative estimate for heterosis for AFC, but nonsignificant \((-26.0 \pm 21.0\) d; \(P = 0.18\)). Breed group effect as a deviation from Zebu is presented in Table 1, evidencing the late AFC for the Zebu breeds. This was in agreement with Magaña and Segura-Correa (2001), who reported a reduction of 5 mo in AFC for F1 (Brown Swiss \(\times\) Zebu) heifers and between 2 or 3 mo for heifers with 25% to 75% of Brown Swiss composition. In this study, the F1, R2, and B2, had a lower average of AFC with 40.5, 40.5, and 38.5 mo, which represents 14.0%, 14.0%, and 18.7% of heterosis, respectively, when compared with the Zebu group \((P = 0.001)\).

Breed percentage effects on AFC are presented in Table 2 and indicate a greater reduction estimated for Angus and Others breed with \((-0.12 \pm 0.08\) mo; \(P = 0.331)\) and \((-0.15 \pm 0.06\) mo; \(P = 0.019)\), respectively. In a similar study described by Vergara et al. (2009) in Colombia, they reported a greater reduction in AFC for the Zebu \(\times\) Angus crossbreed \((-281.2 \pm 41.9\) d; \(P < 0.001)\). These authors stated that Zebu genetics involved in adaptability may have helped the expression of Angus precocity genes. Under tropical conditions, crossbreeding programs focused on taking advantage of the early maturity and complementarity of \(B.\) taurus \(\times\) \(B.\) indicus beef cattle have a high economic impact on the cow–calf system, when compared with \(B.\) indicus females (Núñez-Domínguez et al., 1991). Furthermore, heterotic effects of crossbred individuals are known to be dependent upon the differences in allele frequencies of the loci contributing to variations in the trait, so that, the larger these differences, the greater the heterozygosity and its benefits (Kumar et al., 2018). This is relevant since, in the present study, we can evidence older AFC averages for female with the higher Zebu breed percentage.

The variance components and estimates of heritability are presented in Table 3. The AFC heritability estimate was 0.37 \(\pm\) 0.18, which is higher than the estimates reported by Cammack et al., (2009; 0.1 to 0.3) for breeds in the United States, Vergara et al. (2009; 0.15) for a multibreed population in Colombia, Talhari et al., (2003; 0.13) for the Camchim breed in Brazil, and Casas and Tewolde (2001; 0.28) for Rosomínuan in Costa Rica, but lower than those reported by Magaña and Segura-Correa (2001) and Estrada et al. (2008) (0.46) in Mexico for a Brahman and a multibreed herd. The moderate estimate of AFC heritability in this study suggested an economic benefit to implementing genetic improvement programs, thereby improving the overall herd fertility using the trait AFC. Also, reducing AFC may lead to a shorter first calving interval because these heifers will have enough time to recover their body condition and resume to estrous quickly with optimal management and nutritional conditions (Mercadante et al., 2000).

In conclusion, positive effects of heterosis on AFC (i.e., reduction) were observed in this study, with a better average for the breed groups F1, R2, Three cx, and B2. A moderate heritability was estimated for this multibreed population that focused on taking advantage of the early maturity and complementarity of \(B.\) taurus \(\times\) \(B.\) indicus.

### Table 2. Estimated values (±SE) and significance level of the linear covariates included in the animal model according to breed percentage and degree of outcross in a multibreed beef cattle herd in Panama

| Effect                  | Estimate (±SE) | P-value |
|-------------------------|----------------|---------|
| Brahman (%)             | 0.002 ± 0.01   | 0.548   |
| Nellore (%)             | -0.05 ± 0.01   | 0.587   |
| Undefine Zebu (%)       | -0.05 ± 0.03   | 0.085   |
| Beefmaster (%)          | -0.047 ± 0.087 | 0.882   |
| Wagyu (%)               | -0.057 ± 0.036 | 0.267   |
| Charolais (%)           | 0.05 ± 0.04    | 0.032   |
| Simmental (%)           | -0.03 ± 0.04   | 0.777   |
| Angus (%)               | -0.12 ± 0.08   | 0.331   |
| Guaymi (%)              | 0.03 ± 0.05    | 0.341   |
| Red Angus (%)           | -0.04 ± 0.04   | 0.303   |
| Romosinuano (%)         | 0.06 ± 0.17    | 0.584   |
| Limousine (%)           | -0.010 ± 0.08  | 0.589   |
| Senepol (%)             | -0.01 ± 0.05   | 0.599   |
| Others (%)              | -0.15 ± 0.06   | 0.019   |
| Degree of outcross (%)  | -0.051 ± 0.02  | 0.001   |

### Table 3. Component of variance, Wald F statistics, significance, and heritability for AFC in a multibreed herd beef cattle in Panama

| Effect         | Estimate | P-value |
|----------------|----------|---------|
| Year           | 474.9126 | 0.0001  |
| Degree of outcross (%) | 182.6309 | 0.0001  |
| Genetic variance | 41.507   | —       |
| Residual variance | 68.388   | —       |
| Phenotypic variance | 109.89   | —       |
| Heritability    | 0.37 ± 0.18 | —       |
could assist genetic improvement programs for reproduction.

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Conflict of interest statement. The authors declare that they have no conflict of interest.

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